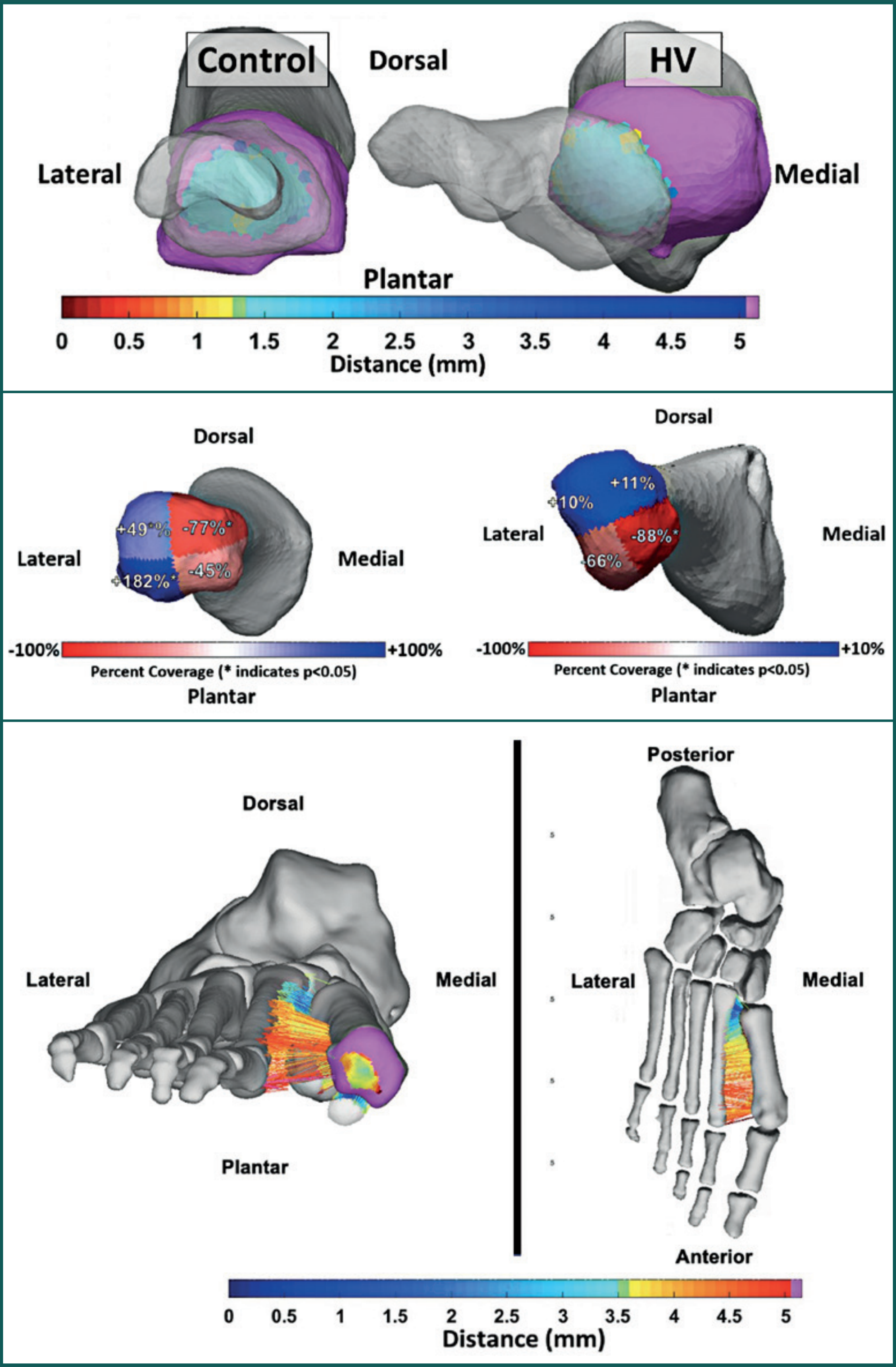
JOURNAL OF THE

Foot & Ankle

Volume 16, Issue 1, January-April



JOURNAL OF THE
Foot & Ankle

Volume 16, Issue 1, January-April

The Journal of the Foot & Ankle (eISSN 2675-2980) is published quarterly in April, August, and December, with the purpose of disseminating papers on themes of Foot and Ankle Medicine and Surgery and related areas. The Journal offers free and open access to your content on our website. All papers are already published with active DOIs.

EDITORIAL TEAM

ASSOCIATED SOCIETIES

Argentina
Sociedad Argentina de Medicina y Cirugía de Pie y Pierna
http://www.samecipp.org.ar/

Bolivia
Sociedad Boliviana de Medicina y Cirugía del Tobillo y Pie
http://sbolot.org.bo/

Brazil
Brazilian Orthopedic Foot and Ankle Society
http://www.abtpe.org.br/

Chile
Comité de Tobillo y Pie de la Sociedad Chilena de Ortopedia y Traumatologia (SCHOT)
http://www.schot.cl/

Colombia
Capítulo de Pie y Tobillo de la Sociedad Colombiana de Cirugía Ortopedia y Traumatología (SCCOT)
http://www.sccot.org.co/

Mexico
Sociedad Mexicana de Pie y Tobillo
https://www.facebook.com/smpieytobillo/

Peru
Capítulo Peruano de Cirugía del Pie y Tobillo (CAPPiTO) – Sociedad Peruana de OyT
http://www.spotrauma.org/

Portugal
Sociedade Portuguesa de Ortopedia e Traumatologia (SPOT)
http://www.spot.pt/

Uruguay
Comité Uruguayo de Estudios del Pie (CUEP) - Sociedad de Ortopedia y Traumatología del Uruguay
http://www.sotu.org.uy/

Venezuela
Comité científico de pie y tobillo de la Sociedad Venezolana de Cirugía Ortopédica y Traumatología (SVCOT)
https://www.svcot.web.ve/index.html

JFA JOURNAL OF THE Foot & Ankle
eISSN 2675-2980

JOURNAL OF THE

JFA Foot & Ankle

Volume 16, Issue 1, January-April

Contents

Case Report

Systematic Review

Technical Tips

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1628

JOURNAL OF THE Foot & Ankle JFA

Forever Ramón Viladot

MARIO HERRERA-PEREZ.

RAMÓN VILADOT AND MARIO HERRERA, 2019.

ORTHOPAEDIC DEPARTMENT, UNIVERSITY HOSPITAL OF CANARY ISLANDS, LA LAGUNA, TENERIFE, SPAIN

Dear colleagues and friends of the Latin American Foot and Ankle world, it is for me an honor and at the same time a great sadness to pass along the sad news that January brought to all of us. Ramón Viladot Pericé, world reference in Foot and Ankle and professor of generations of specialists in Spain and Latin America, passed away in Barcelona. Providence wanted that, in the last months and even years, we had been united by an intense research activity, and I have the honor of having published with him his last scientific article, published last year in this scientific journal.

What can we say... we have plenty of reasons to highlight his impressive scientific legacy and even more reasons to stress his unmeasurable human qualities. His absence leaves an enormous void impossible to fill. From the scientific point of view, his last moments were filled with an unprecedented resurgence of science in all senses: it was not time to end a project to start another, and the hours and days were not enough to meet his goals. Perhaps he never thought of such a hasty end, but even so, destiny prepared him to say goodbye in the best way: communicating how much he knew about Foot and Ankle.

Among many other things, I am left with the calls of the last months, full of affection and cognizance of the perfection of his work, but also with his inexhaustible eagerness for rigorous scientific production. With Ramón Viladot part of the History of Foot and Ankle is gone. Probably nothing will be the same from now on, but we are left with his unequaled personal and scientific legacy, his disposition, his human qualities. Surely many of the readers of this Editorial can identify with these words, as there are many of us who have shared operations and consultations with him both at the Hospital San Rafael and at the Clínica Tres Torres in Barcelona.

The person died, but the memory lives on. As writer Mario Benedetti said:

"If I live in your memory, I will not be alone."

We will all certainly remember him forever. Forever Ramón...

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1589

Special Article

Metatarsal osteotomies in *Hallux Rigidus*

Martín Ferreyra[1], Antonio Viladot Voegeli[2], Ramón Viladot-Pericé[2] (In Memoriam)

1. Instituto Oulton, Córdoba, Argentina.
2. Orthopaedic Department, Clínica Tres Torres, Barcelona, Spain.

Abstract

This work presents the objectives and indications of the three distal osteotomies of the first metatarsal most frequently used in *Hallux Rigidus* surgery: Weil-Barouk oblique osteotomy, Youngswick (modified Chevron) osteotomy, and Watermann dorsal closed wedge osteotomy. The surgical technique, indications, advantages, and disadvantages of each of them are described.

Level of Evidence V; Therapeutic Studies; Expert Opinion.

Keywords: *Hallux rigidus*; Osteotomy; Metatarsal bones; Forefoot, human.

Introduction

The aim of osteotomies is achieving a more mobile and pain free joint, correcting the etiopathogenic factors that caused the deformity. Osteotomy is intended: 1) To decompress the joint. 2) To shorten the first metatarsal in cases of index-plus metatarsal formula or to decompress the joint. 3) To realign the joint. 4) To lower the first metatarsal head to correct *metatarsus primus elevatus* and *Hallux Flexus,* thus reestablishing the rotation center of metatarsal head. 5) To relax muscles and plantar fascia, which are often retracted. 6) To reduce intermetatarsal angle in cases of *Hallux Valgus-Rigidus.*

Indications

According to Coughlin and Shurnas classification[(1)], osteotomies are indicated in advanced grade II and in early grade III with joint surface involvement lower than 50%. Both distal oblique osteotomy, as described by Weil for lateral rays and popularized by Barouk[(2)], and Youngswick osteotomy[(3)] shorten the metatarsal, decompress the joint, lower the first metatarsal head, and relax muscles and fascia plantar. Therefore, they are indicated for most cases of *Hallux Rigidus* in which the first metatarsal is long or elevated (*metatarsus primus elevatus*), and in the presence of *Hallux Flexus* associated with plantar fascia retraction. In cases of index-plus-minus metatarsal formula, shortening caused by osteotomy in the horizontal plane is compensated with lowering of metatarsal head in the frontal plane. Watermann osteotomy[(4)] is indicated in cases of *Hallux Rigidus* with no *metatarsus primus elevatus*, *Hallux Flexus*, or plantar fascia retraction. This type of osteotomy realigns articular surface without shortening the metatarsal or lowering its head.

Surgical Techniques

A. Distal oblique osteotomy

This osteotomy is widely used in the treatment of *Hallux Rigidus* (Figure 1).

A medial incision centered on the first metatarsophalangeal joint (MTPJ) was performed. Subsequently, the joint was subluxated in order to allow for surgeons to operate on it. Oblique osteotomy of the metatarsal head was conducted from the dorsal-distal to the plantar-proximal direction, starting on the articular surface with chondral lesion, with an angle from 35° to 45°, based on the extent to which metatarsal head should be lowered. Osteotomy was finished on the plantar surface, proximal to the entry of the vascular bundle that irrigated the metatarsal head, in order to prevent its necrosis. Subsequently, the first metatarsal head was subjected to proximal plantar displacement, depending on the length of the first metatarsal and its degree of dorsiflexion. In our experiment, displacement was +/- 5mm. Osteosynthesis was performed with two double-threaded cannulated screws measuring 3mm in diameter, paying attention to their location so

Study performed at the Instituto Oulton, Córdoba, Argentina.

Correspondence: Martín Ferreyra. **Adress:** Carrer del Dr. Roux, 76, 08017 Barcelona **E-mail:** martinluisferreyra@hotmail.com. **Conflicts of Interest:** none. **Source of funding:** none. **Date received:** October 09, 2021. **Date accepted:** February 09, 2022. **Online:** April 30, 2022.

How to cite this article: Ferreyra M, Viladot Voegeli A, Viladot-Pericé R (In Memoriam). Metatarsal osteotomies in *Hallux Rigidus*. J Foot Ankle. 2022;16(1):2-5.

that it did not surpass the articular surface. Two screws were used in order to prevent varus-valgus displacements of the first metatarsal head. Finally, the excess or dorsal roof and medial exostosis were resected. Sometimes, if fascial tension persists, we recommend performing a proximal percutaneous plantar fasciotomy. In Egyptian feet, which have a very long hallux, we recommend shortening the proximal phalanx, thus reducing axial pressure resulting from contact between shoes and the distal end of the toe.

In cases of *Hallux Valgus-Rigidus*, this technique allows for act on both deformities.

B. Youngswick (or modified Chevron) osteotomy

This technique was described by Youngswick[3] in 1982 as a modification of the Austin osteotomy. It is also one of the distal metatarsal osteotomies most widely indicated for *Hallux Rigidus* (Figure 2).

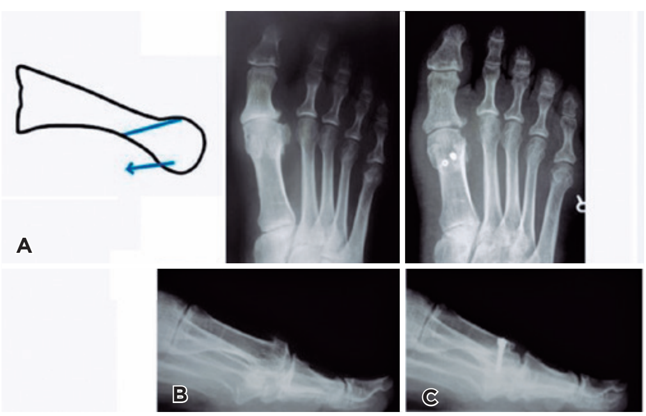


Figure 1. Weil-Barouk oblique osteotomy. A) Intervention scheme. B) Preoperative radiograph. C) Postoperative radiograph.

Using the same approach of the previous technique, a V-shape osteotomy was performed with a slightly dorsal vertex on the metatarsal head and the two diagonal lines directed from dorsal-proximal to plantar-proximal towards the vertex, forming an angle of 60°. Subsequently, a second osteotomy was performed parallel to the dorsal branch of the first osteotomy. The width of this second osteotomy determines shortening and lowering of the first metatarsal and articular decompression. This osteotomy is intrinsically more stable than the previous one; thus, only one screw is required for osteosynthesis. This procedure can also be used in cases of *Hallux Valgus-Rigidus.*

C. Watermann dorsal closed wedge osteotomy

Watermann[4] described this procedure in 1927 as a trapezoidal dorsal closed wedge osteotomy on the first metatarsal neck (Figure 3).

Using the same approach as the previous techniques, dorsal wedge osteotomy is performed on the metatarsal head. When osteotomy is closed by dorsiflexion, the metatarsal head rotates so that the plantar articular cartilage, which is usually healthy, is the segment that comes into contact with the base of the phalanx. Furthermore, this procedure reduces the volumetric content of the first MTPJ. This is a relatively unstable osteotomy, due to its perpendicular direction, and has difficult osteosynthesis.

Results

Currently, most authors[5,6] agree that osteotomies are successful in *Hallux Rigidus* grades I and II, whereas results are more unpredictable in the most advanced phases of disease. We share this view.

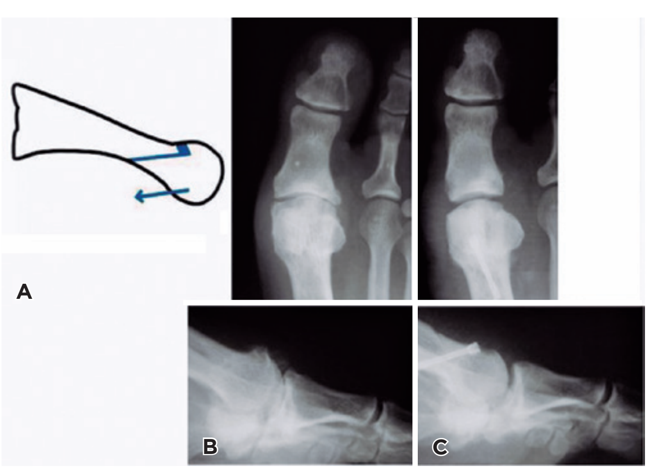


Figure 2. Youngswick osteotomy. A) Intervention scheme. B) Preoperative radiograph. C) Postoperative radiograph

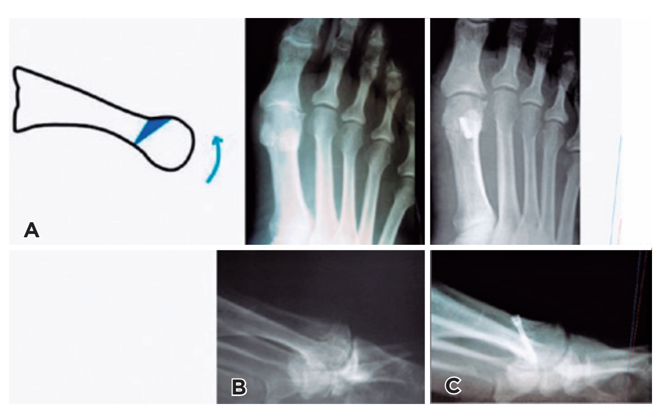


Figure 3. Watermann osteotomy. A) Intervention scheme. B) Preoperative radiograph. C) Postoperative radiograph.

The published literature[7-10] on distal oblique osteotomy is heterogeneous: authors use different classification methods, indicate surgery in different grades of *Hallux Rigidus* (from grade I to III), although it has never been indicated for grade IV, and follow-up time after intervention varies widely: from 12 months up to 11.1 years. However, all authors do agree on the goodness of the technique, with rates of excellent and good outcomes higher than 80%.

Our experiment[11] with distal oblique osteotomy is based on 32 feet, all presenting with grade II of the disease, with a mid-term follow-up of 39.4 months. Results were consistent with those of the reviewed literature: outcomes were excellent in 75% of the cases, and good in 25%, which is explained by the fact that our series did not include patients in advanced disease phases.

Kilmartin[12] compared oblique osteotomy with Reverdin-Green osteotomy and shortening Scarf osteotomy and did not find differences in results as well.

A literature review on Youngswick osteotomy showed similar findings: series were little homogeneous. Dickerson et al.[13] observed 94% of satisfactory outcomes with 32 patients, with a mid-term follow-up of 4 years. Slullitel et al.[14] also found satisfactory long-term outcomes in 61 operated patients with *Hallux Rigidus* of grades II and III. Olof and Jhala-Patel[15] indicate osteotomy in grades III and IV of the disease and obtained a satisfaction level of 85% among their patients.

Since distal oblique osteotomy and Youngswick osteotomy have the same objectives and indications, several comparative studies have been conducted to assess whether one technique is better than the other.

We[16] published a prospective study of both osteotomies in the mid-term, with a minimum postoperative time of 24 months. Twenty-five feet operated with each technique were evaluated, all presenting with grade II of the disease, and there were no significant differences in outcomes. Xu et al.[17] also compared the results of the two osteotomies in 33 feet. In their case, intervention was indicated in grades III and IV of the disease. They did not find differences between the two techniques as well. Interestingly, a study by LaMar et al.[18] performed a mechanical comparison with bone models in a laboratory, in order to assess the stability of the two osteotomies. There was likewise no difference between them.

With regard to distal Watermann dorsiflexion osteotomy, Cho et al.[19] reviewed 42 feet with a mid- to long-term follow-up of at least 3 years, in patients with *Hallux Rigidus* of grades III and IV. Based on the results, the authors conclude that this osteotomy is effective in grade III with viable cartilage on at least 50% of the articular surface, but should not be indicated in grade IV, due to the high rate of reoperations. Laakmann et al.[20] have modified osteotomy by adding a double section in the dorsal line in order to realign the metatarsal head in dorsiflexion and lower it in the frontal plane. This makes it possible to correct *metatarsus primus elevatus-Hallux Flexus* and to relax the plantar fascia, achieving good results.

Lee et al.[21] compared the outcomes of distal oblique osteotomy with those of cheilectomy and concluded that, although the latter technique has a recurrence rate of 30%, which is explained by the fact that it does not resolve the etiopathogenic factors causing *Hallux Rigidus*, the two techniques gave satisfactory outcomes for the patient.

Complications

The complications described with these techniques are the following:

1. Delayed union, malunion, or non-union
2. Avascular necrosis of the metatarsal head
3. Osteotomy fracture
4. Hardware loosening
5. Transfer metatarsalgia
6. Loss of postoperative mobility and persistence of pain.
7. Disease recurrence.

Conclusions

According to the published literature and to our own experiment, we consider that osteotomies are indicated in the treatment of grade II and early grade III *Hallux Rigidus*. Their purpose is to preserve articular surface, decompress the joint, and correct changes in the center of rotation.

Although disease origin is multifactorial, we believe that excessive plantar fascia tension is a determining factor for *metatarsus primus elevatus* and *Hallux Flexus.* In selected cases, plantar fasciotomy on the heel allows for additional joint decompression.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MF *(https://orcid.org/0000-0001-7149-7358) Wrote the article, participated in the review process, bibliographic review, formatting of the article, interpreted the results of the study; AVV *(https://orcid.org/0000-0002-4192-6163) Wrote the article, participated in the review process, bibliographic review, formatting of the article, interpreted the results of the study; RVP (In Memoriam) *(https://orcid.org/0000-0002-8254-2916) Wrote the article, participated in the review process, bibliographic review, formatting of the article, interpreted the results of the study . All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Coughlin MJ, Shurnas PS. Hallux rigidus. Grading and long-term results of operative treatment. J Bone Joint Surg Am. 2003;85(11): 2072-88.
2. Barouk LS. L´ostéotomie cervico-céphalique de Weil dans les métarsalgies medians. Méd Chir Pied. 1994;10:23-33.
3. Youngswick FD. Modifications of the Austin bunionectomy for treatment of metatarsus primus elevatus associated with hallux limitus. J Foot Surg. 1982 Summer;21(2):114-6.
4. Watermann H. Die afthritis deforman des Gross zenhengrundege lenkes als Selbstandiges Krankheitsbild. Z Chir Orthop Chir 1927; 48:346.
5. Shereff MJ, Baumhauer JF. Hallux rigidus and osteoarthrosis of the first metatarsophalangeal joint. J Bone Joint Surg Am. 1998; 80(6):898-908.
6. Haddad SL. The use of osteotomies in the treatment of hallux limitus and hallux rigidus. Foot Ankle Clin. 2000;5(3):629-61.
7. Ronconi P, Monachino P, Baleanu PM, Favilli G. Distal oblique osteotomy of the first metatarsal for the correction of hallux limitus and rigidus deformity. J Foot Ankle Surg. 2000;39(3):154-60.
8. Malerba F, Milani R, Sartorelli E, Haddo O. Distal oblique first metatarsal osteotomy in grade 3 hallux rigidus: a long-term follow up. Foot Ankle Int. 2008;29(7):677-82.
9. Gonzalez JV, Garrett PP, Jordan MJ, Reilly CH. The modified Hohmann osteotomy: an alternative joint salvage procedure for hallux rigidus. J Foot Ankle Surg. 2004;43(6):380-8.
10. Giannini S, Ceccarelli F, Faldini C, Bevoni R, Grandi G, Vannini F. What's new in surgical options for hallux rigidus? J Bone Joint Surg Am. 2004;86-A Suppl 2:72-83.
11. Voegeli AV, Marcellini L, Sodano L, Perice RV. Clinical and radiological outcomes after distal oblique osteotomy for the treatment of stage II hallux rigidus: Mid-term results. Foot Ankle Surg. 2017;23(1):21-6.
12. Kilmartin TE. Phalangeal osteotomy versus first metatarsal decompression osteotomy for the surgical treatment of hallux rigidus: a prospective study of age-matched and condition-matched patients. J Foot Ankle Surg. 2005;44(1):2-12.
13. Dickerson JB, Green R, Green DR. Long-term follow-up of the Green-Watermann osteotomy for hallux limitus. J Am Podiatr Med Assoc. 2002;92(10):543-54.
14. Slullitel G, López V, Calvi JP, D'Ambrosi R, Usuelli FG. Youngswick osteotomy for treatment of moderate hallux rigidus: Thirteen years without arthrodesis. Foot Ankle Surg. 2020;26(8):890-4.
15. Oloff LM, Jhala-Patel G. A retrospective analysis of joint salvage procedures for grades III and IV hallux rigidus. J Foot Ankle Surg. 2008;47(3):230-6.
16. Viladot A, Sodano L, Marcellini L, Zamperetti M, Hernandez ES, Perice RV. Youngswick-Austin versus distal oblique osteotomy for the treatment of Hallux Rigidus. Foot (Edinb). 2017;32:53-8.
17. Xu WB, Zhang F, He PP, Zhu YZ, Yao LF, Shen CC, et al. [Clinical study of Youngswick versus distal oblique osteotomy in the treatment of grade and hallux rigidus]. Zhonghua Yi Xue Za Zhi. 2020;100(27):2144-9.
18. LaMar L, Deroy AR, Sinnot MT, Haut R, Squire M, Wertheimer S. Mechanical comparison of the Youngswick, sagittal V, and modified Weil osteotomies for hallux rigidus in a sawbone model. J Foot Ankle Surg. 2006;45(2):70-5.
19. Cho BK, Park KJ, Park JK, SooHoo NF. Outcomes of the Distal Metatarsal Dorsiflexion Osteotomy for Advanced Hallux Rigidus. Foot Ankle Int. 2017;38(5):541-50.
20. Laakmann G, Green R, Green D. The Modified Watermann Procedure. A Preliminary Retrospective Study. In: Camasta, CA, Vickers NS, Ruch JA, editors. Reconstructive Surgery of the Foot and Leg, Update 96. Tucker GA: The Podiatry Institute; 1996. p. 128-35.
21. Lee JY, Tay KS, Rikhraj IS. Distal oblique osteotomy versus cheilectomy for moderate-advanced hallux rigidus: A 2-year propensity-score-matched study. Foot Ankle Surg. 2021;27(4): 443-9.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1591

Special Article

Surgical treatment in hallux rigidus: dorsal cheilectomy and Moberg osteotomy

Alberto Macklin Vadell[1], Martín Rofrano[1], Andrés Bigatti[1]

1. Sanatorio Finochietto, Buenos Aires, Argentina.

Abstract

Dorsiflexion osteotomy of the proximal phalanx of the hallux was popularized by Moberg. The combination of this technique with dorsal cheilectomy of the first metatarsal head showed good results in the surgical treatment of both mild and severe hallux rigidus. In our opinion, the combination of both techniques is the first choice for the surgical treatment of hallux rigidus.

Level of Evidence V; Case Report; Expert Opinion.

Keywords: Hallux rigidus; Osteotomy; Metatarsophalangeal joint.

Introduction

In 1952, Bonney and Macnab[1] suggested first phalangeal osteotomy for the treatment of hallux rigidus in adolescents with no major osteoarthritis involvement on the first metatarsophalangeal joint (MTPJ). Later, in 1958, Kessel and Bonney[2] published the first results of the technique. However, Moberg[3], in 1979, was the one who popularized this procedure by expanding its indication to adult patients.

Osteotomy partially defunctionalizes the MTPJ by reducing the lever arm during the takeoff phase of gait. In a cadaver study, Kim et al.[4] observed that, although this osteotomy does not reduce pressure on the joint, it leads to plantarization of the point of contact between the phalangeal base and the metatarsal head. This could partly explain patients' symptomatic improvement, considering that the dorsal region of the joint is the most affected one.

Currently, this osteotomy is rarely performed alone. The most frequent combination is that with first metatarsal dorsal cheilectomy, which was first described in 1959 by Du Vries[5]. This procedure consists of resecting part of dorsum of the first metatarsal head and periarticular osteophytes.

However, the first results with these techniques combined were only presented in 1998, by Blyth et al.[6]

The combination of both techniques at the same surgical time does not increase morbidity, maintain MTPJ mobility, allow for early weight-bearing and functional rehabilitation, and does not shorten the metatarsal neither change the bone stock, considering a possible revision surgery (Figure 1).

Indications and contraindications

This possible is usually indicated in early stages of hallux rigidus (grades 1 and 2 of Coughlin and Shurnas classification), ie, in patients with mild to moderate MTPJ pain, who have preserved joint mobility, and who does not present with major radiographic involvement[7]. However, it is also an alternative in grades 3 and 4, with excellent results, but care should be taken in patient selection. Age, type of activity patients perform, their footwear, and preoperative mobility are more important factors than radiographic findings at the time of treatment decision making.

Short female patients who usually wear high-heel shoes deserve further analysis, as well as young athlete patients that require good MTFJ mobility for their sports practice. In these cases, we believe that cheilectomy combined with Moberg osteotomy is the surgical treatment of choice, even in advanced stages.

Dorsomedial wedge osteotomy (Akin-Moberg osteotomy) of the proximal phalanx also enables to correct mild valgus deviations, especially interphalangeal valgus[8].

Study performed at the Sanatorio Finochietto, Buenos Aires, Argentina.

Correspondence: Andrés Bigatti. Arcos 2728 1°14, Ciudad Autónoma de Buenos Aires, Buenos Aires, Argentina. **E-mail:** andres_bigatti9@hotmail.com. **Conflicts of Interest:** none. **Source of funding:** none. **Date received:** October 14, 2021. **Date accepted:** February 09, 2022. **Online:** April 30, 2022.

How to cite this article: Macklin Vadell A, Rofrano M, Bigatti A. Surgical treatment in hallux rigidus: dorsal cheilectomy and Moberg osteotomy. J Foot Ankle. 2022;16(1):6-8.

Surgical technique and postoperative management

Surgery is performed with regional ankle block. The patient is placed in the supine position on the surgical table with hemostatic cuff on the ankle. Medial approach to the hallux is achieved by with divulsion of the soft tissues until reaching the articular capsule, which is usually thinned. Capsulotomy is performed to widely release the joint. Approximately 30% of the dorsum of the metatarsal head is resected in the oblique direction from proximal to distal and from dorsal to plantar, in addition to osteophytes at the proximal phalangeal base. If there are adherences at the plantar region with the sesamoids, they are gently released using a blunt curette in order to achieve a greater dorsiflexion range of motion. Next, proximal phalangeal osteotomy is performed by resecting a dorsal wedge and preserving the cortical plantar surface (osteoclasis), which will provide greater stability and prevent shearing. Osteotomy is closed and fixed with a 10-mm clamp (Figure 2). Execution of dorsomedial osteotomy also makes it possible to simultaneously correct interphalangeal valgus.

Capsulorrhaphy is conducted with the attempt of not exerting too much strength, which could stiffen the joint. The skin is then closed, and drainage and dressing are installed.

Postoperative shoes are used over dressings, and patients are allowed to perform immediate weight-bearing. Drainage removal occurs 24 hours after the procedure. Non-absorbable stitches are removed after 10 days, and passive mobilization of the MTPJ is initiated. Orthopedic footwear is removed on the second postoperative week or before, according to tolerance, and full weight-bearing with comfortable shoes is allowed.

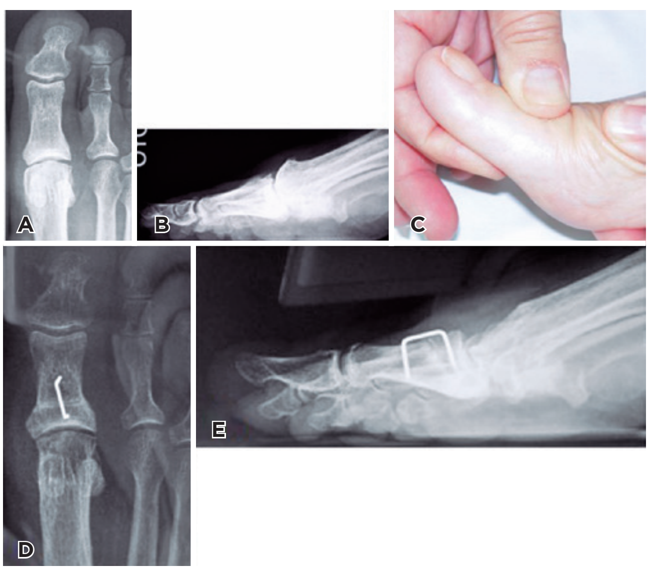


Figure 1. Images from a patient with symptomatic hallux rigidus. Front (A) and profile (B) radiographies and dorsiflexion range of motion (C). Postsurgical front (D) and profile (E) radiographies.

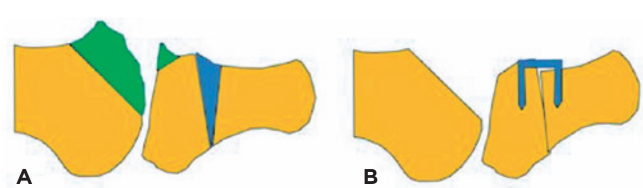


Figure 2. Sagittal scheme of the first metatarsophalangeal joint. The green area shows the portion of the metatarsal head (approximately 30%) and of the proximal phalanx that should undergo resection. The blue area shows dorsal subtraction wedge (measuring approximately 3mm. A). Immediate postoperative image of dorsal cheilectomy and Moberg osteotomy with clamp fixation (B).

Discussion

Our first experience with this procedure was in young patients with mild hallux rigidus (grades I and II). The results with these patients encouraged us to expand the indication to older patients and with more advanced grades of disease. Currently, this is the procedure most usually performed for the treatment of hallux rigidus, especially in active patients. Although radiographic progression of the lesion is a common phenomenon in the medium and long term, this does not coincide with clinical manifestation and rate of conversion to metatarsophalangeal arthrodesis is low.

Thomas and Smith(9) retrospectively assessed the results of Moberg osteotomy combined with cheilectomy in 24 feet, with a mean follow-up of 5 years, showing that 96% of patients would undergo the same procedure and did not report complications.

O'Malley et al.(10) reported their results in 84 feet with severe hallux rigidus, with a mean follow-up of 4 years, and found that 85% patients were satisfied, and 4 procedures underwent revision with metatarsophalangeal arthrodesis.

In 2010, Roukis(11) presented a meta-analysis of 11 studies covering a total of 374 feet treated with Moberg osteotomy and dorsal cheilectomy. The author found that 77% of patients reported being satisfied, and that pain was relieved or improved in 89% of procedures. Moreover, AOFAS scores improved by 39 points, and 4.8% of procedures underwent surgical revision with arthrodesis.

Conclusion

According to our work group, the association of cheilectomy with Moberg osteotomy is the first choice for the surgical treatment of hallux rigidus, both in initial and advanced stages. Patients' age, the type of activity they perform, and preoperative mobility are essential factors in treatment decision making.

Authors' contributions: Each author contributed individually and significantly to the development of this article: AMV *(https://orcid.org/0000-0002-0384-4044) Conceived and planned the activity that led to the study, interpreted the results of the study and approved the final version; MR *(https://orcid.org/0000-0003-1947-8218) Conceived and planned the activity that led to the study and interpreted the results of the study; AB *(https://orcid.org/0000-0003-1690-025X) Interpreted the results of the study, bibliographic review, data collection and formatting of the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) .

References

1. Bonney G, Macnab I. Hallux valgus and hallux rigidus; a critical survey of operative results. J Bone Joint Surg Br. 1952;34(3):366-85.
2. Kessel L, Bonney G. Hallux rigidus in the adolescent. J Bone Joint Surg Br. 1958;40(4):669-73.
3. Moberg E. A simple operation for hallux rigidus. Clin Orthop Relat Res. 1979;(142):55-6.
4. Kim PH, Chen X, Hillstrom H, Ellis SJ, Baxter JR, Deland JT. Moberg osteotomy shifts contact pressure plantarly in the first metatarsophalangeal joint in a biomechanical model. Foot Ankle Int. 2016;37(1):96-101.
5. Du Vries HL. Surgery of the foot. St Louis: Mosby; 1959.
6. Blyth MJ, Mackay DC, Kinninmonth AW. Dorsal wedge osteotomy in the treatment of hallux rigidus. J Foot Ankle Surg. 1998;37(1):8-10.
7. Coughlin MJ, Shurnas PS. Hallux rigidus. Grading and long-term results of operative treatment. J Bone Joint Surg Am. 2003; 85(11):2072-88.
8. Maes DJA, De Vil J, Kalmar AF, Lootens T. Clinical and radiological outcomes of hallux rigidus treated with cheilectomy and a Moberg-Akin osteotomy. Foot Ankle Int. 2020;41(3):294-302.
9. Thomas PJ, Smith RW. Proximal phalanx osteotomy for the surgical treatment of hallux rigidus. Foot Ankle Int. 1999;20(1):3-12.
10. O'Malley MJ, Basran HS, Gu Y, Sayres S, Deland JT. Treatment of advanced stages of hallux rigidus with cheilectomy and phalangeal osteotomy. J Bone Joint Surg Am. 2013;95(7):606-10.
11. Roukis TS. Outcomes after cheilectomy with phalangeal dorsiflexory osteotomy for hallux rigidus: a systematic review. J Foot Ankle Surg. 2010;49(5):479-87.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1593

Special Article

Minimal incision surgery in hallux rigidus

Mariano de Prado[1], Manuel Cuervas-Mons[2]

1. Servicio de Cirugía Ortopédica y Traumatología, Hospital Quirón Salud Murcia, Murcia, Spain.
2. Servicio de Cirugía Ortopédica y Traumatología, Hospital General Universitario Gregorio Marañón, Madrid, Spain.

Abstract

The choice of surgical technique in the treatment of hallux rigidus is an individual decision of the surgeon. Minimally invasive osteotomies have proven to be valid techniques, allowing us to perform cheilectomies, first proximal phalangeal osteotomies, and distal first metatarsal osteotomies. We describe the minimally invasive technique for the treatment of hallux rigidus.

Level of Evidence V; Therapeutic Study; Expert opinion.

Keywords: Hallux rigidus; Minimally invasive surgical procedures; Osteotomy.

Introduction

The choice of surgical technique for the treatment of hallux rigidus is still an individual decision of the treating surgeon[1]. Different therapeutic algorithms have been proposed[2,3] and, although none of them has been validated, minimally invasive surgery (MIS), which consists of procedures such as minimally invasive osteotomies, has proven to be a valid technique that yield results similar to those of open osteotomies for the treatment of forefoot problems[4].

Indications

Initially, conservative treatment is indicated for all patients, with the use of rocket-bottom shoes and stretching exercises of the Achillean-calcaneus-plantar system. In case of treatment failure and persistence of clinical manifestations, surgical treatment is proposed. MIS techniques allow us to perform different procedures, such as cheilectomy, first proximal phalangeal (P1) osteotomy, and distal first metatarsophalangeal (M1) osteotomy[5], with different indications according to patient's functional demand and to Coughlin and Shurnas[6] classification, as shown below:

Grade 0: conservative treatment

Grades 1-2-3:

- *Young patient with functional demand:* association of cheilectomy, descending M1 osteotomy and Moberg phalangeal osteotomy. The indication may be expanded to the initial stages of grade 4 when more than 45% of joint cartilage is of good quality, especially in cases of *metatarsus primus elevatus*.
- *Older patient or with low functional demand:* isolated cheilectomy. This procedure should be performed alone with MIS techniques only in older patients whose pain does limit everyday activities. In these patients, the main problem is the conflict of space between produced exostosis and the shoe; therefore, our surgical approach will improve clinical symptoms.

Grade 4: metatarsophalangeal arthrodesis.

Surgical technique

Cheilectomy

A 5-mm incision is made in the medial surface, dorsal to the plantar edge of the first metatarsal, proximal and dorsal to the medial sesamoid (Figure 1). A perpendicular incision is made to the skin through the capsule towards the metatarsophalangeal joint. With a movement to the dorsal and plantar direction, the entire capsule is detached from the superior and external surface of the metatarsal head, creating a space between the latter and the bone, where it will be possible to «work on»; a DPR rasp is introduced to check the space created, which will prevent soft tissue injuries. A reamer is introduced at a slow velocity, from 2,000 to 6,000 rpm, and exostosis is eliminated using oscillatory movements exactly

Study performed at the Hospital Quirón Salud Murcia, Murcia, Spain.

Correspondence: Manuel Cuervas-Mons. **Adress:** C. Dr. Esquerdo, 46, 28007, Madrid, Espanha. **E-mail:** manuel.cuervasmons@gmail.com. **Conflicts of Interest:** none. **Source of funding:** none. **Date received:** October 18, 2021. **Date accepted:** February 09, 2022. **Online:** April 30, 2022.

How to cite this article: De Prado M, Cuervas-Mons M. Minimal incision surgery in hallux rigidus. J Foot Ankle. 2022;16(1):9-11.

up to the desired level, which will be confirmed under fluoroscopic control. This process is interrupted on two or three occasions to extract the produced bone paste by pressing the capsule on the metatarsal head towards the skin incision, as well as to introduce the DPR rasp, in order to extract fine body remains and adherences to the deep surface of the capsule. The repetition of these procedures makes it possible to perform complete exostectomy and appropriate cleaning.

Distal M1 osteotomy

A Shannon 44 reamer is introduced through the portal created for cheilectomy. Under fluoroscopic control, the reamer is placed in an angle of approximately 45° in relation to the M1 axis, in the plantar-proximal direction. Osteotomy is performed is performed in an oblique direction of 45° from distal-dorsal to plantar-proximal, with the upper limit defined as the final portion of the neck when reaching the joint cartilage. Subsequently, the metatarsal head is lowered and moved back by pressing it to the proximal direction.

P1 osteotomy

An incision is made over the dorsomedial surface of the P1 base, medial to the extensor hallucis tendon (Figure 2). A rasp is introduced to conduct periosteal section, a straight 2-15 reamer is introduced, supported on the cortical bone, and then a digital extension movement is performed to prevent damages to the surrounding neurovascular structures. Osteotomy perpendicular to the proximal phalangeal axis and starts with a lateral rotation movement, using the skin incision as a pivot point. Osteotomy is completed sparing some millimeters of the plantar cortical surface. The desired dorsal wedge is created by applying dorsal pressure on the toe whereas the reamer performs a slightly oscillatory movement.

Postoperative care

Weight bearing with postoperative shoes is allowed soon after intervention. A clinical follow-up is performed on the 7th postoperative day, suture stitches are removed, and postoperative bandage is changed to metatarsal band and Coban™ cohesive bandage, and patients are instructed on how to apply it so that they can change it every day after foot personal hygiene. During the first 4 weeks, gait is allowed only with postoperative shoes. One month later, a new clinical and radiological follow-up is performed, and patients are allowed to wear new shoes, provided that they have rigid soles, are wide, and have laces so that they can be properly adjusted in order to prevent slapping. Intense physical activity is not allowed up to nearly 2 months after intervention.

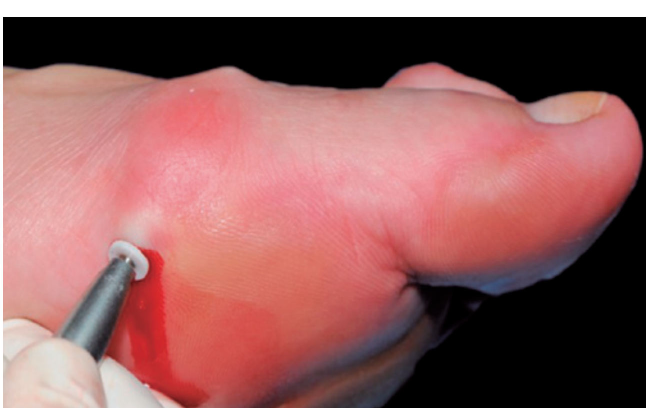


Figure 1. Cheilectomy and distal M1 osteotomy approach.

Figure 2. P1 osteotomy approach.

Figure 3. Pre-and postoperative radiographic study.

Complications

The rate of complications may decrease significantly with the participation in specific training courses. Possible complications resulting from the technique include postsurgical hematoma, persistent edema, joint stiffness, transfer metatarsalgia, displacement secondary to osteotomies, and delayed union. Delayed union of first metatarsal osteotomies is frequent, the presence of nonunion cannot be considered except for cases that exceed the minimum time of progression of 18 months. This delayed union is produced by osteotomy mobility, and, on other occasions, it may be favored by possible bone necrosis produced by the action of cutting reamers at more than 10,000 rpm. It may also be observed in cases when metatarsal head was excessive and did not receive any weight-bearing stimulation.

Results

We conducted an analysis of surgical treatment results of patients with *hallux rigidus* whose conservative treatment failed. Surgical treatment was performed in 42 patients, with mean age of 51 years, 24 men and 18 women; *hallux rigidus* was classified as grade II in 14 patients, and as grade III in 28 of them, according to the Coughlin and Shurnas classification. All patients were subjected to a minimally invasive technique combining cheilectomy, Moberg P1 base osteotomy, and distal dorsal closing M1 descending osteotomy. Mean follow-up time was 27 months, with clinical and radiological follow-up (Figure 3). Pre-and postoperative AOFAS scores were assessed. Mean AOFAS score was 44 preoperatively and 82 at the end of follow-up, and outcomes were classified as good or excellent in 86% of patients.

Complications were present in five patients: two cases of transfer metatarsalgia, one case of delayed union, one case of postoperative stiffness, and one case of postoperative hematoma. Stiffness was treated using percutaneous arthrolysis, delayed union was achieved at 8 months of follow-up, and postoperative hematoma spontaneously resolved with no need for drainage.

Radiological outcomes are comparable to those of open surgery, with osteotomies exhibiting union rates of 100% of the reviewed cases.

Conclusion

Minimally invasive surgery for the treatment of hallux rigidus allows us to perform different surgical techniques and is a useful therapeutic tool for our patients, with results similar to those of open surgery.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MP *(https://orcid.org/0000-0002-1455-0148) Conceived and planned the activities that led to the study, interpreted the results of the study, performed the surgeries and data collection, survey of the medical records, and approved the final version; MCM *(https://orcid.org/0000-0001-9310-5853) Participated in the review process, statistical analysis, bibliographic review and formatting of the article, clinical examination. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Polzer H, Polzer S, Brumann M, Mutschler W, Regauer M. Hallux rigidus: Joint preserving alternatives to arthrodesis - a review of the literature. World J Orthop. 2014;5(1):6-13.
2. Asunción Márquez J, Martin X. Hallux rigidus: aetiology, diagnosis, classification and treatment. Rev Esp Cir Ortop Traumatol. 2010;54(5):321-8.
3. Viladot-Pericé R, Álvarez-Goenaga F, Formiguera-Sala S. Update on the Treatment of Hallux Rigidus. Rev Ortop Traumatol. 2006;50(3):233-40.
4. Bauer T, de Lavigne C, Biau D, De Prado M, Isham S, Laffenétre O. Percutaneous hallux valgus surgery: a prospective multicenter study of 189 cases. Orthop Clin North Am. 2009;40(4):505-14.
5. De Prado M, Ripoll PL, Golanó P. Minimally invasive foot surgery: surgical techniques, indications, anatomical basis. Barcelona: About Your Health; 2009. p. 63-109.
6. Coughlin MJ, Shurnas PS. Hallux rigidus: demographics, etiology, and radiographic assessment. Foot Ankle Int. 2003;24(10):731-43.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1594

Special Article

Keller resection arthroplasty

Antonio Viladot Voegeli[1], Mariano Nuñez-Samper[2]

1. Orthopaedic Department, Clínica Tres Torres, Barcelona, Spain.
2. Hospital Virgen del Mar, Madrid, Spain.

Abstract

The resection arthroplasty first described by Keller for *hallux valgus* has subsequently been applied to treat *hallux rigidus*. Some variations to the original procedure have been described, such as the interposition of soft tissue in the resection area (joint capsule, tendon, etc.), as a spacer, in order to reduce the amount of phalanx to be resected and improve stability and mobility. Another procedure, proposed by Valente Valenti, consists of performing a "V" shaped arthrectomy in the sagittal plane, at the level of the metatarsal and the phalanx. We are faithful to the original technique, resecting approximately one third of the phalangeal base and the periarticular osteophytes, seeking for the correct balance between the flexor and extensor muscles of the hallux. Resection arthroplasty is indicated in stage III or in stage III-IV of the Regnauld and Coughlin and Shurnas classifications, respectively. Both in our own experience and when reviewing the bibliography, we find that very acceptable results are obtained.

Level of Evidence V; Therapeutic Studies; Expert Opinion.

Keywords: Hallux rigidus; Arthroplasty; Osteoarthritis.

Introduction

Resection arthroplasty was described by Keller[1] in 1904 for the surgical treatment of *hallux valgus* and subsequently started being used in the treatment of *hallux rigidus.* It bears noting that this technique has yielded better results in the treatment of *hallux rigidus* than in that of *hallux valgus*[2].

Some authors[3] proposed soft tissue interposition in the resection area, by way of spacer, in order to reduce the amount of phalanx to be resected and improve stability and mobility.

In 1985 Valenti[4] proposed a change in resection arthroplasty that consisted of performing a V-shaped hinge arthrectomy in the sagittal plane, at the level of the metatarsal and the phalanx. This technique preserves length of first ray and function of *flexor hallucis brevis* and sesamoids.

Indications

Resection arthroplasty, with or without interposition, and Valenti technique, are indicated in advanced disease stages (grade III of the Regnauld classification[5] and grade III-IV of the Coughlin and Shurnas classification[6], in which patients feel constant pain during gait, which is often performed in a supine position, and present with plantar keratosis and significant joint stiffness. Radiological findings show markedly reduced or absent joint space, deformities of the phalangeal base, great osteophytic reaction, and periarticular osteoarthritic sclerosis, behaving as a true "joint disease".

For the surgical treatment in these stages, basically three techniques have been proposed: arthrodesis, arthroplasty with partial or complete prosthesis, and resection arthroplasty, which is the object of the present study.

For many authors[7,8], metatarsophalangeal arthrodesis is the technique of choice, despite presenting a series of complications[9-11]. These complications have an increased incidence in older patients and in those with inflammatory diseases, such as rheumatoid arthritis, or with diabetes[12].

Metatarsophalangeal prostheses, either total or partial, are techniques currently under development. In the literature published so far, there are no satisfactory medium-long term outcomes[7,13].

Surgical technique

To obtain good results with the Keller technique (Figure 1), several important technical details should be considered:

Study performed at the Hospital Virgen del Mar, Madrid, Spain.

Correspondence: Antonio Viladot Voegeli. **Adress:** C. de Honduras, 14, 28016, Madrid, Spain. **E-mail:** 9393avv@gmail.com. **Conflicts of Interest:** none. **Source of funding:** none. **Date received:** October 24, 2021. **Date accepted:** February 8, 2022. **Online:** April 30, 2022.

How to cite this article: Viladot Voegeli A, Nuñez-Samper M. Keller resection arthroplasty. J Foot Ankle. 2022;16(1):12-5.

- *Avoid excessive resection*. It is usually sufficient to resect one-third of the phalanx, so that to prevent *hallux* instability.
- Seek for *sufficient resection.* This prevents postoperative joint stiffness and recurrence. At the end of the procedure, it is important to check joint mobility.
- At the end of intervention, there should be a *balance between flexor and extensor muscles.* Flexor insufficiency leads to flaccid *hallux* in the capacity of impulse in the third rocker of the gait. Extensor predominance will lead to claw *hallux* and valgus deviation. In order to prevent these complications, extensor elongation should be performed, if necessary, and the plantar plate should always be anchored to the flexor hallucis longus to maintain the flexor strength of the toe.
- *Hallux rigidus* usually appears in an Egyptian forefoot or in a square forefoot; therefore, phalangeal resection, if properly performed, does not cause excessive shortening of the *hallux* in relation to the second toe. The Keller technique should be ruled out in some cases when the *hallux* is preoperatively much shorter than the second toe (Greek forefoot), due to the esthetic and functional problem that it causes.

If soft tissue interposition arthroplasty is indicated, several surgical options are available, which use different bioimplants:

- *Resection arthroplasty with capsular interposition*[14]: the classical Keller technique is combined with the interposition of the dorsal capsule and the extensor *hallucis brevis* tendon.
- *Semitendinosus tendon allograft arthroplasty*[15]: this technique, which uses cryopreserved semitendinosus tendon, may be a salvage option for failed procedures in *hallux rigidus* surgery.
- *Tendon allograft arthroplasty of the metatarsophalangeal joint*[16] consists of interposing the tendon allograft rolled in the form of an *"anchovy"* within the joint. Subsequently, the interposition graft is stabilized through a bone tunnel and suture anchors.

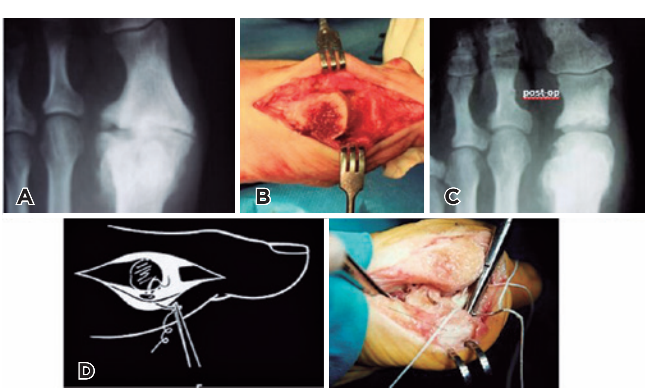


Figure 1. Keller technique. A) Preoperative radiograph; B) Surgical photograph of resection; C) Postoperative radiograph; D) Anchor of the flexor hallucis longus to the plantar plate, maintaining Hallux flexor strength.

- *Soft tissue interposition arthroplasty.* Arthroplasty with interposition of autogenous soft tissue is another option proposed as an alternative to arthrodesis, due to its safety and efficacy, as presented by Schenk et al.[17] in their studies.
- *Interposition arthroplasty using a regenerative tissue matrix.* In this procedure, a human acellular dermal regenerative matrix is used as an interposition graft (*Allo-derm*). Berlet et al.[18] confirmed good outcomes with this technique.

As an anecdote, it is worth remembering that a procedure of metallic interposition arthroplasty, named "en Bouchon", was used in France some years ago, consisting of the placement of a metallic button that was stabilized with a Kirschner needle. The needle and then the implant were removed after some weeks. This technique is not currently used.

In Valenti resection arthroplasty, osteotomy is performed with cuneiform resection of the metatarsal head at an angle of 45°, starting behind dorsal exostosis, directed from dorsal to plantar and from proximal to distal. Next cuneiform resection at an angle of 45° is performed on the phalangeal base, directed from dorsal to plantar and from distal to proximal. Subsequently, sesamoids are released and corrected. At the end of the surgery, *hallux* dorsiflexion should reach 90º.

Results

Good results have been published in the literature[19,20] when the Keller technique is successfully conducted. Our personal experience is also favorable. In 2005, Gasch-Blasi et al.[21] conducted a long-term review of 48 feet with a mean follow-up of 121 months (minimum 60 months, maximum 216 months). They found that 92% of patients were satisfied with the procedure and, considering the result, would undergo surgery again, and that the 8% of dissatisfied patients presented with recurrence of clinical manifestations.

We agree with Jahss[22] that the poor outcomes that are attributed to the Keller technique in *hallux rigidus* may be in fact attributable to a poor execution of the surgical technique rather than to the technique itself.

An interesting study by O'Doherty et al.[23] compared the results of metatarsophalangeal arthrodesis with those of Keller resection arthroplasty. The authors highlight the great patients' satisfaction with both techniques and did not find differences in terms of pain relief, improved gait, comfort with shoes, and transfer metatarsalgia. According to these authors, with whose opinion we agree, the advantages of the Keller technique lie in its simplicity, its more comfortable postoperative period for the pain, its low level of reoperation (in their series, nonunion was found in 44% of arthrodesis procedures, although most of them were asymptomatic).

With regard to interposition arthroplasty, despite the theoretical advantages of the modified technique, some authors did not find better outcomes compared with those of the traditional Keller technique[17]. In a clinical and radiological study, Watson et al.[14] compared 22 feet treated with interposition arthroplasty with 30 feet subjected to the traditional Keller procedure. The authors did not observe any statistically significant difference between the two groups in terms of patients' satisfaction.

As for the Valenti technique, there are few studies published in the literature, but the scarce results published so far are very similar.

In a review study conducted by Colò et al.[24] analyzed 8 articles, for a total of 347 patients, and a mean follow-up of 6±7 years. They did not find substantial differences in clinical outcomes between the original and modified techniques.

Complications

The most frequent complications of resection arthroplasty are (Figure 2):

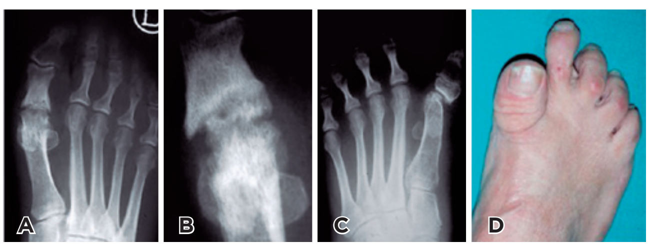


Figure 2. Complications of the Keller technique. A) Stiffness; B) Necrosis; C) Instability and secondary deviation; D) Excessively short *Hallux*

- *Joint Instability,* usually related to excessive resection of the phalanx. It leads to dorsiflexion valgus deformity of the *hallux*, to a flaccid toe that is unable to touch the ground and to perform the third rocker of gait, and to transfer metatarsalgia.
- *Joint stiffness and secondary arthrosis*, both related insufficient resection of the phalangeal base.
- *Avascular necrosis* of the metatarsal head, caused by excessive release of soft tissues and section of the vascular plantar package.
- *Esthetic problems.* In some cases, there is excessive shortening of the *hallux* in relation to the second toe.

Interposition arthroplasty may present the same complications, in addition to soft tissue reactions or failure of biological material.

The Valenti technique does not involve shortening of the ray; however, in addition to the previously described complications, sesamoiditis is a relatively frequent problem (7.4%), although it is often transient[25].

Conclusion

We believe that Keller resection arthroplasty, with or without interposition, and the Valenti technique are the techniques of choice in older patients with end-stage *hallux rigidus* and severe joint involvement.

Authors' contributions: Each author contributed individually and significantly to the development of this article: AVV *(https://orcid.org/0000-0002-4192-6163) Conceived and planned the activities that led to the study, interpreted the results of the study, performed the surgeries and data collection, survey of the medical records, and approved the final version; MNS *(https://orcid.org/0000-0001-9398-0375) Participated in the review process, statistical analysis, bibliographic review and formatting of the article, clinical examination. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Keller WL. Surgical treatment of bunions and hallux valgus. New York Med J. 1904;80:741.
2. Wrighton JD. A ten-year review of Keller's operation. Review of Keller's operation at the Princess Elizabeth Orthopaedic Hospital, Exeter. Clin Orthop Relat Res. 1972;89:207-14.
3. Hamilton WG, O'Malley MJ, Thompson FM, Kovatis PE. Roger Mann Award 1995. Capsular interposition arthroplasty for severe hallux rigidus. Foot Ankle Int. 1997;18(2):68-70.
4. Valenti V. L´artrectomia "a cerniera" di valenti nel tratamento chirurgico dell´alluce rigido. Chir Piede. 1985;9:261-6.
5. Regnauld B. The foot: pathology, etiology, semiology, clinical investigation and therapy. Berlin: Springer Verlag; 1986.
6. Coughlin MJ, Shurnas PS. Hallux rigidus. Grading and long-term results of operative treatment. J Bone Joint Surg Am. 2003; 85(11):2072-88.
7. Simpson GA, Hembree WC, Miller SD, Hyer CF, Berlet GC. Surgical strategies: hallux rigidus surgical techniques. Foot Ankle Int. 2011;32(12):1175-86.
8. Deland JT, Williams BR. Surgical management of hallux rigidus. J Am Acad Orthop Surg. 2012;20(6):347-58.
9. Lombardi CM, Silhanek AD, Connolly FG, Dennis LN, Keslonsky AJ. First metatarsophalangeal arthrodesis for treatment of hallux rigidus: a retrospective study. J Foot Ankle Surg. 2001; 40(3):137-43.
10. Goucher NR, Coughlin MJ. Hallux metatarsophalangeal joint arthrodesis using dome-shaped reamers and dorsal plate fixation: a prospective study. Foot Ankle Int. 2006;27(11):869-76.
11. Roukis TS. Nonunion after arthrodesis of the first metatarsal-phalangeal joint: a systematic review. J Foot Ankle Surg. 2011; 50(6):710-3.

12. Anderson JJ, Rowe GP, Hansen M. Complication rates in diabetics with first metatarsophalangeal joint arthrodesis. Diabetic Foot Ankle. 2014;5:24649.
13. Fuhrmann RA, Wagner A, Anders JO. First metatarsophalangeal joint replacement: the method of choice for end-stage hallux rigidus?.Foot Ankle Clin 2003:8(4):711-21.
14. Watson TS. Panicco J, Parek H. Allograft tendon interposition arthroplasty of the hallux metatarsophalangeal joint: a technique guide and literature review. Foot Ankle Int. 2019;40(1):113-9.
15. Miller D, Maffulli N. Fee gracilis interposition arthroplasty for severe hallux rigidus. Bull Hosp Jt Dis. 2005;62(3-4):121-4.
16. Thomas D, Thordarson D. Rolled Tendon Allograft Interposition Arthroplasty for Salvage Surgery of the Hallux Metatarsophalangeal Joint. Foot Ankle Int. 2018;39(4):458-62.
17. Schenk S, Meizer R, Kramer R, Aigner N, Landsiedl F, Steinboeck G. Resection arthroplasty with and without capsular interposition for treatment of severe hallux rigidus. Int Orthop. 2009;33(1):145-50.
18. Berlet GC, Hyer CF, Lee TH, Philbin TM, Hartman JF. Active Interpositional arhrtoplasty of the first MTP joint. A regenerative tissue matrix for the treatment of advanced hallux rigidus Foot Ankle Int. 2008;29(1):10-21.
19. Easley ME, Anderson RB. Hallux rigidus in the adult and adolescent. In: Adelaar R, editor. Disorders of the Great Toe. Rosemont, IL: American Academy Orthopaedic Surgeons; 1997. p. 23–32.
20. Schneider W, Kadnar G, Kranzl A, Knahr K. Long-term results following Keller resection arthroplasty for hallux rigidus. Foot Ankle Int. 2011;32(10):933-9.
21. Gasch-Blasi J, Marzal E, Viladot-Voegeli A. Resultados de la técnica de Brandes-Keller para la corrección del hallux rigidus. In: Actas del 27 Congreso Nacional AEMCP. Madrid: AEMCP; 2005. p. 60.
22. Jahss MH. Editorial. Foot Ankle. 1984;4:227-8.
23. O'Doherty DP, Lowrie IG, Magnussen PA, Gregg PJ. The management of the painful first metatarsophalangeal joint in the older patient. Arthrodesis or Keller's arthroplasty? J Bone Joint Surg Br. 1990;72(5):839-42.
24. Colò G, Samaila EM, Magnan B, Felli L. Valenti resection arthroplasty for hallux rigidus: A systematic review. Foot Ankle Surg. 2020;26(8):838-44.
25. Harisboure A, Joveniaux P, Madi K, Dehoux E. The Valenti technique in the treatment of hallux rigidus. Orthop Traumatol Surg Res. 2009;95(3):202-9.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1592

Special Article

Hallux Arthrodesis

Jesús Vilá y Rico[1,2,3], Yolanda Hernanz[1], Ana Abarquero-Diezhandino[1,2]

1. Hospital Universitario 12 de octubre, Madrid, Spain.
2. Hospital Quirónsalud Ruber, Madrid, Spain.
3. Universidad Complutense de Madrid, Madrid, Spain.

Abstract

Hallux arthrodesis is a prominent technique, both in primary surgery and in reoperations. New devices and instruments have significantly improved outcomes, minimizing complications, although it is a demanding intervention from the technical point of view and not exempt from complications. Arthrodesis is indicated in cases of primary or secondary *hallux rigidus*, and also as a salvage surgery for previous failed treatments such as joint sparing osteotomies or arthroplasty. Proper arthrodesis positioning is important, maintaining a dorsiflexion of 10-15º with a *hallux valgus* angle of nearly 10° and neutral rotation, in order to prevent complications such as *hallux varus* or interphalangeal joint arthritis. Arthrodesis outcomes are excellent from the clinical-functional and radiological point of view, with a union rate of 93.5%; however, this technique is not exempt from complications such as nonunion, malunion, need for hardware removal, and skin and healing problems. Nonetheless, this technique provides excellent outcomes.

Level of Evidence V; Therapeutic Studies; Expert Opinion.

Keywords: Arthrodesis; Hallux rigidus; Metatarsophalangeal joint.

Introduction

Hallux rigidus is defined as a metatarsophalangeal (MTP) and metatarsosesamoid arthritis of the great toe that causes limited mobility, especially in dorsiflexion range of motion. As a consequence, patients experience changes in gait and pain. During the takeoff phase of gait, or "third rocker", dorsiflexion of 65°-75° of the MTP joint (MTPJ) of the great toe is required[1].

Hallux rigidus may be distinguished into primary and secondary. Secondary *hallux rigidus* appears as a sequel of previous surgeries, especially of interventions such as Keller resection arthroplasty or percutaneous surgery, as well as in other conditions such as after trauma or microtrauma, in metabolic changes such as gout, in inflammatory processes such as rheumatoid arthritis or osteochondritis dissecans (Figure 1).

Methods

Indications

Main indications are primary end-stage *hallux rigidus* (grades III or IV), in cases of secondary hallux rigidus, especially in sequelae of Keller-Brandes-Lelievre resection arthroplasty, minimally invasive percutaneous surgery, or in cases of failure with other techniques for the treatment of *hallux rigidus*, whether joint sparing surgical procedures such as osteotomy or arthroplasty or hemiarthoplasty[2].

Study performed at the Hospital Universitario 12 de octubre, Madrid, Spain.

Correspondence: Ana Abarquero-Diezhandino. Hospital Universitario 12 de Octubre. Av. de Córdoba, s/n, 28041. Madrid, Spain. **E-mail:** ana.abarquero@gmail.com.
Conflicts of Interest: none. **Source of funding:** none. **Date received:** October 16, 2021. **Date accepted:** January 28, 2022. **Online:** April 30, 2022.

How to cite this article: Vilá y Rico J, Hernanz Y, Abarquero-Diezhandino A. Hallux Arthrodesis. J Foot Ankle. 2022;16(1):16-20.

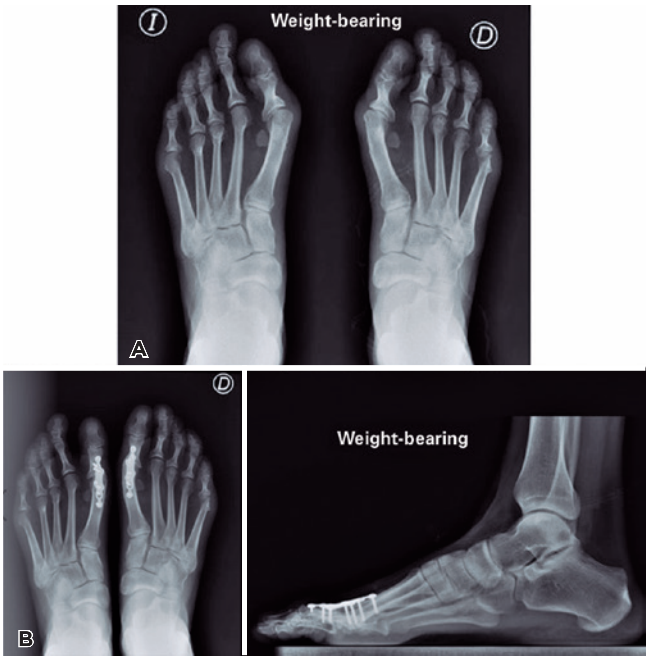


Figure 1. A) A 42-year-old patient who presents *hallux rigidus* secondary to percutaneous forefoot surgery with severe degenerative changes and joint incongruence. B) Final radiological outcome after arthrodesis with dorsal plate and concave-convex reaming with proper position both in frontal and sagittal planes.

It is important to maintain a mobile interphalangeal joint for the success of intervention. Arthrolysis may also be performed if necessary.

At the time of selecting the surgical technique, it is essential to assess the size of the proximal phalanx of the *hallux* (P1) in order to perform single-or two-stage arthrodesis, as we will subsequently show. Furthermore, other comorbidities that may be associated with a higher rate of complications should be considered, such as diabetes mellitus, obesity, smoking, vascular diseases, etc.

Surgical Technique

Approach

Most cases consist of severe *hallux rigidus* and primary arthrodesis; thus, we recommend using dorsal approach. In reoperations in which medial approach to the MTPJ was previously used, this is the preferred approach. The advantage of dorsal approach is better exposure of the joint; however, if we choose dorsal plaque fixation, the implant is positioned immediately below the extensor tendon of the great toe, with the possible complications resulting from tendon irritation.

Joint surface preparation

Currently, the most used form of joint preparation are concave-convex reamers, which allows for a greater joint congruence and the possibility of correcting spatial plane deviations. There are other forms of joint surface preparation, such as simple chondral resection[3] with gouge and cartilage excision, planar sections using a saw[4], or minimally invasive arthroscopic[5] or percutaneous[6,7] techniques.

In a systematic review, Hodel et al.[6] concluded that minimally invasive techniques are promising in terms of clinical outcomes, complication rate, and union rate. These techniques have the advantage of leading to fewer soft tissue injuries, and their disadvantages result from poorer osteosynthesis and limitations in placing the *hallux* in the proper position.

We recommend preparation with concave-convex reams and subsequent both stimulation through perforations with the same reaming guide wire on the surfaces of metatarsal head and P1 base. From the technical point of view, it is important to perform reaming directly with the approximate size of reams rather than progressive increasing from an initial small reaming.

Arthrodesis position

The most commonly accepted position is 10-15º of dorsiflexion with a *hallux valgus* or metatarsophalangeal angle of 0-15° in the axial plane and neutral rotation. Over the last years, there has been a trend to reduce MTPJ dorsiflexion. This optimal position is essential for the correct contact of joint surfaces. Arthrodesis position may be intraoperatively tested using a hard surface and performing a load simulation test. It is important for the nail to the directed towards the zenith, in order to prevent malrotations.

Correct arthrodesis position is important to prevent complications such as *hallux varus* or interphalangeal joint arthritis[8,9].

Fixation methods

Numerous types of implants have been developed over the last years. In the early 1990's, dorsal plates started to experience a significant growth. Previously, Kirschner wires, cannulated screws, usually crossed, or pines biodegradables had been employed. Several biomechanical studies have endorsed the superiority of plates, whether associated with interfragmentary compression screws or not[10-12]. New designs of low-profile plates with the possibility of employing threaded screws increase stability, including in situations of bones with osteoporosis.

Asif et al.[3] advocate for the use of cannulated screws, stating that it is a simple technique with a lower economic cost than dorsal plates and with good results in terms of union rate, showing a nonunion rate of 6.6%, although up to 36% of these cases are asymptomatic. Other authors also endorse the use of cross cannulated screws, based on biomechanical stability and union rates[13-15].

Recently, intramedullary devices have been developed for MTPJ fixation. These devices have the advantage of prevented hardware removal related to dorsal plates, and satisfactory outcomes have been published from the clinical point of view and high union rates (95%)[16].

Roukis[17] conducted a systematic review of 2,656 arthrodesis procedures performed in cases of *hallux valgus* (47.2%), *hallux rigidus* (32%), rheumatoid arthritis (11.5%), and revision of failed surgery (9.3%) and fixed with cannulated screws, dorsal plaques, and staples. The incidence of nonunion was 5.4%, of malunion was 6.1%, and of hardware removal was 8.5%. The author concluded that union rate is higher when joint surfaces are prepared with low velocity systems and did not find statistically significant differences in fixation when comparing cannulated screws, locked plates, or non-locked plates, with a union rate of 93.5%, showing better results when the procedure is indicated for *hallux rigidus*.

Over the last years, nickel and titanium staples have been increasing popular, with or without shape memory for MTP arthrodesis, isolated or associated with other fixation systems such as screws or intramedullary devices, with good outcomes and high union rates[18,19].

Arthrodesis - distraction with intercalary graft

In cases of P1 deficiency due to shortening of 2.5-3 cm in length, it will be necessary to a cortico-spongy intercalary graft from the iliac crest and to perform single- or two-stage arthrodesis (Figure 2). The advantage of two-stage surgery with the first stage of surgical debridement, correction of deformity, and placement of a monolateral fixator is preventing neurovascular complications resulting from elongation[20]. Gradual elongation is gradually performed at a rate of 2 mm per day, with the close monitoring of toe vascularization of toe vascularization.

Since desired elongation is achieved, a new intervention is conducted after 2-3 weeks, with the removal of fixator through the same incision, resection of fibrous tissue remnants, and placement of autologous cortico-spongy bone graft from the iliac crest with the size previously measured between the two bone surfaces.

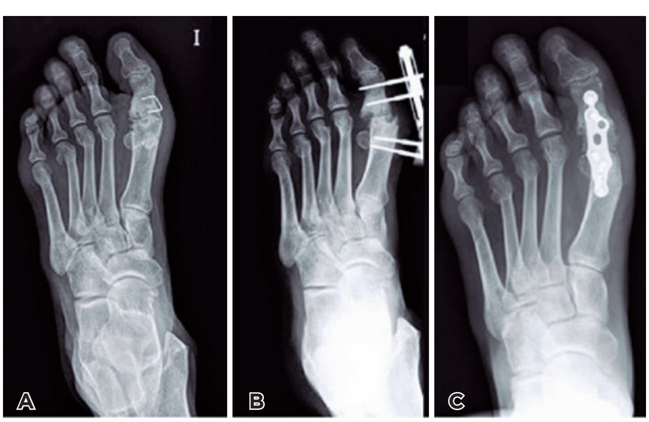


Figure 2. Technique of two-stage distraction arthrodesis for *hallux rigidus* as a sequel of Keller-Brandes-Lelievre intervention in a 29-year-old patient. A) initial x-rays. B) first stage of arthrodesis with monolateral Hoffman minifixator. C) final outcome after placement of a cortico-spongy graft and osteosynthesis with a revision dorsal plate.

Afterwards, the entire assembly is stabilized with an appropriately contoured low-profile plate or with the same fixator exerting compression. Stability is greater with the plate. Currently, there are two plates available specific for reoperations that improve stability. Maintaining the external fixator as a definitive treatment is especially indicated in cases of poor soft tissue status or sequelae from infection.

Nuñez-Samper and Viladot[20,21] published the surgical technique in a series of 40 patients, with satisfactory outcomes from the clinical point of view and a nonunion rate of 7.5%.

Postoperative care

Currently, the most spread postoperative protocol allows for immediate partial weight-bearing with rigid shoes during the first 6 weeks and for their subsequent removal and progressive weight-bearing with conventional shoes.

Discussion

Metatarsophalangeal arthrodesis is the procedure of choice for the surgical correction of severe *hallux valgus* with great MTPJ instability, especially when associated with osteoarthritic degenerative processes or rheumatoid arthritis. It is equally useful and provides good results for first ray reconstruction due to sequelae from previous operations. Moreover, arthrodesis is an excellent option in young active patients, allowing for resumption of sports activities in 88% of patients[22].

Arthrodesis success depends on technical and biological factors. Technical factors include satisfactory joint surface preparation, proper fusion position, and fixation technique. Biological factors include comorbidities (such as inflammatory arthropathy and vascular diseases), regular medications (such as corticosteroids, non-steroidal anti-inflammatory drugs, or immunosuppressive agents) that may impair union, and smoking. Joint surface preparation with cup and cone reamers has the advantage of being versatile in the positioning of fusion site and increasing stiffness at the fusion site[23]. The use of planar sections in joint surfaces may increase the area of fusion surface; Politi et al.[24] suggest that this preparation provide more stability than conical reaming when oblique compression screws are used for fixation; however, this type of planar preparation predetermines arthrodesis alignment.

Postoperative treatment may also be a determining factor for union success. Ellington et al.[25] found a nonunion rate of 12% in patients who started weight-bearing with a boot on the second postoperative week. Hunt et al.[26] described a nonunion rate of 23% with locked plate using the same postoperative protocol. Our protocol allows performing partial weight-bearing in the immediate postoperative period with rigid-sole shoes for 6 weeks, which enables earlier mobilization, facilitates patient's discharge on the day of the surgery, allows for an earlier return to work, and does not seem to have an adverse effect on union.

Figure 3. Protrusion of locked screws from a dorsal plate.

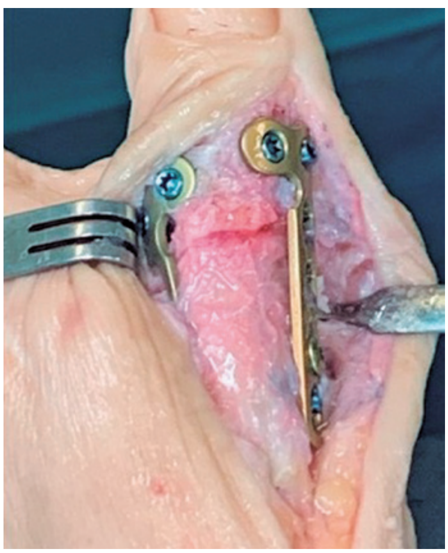


Figure 4. Double plating and grafting in a reoperation for nonunion.

Malunion is not well tolerated by patients[27]. Dorsiflexion of less than 10 degrees may increase pressure on the tip of the great toe, whereas excessive dorsiflexion leads to increased pressure below the first metatarsal head. Excessive pronation or medial rotation of the great toe may lead to increased pressure along the medial area.

With regard to the comparison between arthrodesis and total arthroplasty, Gibson and Thomson[28] conducted a prospective randomized study (level II) and found that arthrodesis is more effective than total arthroplasty, observing a rate of up to 16% of early failure of MTP prosthesis, establishing a grade of recommendation B or moderate for the treatment of end-stage hallux rigidus (grade IV).

The main complication of arthrodesis is nonunion, whose frequency ranges from 0 to 30%[29]. The proper positioning of the *hallux* in the coronal and sagittal planes is essential to the success of intervention and to prevent complications. Most complications of *hallux* arthrodesis are related to technical failures[30]. The main complications are nonunion and malunion[31,32]. Other complications include problems related to hardware (Figure 3), progression of interphalangeal joint arthritis, and transfer metatarsalgia. The overall incidence of malunion is 6.1%, a phenomenon that 87.1% of the cases result from dorsiflexion position of joint surfaces, which also leads to microtrauma from footwear and presence of subungual ecchymosis. Furthermore, the dorsiflexion position overloads the first metatarsal and the sesamoids, resulting in residual pain. In the coronal plane, excessive abduction damages the skin of the first interdigital space and there is difficulty in wearing shoes due to excessive varus. The nonunion rate of after primary arthrodesis ranges from 0 to 20% in the literature[19]. It is critical to perform a correct joint surface preparation until reaching a properly vascularized healthy subchondral bone and an appropriate and stable fixation.

Cases of nonunion should be treated with placement of cortico-spongy graft and stabilization with a revision single dorsal plate, or sometimes double-plating, in order to improve arthrodesis stability[33] (Figure 4).

Conclusions

Hallux arthrodesis is the current gold standard, or standard technique, for the treatment of severe symptomatic *hallux rigidus* (grades III and IV). Better outcomes are related with proper fusion positioning (10-15° of dorsiflexion and 10-15° of valgus) and careful joint surface preparation.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JVR *(https://orcid.org/0000-0002-8558-0109) Wrote the article, participated in the review process, bibliographic review, formatting of the article, interpreted the results of the study, performed the surgeries; YH *(https://orcid.org/0000-0001-9590-9142) Participated in the review process, bibliographic review; AAD *(https://orcid.org/0000-0001-9729-5471) Participated in the review process, bibliographic review. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Viladot-Pericé R, Álvarez-Goenaga F, Formiguera-Sala S. Update on the treatment of hallux rigidus. Rev OrtopTraumatol. 2006; 50:233-40.

2. Herrera-Pérez M, Andarcia-Bañuelos C, de Bergua-Domingo J, Paul J, Barg A, Valderrabano V. Proposed global treatment algorithm for Hallux rigidus according to evidence-based medicine. Rev Esp Cir Ortop Traumatol. 2014;58(6):377-86.

3. Asif M, Qasim SN, Kannan S, Bhatia M. A consecutive case series of 166 first metatarsophalangeal joint fusions using a combination of cup and cone reamers and crossed cannulated screws. J Foot Ankle Surg. 2018;57(3):462-5.
4. Korim MT, Mahadevan D, Ghosh A, Mangwani J. Effect of joint pathology, surface preparation and fixation methods on union frequency after first metatarsophalangeal joint arthrodesis: A systematic review of the English literature. Foot Ankle Surg. 2017;23(3):189-94.
5. Carro LP, Vallina BB. Arthroscopic-assisted first metatarsophalangeal joint arthrodesis. Arthroscopy. 1999;15(2):215-7.
6. Hodel S, Viehöfer A, Wirth S. Minimally invasive arthrodesis of the first metatarsophalangeal joint: A systematic literature review. Foot Ankle Surg. 2020;26(6):601-6.
7. De Prado M, Cuervas-Mons M, De Prado V, Golanó P. Minimally invasive management of hallux rigidus. In: Scuderi G, Tria A, editors. Minimally invasive surgery in orthopedics. New York: Springer; 2010. p. 75-87.
8. Hamilton GA, Ford LA, Patel S. First metatarsophalangeal joint arthrodesis and revision arthrodesis. Clin Podiatr Med Surg. 2009; 26(3):459-73.
9. Coughlin MJ, Shurnas PS. Hallux rigidus. Grading and long-term results of operative treatment. J Bone Joint Surg Am. 2003; 85(11):2072-88.
10. Bennett GL, Sabetta J. First metatarsalphalangeal joint arthrodesis: evaluation of plate and screw fixation. Foot Ankle Int. 2009; 30(8):752-7.
11. Chraim M, Bock P, Alrabai H, Trnka HJ, Alrabai HM, Trnka HJ. Long-term outcome of first metatarsophalangeal joint fusion in the treatment of severe hallux rigidus. Int Orthop. 2016;40(11):2401-8.
12. Doty J, Coughlin M, Hirose C, Kemp T. Hallux metatarsophalangeal joint arthrodesis with a hybrid locking plate and a plantar neutralization screw: a prospective study. Foot Ankle Int. 2013; 34(11):1535-40.
13. Claassen L, Plaass C, Pastor MF, Ettinger S, Wellmann M, Stukenborg-Colsman C, et al. First metatarsophalangeal joint arthrodesis: a retrospective comparison of crossed-screws, locking and non-locking plate fixation with lag screw. Arch Bone Jt Surg. 2017;5(4):221-5.
14. Harris E, Moroney P, Tourne Y. Arthrodesis of the first metatarsophalangeal joint-a biomechanical comparison of four fixation techniques. Foot Ankle Surg. 2017;23(4):268-74.
15. Fuld RS 3rd, Kumparatana P, Kelley J, Anderson N, Baldini T, Younger ASE, et al. Biomechanical Comparison of Low-Profile Contoured Locking Plate With Single Compression Screw to Fully Threaded Compression Screws for First MTP Fusion. Foot Ankle Int. 2019;40(7):836-44.
16. Singhal R, Kwaees T, Mohamed M, Argyropoulos M, Amarasinghe P, Toh EM. Result of IOFIX (Intra Osseous FIXation) device for first metatarsophalangeal joint arthrodesis: A single surgeon's series. Foot Ankle Surg. 2018;24(5):466-70.
17. Roukis TS. Nonunion after arthrodesis of the first metatarsal-phalangeal joint: a systematic review. J Foot Ankle Surg. 2011; 50(6):710-3.
18. Chan JJ, Sarker SS, Nordio A, Guzman JZ, Hasija R, Vulcano E. Failure of fixation with nickel-titanium staples in first metatarsophalangeal arthrodesis with hallux valgus deformity. Orthopedics. 2019;42(4):e402-4.
19. Challagundla SR, Thomas R, Ferdinand R, Crane E. First metatarsophalangeal joint arthrodesis using memory staples: clinical and functional results. Foot Ankle Spec. 2021;14(5):410-4.
20. Núñez-Samper M, Viladot R, Ponce SJ, Lao E, Souki F. Serious sequellae of the hallux valgus surgery: More options for its surgical treatment. Rev Esp Cir Ortop Traumatol. 2016;60(4):234-42.
21. Núñez-Samper M. Tratamiento de las secuelas de la cirugía del 1.er radio. In: Martin Oliva X, Vila y Rico J, Viladot Voegeli A. Tratado de cirugía de antepié. Barcelona: Euromedice; 2010. Cap.7. p. 99-112.
22. Da Cunha RJ, MacMahon A, Jones MT, Savenkov A, Deland J, Roberts M, et al. Return to sports and physical activities after first metatarsophalangeal joint arthrodesis in young patients. Foot Ankle Int. 2019;40(7):745-52.
23. Curtis MJ, Myerson M, Jinnah RH, Cox QG, Alexander I. Arthrodesis of the first metatarsophalangeal joint: a biomechanical study of internal fixation techniques. Foot Ankle 1993;14(7):395–9.
24. Politi J, John H, Njus G, Bennett GL, Kay DB. First metatarsal-phalangeal joint arthrodesis: a biomechanical assessment of stability. Foot Ankle Int. 2003;24(4):332-7.
25. Ellington JK, Jones CP, Cohen BE, Davis WH, Nickisch F, Anderson RB. Review of 107 hallux MTP joint arthrodesis using dome-shaped reamers and a stainless-steel dorsal plate. Foot Ankle Int 2010;31(5):385–90.
26. Hunt KJ, Ellington JK, Anderson RB, Cohen BE, Davis WH, Jones CP. Locked versus nonlocked plate fixation for hallux MTP arthrodesis. Foot Ankle Int. 2011;32(7):704-9.
27. Coughlin MJ, Saltzman CL, Anderson RB. Mann's surgery of the foot and ankle. 9th ed. Philadelphia: Elsevier/Saunders; 2013.
28. Gibson JN, Thomson CE. Arthrodesis or total replacement arthroplasty for hallux rigidus: a randomized controlled trial. Foot Ankle Int. 2005;26(9):680-90.
29. Stevens J, de Bot RTA, Hermus JPS, van Rhijn LW, Witlox AM. Clinical Outcome Following Total Joint Replacement and Arthrodesis for Hallux Rigidus: A Systematic Review. JBJS Rev. 2017;5(11):e2.
30. Lunati MP, Manz WJ, Maidman SD, Kukowski NR, Mignemi D, Bariteau JT. Effect of Age on Complication Rates and Outcomes Following First Metatarsophalangeal Arthrodesis for Hallux Rigidus. Foot Ankle Int. 2020;41(11):1347-54.
31. Deland JT, Williams BR. Surgical management of hallux rigidus. J Am Acad Orthop Surg. 2012;20(6):347-58.
32. Galois L, Hemmer J, Ray V, Sirveaux F. Surgical options for hallux rigidus: state of the art and review of the literature. Eur J Orthop Surg Traumatol. 2020;30(1):57-65.
33. Bei C, Gross CE, Adams S, Parekh SG. Dual plating with bone block arthrodesis of the first metatarsophalangeal joint: A clinical retrospective review. Foot Ankle Surg. 2015;21(4):235-9.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1590

Special Article

Metatarsophalangeal prosthesis for hallux rigidus. Review of current models and Cartiva™ interposition endorthesis

Mariano Nuñez-Samper[1], **Ramon Viladot-Pericé *(In Memoriam)***[2]

1. Hospital Virgen del Mar, Madrid, Spain.
2. Orthopaedic Department, Clínica Tres Torres, Barcelona, Spain.

Abstract

Hallux rigidus of the first metatarsophalangeal joint affects between 35% and 60% of the population over 65 years of age and has multiple treatment options, among which we highlight metatarsophalangeal arthrodesis and prosthesis. Regarding the arthroplasty technique, we aim to provide information on the characteristics of the material, model, and design and on which one offers better results, relating it to the characteristics of the patient, such as age, presence of inflammatory joint diseases, and viability and durability of the implant. Some studies on the clinical and functional results with different prosthesis models are briefly exposed. According to the AOFAS criteria, prosthesis and arthrodesis present similar effectiveness values and the decision of which technique to use will be determined considering several factors and characteristics previously exposed. Cartiva™ is a synthetic polyvinyl alcohol hydrogel implant that has a water content with a compressive and tensile modulus similar to that of human articular cartilage. Thus, it is suitable for use in metatarsophalangeal hemiarthroplasties, and published studies in this regard report excellent short- and long-term clinical results.

Level of Evidence V; Therapeutic Studies; Expert Opinion.

Keywords: Arthroplasty; Hallux rigidus; Metatarsophalangeal joint; Prosthesis design; Prostheses and implants.

Introduction

Although arthrodesis is the treatment of choice for advanced hallux rigidus (HR), the greater patients' demand and technical advances support the indication for implanting a prosthesis on the affected joint.

Many publications advocate for this indication; however, no prospective study assessed patient's satisfaction and clinical results obtained with prosthesis implantation, despite the large body of critical literature on implants for HR, especially about those made of silicone, which present with many cases of reactive synovitis[1].

Metatarsophalangeal arthrodesis is still the safer and more predictable gold standard treatment to correct advanced HR, with acceptable functional results and lower rates of complications and reoperations compared with prosthesis[2].

In general, the following indications are established for the use of metatarsophalangeal prosthesis: *HR with severe ankylosis, rescue of silicone implant, failed previous surgery, deforming rheumatoid arthritis, and young patients requiring mobility*. Contraindications are the following: *vascular failure, tendon failure, infection, and osteoporosis; the latter being a relative contraindication*[3].

Characteristics and evolution of implants (Chart 1)

Prosthesis models

The first prosthesis used in the first metatarsophalangeal joint (MTPJ) of the foot was made of silastic and was widely used in the 1970s. However, due to prosthesis wear that caused reactive synovitis, the use of this type of prosthesis, as well as its subsequent modifications, was soon discontinued.

Subsequently, prostheses with two unconstrained, uncemented components were developed, as well as other two-piece ceramic models implanted by a press fit technique[4-6].

Study performed at the Hospital Virgen del Mar, Madrid, Spain.

Correspondence: Mariano Nuñez-Samper. **Adress:** C. de Honduras, 14, 28016, Madrid, Spain. **E-mail:** mnusamp1@nunezsamper.com. **Conflicts of Interest:** none. **Source of funding:** none. **Date received:** October 12, 2021. **Date accepted:** February 11, 2022. **Online:** April 30, 2022.

How to cite this article: Nuñez-Samper M, Viladot-Pericé R. Metatarsophalangeal prosthesis for hallux rigidus. Review of current models and CartivaTM interposition endorthesis. J Foot Ankle. 2022;16(1):21-4.

Chart 1. Characteristics and evolution of implants

PARTIAL	TOTAL	MATERIAL	INTERFACE	GENERATION
PHALANGEAL HEMIARTHROPLASTY	POLYETHYLENE	SILICONE	CEMENTED	1ST SILICONE
	GRAFT			
	MOBILE MENISCUS	METALLIC	UN	2ND WITH
			CEMENTED	RINGS
METATARSAL		CHROMIUM COBALCOBAL		
HEMIARTHROPLASTY	THREE	COBALT		3RD POLYETHYLENE
	COMPONENTS			GRAFT
		TITANIUM		
CARTIVA				4TH METALLIC
		CERAMIC		MOBILE
				MENISCUS
		HYDROGEL		THREADED
				PHALANX

Currently, last-generation prostheses present the following characteristics:

- Three components.
- Limited bone resection.
- Unconstrained.
- Uncemented bone anchoring.
- Threaded phalangeal component with coating (Figure 1).

Characteristics of implantation

The choice for prosthesis implantation surgery involves a number of basic requirements that patients should comply with[7]:

- Good bone quality to ensure accurate fixation of the two prosthetic components;
- Functional stabilizing structure of the joint;
- Proper metatarsophalangeal alignment;
- If the intermetatarsal angle is greater than 12 degrees, previous osteotomy should be performed;
- The rest of the phalanx should be of a sufficient size;
- Low functional demand;
- Absence of septic processes from previous interventions;

Results

In a study on the outcomes of patients with two-piece ceramic Moje implant, Fuhrmann and Martin[8] reported 12.5% of revision operations and only 63% of «much satisfactory» results, although postoperative mobility was much unsatisfactory in 4 patients, which was significantly associated with reduced American Orthopedics Foot and Ankle Society (AOFAS) scores (p=0.01).

Other study published by Dos Santos et al.[9] in *Acta Ortopédica Brasileira* in 2013 analyzes the outcomes of 11 patients treated through partial arthroplasty of the first MTPJ with Arthrosurface-HemiCAP™ technique from June 2008 to May 2009. All patients were initially treated with stretching of triceps surae muscles and footwear modification for 6 months without symptomatic improvement. After surgery, patients presented with a statistically significant improvement in AOFAS scores for hallux, visual analog scale for pain, and range of motion (in degrees) of the first MTPJ.

Small study sample and follow-up time shorter than 3 years do not allow for yielding robust results in favor of hemiarthroplasty for hallux rigidus.

In 2014, Duncan et al.[10] published the results of a retrospective review on the implantation of the ToeFit-Plus™ prosthesis, a modular, unconstrained, CoCr-polyethylene implant with titanium rods. HR was classified as stage III in 17 patients (65.4%) and stage IV in 9 (34.6%), with average follow-up time of 29.9 months. These patients had a remarkable increase in AOFAS and a decrease in pain that continued over time. Furthermore, there was an increase in dorsiflexion of hallux from 10 to 20 degrees.

Functional results, according to overall average AOFAS scores, were 77.5 points. Only 16 patients (15%) complained of pain in the hallux. Eight-two patients (78%) did not present with pain, and occasional pain was reported for 5 feet (4.8%). Average active range of motion was 36.8 degrees, and average passive range of motion was 46.82 degrees.

Another study published by Unger et al.[5] describes the results of 27 patients treated with 28 prostheses of the first MTPJ (Bio-Action Great Toe Implant, Osteo Med, Addison, TX). Average follow-up time was 8.8 years, and 53.6% of patients did not present with pain, which means that a little less than a half of the sample experienced postoperative pain

Figure 1. Different models of total and partial metatarsophalangeal prostheses.

Figure 2. Cartiva™. A) Implant. B) Intraoperative image (the implant should be placed on the edge of the articular cartilage). C) Postoperative radiograph.

with some degree of severity. Less than a half of patients remained with good range of motion. Overall, 85.7% of patients were satisfied, 3 (11%) of them presented with loosening of the phalangeal component, and 2 required revision operation.

In 2017, Kofoed et al.[11] published a 15-year follow-up of 90 Rotoglide™ third-generation implants placed on 80 patients (53 women and 27 men) with mean age of 58 years; they observed that median AOFAS scores increased significantly from 40 to 95 points after surgery. Four implants (4.4%) were extracted for other reasons than loosening. No aseptic loosening was reported. The survival rate at 15 years was 91.5% (83-100); thus, the authors concluded that this prosthesis has stood the test of time and observed that the results justify its further use.

An analysis of this retrospective study enables to infer that the last generations of metatarsophalangeal prosthesis of the hallux allow for patients with HR to reduce pain while maintaining, at least to some extent, previous articular movement.

Cartiva™ interposition endorthesis

It is a synthetic polyvinyl alcohol hydrogel implant that has a water content with a compressive and tensile modulus similar to that of human articular cartilage[6] (Figure 2), which makes it an ideal material for use in metatarsophalangeal hemiarthroplasties of the hallux[6,12]. A study conducted in 12 centers in Canada and in the United Kingdom with a 2-year follow-up showed improvement in pain and functional results equivalent to those of hemiarthroplasty and arthrodesis, with no cases of fragmentation or wear of the implant or bone loss. After 5 years, a new assessment was performed with 27 patients, showing an implant survival rate of 96% at 5.4 years.

Conclusion

In conclusion, this implant maintained function and dorsiflexion after 5 years of follow-up, showing excellent survival and overall satisfaction of patients, who would be willing to undergo the same surgery.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MNS *(https://orcid.org/0000-0001-9398-0375) Wrote the article, participated in the review process, bibliographic review, formatting of the article, interpreted the results of the study, performed the surgeries; RVP *(https://orcid.org/0000-0002-8254-2916) Conceived and planned the activity that led to the study, participated in the review process, bibliographic review, interpreted the results of the study. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Morgan S, Ng A, Clough T. The long-term outcome of silastic implant arthroplasty of the first metatarsophalangeal joint: a retrospective analysis of one hundred and eight feet. Int Orthop. 2012;36(9):1865-9.
2. Brewster M. Does total joint replacement or arthrodesis of the first metatarsophalangeal joint yield better functional results? A systematic review of the literature. J Foot Ankle Surg. 2010; 49(6):546-52.
3. Sullivan MR. Hallux rigidus: MTP implant arthroplasty. Foot Ankle Clin. 2009;14(1):33-42.
4. Sorbie C, Saunders GA. Hemiarthroplasty in the treatment of hallux rigidus. Foot Ankle Int. 2008;29(3):273-81.
5. Unger AC, Stoica LA, Olms KH, Renken FG, Kasch R, Schulz AP. Eine retrospektive Analyse [Intermediate and long-term outcome after total joint replacement for hallux rigidus: a retrospective analysis]. Orthopade. 2013;42(7):561-8.
6. Grady JF, Axe TM, Zager EJ, Sheldon LA. A retrospective analysis of 772 patients with hallux limitus. J Am Podiatr Med Assoc. 2002; 92(2):102-8.
7. Erkocak OF, Senaran H, Altan E, Aydin BK, Acar MA. Short-term functional outcomes of first metatarsophalangeal total joint replacement for hallux rigidus. Foot Ankle Int. 2013;34(11):1569-79.
8. Fuhrmann RA, Martin X. Intrinsisches Implantatversagen der Moje-Prothese an den ZehengrundgelenkenIntrinsic failure of the Moje prosthesis at the metatarsophalangeal joint. Fuß & Sprunggelenk 2009;7(1):31-8.
9. Dos Santos AL, Duarte FA, Seito CA, Ortiz RT, Sakaki MH, Fernandes TD. Hallux Rigidus: prospective study of joint replacement with hemiarthroplasty. Acta Ortop Bras. 2013;21(2):71-5.
10. Duncan NS, Farrar NG, Rajan RA. Early results of first metatarsophalangeal joint replacement using the ToeFit-Plus™ prosthesis. J Foot Ankle Surg. 2014;53(3):265-8.
11. Kofoed H, Danborg L, Grindsted J, Merser S. The Rotoglide™ total replacement of the first metatarso-phalangeal joint. A prospective series with 7-15 years clinico-radiological follow-up with survival analysis. Foot Ankle Surg. 2017;23(3):148-52.
12. Baker MI, Walsh SP, Schwartz Z, Boyan BD. A review of polyvinyl alcohol and its uses in cartilage and orthopedic applications. J Biomed Mater Res B Appl Biomater. 2012;100(5):1451-7.

DOI: https://doi.org/10.30795/jfootankle.2021.v15.1616

Special Article

Anatomo-arthroscopic approach of the lateral ligament complex of the ankle

Jorge Pablo Batista[1], Guillermo Arrondo[2], Lucas Logioco[1], Leandro Casola[2], Lucía Verónica Cangiano[1], Germán Matías-Joannas[1,2,3]

1. Centro Artroscopico Jorge Batista, CABA, Buenos Aires, Argentina.
2. Instituto Dupuytren, CABA, Buenos Aires, Argentina.
3. Instituto Barrancas, Quilmes, Buenos Aires, Argentina.

Abstract

Injuries of the lateral ligament complex of the ankle have become increasingly frequent over the last years due to increase in sports practice among the population. These injuries present with good outcomes when treated conservatively. However, 20-25% of patients experience persistent pain or instability and should be approached surgically. Countless open surgical techniques have been published over the last 50 years. Currently knowledge on superficial, deep, and arthroscopic anatomy of ankle has allowed for the development of completely arthroscopic procedures to treat chronic lateral instability of the ankle.

The aim of this article is to describe the superficial and deep anatomy of lateral ligament complex of the ankle, specifically from the arthroscopic point of view, for it to be applied to the multiple currently described surgical procedures.

Level of Evidence III; Therapeutic Studies; Comparative Retrospective Study.

Keywords: Arthroscopy; Ankle injuries; Lateral ligament, ankle; Fractures, bone.

Introduction

Injuries of the lateral ligament complex of the ankle are frequent in athletes, and numerous surgical treatments have been described over the last 50 years to treat both acute and chronic instability. Arthroscopic techniques have emerged and have been constantly developed over the last 20 years aiming to reestablish joint stability through minimally invasive approaches.

Increase in the use of these arthroscopic techniques, along with the development and technological advances in the industry, have led to significant changes in the therapeutic field of this type of diseases.

This increase has led ankle joint anatomy to be understood from an arthroscopic perspective. Descriptions of ankle ligaments have usually a classic 2-dimensional anatomic approach and are usually brief in most classic anatomy books[1,2].

Several studies have been conducted over the last 15 years to assess the arthroscopic approach to the treatment of chronic ankle instability; however, few published works provide a detailed anatomical description[3]. Therefore, a new anatomo–arthroscopic approach has been widely developed by internationally anatomists over the last decades[4,5].

The aim of this article is to present the superficial and deep anatomy of the lateral ligament complex of the ankle, specifically from the arthroscopic perspective, relating it with some surgical procedures[6,7].

The 2 joints that participate in ankle configuration are the tibiotalar (tibioastragalar) and the subtalar (talocalcaneal) joints[8] (Figure 1).

The tibiotalar joint (TTJ) is the most important and connects the distal extremities of the tibia and the fibula to the talus bone (Figure 2A-B).

Study performed at the Centro Artroscopico Jorge Batista, CABA, Buenos Aires, Argentina.

Correspondence: Jorge Pablo Batista. Av. Pueyrredón 2446, C1119ACU CABA, Argentina. **E-mail:** jbatista20@hotmail.com. **Conflicts of Interest:** none. **Source of funding:** none. **Date received:** March 1, 2022. **Date accepted:** April 15, 2022. **Online:** April 30, 2022.

How to cite this article: Batista JP, Arrondo GM, Logiocco LD, Casola L, Cangiano LV, Matías-Joannas G. Anatomo-arthroscopic approach of the lateral ligament complex of the ankle. J Foot Ankle. 2022;16(1):25-34.

The tibia and the fibula are firmly connected by strong ligaments forming a joint mortise or dome on which the trochlea or pulley of the talus is fitted. Therefore, this trochlear joint is formed by 3 bones: tibia, fibula, and talus, consisting of a joint with a triangular morphology and with a proximal base that accounts for 30% of ankle joint stability. This stability depends mainly on the shape of joint surfaces of the talus and the tibia (Figure 3A-B).

The subtalar joint (STJ) is formed by the inferior side of the talus and the superior side of the calcaneus. This joint is stabilized through a series of very strong ligamentous structures well adapted to bear load and forces exerted during gait. Traditionally, 2 joint compartments are described: one posterior or talocalcaneal compartments (trochoid), and other anterior or talocalcaneonavicular (enarthrosis).

The anatomy of the STJ is complex. In its inferior side, it presents 2 joint segments divided by an osseous canal that ends at the sinus tarsi. In the anterior region, the anterior and medial facets of the inferior side of the talus articulate with the anterior facet of the calcaneus, whereas, in the posterior region, the posterior facet of the talus articulates with the posterolateral facet of the calcaneus. Many ligamentous structures originate from the sinus tarsi and the tarsal canal. Harper categorized these ligamentous structures into 3 well-defined groups: superficial, intermediate, and deep layers[9].

The main ligament is the interosseous talocalcaneal ligament, a thick and strong band of 2 partially united fibers that connect the talus and the calcaneus. It is located medially in the tarsal canal and has the peculiarity of fusing with the medial root of the inferior extensor retinaculum (IER) at the level of the calcaneus in a V-shape configuration (Figure 4A-B).

The lateral interosseous talocalcaneal ligament, which is short and strong, connects from the lateral talus under the peroneal facet up to lateral calcaneus and runs parallel to the calcaneofibular ligament (CFL)[10,11].

The medial interosseous talocalcaneal ligament extends from the medial tubercle of the talus up to the sustentaculum tali at the medial surface of the calcaneus.

Another important ligament of the STJ is the anterior capsular ligament. This thick flat ligament was defined by some authors as a thickened segment of the anterior joint capsule of the posterior talocalcaneal facet.

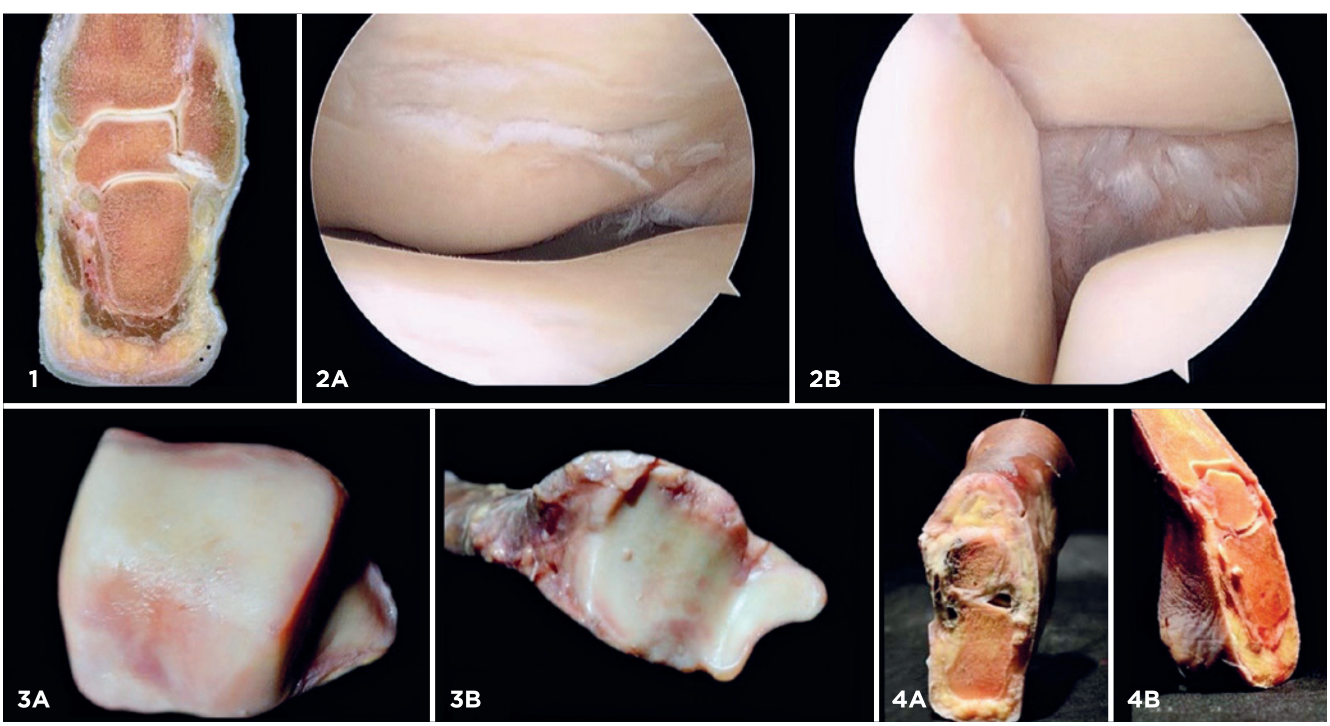


Figure 1. Anatomical slice of the frontal plane of the ankle showing tibiotalar and subtalar joints. **Figure 2.** A) Arthroscopic image of the tibiotalar joint. B) Arthroscopic image showing the tibia (above), the talus (below) and the fibula laterally. **Figure 3.** A) Anatomical piece of the talus visualized from above (talar dome). B) Anatomical piece of the joint facet of the tibia (tibial plafond). **Figure 4.** A) Frontal anatomical slice showing the interosseous talocalcaneal ligament. B) Oblique anatomical slice showing the interosseous talocalcaneal ligament.

The TTJ presents a joint capsule that is superiorly inserted into the anterior side of the tibia at nearly 8 to 10 millimeters from the cartilaginous lining. It is worth highlighting that it slightly expands to fatty tissue attachments between the distal epiphysis of the extremities of the tibia and the fibula, it is prolonged up to the inferior tibiofibular joint (tibiofibular syndesmosis). Similarly, it is inserted into the neck of the talus at nearly 6 to 8 millimeters from the cartilaginous line (Figure 5).

The lateral joint capsule of the ankle is supported by the anterior talofibular ligament (ATFL), the posterior talofibular ligament (PTFL), and the CFL.

These structures, together with superior and inferior retinaculi and the medial collateral ligament, are important static stabilizers of the ankle[12] (Figure 6).

The joint capsule is relaxed in ankle dorsiflexion and is flattened in ankle plantar flexion. Therefore, in anterior arthroscopic procedures of the ankle, surgeons will benefit from operating with the patient in the dorsiflexed position, since it will expand the surgical site, will move neurovascular structures away from potentially hazardous instruments such as shaver or other sharp elements, and will prevent possible iatrogenic talar dome injuries by hiding the joint surface under the tibiofibular mortise.

Anterior talofibular ligament (ATFL)

The ATFL is flat and quadrilateral, according to early descriptions made by Testut[13], and relatively thin, being the weakest lateral ligamentous structure. It is inserted in the anterior edge of the lateral malleolus of the fibula and courses towards the lateral side of the talus, being immediately inserted under a triangular area, whose identification is extremely important in procedures of anatomical reconstruction or capsular augmentation in chronic ankle instabilities[2,8,14] (Figure 7A-E).

This ligament has an approximate length from 15 to 20mm, width from 6 to 10mm, and thickness of 2mm[15,16].

In thin individuals with no history of sprains, it is possible to identify the ATFL and the CFJ by visualization and palpation. Visualization and palpation of the ATFL are improved in plantar flexion and supination, whereas the CFJ is better palpated in ankle inversion (Figure 8A-C).

The ATFL plays an important role in limited anterior translation of the talus over the tibia and in plantar flexion of the ankle (Figure 9).

The 2 traditional maneuvers to assess its integrity are the anterior drawer test, which assesses the degree of ATFL integrity through anterior translation of the knee, and the Tilt test, which assess the integrity of both ligaments, primarily the CFL, and the degree of restriction of ankle inversion.

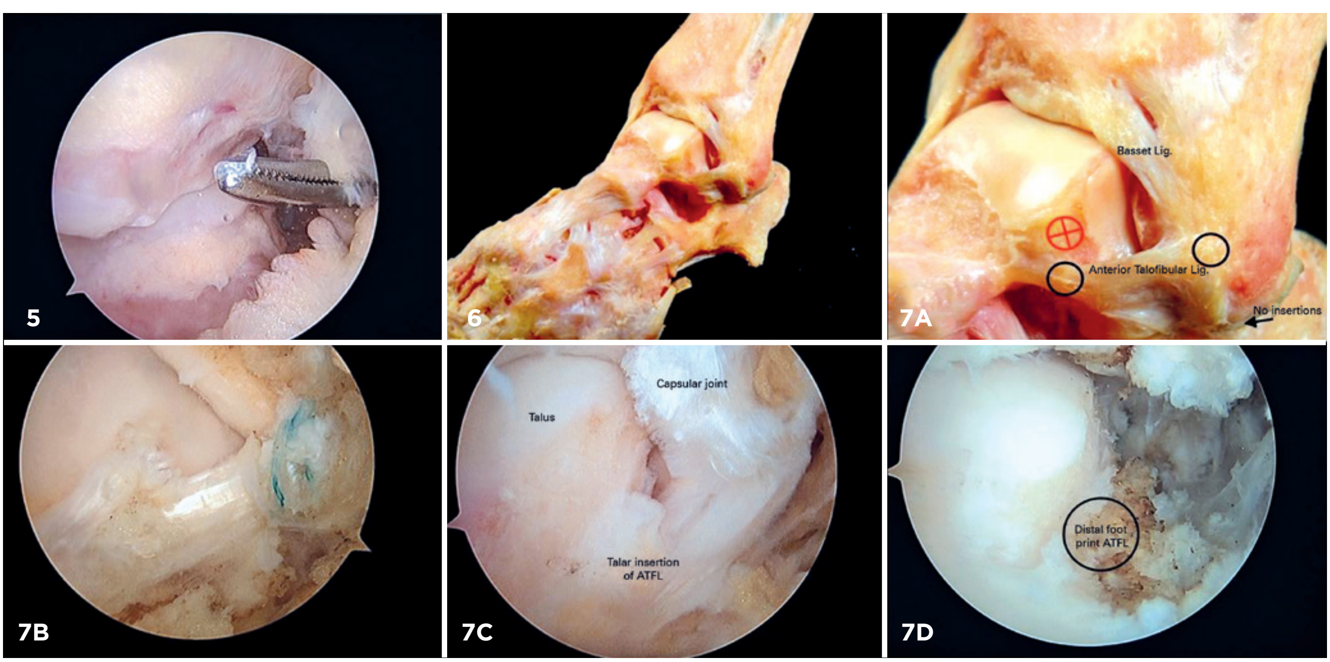


Figure 5. Arthroscopic image showing insertion of the joint capsule distant 8-10 mm from the joint cartilage of the tibia. **Figure 6.** Panoramic image of anatomical dissection of the anterolateral ligament complex of the ankle. **Figure 7.** Anatomo-arthroscopic images of proximal and distal insertions of the anterior talofibular ligament (ATFL). A) Image of anatomical dissection with sites of proximal and distal insertions of the ATFL indicated with black circles. The red circle shows the reference triangle bellow which the distal footprint of the ATFL is located. B) Arthroscopic image from the anterolateral portal showing normal distal insertion of a proximally repaired ATFL. C) Arthroscopic image of normal structures of the distal insertion of the ATFL. D) Arthroscopic image of the distal footprint of the ATFL.

In standing position, the ATFL runs parallel to the plantar support surface, but in ankle plantar flexion of the ankle, its orientation changes, it becomes more tense, and becomes aligned perpendicularly with the support surface; therefore, this is the position in which the ATFL is more vulnerable and more prone to injuries (Figure 10A-C).

In the 1950s and in the 1980s, 2 early cadaveric dissection studies[(12,17)] showed that the ATFL was the main primary restrictor of supination and anterior talar translation in all positions. Rasmussen[(18,19)] described that this ligamentous structure played a crucial role in controlling plantar flexion and internal rotation of the talus.

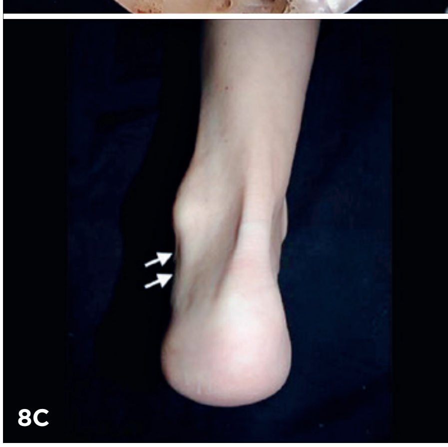
Stormont et al.[(20)] also determined that the ATFL was the major primary restrictor of internal rotation of TTJ. This finding, made 4 decades ago, was confirmed by contemporary authors such as Vega et al.[(21,22)], who have shown the impact experienced by the medial axilla of the tibia, the medial segment of the talus and even, in certain occasions, the compromise of the anterior fascicle of the deltoid, turning a lateral instability into a rotational ankle instability with osseous or osteochondral sequelae in many cases (Figure 11A-C).

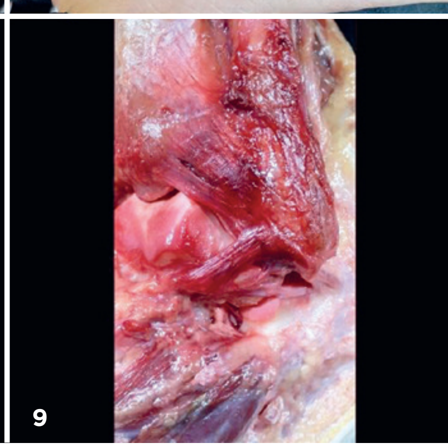
The ATFL presents 2 clearly defined bands, the superior and the inferior ones, which are separated by a small perforating peroneal artery that anastomoses with the lateral malleolar artery. This small branch is responsible for the bleeding and subsequent ecchymosis following an ankle sprain[(5)] (Figure 12).

Some authors, such as Kelikian and Sarrafian[(23)], described 3 bands of the ATFL. However, Golano et al.[(3-5)] and Kitaoka[(24)] were not able to systematically detect these 3 bands in their dissections. The superior band is the only one that can be arthroscopically visualized by directing the optical trocar towards the lateral gutter. This maneuver should be performed with the ankle flexed at 90º in this postion superior band of the ATFL, the distal extremity of the fibula, and the lateral side of the talus can be clearly visualized, inspected, and palpated (Figure 13A-C).

It is extremely important not positioning the ankle in plantar flexion, because in this postion , it s not able to visualize the fibula insertion of at ATFL[(25)].

The tip of the peroneal malleolus is free of any insertions. The footprint of the ATFL is one centimeter above and in front of





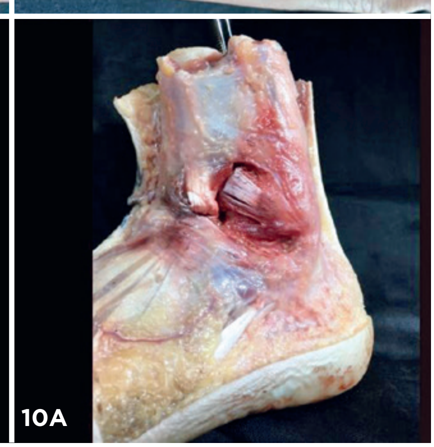


Figure 7. E) Site where a talar tunnel is carved in augmentations or reconstructions of the anterior talofibular ligament. **Figure 8.** Images of superficial anatomy of the ankle. A) Superficial anatomical image of the anterior talofibular ligament (ATFL). B) Superficial anatomical image of the ATFL in ankle inversion (the ligament is tensioned, thus improving its visualization and palpation). C) Superficial anatomical image of the ATFL visualized from a posterior view. **Figure 9.** Panoramic image of the anterior talofibular ligament (specimen with only 1 band). **Figure 10.** Anatomical images of the anterior talofibular ligament (ATFL) in relaxation, plantar flexion, and supination. A) Image of ankle at 90º with the ATFL relaxed.

the tip of the peroneal malleolus[26]. This anatomic detail can be clearly seen during arthroscopic exploration of the ankle and should be considered when carving a tunnel in the fibula during ligament repair or reconstruction (Figure 14).

The proximal insertion of these bands are different. The superior band reaches the origin of the ATFJ (Bassett's ligament), whereas the proximal insertion of the inferior band connects with fibers of the calcaneofibular and talocalcaneal ligaments through arciform fibers in its malleolar origin[11].

The superior band of the ATFJ is the first structure to be injured during an inversion trauma of the ankle, presenting an injure incidence of 80%, according bibliography [27,28].

In magnetic resonance imaging (MRI) studies with 22 patients with no history of ankle sprain, Delfaut et al.[29] found that the ATFJ was monofasciculated in 9% of the cases, bifasciculated in 55%, and striated in 36%.

Calcaneofibular ligament (CFL)

Unlike the ATFL, which acts only on the TTJ[19], the CFL is extracapsular and plays an important role in the stability of the TTJ and the STJ. Morphologically, it has a thick and cord-like shape. Moreover, it is inserted on the anterior side of the vortex of the lateral malleolus, immediately below, and very close to the insertion of the ATFL, to which it is usually joined by arciform fibers[13,30] (Figure 15A-B).

It measures approximately 4 to 8 mm in diameter and has a length of nearly 20mm and width of 4 to 5.5mm[19,31,32].

Its direction is oblique, towards posterior and distal, inserting on the lateral side of the calcaneus, 15mm or 20mm dorsally and posteriorly in relation to the lateral tubercle of this osseous structure, involving itself in its medial surface with the lateral talocalcaneal ligament (LTCL) (Figure 16). Immediately over its anterior edge and separated by a thin, and fatty tissue which sometimes goes unnoticed, we find the talocalcaneal ligament, separates the CFL from the STJ. The CFL is superficially crossed by the peroneal tendons and their sheaths, and only about 1cm of the ligament is uncovered. It is proximally fused with the fibers that form the floor of peroneal tendon retinaculum (Figure 17A).

During the plantar flexion of the ankle, the CFL is set horizontally; meanwhile, when flexed, it is set vertically, though, in both cases, it is tensed throughout during the arc of motion. This is a very strong ligament, and the only ankle movements during which it is relaxed is the ankle valgus position and the ankle eversion. In some situations of varus stress, the CFL is

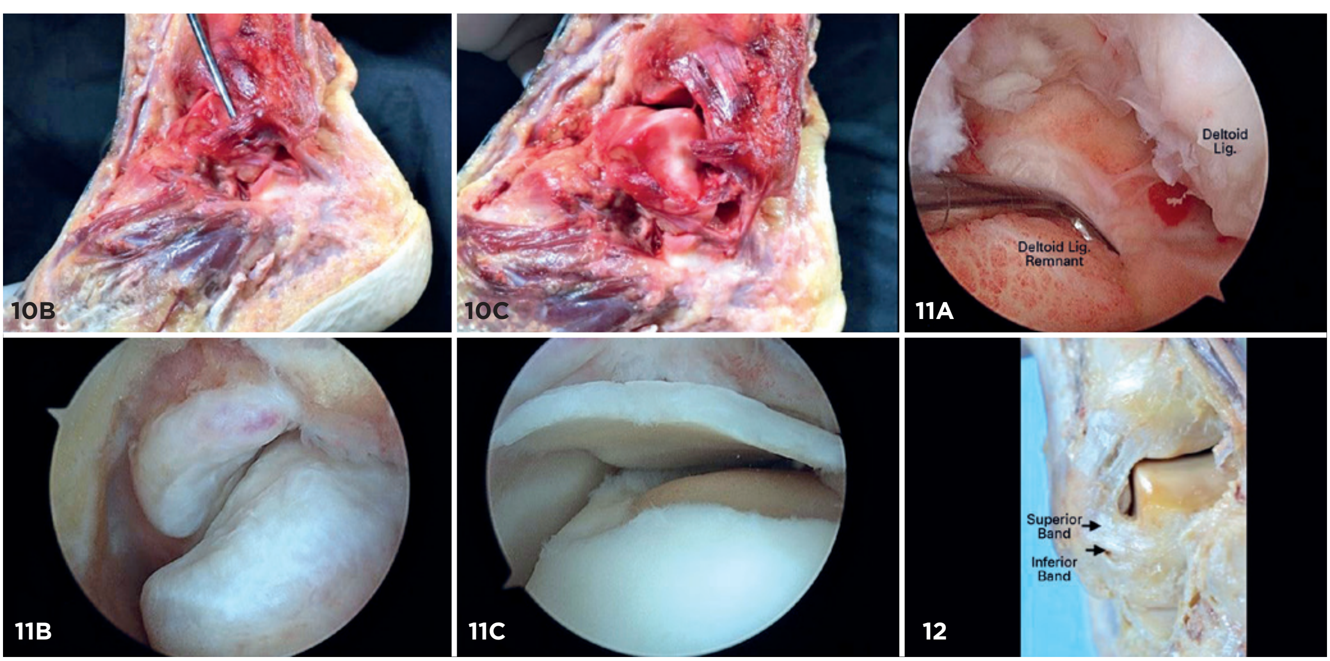


Figure 10. B) Image of the ankle in plantar flexion with the ATFL tensioned at palpation. C) Anatomic image with the ATFL sectioned showing increased internal rotation and anterior translation of the ATFL. **Figure 11.** Impairment of the medial compartment of the ankle in patients with chronic lateral instability. A) Injury of the anterior fascicle of the deltoid ligament. B) Mirrored mushroom-shaped injury at the level of medial axilla of the tibia. Medial tibiotalar exostosis developed as a sequela of chronic lateral instability. C) Chondral flap in the anteromedial portion of the talus in a patient with chronic lateral instability of the ankle. **Figure 12.** Anatomical image of the anterior talofibular ligament with its 2 bands: superior (intra-articular) and inferior (extra-articular).

tensioned and may be injured event the ankle is not moving in flexion-extension (Figure 17B-C).

This ligament is the second structure to become injured during an ankle sprain, with an injury incidence of approximately 20%. When the CFL is injured, the ATFL is usually injured as well[10,26].

Posterior talofibular ligament (PTFL)

Testut describes the PTFL as a flat ligament that occupies the posterior region of the joint. However, anatomic dissections and arthroscopic visualizations represent it with a semi-cord-like shape and as the strongest and more resilient of the 3 ligaments[8,13] (Figure 18).

It has a trapezoid aspect and measures 30mm in length, 5mm in width, and 5-8mm in thickness[23,33].

This ligament is rarely injured, except in cases of peritalar ankle fracture or dislocation. Rasmussen and Tovborg-Jensen[18] state that the PTFL plays a minor role in ankle stability when the rest of the lateral structures are intact. Golanó described this ligament arthroscopically in numerous occasions, highlighting that this is a intracapsular but extrasynovial ligament; therefore, it can be easily visualized during posterior ankle arthroscopy[4,34,35] (Figure 19).

It inserts in the digital fossa, located in the medial, posterior part of the fibula and, from this point it runs medially, almost horizontally towards its insertion in the posterior area of talus. The footprint on this bone is quite large, which is why, descriptions of the surgical technique to resect the tail of the talus or an os trigonum show that is necessary to disinsert the fibers of this ligament that are inserted in the more distal area of the tail of the talus and to cut the retinaculum of the flexor hallucis muscle in order to resect the fragment in a technically appropriate manner[35,36].

Some fibers originated from the superior part of the PTFL, near its origin, lie proximally and medially, inserting themselves into the posterior edge of the tibia, and are fused with the fibers of the deep layer of the posterior tibio fibular ligament.

In cadaveric dissections, it has been noted that these fibers reach, in more than 90% of the cases, the posterior surface of the medial malleolus, creating a true labrum on the posterior margin of the tibia. This cluster of fibers has been given different names: capsular reinforcement bundle, ascending or tibial bundle of the PTFL; however, following the concepts of Golanó et al.[4,37] and Kitaoka[24], we prefer to use the term proposed by Paturet: posterior intermalleolar ligament (Figure 20).

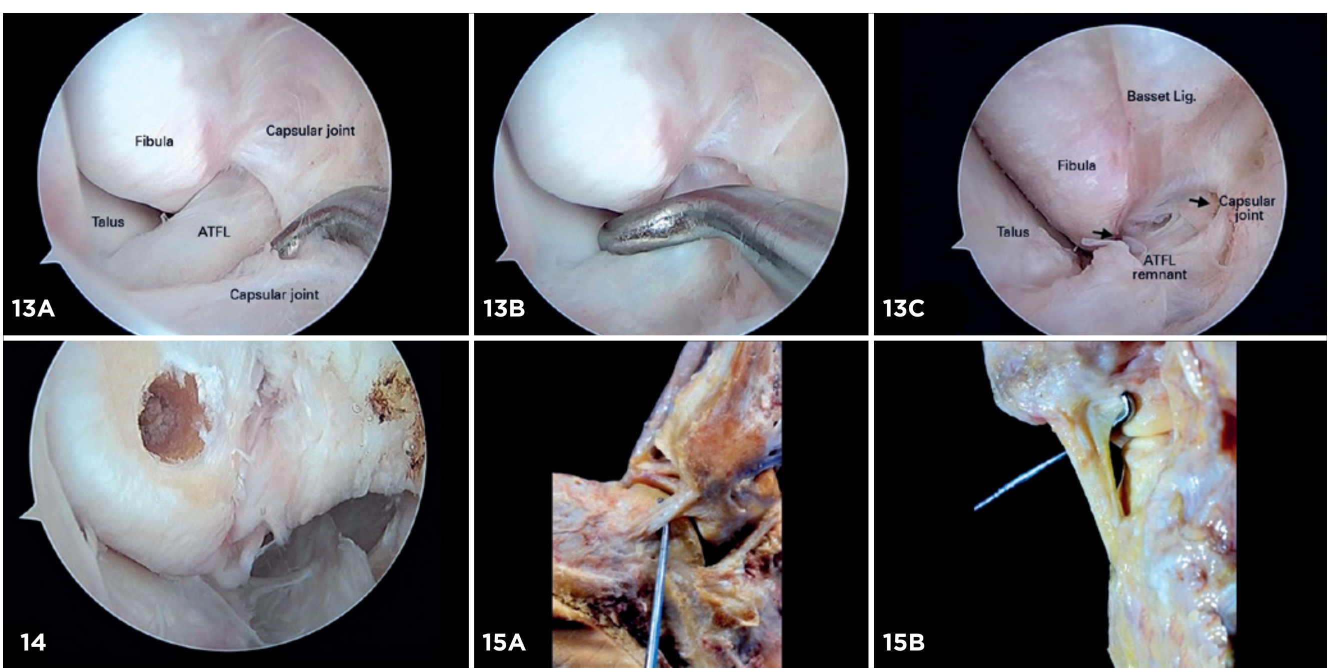


Figure 13. Arthroscopic images of the lateral gutter. A) Normal talofibular ligament (TFL) and joint capsule. B) Palpation of normal proximal insertion of the anterior TFL. C) Black arrows indicating proximal injury of the anterior TFL and of the joint capsule. **Figure 14.** Arthroscopic image showing normal tip of the peroneal malleolus with no ligamentous insertions and the hole where a tunnel is carved to perform arthroscopic repair of the anterior talofibular ligament. **Figure 15.** Anatomical images of the calcaneofibular ligament (CFL). A) Sagittal anatomical view of insertions of the CFL into the fibula and the calcaneus. B) Posterior anatomical image showing the CFL and fan-shaped arciform fibers.

Disinsertion of these distal fibers of the PTFL does not generate residual instability.

Arciform fibers

These fibers are an expansion of the regular, collagenous, and elastic dense connecting tissue, in the shape of a triangle or a semicircle, with an anteroinferior base that connects the inferior band of the ATFL with the LTCL and the CFL in a constant way. These structures have been clearly described by Kelikian and Sarrafian[23] in 2011, and has been confirmed by Golanó et al.[5,14], but attracted attention again in recent years due to the critical role they play in endoscopic repairs of the ATFL[35] (Figure 21).

Arciform fibers are clearly identified in all cadaveric dissections and play a critical role within the lateral ligament complex of the ankle[8,30].

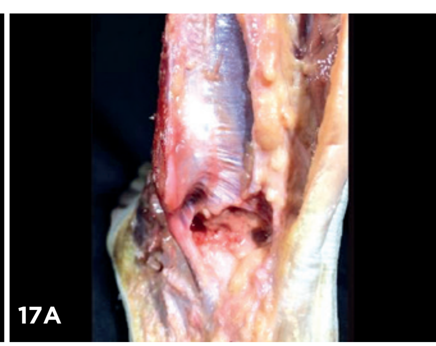
We assessed the macroscopic and microscopic morphology of these arciform fibers, and found that the histological structure of these fibers is similar to that of ligamentous structures[7,35] (Figure 22A-B).

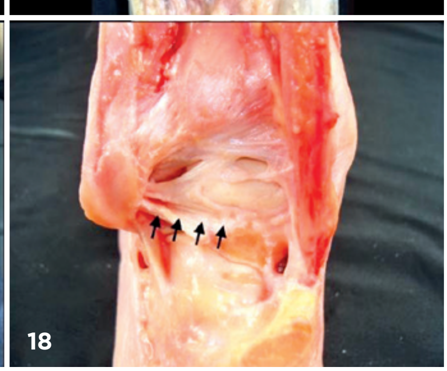
Inferior extensor retinaculum (IER)

The IER is a very strong aponeurotic structure located in the anterior area of the ankle and the tarsus and is continuity with the crural fascia. It can have different morphological shapes, but it commonly has a ‘Y’ or ‘X’ shape. This powerful retinaculum is responsible for preventing that the anterior tibial, extensor hallucis longus, extensor digitorum, and peroneus tertius tendons are dislocated to the anterior side of the ankle[24]. The lying ‘Y’ shape, the most common one, is formed, from medial to lateral, by oblique superomedial and inferomedial bands, and continues through a single branch, the frondiform ligament (Figure 23).

This lateral part of the IER stem from the sinus tarsi and is divided into 2 branches at the extensor digitorum tendon: the oblique superomedial band, which runs proximally and end by inserting itself in the anterior portion anterior of the tibial malleolus, and the oblique inferomedial bands, which end by inserting itself into the abductor hallucis muscle and into the scaphoid and medial cuneiform bones.

The superomedial and inferomedial bands are located over the anteromedial region of the ankle, whereas the frondiform ligament is in the anterolateral region of the ankle and is the portion of the IER that could be used in augmentation surgical procedures to treat chronic ankle instability. It is worth highlighting that this structure is not close enough, nor crosses the ATFL, which could enable for it to be used in augmentation procedures.





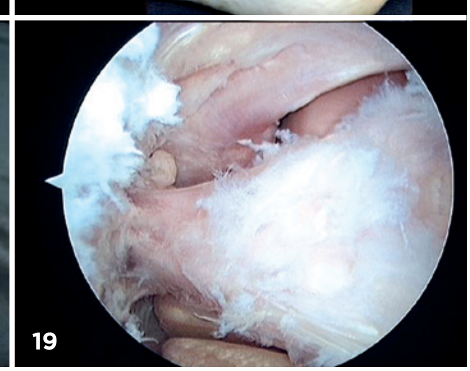


Figure 16. Anatomical image of the lateral talocalcaneal and the calcaneofibular ligaments. **Figure 17.** A) Anatomical image in which the fibula was removed. It is possible to visualize the continuity of the CFL with the floor of the peroneal tendon groove. B) Anatomy of the ankle in dorsiflexion. C) Anatomy of the ankle in plantar flexion. It bears noting that the calcaneofibular ligament is tensioned in both positions. **Figure 18.** Anatomical image of posterior dissection of the ankle. The black arrow shows the route of the posterior talofibular ligament. **Figure 19.** Arthroscopic image of the posterior talofibular ligament.

However, in 25% of the cases, some authors observed that oblique superolateral band varies considerably in shape and is responsible for the X-shape of the IER[7,33,38] (Figure 24).

When this band is present, it crosses the ATFL and inserts into the lateral surface of the peroneal malleolus. Only this band should be used to perform IER augmentation following ATFL ligament repair.

Some fibers of this oblique superolateral band are in continuity with the superior peroneal retinaculum and run over the submalleolar portion of peroneal tendons. The IER have been often used by many surgeons worldwide over several decades to increase the repair of ATFL (Brostrom-Gould), a technique that is considered the gold standard by most of these surgeons, due to the excellent clinical and biomechanical outcomes obtained in large series with long-term follow-ups[35,39].

Several authors have shown that advancing the IER and inserting it into the fibular periosteum promotes a function similar to the role played by CFL, thus stabilizing the STJ[40,41].

As previously mentioned, the frondiform ligament crosses the STJ; sometimes, overtensioning of this structure during a surgical procedure of augmentation may lead to greater STJ stiffness and to plantar flexion deficit in these patients, which can be a problem, especially when dealing with athletes[38,42].

Despite this last assumption, long-term studies did not show degenerative changes in the STJ among patients which chronic instability who were treated with these so-called "anatomical" techniques of repair and augmentation.

Conclusion

The ankle joint has been widely investigated from the anatomical, biomechanical, and surgical perspectives, producing a vast series of experimental observations.

The introduction of arthroscopy as a therapeutic element, along with the development of several completely arthroscopic techniques of ankle joint repair, augmentation and/or reconstruction have obliged surgeons to understand arthroscopic anatomy, which is nothing but a visualization different from the anatomy we all have studied.

Understanding the superficial, deep, and arthroscopic anatomy of the ankle allows for performing arthroscopic procedures to treat chronic lateral instability of the ankle in a systematized, reproducible, and safe manner.

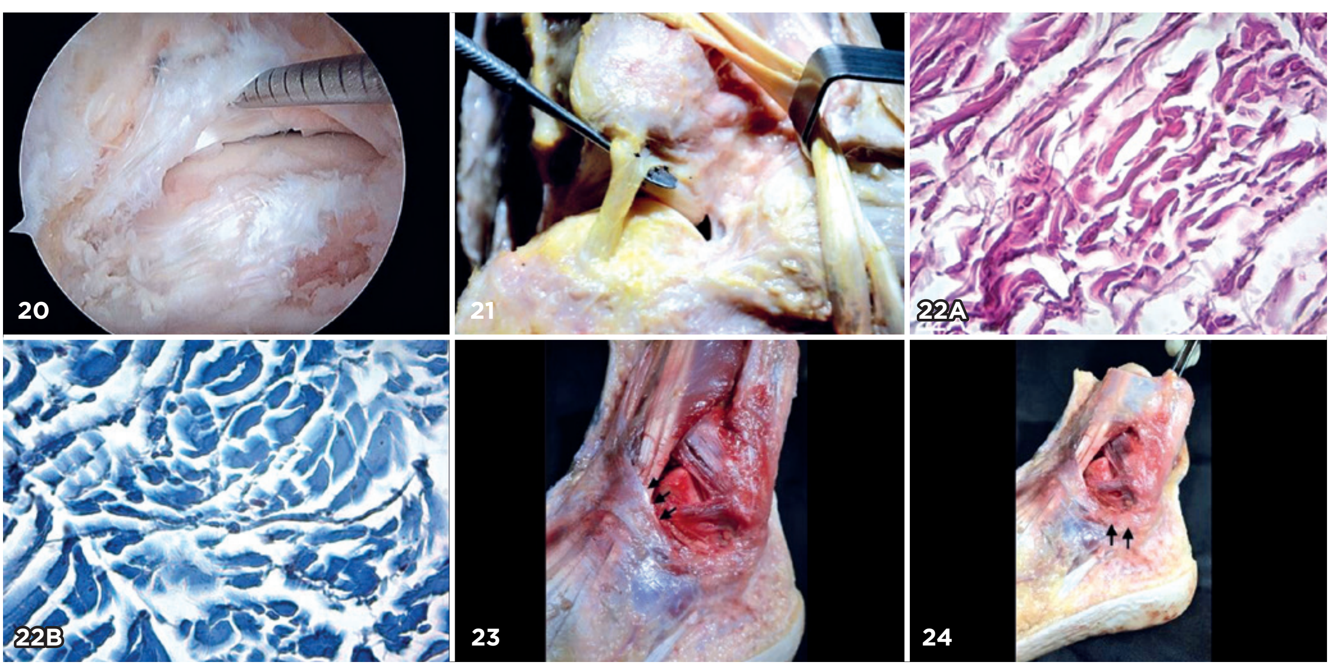


Figure 20. Arthroscopic image of the posterior intermalleolar ligament. **Figure 21.** Anatomical image of arciform fibers that connect the calcaneofibular and anterior talofibular ligaments. **Figure 22.** Images of histological slices of hematoxylin and eosin. A) And of Masson's trichrome stain. B) Showing the histological composition of arciform fibers similar to the calcaneofibular and anterior talofibular ligaments. **Figure 23.** Frondiform ligament (component of inferior extensor retinaculum). **Figure 24.** Superolateral band of the inferior extensor retinaculum identified in 25% of the cases.

Authors' contributions: Each author contributed individually and significantly to the development of this article JPB *(https://orcid.org/0000-0003-0910-4140) Conceived and planned the activities that led to the study, performed the surgery; GMA *(https://orcid.org/0000-0003-4767-5489) Data collection, bibliographic review; GMJ *(https://orcid.org/0000-0001-9998-190X) Interpreted the results of the study; LC *(https://orcid.org/0000-0003-1187-0864) Interpreted the results of the study, participated in the review process; LL *(https://orcid.org/0000-0001-9094-7609) Clinical examination, survey of the medical records, bibliographic review; LVC *(https://orcid.org/0000-0002-0202-9603) Clinical examination, survey of the medical records, bibliographic review. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Latarjet M, Ruiz Liard A. Anatomía humana. 4ª. ed. Buenos Aires: Editorial Médica Panamericana; 2004. Available from: https://books.google.co.ve/books?id=Gn64RKVTw0cC&printsec=frontcover&hl=es#v=onepage&q&f=false
2. Johna S. Gray's Anatomy: The Anatomical Basis of Clinical Practice Elsevier / Churchill Livingstone, 2005, ISBN 0-443-06676-0 [Internet]. Vol. 30, World Journal of Surgery. 2006. p. 1624–5. Available from: http://dx.doi.org/10.1007/s00268-006-0109-2
3. Golanó P, Forcada P, Carrera A, Rodríguez M, Sáenz I, León M, et al. Arterias potencialmente. Cuadernos de Artroscopic [Internet]. 1996;3(12):50-7. Available from: https://fondoscience.com/sites/default/files/articles/pdf/fs_03206.fs9610007.arterias-potencialmente-lesionables.pdf
4. Golanò P, Mariani PP, Rodríguez-Niedenfuhr M, Mariani PF, Ruano-Gil D. Arthroscopic anatomy of the posterior ankle ligaments. Arthroscopy. 2002;18(4):353-8.
5. Golanó P, Vega J, de Leeuw PA, Malagelada F, Manzanares MC, Götzens V, et al. Anatomy of the ankle ligaments: a pictorial essay. Knee Surg Sports Traumatol Arthrosc. 2010;18(5):557-69.
6. Pijnenburg AC, Bogaard K, Krips R, Marti RK, Bossuyt PM, van Dijk CN. Operative and functional treatment of rupture of the lateral ligament of the ankle. A randomised, prospective trial. J Bone Joint Surg Br. 2003;85(4):525-30.
7. Dalmau-Pastor M, Malagelada F, Kerkhoffs GM, Karlsson J, Guelfi M, Vega J. Redefining anterior ankle arthroscopic anatomy: medial and lateral ankle collateral ligaments are visible through dorsiflexion and non-distraction anterior ankle arthroscopy. Knee Surg Sports Traumatol Arthrosc. 2020;28(1):18–23.
8. Johnson EE, Markolf KL. The contribution of the anterior talofibular ligament to ankle laxity. J Bone Joint Surg Am. 1983;65(1):81–8.
9. Harper MC. The lateral ligamentous support of the subtalar joint. Foot Ankle. 1991;11(6):354–8.
10. Michels F, Matricali G, Vereecke E, Dewilde M, Vanrietvelde F, Stockmans F. The intrinsic subtalar ligaments have a consistent presence, location and morphology. Foot Ankle Surg. 2021; 27(1):101–9.
11. Poonja AJ, Hirano M, Khakimov D, Ojumah N, Tubbs RS, Loukas M, et al. Anatomical Study of the Cervical and Interosseous Talocalcaneal Ligaments of the Foot with Surgical Relevance. Cureus. 2017;9(6):e1382.
12. Golanó P, Pérez-Carro L, Saenz I. Anatomía de los ligamentos del tobillo (Comunicación oficial 1 (SECOT, Madrid, octubre 2004)). Rev Ortop Traumatol. 2004;48(Supl 3):35-44.
13. Testut L, Latarjet A, Others. Tratado de anatomía humana. Barcelona: Salvat; 1964.
14. Golanó P, Dalmau-Pastor M, Vega J, Batista JP. Anatomy of the Ankle. In: D'Hooghe PPRN, Kerkhoffs GMMJ, editors. The ankle in football. Paris: Springer; 2014. p. 1-24.
15. Prins JG. Diagnosis and treatment of injury to the lateral ligament of the ankle. A comparative clinical study. Acta Chir Scand Suppl. 1978;486:3–149.
16. Ludolph E, Hierholzer G, Gretenkord K, Ryan U. Research into the anatomy and X-ray diagnostics of the fibular ligaments at the ankle joint. Arch Orthop Trauma Surg. 1984;103(5):348–52.
17. Attarian DE, McCrackin HJ, DeVito DP, McElhaney JH, Garrett WE Jr. Biomechanical characteristics of human ankle ligaments. Foot Ankle. 1985;6(2):54–8.
18. Rasmussen O, Tovborg-Jensen I. Anterolateral rotational instability in the ankle joint. An experimental study of anterolateral rotational instability, talar tilt, and anterior drawer sign in relation to injuries to the lateral ligaments. Acta Orthop Scand. 1981;52(1):99–102.
19. Rasmussen O. Stability of the ankle joint. Analysis of the function and traumatology of the ankle ligaments. Acta Orthop Scand Suppl. 1985;211:1-75.
20. Stormont DM, Morrey BF, An KN, Cass JR. Stability of the loaded ankle. Relation between articular restraint and primary and secondary static restraints. Am J Sports Med. 1985;13(5):295–300.
21. Vega J, Dalmau-Pastor M, Malagelada F, Fargues-Polo B, Peña F. Ankle arthroscopy: an update. J Bone Joint Surg Am. 2017; 99(16):1395-407.
22. Vega J, Allmendinger J, Malagelada F, Guelfi M, Dalmau-Pastor M. Combined arthroscopic all-inside repair of lateral and medial ankle ligaments is an effective treatment for rotational ankle instability. Knee Surg Sports Traumatol Arthrosc. 2020;28(1):132–40.
23. Kelikian AS, Sarrafian SK, editor. Sarrafian's anatomy of the foot and ankle: descriptive, topographic, functional. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2011.
24. Kitaoka HB. Anatomy of the foot and ankle. descriptive, topographic, functional. J Bone Joint Surg. 1993;75(12):1886.
25. Vega J, Malagelada F, Manzanares Céspedes M-C, Dalmau-Pastor M. The lateral fibulotalocalcaneal ligament complex: an ankle stabilizing isometric structure. Knee Surg Sports Traumatol Arthrosc. 2020;28(1):8-17.
26. Michels F, Cordier G, Burssens A, Vereecke E, Guillo S. Endoscopic reconstruction of CFL and the ATFL with a gracilis graft: a cadaveric study. Knee Surg Sports Traumatol Arthrosc. 2016;24(4):1007–14.
27. Karlsson J, Lansinger O. Lateral instability of the ankle joint. Clin Orthop Relat Res. 1992;(276):253–61.
28. Kim ES, Lee KT, Park JS, Lee YK. Arthroscopic anterior talofibular ligament repair for chronic ankle instability with a suture anchor technique. Orthopedics. 2011;34(4).
29. Delfaut EM, Demondion X, Boutry N, Cotten H, Mestdagh H, Cotten A. Multi-fasciculated anterior talo-fibular ligament: reassessment of normal findings. Eur Radiol. 2003;13(8):1836-42.
30. Rouvière H, Canela Lazaro M. Le ligament peroneo-astragalo-calcaneen. Ann Anat Pathol. 1932;7(9):745-50.

31. Milner CE, Soames RW. Anatomy of the collateral ligaments of the human ankle joint. Foot Ankle Int. 1998;19(11):757-60.
32. Milner CE, Soames RW. Anatomical variations of the anterior talofibular ligament of the human ankle joint. J Anat. 1997; 191(Pt 3):457-8.
33. Dalmau-Pastor M, Yasui Y, Calder JD, Karlsson J, Kerkhoffs GM, Kennedy JG. Anatomy of the inferior extensor retinaculum and its role in lateral ankle ligament reconstruction: a pictorial essay. Knee Surg Sports Traumatol Arthrosc. 2016;24(4):957-62.
34. van Dijk CN, Vuurberg G, Batista J, d'Hooghe P. Posterior ankle arthroscopy: current state of the art. J ISAKOS. 2017;2(5): 269–77. Available from: https://www.jisakos.com/article/S2059-7754(21)00253-4/fulltext
35. Gould N, Seligson D, Gassman J. Early and late repair of lateral ligament of the ankle. Foot Ankle. 1980;1(2):84-9.
36. van Dijk CN. Hindfoot endoscopy. Foot Ankle Clin. 2006;11(2):391-414.
37. Golanó P, Vega J, Pérez-Carro L, Götzens V. Ankle anatomy for the arthroscopist. Part I: The portals. Foot Ankle Clin. 2006;11(2):253-73.
38. Prisk VR, Imhauser CW, O'Loughlin PF, Kennedy JG. Lateral ligament repair and reconstruction restore neither contact mechanics of the ankle joint nor motion patterns of the hindfoot. J Bone Joint Surg Am. 2010;92(14):2375-86.
39. Kakwani R., Siddique M. Sprained Ankles. VI. Surgical treatment of chronic ligament ruptures. In: Banaszkiewicz P, Kader D, editors. Classic papers in orthopaedics. London: Springer; 2014. Available from: https://doi.org/10.1007/978-1-4471-5451-8_57
40. Nery C, Raduan F, Del Buono A, Asaumi ID, Cohen M, Maffulli N. Arthroscopic-assisted Broström-Gould for chronic ankle instability: a long-term follow-up. Am J Sports Med. 2011;39(11):2381-8.
41. Lee KT, Park YU, Kim JS, Kim JB, Kim KC, Kang SK. Long-term results after modified Brostrom procedure without calcaneofibular ligament reconstruction. Foot Ankle Int. 2011;32(2):153-7.
42. Guillo S, Bauer T, Lee JW, Takao M, Kong SW, Stone JW, et al. Consensus in chronic ankle instability: aetiology, assessment, surgical indications and place for arthroscopy. Orthop Traumatol Surg Res. 2013;99(8 Suppl):S411-9.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1626

Original Article

Treatment of hallux rigidus: allograft interpositional arthroplasty vs arthrodesis

Drew Bennett Krumm[1], Daniel Jonathan Patton[2], Tyler Scott Madden[1], John Gregory Anderson[2], John David Maskill[2], Donald Raymond Bohay[2], Michelle Arisleida Padley[2], Lindsey Adele Behrend[2]

1. Spectrum Health/Michigan State University, Michigan, United States.
2. Orthopaedic Associates of Michigan, Michigan, United States.

Abstract

Objective: Surgery for severe hallux rigidus includes interpositional arthroplasty and arthrodesis. Interpositional arthroplasty maintains joint mobility, while arthrodesis limits motion. The aim of this study was to compare changes in Visual Analog Scale and American Orthopedic Foot and Ankle Society scores between interpositional arthroplasty and arthrodesis patients.

Methods: A retrospective cohort study of 48 patients was performed. There were 24 patients in the interpositional arthroplasty group and 24 patients in the arthrodesis group. A follow-up phone survey was administered from which updated Visual Analog Scale and American Orthopedic Foot and Ankle Society scores were obtained.

Results: Visual Analog Scale scores improved by 4.08 (SD, 2.02) points after interpositional arthroplasty and 4.54 (SD, 3.64) points after arthrodesis. American Orthopedic Foot and Ankle Society scores improved by 28 (SD, 16) points after interpositional arthroplasty and 29 (SD, 26) points after arthrodesis.

Conclusion: In hallux rigidus patients, pain improvement results were similar for both interpositional arthroplasty and arthrodesis. Interpositional arthroplasty has been reported in the literature as maintaining mobility, which is an important goal of many patients.

Level of Evidence III; Therapeutic Studies; Case-Control Study.

Keywords: Hallux rigidus; Arthroplasty; Arthrodesis.

Introduction

Hallux rigidus, a degenerative condition of the first metatarsophalangeal (MTP) joint, is characterized by common symptoms of arthritis, including a painful range of motion and functional limitations. Patients commonly present with pain at the extreme ranges of motion, or during mid-motion in advanced disease. Hallux rigidus also demonstrates classic radiographic findings of decreased joint space, subchondral sclerosis, and osteophyte formation. Jacob et al.[1] reported that the first MTP joint carries 119% of an individual's body weight with each step. This leads to significant MTP joint reactive forces, which become exacerbated with arthritis, causing severe pain and loss of motion and function. Hallux rigidus is second only to bunions in great toe pain. The etiology can be degenerative, post-traumatic, inflammatory, or idiopathic. It is associated with female sex, hallux valgus interphalangeus, and positive family history in bilateral cases[2].

Conservative management of hallux rigidus includes rigid shoe inserts, steroid injections, oral anti-inflammatory medications, and activity modification. When conservative management fails, a variety of surgical treatment options are available. These include cheilectomy, osteotomy, arthrodesis, synthetic cartilage, resurfacing[3,4], hemiarthroplasty[5], implant-based interpositional arthroplasty, and resection arthroplasty. Joint-preserving procedures like cheilectomy are recommended for early stages of the disease[6]. When pain is present with MTP dorsiflexion and there is evidence of dorsal osteophyte formation, the osseous dorsal block to motion can be removed through cheilectomy. An additional procedure is the Moberg osteotomy, which consists of a dorsal closing-wedge osteotomy of the proximal phalanx. This technique decreases joint forces by creating a rocker in the foot and shifting the point of maximal pressure plantarly[7]. Arthrodesis or interpositional arthroplasty are generally recommended for severe

Study performed at the Spectrum Health/Michigan State University, Michigan, United States.

Correspondence: Drew Bennett Krumm. 1659 Edith Ave NE, Grand Rapids, 49505, Michigan, MI, USA. **E-mail:** krummdrew@gmail.com. **Conflicts of Interest:** none. **Source of funding:** none. **Date received:** April 8, 2022. **Date accepted:** April 10, 2022. **Online:** April 30, 2022.

How to cite this article: Krumm DB, Patton DJ, Madden TS, Anderson JG, Maskill JD, Bohay DR, et al. Treatment of hallux rigidus: allograft interpositional arthroplasty vs arthrodesis. J Foot Ankle. 2022;16(1):35-40.

grades of the disease (Coughlin and Shurnas 3 or 4). There are numerous classification systems for hallux rigidus, and they are used inconsistently in the literature[8].

Arthrodesis of the first MTP joint is the standard of care for end-stage hallux rigidus, with reported fusion rates between 77% and 100%[9]. The procedure has been shown to predictably reduce pain, restore stability to the MTP joint, and improve weight-bearing in the foot among patients with severe hallux rigidus[10]. However, motion preservation is the goal of both patient and surgeon whenever possible, and motion limitation is a common reason for patient reluctance toward this treatment option. Patients are also often disappointed with the residual stiffness and limited activities and footwear after surgery. Moreover, the literature reports a 13% nonunion rate for first MTP arthrodesis[11].

A number of new techniques and implants have recently been developed to meet the goals of both pain relief and motion preservation. Implant-based joint arthroplasty, both total and hemiarthroplasty, is associated with complications such as instability, aseptic loosening, pathological wear, failure, limited soft tissue coverage, and infection[12,13]. The high complication rate of implant-based arthroplasty has led surgeons to use this option less frequently[14]. Bone loss with implant failure creates a challenging salvage scenario. Arthrodesis can also be considered as a salvage procedure for failed interpositional arthroplasty and end-stage hallux rigidus. Polyvinyl alcohol hydrogel is used in hemiarthroplasty implants to minimize bone loss while preserving motion. Assessing this implant type in 27 patients over a mean follow-up of 5.4 years, Daniels et al.[15] reported a mean maximum dorsiflexion of 29.7° (range 10-45°). Patient-reported outcome scores also improved. This study demonstrated good survivorship with no implant failure or bone loss.

Methods

A retrospective cohort study was performed on patient data collected from 2002 to 2015 at a single institution after approval by the Institutional Review Board. The inclusion criteria were age ≥18 years, painful end-stage hallux rigidus, decreased first MTP motion, and decreased joint space with evidence of osteophytes. The exclusion criteria were ipsilateral peripheral neuropathy, inflammatory arthritis, non-English speakers, interphalangeal arthritis, and simultaneous ankle/hindfoot fusion procedures. A total of 48 patients met the inclusion criteria and were included in the retrospective chart review, with 24 patients in each group. Basic demographic data was obtained, as well as symptom duration (Table 1 and Figure 1), pre-operative Visual Analog Scale (VAS) and American Orthopedic Foot and Ankle Society (AOFAS) scores, and post-operative VAS and AOFAS scores. The VAS is a universal pain assessment tool in which patients rate pain on a scale of 0-10. AOFAS scores are derived from several variables, including pain, functional limitation, footwear, walking distance, walking surfaces, gait abnormality, and alignment. Range of motion was not quantitatively documented in the electronic health records. The three surgeons in the study performed either procedure. The initial decision to pursue arthroplasty vs arthrodesis was based on patient preference and shared decision-making, since either operation was performed after failed conservative management or cheilectomy. A regenerative acellular allograft dermal matrix (GraftJacket Regenerative Tissue Matrix, Wright Medical, Memphis, TN, USA) was used for patients undergoing interpositional arthroplasty. The specific operative technique is described below.

A modification to the study, approved by the Institutional Review Board, allowed the patients to be contacted via phone for a follow-up survey. This was done to increase the follow-up time after surgery and determine how well patients were functioning years after their procedures. A total of 15 patients in the interpositional arthroplasty group and 11 patients in the arthrodesis group could be contacted and agreed to participate in the telephone survey. The rest of the patients could not be reached by telephone. Updated VAS and AOFAS scores were obtained through these calls. The mean total follow-up time after surgery was 44 months in the interpositional arthroplasty group and 39 months in the arthrodesis group. Statisticians in the Grand Rapids Medical Education Partners department assisted with data analysis, including mean, standard deviation, and analysis of variance tests to determine significance of changes in subjective pain scores.

Table 1. Duration of Symptoms for Each Treatment Group

Duration of Symptoms	Arthroplasty	Fusion		Total
Duration of Symptoms	≤1 year	5	4	9
	1 to 5 years	8	14	22
	6 to 10 years	4	0	4
	>10 years	4	3	7
Total		21	21	42

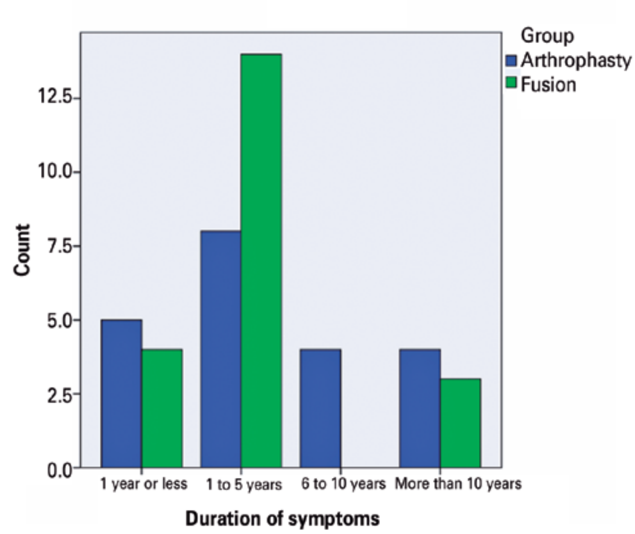


Figure 1. Duration of Symptoms for Each Treatment Group.

Surgical Techniques

MTP interpositional arthroplasty: An approximately 3cm dorsal incision was made over the extensor hallucis longus (EHL) tendon and MTP joint. Sharp dissection was carried down to the EHL tendon sheath. The tendon sheath was opened sharply and the tendon was retracted medially. The joint capsule was then opened in line with the skin incision and elevated medially and laterally around the joint for visualization. The medial and lateral release was needed to allow adequate plantar flexion of the proximal phalanx to view the entire metatarsal head. The metatarsal head typically showed signs of degeneration, more prominent dorsally. Osteophytes from the base of the proximal phalanx and the metatarsal head were resected with a rongeur. Any loose bodies were removed as well. Once adequate debridement had taken place, a small microsagittal saw was used to resect the dorsal third of the metatarsal head, exiting dorsally and in plane with the dorsal diaphysis of the metatarsal. Dorsiflexion of the joint was assessed to ensure that adequate cheilectomy had been performed to increase postoperative range of motion in the joint.

After the cheilectomy was completed, a 2.5-mm drill bit was used to create two tunnels in the head of the metatarsal from proximal-dorsal to distal-plantar. Care was taken to ensure that the tunnels ended plantarly at the base of the articular surface of the metatarsal head. On the back table, the acellular allogenic dermal matrix graft (GraftJacket) was opened. The graft was prepared with two 0 Ethibond sutures on a free needle, which were placed in the corner in horizontal mattress fashion, with a similar spread to the metatarsal drill holes. Once both sutures had been passed and secured, a suture passer was used to pass them plantar-to-dorsal out of the tunnels. We ensured that the graft was adequately positioned over the metatarsal head prior to continuing. At this point, with the graft in the correct position, the free needle was used to pass the sutures through the graft over the drill holes dorsally. Once all four strands had been passed, the pairs were tied down over the graft and the corresponding drill hole, securing the graft in place. Redundant graft was removed with scissors. The wound was irrigated and closed in a layered fashion. See Figure 2 for a postoperative radiograph.

MTP arthrodesis: A dorsal incision of approximately 3 cm was made over the EHL tendon and MTP joint. Sharp dissection was carried down to the EHL tendon sheath. The EHL tendon sheath was opened sharply and the tendon retracted medially. The joint capsule was then opened in line with the skin incision and elevated medially and laterally around the joint for visualization. The first MTP joint was prepared for arthrodesis by removing all cartilage with a combination of curved Lambotte osteotomes and curettes. Cup and cone reamers were also used to clear all cartilage. A 2.0 mm drill bit or 0.45 K-wire was then used to perforate the articular surface to increase postoperative bleeding. The MTP joint was then placed in the appropriate position. A non-cannulated screw was placed in a lag fashion across the MTP joint, and dorsal plating was used according to the surgeon's preference. Intra-operative X-rays were obtained to show appropriate implant position and MTP joint alignment. The wound was irrigated and closed in a layered fashion. See Figure 2 for a postoperative radiograph.

Results

The mean patient age and smoking status were similar between groups, but BMI and sex were not (Table 2). No patients had a history of diabetes. Mean VAS scores decreased by 4.08 (SD, 2.02) points after surgery in the interpositional arthroplasty group and 4.54 (SD, 3.64) points in the arthrodesis group. According to an analysis of variance test, VAS score improvement did not differ significantly between the groups (p=0.592). Mean AOFAS scores increased by 28 (SD, 16) points in the interpositional arthroplasty group and 29 (SD, 26) points in the arthrodesis group. According to an analysis of variance test, the AOFAS score improvement also did not differ significantly between the groups (p=0.969) (see Tables 3 and 4 below).

Figure 2. Postoperative radiograph of MTP arthrodesis (left) and postoperative radiograph of MTP interpositional arthroplasty (right).

Table 2. Demographic Data for Each Treatment Group

	Interpositional Arthroplasty	Arthrodesis
Male	2	8
Female	22	16
Mean Age	55.5	57.7
Mean BMI	26.2	29.0
BMI Range	19.6-33.4	23.0-36.0
Current Smoker	1	2
Former Smoker	4	5
Never Smoker	19	16
Unknown smoking history	0	1

Discussion

Few high-quality studies have compared interpositional arthroplasty to arthrodesis for hallux rigidus: the majority being level III, IV, or V[16]. In this study, we found no significant difference between interpositional arthroplasty and arthrodesis for mean improvement in VAS or AOFAS scores. The degree of improvement in AOFAS scores is markedly similar to previous studies on interpositional arthroplasty. Berlet et al. performed a retrospective study on 9 patients with hallux rigidus, following them for a mean of 12.7 months after interpositional arthroplasty. The mean total AOFAS scores at the most recent follow-up (87.9) were significantly higher than preoperatively (63.9)[17]. These results were reproduced in their same cohort at 5 years of follow-up, with mean AOFAS scores improving from 38 preoperatively to 65.8 postoperatively[18]. The 24-point difference at 12.7 months and 27.8-point difference at five years were almost identical to the 28-point difference found in our study at 3.5 years. However, their results are limited by the small sample size of 6 patients.

Long-term outcomes published by Vulcano et al.[19] had a mean follow-up of 11.3 years for 42 patients treated with capsular interposition arthroplasty. This retrospective case series evaluated patients using the VAS, Foot Function Index, and Short Form 12 scores. All categories showed statistically significant improvement, with 92.9% of patients stating they would have the surgery again. Four patients required conversion to fusion an average of 6.1 years after the index procedure. A recent retrospective case series of 133 patients by Aynardi et al.[20] showed an overall failure rate of 3.8% for interpositional arthroplasty in a mean follow-up of 62.2 months. Complications included infection (1.5%), cock-up deformity of the first MTP joint (4.5%), and metatarsalgia (17.3%). Of 133 patients, 101 were able to return to normal or fashionable footwear. This high rate of metatarsalgia after interpositional arthroplasty has also been reported in other studies. In a study by Lau and Daniels[21], pedobarographic analysis showed that cheilectomy patients had more normal plantar pressure distribution than interpositional arthroplasty patients. In our study, we did not obtain quantitative complication rates. However, stiffness, malalignment, and difficulty with footwear or certain activities were common concerns in both patient groups (Table 5). Patients in both groups also wished the recovery process was faster.

The advantage of MTP interpositional arthroplasty, as described in previous reports, is preserved joint mobility. This is especially relevant in active individuals and middle-aged patients with severe hallux rigidus[22]. Studies have shown that cheilectomy alone improves first MTP motion by an mean of 16.7°[23]. Roukis[24] performed a systematic review of patients undergoing soft tissue interpositional arthroplasty, finding that MTP joint dorsiflexion improved from a mean of 16.7° pre-operatively to 51.1° post-operatively. Coughlin and Shurnas[25] reported results of soft-tissue interposition arthroplasty in 7 patients with a 42-month follow-up. AOFAS scores improved substantially (from 46 to 86 points), as did mean

Table 3. Pre-and Postoperative VAS and AOFAS Scores

Group	VAS Pre	VAS Post	AOFAS Pre	AOFAS Post
Interpositional Arthroplasty	5.58	1.50	47	75
Arthrodesis (Fusion)	5.33	0.79	48	77

AOFAS: American Orthopedic Foot and Ankle Society; VAS: Visual Analog Scale

Table 4. Mean VAS and AOFAS Score Improvement After Surgery

Group	VAS Improvement	AOFAS Improvement
Interpositional Arthroplasty	4.08 (SD, 2.02)	28 (SD, 16)
Arthrodesis (Fusion)	4.54 (SD, 3.64)	29 (SD, 26)

p=0.592 (VAS); p=0.969 (AOFAS). AOFAS: American Orthopedic Foot and Ankle Society; VAS: Visual Analog Scale

Table 5. Patient Complaints via Follow-Up Telephone Survey

Interpositional Arthroplasty	Arthrodesis
• Persistent pain	• Residual surgical site numbness, unable to pick up stones with feet
• Transfer metatarsalgia	• Lesser toe malalignment and instability
• Toe malalignment	• Stiffness
• Stiffness	• Cannot wear heels or shoes that bend at the toe
• Cannot wear heels or ballerina shoes	• Difficulty with yoga or push-ups, cannot bend toes
• Difficult time with yoga and running, especially on sand	• Foot cramps
• Feels “lump on foot” or “bone chip”	• Long recovery
• Long recovery, only achieved 75-80% function	

MTP dorsiflexion (9° to 34°). DelaCruz et al.[26] found first MTP dorsiflexion improvement from 15.77° to 47.77° for 12 patients who underwent cadaver meniscus allograft interposition arthroplasty. Quantitative measurements of MTP dorsiflexion were not performed in our study, but it would be useful to objectively assess and compare mobility and its effect on patient outcomes in future studies. Since both operations lead to a comparable reduction in pain, MTP interpositional arthroplasty remains an alternative treatment for preserving motion and reducing pain in hallux rigidus in select patient populations.

Our study does have limitations. Due to its retrospective design, this study inherently involves selection bias, given the lack of randomized matched patient cohorts. Although the mean age and smoking status of our patient cohorts were similar, BMI and sex differed between the groups (Table 2). This might have been due to selection bias toward enrolling more active patients who had a greater desire to preserve motion and undergo interpositional arthroplasty. Further studies with matched cohorts are needed in the future to minimize selection bias and increase the external validity of our results. While this study does have limitations, it does provide insight. These data can be used as a guide to counsel patients about treatment outcomes and expected pain improvement after hallux rigidus surgery. Few other studies involve long-term follow-up of at least 3 years. Furthermore, previously published studies have not included as many patients. While arthrodesis has been established as the gold standard, interpositional arthroplasty may be an alternative in select patient populations. However, further studies are needed to establish the ideal candidates for interpositional arthroplasty.

Conclusions

Although it is difficult to draw extensive conclusions from a retrospective study of this sample size, our data has shown that pain improvement is similar for patients who undergo MTP interpositional arthroplasty or MTP arthrodesis for hallux rigidus at 3 years. Interpositional arthroplasty maintains greater joint mobility, which is an important goal of many patients.

Acknowledgements

The authors would like to gratefully acknowledge the invaluable assistance of Dr. Allen Shoemaker and the Grand Rapids Medical Education Partners Research Department.

Financial Support

This study received no specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions: Each author contributed individually and significantly to the development of this article: DBK *(https://orcid.org/0000-0003-2930-5521) Conceived and planned the activities that led to the study, wrote the article, participated in the reviewing process, approved the final version; DJP*(https://orcid.org/0000-0002-1138-4332) Conceived and planned the activities that led to the study, interpreted the results of the study, approved the final version; TSM *(https://orcid.org/0000-0002-2241-4250) Participated in data collection, participated in the reviewing process, approved the final version; JGA *(https://orcid.org/0000-0001-7877-9972) Conceived and planned the activities that led to the study, interpreted the results of the study, approved the final version; JDM *(https://orcid.org/0000-0002-7221-3342) Conceived and planned the activities that led to the study, interpreted the results of the study, approved the final version; DRB *(https://orcid.org/0000-0001-6273-4833) Conceived and planned the activities that led to the study, interpreted the results of the study, and approved the final version; MAP *(https://orcid.org/0000-0001-5776-4202) Planned the activities that led to the study, approved the final version; LAB *(https://orcid.org/0000-0003-3082-0491) Planned the activities that led to the study, approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Jacob HA. Forces acting in the forefoot during normal gait-an estimate. Clin Biomech (Bristol, Avon). 2001;16(9):783-92.
2. Coughlin MJ, Shurnas PS. Hallux rigidus: demographics, etiology, and radiographic assessment. Foot Ankle Int. 2003;24(10):731-43.
3. Kline AJ, Hasselman CT. Metatarsal head resurfacing for advanced hallux rigidus. Foot Ankle Int. 2013;34(5):716-25.
4. Kline AJ, Hasselman CT. Resurfacing of the Metatarsal Head to Treat Advanced Hallux Rigidus. Foot Ankle Clin. 2015;20(3):451-63.
5. Giza E, Sullivan M, Ocel D, Lundeen G, Mitchell M, Frizzell L. First metatarsophalangeal hemiarthroplasty for hallux rigidus. Int Orthop. 2010;34(8):1193-8.
6. Waizy H, Czardybon MA, Stukenborg-Colsman C, Wingenfeld C, Wellmann M, Windhagen H, et al. Mid- and long-term results of the joint preserving therapy of hallux rigidus. Arch Orthop Trauma Surg. 2010;130(2):165-70.
7. Kim PH, Chen X, Hillstrom H, Ellis SJ, Baxter JR, Deland JT. Moberg Osteotomy Shifts Contact Pressure Plantarly in the First Metatarsophalangeal Joint in a Biomechanical Model. Foot Ankle Int. 2016;37(1):96-101.
8. Maffulli N, Papalia R, Palumbo A, Del Buono A, Denaro V. Quantitative review of operative management of hallux rigidus. Br Med Bull. 2011;98:75-98.
9. Chraim M, Bock P, Alrabai HM, Trnka HJ. Long-term outcome of first metatarsophalangeal joint fusion in the treatment of severe hallux rigidus. Int Orthop. 2016;40(11):2401-8.
10. Brodsky JW, Baum BS, Pollo FE, Mehta H. Prospective gait analysis in patients with first metatarsophalangeal joint arthrodesis for hallux rigidus. Foot Ankle Int. 2007;28(2):162-5.
11. Gibson JN, Thomson CE. Arthrodesis or total replacement arthroplasty for hallux rigidus: a randomized controlled trial. Foot Ankle Int. 2005;26(9):680-90.

12. Horisberger M, Haeni D, Henninger HB, Valderrabano V, Barg A. Total Arthroplasty of the Metatarsophalangeal Joint of the Hallux. Foot Ankle Int. 2016;37(7):755-65.
13. Raikin SM, Ahmad J, Pour AE, Abidi N. Comparison of arthrodesis and metallic hemiarthroplasty of the hallux metatarsophalangeal joint. J Bone Joint Surg Am. 2007;89(9):1979-85.
14. Lam A, Chan JJ, Surace MF, Vulcano E. Hallux rigidus: How do I approach it? World J Orthop. 2017;8(5):364-71.
15. Daniels TR, Younger AS, Penner MJ, Wing KJ, Miniaci-Coxhead SL, Pinsker E, et al. Midterm Outcomes of Polyvinyl Alcohol Hydrogel Hemiarthroplasty of the First Metatarsophalangeal Joint in Advanced Hallux Rigidus. Foot Ankle Int. 2017;38(3):243-7.
16. McNeil DS, Baumhauer JF, Glazebrook MA. Evidence-based analysis of the efficacy for operative treatment of hallux rigidus. Foot Ankle Int. 2013;34(1):15-32.
17. Berlet GC, Hyer CF, Lee TH, Philbin TM, Hartman JF, Wright ML. Interpositional arthroplasty of the first MTP joint using a regenerative tissue matrix for the treatment of advanced hallux rigidus. Foot Ankle Int. 2008;29(1):10-21.
18. Hyer CF, Granata JD, Berlet GC, Lee TH. Interpositional arthroplasty of the first metatarsophalangeal joint using a regenerative tissue matrix for the treatment of advanced hallux rigidus: 5-year case series follow-up. Foot Ankle Spec. 2012;5(4):249-52.
19. Vulcano E, Chang AL, Solomon D, Myerson M. Long-Term Follow-up of Capsular Interposition Arthroplasty for Hallux Rigidus. Foot Ankle Int. 2018;39(1):1-5.
20. Aynardi MC, Atwater L, Dein EJ, Zahoor T, Schon LC, Miller SD. Outcomes After Interpositional Arthroplasty of the First Metatarsophalangeal Joint. Foot Ankle Int. 2017;38(5):514-8.
21. Lau JT, Daniels TR. Outcomes following cheilectomy and interpositional arthroplasty in hallux rigidus. Foot Ankle Int. 2001; 22(6):462-70.
22. Sanhudo JA, Gomes JE, Rodrigo MK. Surgical treatment of advanced hallux rigidus by interpositional arthroplasty. Foot Ankle Int. 2011;32(4):400-6.
23. Smith SM, Coleman SC, Bacon SA, Polo FE, Brodsky JW. Improved ankle push-off power following cheilectomy for hallux rigidus: a prospective gait analysis study. Foot Ankle Int. 2012;33(6):457-61.
24. Roukis TS. Outcome following autogenous soft tissue interpositional arthroplasty for end-stage hallux rigidus: a systematic review. J Foot Ankle Surg. 2010;49(5):475-8.
25. Coughlin MJ, Shurnas PJ. Soft-tissue arthroplasty for hallux rigidus. Foot Ankle Int. 2003;24(9):661-72.
26. DelaCruz EL, Johnson AR, Clair BL. First metatarsophalangeal joint interpositional arthroplasty using a meniscus allograft for the treatment of advanced hallux rigidus: surgical technique and short-term results. Foot Ankle Spec. 2011;4(3):157-64.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1629

Original Article

Automated three-dimensional distance and coverage mapping of hallux valgus: a case-control study

Kepler Alencar Mendes de Carvalho[1], Andrew Behrens[1], Vineel Mallavarapu[1], Ryan Jasper[1], Nacime Salomão Barbachan Mansur[1,2], Matthieu Lalevee[1,3], Kevin Dibbern[1], César de César Netto[1]

1. Department of Orthopedics and Rehabilitation, Carver College of Medicine, University of Iowa.
2. Department of Orthopedics and Traumatology, Paulista School of Medicine. Federal University of Sao Paulo.
3. Department of Orthopedic Surgery, Rouen University Hospital, Rouen, France.

Abstract

Objective: To develop distance-mapping and coverage-mapping algorithms to assess metatarsophalangeal and metatarsal-sesamoid joint interaction in hallux valgus patients, comparing them to a control group.

Methods: A total of 9 hallux valgus patients (mean age 37.1 y; 6 F/3 M) and 5 controls (mean age 39 y; 4 F/1 M) underwent weight-bearing computed tomography. Specific software was used to obtain bone segmentation images of the first and second metatarsals, the first and second proximal phalanxes, and the tibial and fibular sesamoids. Joint interaction based on distance mapping and coverage mapping of the first and second metatarsophalangeal joints and the metatarsal-sesamoid joints were calculated. The surfaces of the metatarsophalangeal joints were divided in a 2-by-2 grid using the principal axes to provide a more detailed analysis. P-values <0.05 were considered significant.

Results: Coverage maps of hallux valgus and control patients revealed marked lateral and dorsal displacement in joint interaction of the first metatarsophalangeal joint, including decreased joint coverage of the medial facet of the joint. When comparing first metatarsophalangeal joint coverage, hallux valgus patients had significantly lower coverage of the dorsomedial quadrant (77%, p=0.0002) than controls, as well as significantly higher coverage of the plantarlateral (182%, p=0.005) and dorsolateral quadrants (44.9%, p=0.035).

Conclusions: In this case-control study, we developed a distance and coverage map weight-bearing computed tomography algorithm to objectively assess 3D joint interaction, joint coverage, and subluxation in hallux valgus deformity. We observed significantly greater first and second metatarsophalangeal joint subluxation in hallux valgus patients than controls.

Level of Evidence III; Case Control Study.

Keywords: Imaging, three-dimensional; Hallux valgus; Metatarsal bones; Weight-bearing.

Introduction

Hallux valgus deformity (HVD) is a complex three-dimensional (3D) distortion that involves varus, dorsiflexion, and pronation of the first metatarsal. HVD is usually assessed by conventional 2D measurements, such as hallux valgus and intermetatarsal angle(1,2). However, weight-bearing computed tomography (WBCT) and 3D distance mapping and coverage mapping allow for assessment of the relative positioning between opposing articular surfaces. This provides information about joint coverage and joint subluxation that could influence the development of arthritic degeneration and associated symptoms, which can dictate outcomes(3).

Study performed at the UIOWA Orthopedic Functional Imaging Research Laboratory (OFIRL).

Correspondence: Kepler Alencar Mendes de Carvalho. Department of Orthopaedic and Rehabilitation, University of Iowa, Carver College of Medicine. 200 Hawkins Dr. John PappaJohn Pavillion (JPP). Room 01066, Lower Level. Iowa City, IA, 52242, United States. **Email:** kepler-carvalho@uiowa.edu. **Conflicts of interest**: **César De César Netto:** CurveBeam: Paid consultant; Stock or stock Options; Foot and Ankle International: Editorial or governing board; Editor in Chief Foot and Ankle Clinics; Nextremity: Paid consultant; Ossio: Paid consultant; Paragon 28: IP royalties; Paid consultant; Weightbearing CT; International Study Group: Board or committee member; Zimmer: Paid consultant. **Nacime Salomao Barbachan Mansur:** Brazilian Foot and Ankle Society: Board or committee member; American Orthopaedic Foot and Ankle Society: Board or committee member. **Source of funding:** none. **Date received:** April 14, 2022. **Date accepted:** April 18, 2022. **Online:** April 30, 2022.

How to cite this article: Carvalho KAM, Behrens A, Mallavarapu V, Jasper R , Mansur NSB , Lalevee M, et al. Automated three-dimensional distance and coverage mapping of hallux valgus: a case-control study. J Foot Ankle. 2022;16(1):41-5.

This advanced 3D imaging modality is not influenced by foot projection or orientation, allowing for visualization of multiplanar bone anatomy in an upright position. WBCT has led to significant advances, including the ability to perform traditional HVD measurements in a 3D setting that reliably and accurately assess joint morphology(1,2,4,5). WBCT provides a more comprehensive illustration of the deformity than standard radiographs, thus allowing a better understanding of the relative positioning of the bones of the first and second rays(1,2,4). This semi-automated technique may also reduce the potential for misinterpreting standard radiographs(6).

Distance mapping, a recently developed technique for 3D analysis of the relative positions between joint surfaces (joint interaction) of the foot and ankle, provides insight into the effects of weight bearing on both healthy and pathologic conditions(3,7-10). This 3D tool evaluates joint space in the foot and ankle across entire bony interfaces through thousands of distance measurements between opposing articular surfaces. These measurements can then be illustrated qualitatively to demonstrate the distribution of distances from the articular surface. This can be enhanced with color-coded maps for each bone, which can also be used to quantify and compare the interaction of the articular surface(3,8-10).

The surface-to-surface interaction in a joint can be broken down into two major interrelated components. The first component consists of the contact sites and the surface pressure distribution between the hinged surfaces(11-13). The second component is the spatial relationship between joint surfaces during joint movement(11-14). This property can be characterized through distance maps that describe the distribution of distances between the joint surfaces at each position. In an important study, Dibbern et al.(3) expanded upon 3D distance mapping of WBCT to assess subluxation through colored coverage mapping. These maps, which are based on distance mapping, identify areas of adequate joint interaction, joint subluxation, and impact, providing images that are more interpretable and potentially clinically useful. This facilitates understanding of areas of interest where subluxation and impact can occur(3).

Thus, the aim of this study was to develop a distance- and coverage-mapping algorithm to assess metatarsophalangeal (MTP) and metatarsal-sesamoid joint interactions in HVD patients and compare them to healthy controls. We hypothesized that significantly greater MTP and metatarsal-sesamoid joint lateral subluxation would be observed in the HVD group.

Methods

This retrospective case-control study was approved by the institutional review board (#202006176) and conformed to the Health Insurance Portability and Accountability Act and Declaration of Helsinki guidelines. The sample included 9 feet from patients diagnosed with HVD, which were compared to 5 feet from healthy controls, all ipsilateral.

Disior Bonelogic® 2.0 was used to create models of all bones proximal to the first distal phalanx in STL files. These models were then analyzed using a semiautomatic segmentation protocol in MatLab code (Mathworks Inc., Natick, MA, USA). Distance mapping was then performed to determine the boundaries of the first and second metatarsals, the proximal phalanx of the hallux, and the second toe from WBCT images. The segmentations were then reviewed by a trained doctoral researcher and exported as triangulated surface models. These models were smoothed using Geomagic Design X (Artec 3D, Luxembourg) to remove any voxellation artifacts and mild irregularities.

Distances along the entire surface of the first and second MTP joint were measured. The surfaces of the first and second MTP were divided into two-by-two grids using the principal axes of the joint surface to provide a more detailed analysis. Using the distance along the normal direction of vectors projected from the first metatarsal head subchondral surface to the opposed surface of the phalanx proximal (standard distance)(3,14), measurements were performed in the MTP joint areas (Figures 1 and 2).

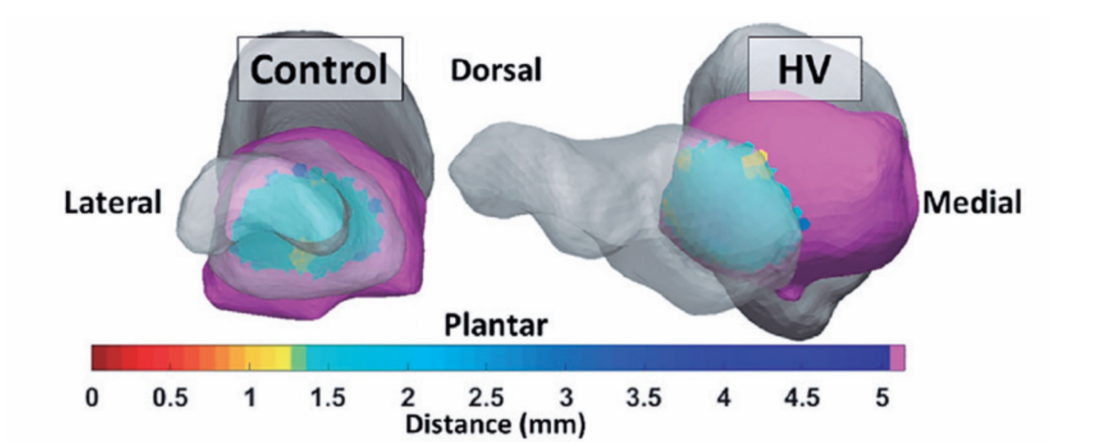


Figure 1. Summary of coverage map changes in the control (left) and hallux valgus (right) groups.

Due to the highly curved surfaces of nonarticular regions, such as the space between the first and second metatarsal bones, aberrantly large distances can exist. These distances are unrelated to loading and deviate significantly from neighboring regions[3]. To account for this, the vertical distance from each point to the opposite surface, based on the scanner's coordinate system, was used to compute distances in highly curved/uneven regions (Figure 3).

Regions of interest in distance mapping were highlighted in color (Figure 2). It has been observed that subchondral bone-to-bone distances rarely exceed 2.5 mm in the MTP joint[14]. Blue regions represent expected distances in joint interaction, which range from 1 to 3 mm. Regions > 3 mm were represented in red (Figure 2). Comparisons were performed with independent *t*-tests, assuming unequal variances, with P-values <0.05 considered significant.

Results

Figure 1 shows sample coverage maps from a HVD patient and a control, which demonstrate clear lateral and dorsal displacement of joint interaction in the first MTP joint, with decreased coverage of the medial facet of the joint. Comparison of first MTP joint coverage showed that the HVD group had significantly lower coverage of the dorsomedial quadrant (77%, p=0.0002), and significantly greater coverage of the plantarlateral (182%, p=0.005) and dorsolateral quadrants (44.9%, p=0.035). These findings are consistent with lateral subluxation and dorsiflexion of the first metatarsal in the first MTP joint. In the second MTP joint, the findings were consistent with the dorsiflexion contracture and dorsolateral joint subluxation characteristic of early hammertoe deformity, with significantly decreased joint coverage of the plantar-me-

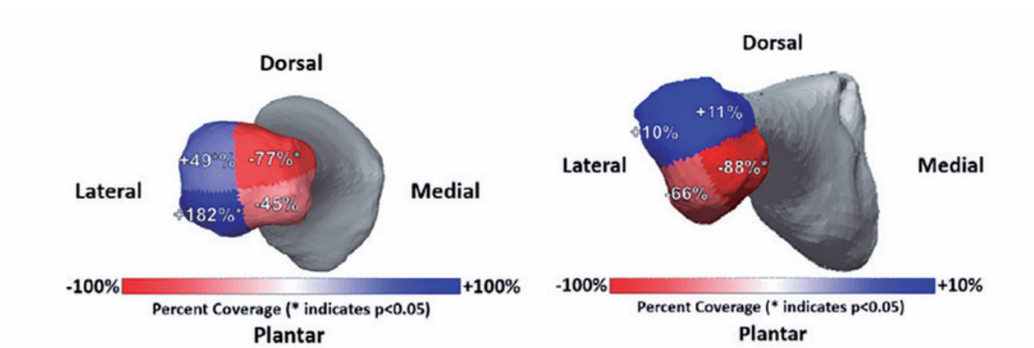


Figure 2. Summary of coverage changes in the first (left) and second (right) metatarsals.

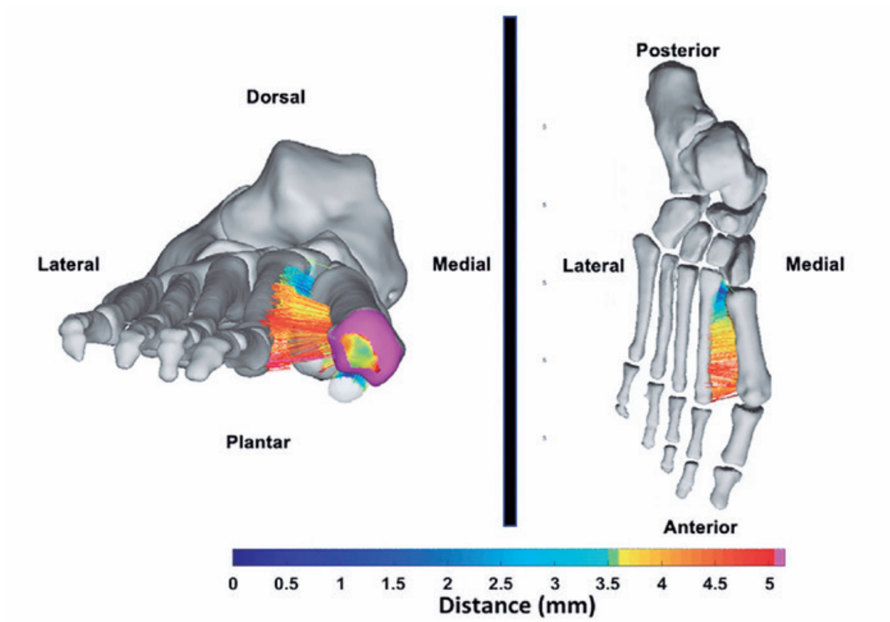


Figure 3. Average normal spacing between each point and the opposite surface in the first and second metatarsals used to calculate distances in highly curved/unequal regions.

dial quadrant (88%, p=0.01). Although no significant joint coverage changes were observed in the metatarsal-sesamoid joints, a significant widening of the fibular metatarsal-sesamoid joint was observed (76.7%, p=0.013).

Discussion

To our knowledge, this is the first study to evaluate distance and coverage maps in HVD patients, as well as the first study to use fully automated methods to compute joint coverage in the forefoot.

The normal bony anatomy of the metatarsal heads is complex due to various bony protuberances and concavities, including distinct contour changes across a spectrum of soft tissue structures. Differentiating between normal and abnormal anatomical findings can prove challenging because the typical bony structures can simulate erosive changes in the image. To better differentiate normal bone anatomy from pathologically induced changes, it is necessary to understand the normal contours of metatarsal heads[15].

In a cadaveric study, Hull et al.[16] attempted to determine how much of the articular surface of the MTP joint can be visualized during joint arthroscopy, finding that an average of 57.5% of the metatarsal head and 100% of the base of the proximal phalanx were visualized in distal 2D projection. They concluded that incomplete visualization of the metatarsal head occurred due to the technical limitations of their methods, demonstrating how difficult it is to visualize and properly study the articular surface of the MTP joints.

In another cadaveric study, Torshizy et al.[15], evaluated the anatomical characteristics of the first metatarsal head with CT and MRI in an attempt to characterize contours of the metatarsal heads that can simulate erosive changes. They concluded that the normal anatomical contours of the metatarsal head may be the primary source of diagnostic error when viewing CT and MRI images in patients with suspected erosive arthritis. They also concluded that these variations, although typical, produce findings that can make distinguishing between normal and pathological states difficult.

In this context of diagnostic difficulties for 3D structures such as metatarsal heads, new technologies like WBCT and associated software for distance and coverage mapping of the forefoot can allow a better understanding of anatomical variations and the effects of weight-bearing in both healthy and pathological conditions.

This type of non-invasive methodology to quantify joint interaction was first used by Siegler et al.[9] in a cadaveric study to characterize surface-to-surface interaction in the ankle and subtalar joints. They used an imaging-based distance mapping approach based on high-resolution CT, which provided detailed insight into the interaction of joint surfaces in healthy ankle and subtalar joints in neutral and extreme joint positions.

Lintz et al.[8] expanded the use of distance mapping by characterizing abnormal interaction of articular surfaces in the ankle, hindfoot, and midfoot joints of cavovarus foot compared to normally aligned feet. Their cavovarus group had significantly greater surface-to-surface distance at the posterior tibiotalar joint, a shorter distance at the anterior section, and a greater distance at the posterior half of the medial gutter. They concluded that distance mapping analysis of WBCT imaging could identify significant differences in surface-to--surface interaction in foot and ankle joints between cavovarus and normally aligned feet.

In a recent case-control study of stage 1 flexible progressive collapsing foot deformity patients, Dibbern et al.[3] introduced the concept of coverage mapping images in association with WBCT and distance mapping to assess subluxation and joint impingement associated with peritalar subluxation across the entire subtalar joint surface. With this technique, they objectively identified middle facet subluxation as the only peritalar subluxation marker, with a mean 46% increase in subluxation in progressive collapsing foot deformity patients compared to controls.

Using the same technique in our study, we found significant subluxation on the medial side of the first metatarsal in HVD patients. However, beyond visualizing subluxation, which could also be done other imaging methods, we were able to quantify it for the first time in the literature. In our series, there was 77% less coverage in the upper medial facet (dorsomedial quadrant) and 45% less coverage in the inferomedial facet (medial plantar quadrant) than the control group. Similarly, inferolateral and inferomedial coverage were 66% and 88% lower, respectively, in the in the second metatarsal head.

Finally, the results of this study could have a significant impact on clinical practice. This is the first study to apply distance mapping to HVD, opening the way for future investigations of early thresholds and determining the risk of progression to HVD. Although our findings reflect known changes in HVD (subluxation of the proximal phalanx), for the first time the interaction between the joint surfaces in the MTP joints has now been quantified through distance mapping, making the assessment more objective and reproducible. The practical implications of this finding are that advanced analysis of 3D datasets with distance and coverage mapping can allow for rapid quantitative analysis of the MTP joint, rather than relying on a subjective visual assessment of the joint space.

This study has several limitations. First, the control group consisted of patients with contralateral foot and ankle injuries and deformities. Therefore, subtle asymmetries resulting from antalgic posture could confound the results. Second, no formal power analysis was performed, and our sample size may have been insufficient to demonstrate differences in some of the measurements. Third, we did not compare the findings with traditional 2D coronal plane MTP joint subluxation measurements or other classic HVD measurements. We expect a significant correlation between them, and these comparisons should be included in future investigations. Fourth, since the images were taken in a static standing position, they do not tell a dynamic story. Other parts of the gait cycle can add stress and more significant displacement of the involved topologies. In addition, we did not evaluate clinical outcomes or correlate them with progression of HVD, thus limiting the immediate clinical implications of the findings. Future prospective and longitudinal investigations will be critical to determine the role of distance and coverage mapping in MTP joint subluxation with respect to HVD progression.

Conclusion

In this case-control study, we developed a distance- and coverage-mapping WBCT algorithm to objectively assess 3D joint interaction and joint coverage and subluxation in HVD. We observed a significantly greater joint subluxation in HVD patients than controls in a plantar-medial and dorsolateral direction for the first and second MTP joints, respectively. No significant joint subluxation of the metatarsal-sesamoid joint was observed. Our hope is that distance and coverage mapping can optimize the diagnosis, staging, and assessment of both treatment and outcomes in HVD and lesser toe deformities. Additional appropriately sized prospective studies are needed.

Authors' contributions: Each author contributed individually and significantly to the development of this article: KAMC *(https://orcid.org/0000-0003-1082-6490) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process and approved the final version; AB *(https://orcid.org/0000-0002-4588-9291) Image creation, data collection and interpreted the results of the study; VM *(https://orcid.org/0000-0002-8612-5941) Data collection and interpreted the results of the study; RJ *(https://orcid.org/0000-0003-3448-1300) Data collection and interpreted the results of the study; ML *(https://orcid.org/0000-0001-5058-8867) Data collection and interpreted the results of the study; NSBM *(https://orcid.org/0000-0003-1067-727X) Interpreted the results of the study and approved the final version; KD *(https://orcid.org/0000-0002-8061-4453) Interpreted the results of the study and approved the final version; CCN *(https://orcid.org/0000-0001-6037-0685) Interpreted the results of the study and approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. de Cesar Netto C, Richter M. Use of Advanced Weightbearing Imaging in Evaluation of Hallux Valgus. Foot Ankle Clin. 2020; 25(1):31-45.
2. Braza S, Mansur NSB, Mallavarapu V, Carvalho KAM, Dibbern K, Nery CAS, et al. Hallux valgus measurements using weight-bearing computed tomography: what changes?. J Foot Ankle. 2021;15(3):259-64.
3. Dibbern KN, Li S, Vivtcharenko V, Auch E, Lintz F, Ellis SJ, et al. Three-dimensional distance and coverage maps in the assessment of peritalar subluxation in progressive collapsing foot deformity. Foot Ankle Int. 2021;42(6):757-67.
4. Collan L, Kankare JA, Mattila K. The biomechanics of the first metatarsal bone in hallux valgus: a preliminary study utilizing a weight bearing extremity CT. Foot Ankle Surg. 2013;19(3):155-61.
5. Welck MJ, Singh D, Cullen N, Goldberg A. Evaluation of the 1st metatarso-sesamoid joint using standing CT - The Stanmore classification. Foot Ankle Surg. 2018;24(4):314-9.
6. Mansur NSB, Lalevee M, Schmidt E, Dibbern K, Wagner P, Wagner E, et al. Correlation between indirect radiographic parameters of first metatarsal rotation in hallux valgus and values on weight-bearing computed tomography. Int Orthop. 2021;45(12):3111-8.
7. Day MA, Ho M, Dibbern K, Rao K, An Q, Anderson DD, et al. Correlation of 3D Joint Space Width From Weightbearing CT With Outcomes After Intra-articular Calcaneal Fracture. Foot Ankle Int. 2020;41(9):1106-16.
8. Lintz F, Jepsen M, De Cesar Netto C, Bernasconi A, Ruiz M, Siegler S; International Weight-Bearing CT Society. Distance mapping of the foot and ankle joints using weightbearing CT: The cavovarus configuration. Foot Ankle Surg. 2021;27(4):412-20.
9. Siegler S, Konow T, Belvedere C, Ensini A, Kulkarni R, Leardini A. Analysis of surface-to-surface distance mapping during three-dimensional motion at the ankle and subtalar joints. J Biomech. 2018;76:204-11.
10. Bernasconi A, De Cesar Netto C, Siegler S, Jepsen M, Lintz F; International Weight-Bearing CT Society. Weightbearing CT assessment of foot and ankle joints in Pes Planovalgus using distance mapping. Foot Ankle Surg. 2021:S1268-7731(21)00205-8.
11. Kimizuka M, Kurosawa H, Fukubayashi T. Load-bearing pattern of the ankle joint. Contact area and pressure distribution. Arch Orthop Trauma Surg. 1980;96(1):45-9.
12. Calhoun JH, Li F, Ledbetter BR, Viegas SF. A comprehensive study of pressure distribution in the ankle joint with inversion and eversion. Foot Ankle Int. 1994;15(3):125-33.
13. Corazza F, Stagni R, Castelli VP, Leardini A. Articular contact at the tibiotalar joint in passive flexion. J Biomech. 2005;38(6):1205-12.
14. Moeller T. Normal findings in radiography. Translation of the 2nd, German ed. New York: Thieme; 2000.
15. Torshizy H, Hughes TH, Trudell D, Resnick D. Anatomic features of metatarsal heads that simulate erosive disease: cadaveric study using CT, radiography, and dissection with special emphasis on cross-sectional characterization of osseous anatomy. AJR Am J Roentgenol. 2008;190(3):W175-81.
16. Hull M, Campbell JT, Jeng CL, Henn RF, Cerrato RA. Measuring visualized joint surface in hallux metatarsophalangeal arthroscopy. Foot Ankle Int. 2018;39(8):978-83.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1627

Original Article

Progressive collapsing foot deformity treated by calcaneus osteotomy, flexor digitorum longus transfer, and peroneus brevis-to-longus tenodesis

José Antonio Veiga Sanhudo[1], **Giorgio Marin Canuto**[2]

1. Hospital Moinhos de Vento, Porto Alegre, Rio Grande do Sul, Brazil.
2. Hospital de Clínicas de Porto Alegre, Porto Alegre, Rio Grande do Sul, Brazil.

Abstract

Objective: This study presents the results of progressive collapsing foot deformity treatment with calcaneus osteotomy, flexor digitorum longus transfer, and peroneus brevis-to-longus transfer as an adjuvant in the correction of the deformity.

Methods: The outcomes of 22 patients with posterior tibial tendon dysfunction who underwent calcaneal osteotomy and flexor digitorum longus transfer combined with peroneus brevis-to-longus transfer (tenodesis) were evaluated retrospectively.

Results: According to the Visual Analog Scale, pain scores improved from a mean of 7.1 at baseline to 1.6 after a mean follow-up of 32 months. The mean AOFAS score was 45.3 points preoperatively and 86.3 points at follow-up. Comparison of preoperative and postoperative radiographic parameters was possible in 16 patients (73%), demonstrating significant improvements in Meary's angle and calcaneal pitch.

Conclusion: Based on these findings, we conclude that correction of progressive collapsing foot deformity through a combination of calcaneal osteotomy, flexor digitorum longus transfer, and peroneal tenodesis leads to improvement in clinical and radiographic parameters.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Posterior tibialis tendon dysfunction; Tendon transfer; Tendon injuries.

Introduction

Adult-acquired flatfoot deformity, recently renamed progressive collapsing foot deformity, is often associated with dysfunction and consequent insufficiency of the posterior tibial tendon[1]. Once the posterior tibial tendon loses its key function of stabilizing the hind- and midfoot, pathological forces begin to act at the site of injury, resulting in collapse of the midtarsal joint and forefoot abduction. The peroneus brevis tendon plays an essential role in the development and worsening of valgus hindfoot deformity and forefoot abduction, considering the weakening of its main antagonist[2,3]. This muscle imbalance causes elongation of plantar structures, progressive plantar flexion of the talus, collapse of the medial longitudinal arch, hindfoot valgus, and forefoot supination[4].

The clinical presentation of this disorder includes pain in the medial retromalleolar region of the ankle, valgus hindfoot deformity, and forefoot abduction and supination[5,6]. Radiological evaluation of the medial longitudinal arch is usually performed by assessing the alignment of the talus and first metatarsal as measured by Meary's angle and the calcaneal pitch angle. Measurement of talar head coverage by the navicular bone assesses the degree of forefoot abduction, although this measurement's accuracy is not high[7,8].

Conservative management can be attempted initially with orthotics, anti-inflammatory drugs, and exercise[9-11], but is usually unsuccessful due to the poor reparative capacity of the posterior tibial tendon at the site of rupture and perpetuation of the deformity due to biomechanical changes secondary to hindfoot valgus[12]. The goals of surgical treatment

Study performed at the Hospital Moinhos de Vento, Porto Alegre, RS, Brazil.

Correspondence: José Antônio Veiga Sanhudo. Av. Soledade 569/701, Torre Beta, 90.470-340, Porto Alegre, RS, Brazil. **E-mail:** josesanhudo@yahoo.com.br. **Conflicts of Interest:** none. **Source of funding:** none. **Date received:** April 9, 2022. **Date accepted:** April 11, 2022. **Online:** April 30, 2022.

How to cite this article: Sanhudo JAV, Canuto GM. Progressive collapsing foot deformity treated by calcaneus osteotomy, flexor digitorum longus transfer, and peroneus brevis-to-longus tenodesis. J Foot Ankle. 2022;16(1):46-51.

involve correction of the deformity through osteotomy or arthrodesis, depending on the severity and flexibility of the deformity, and muscle rebalancing through tendon transfers[13,14].

Flexor digitorum longus (FDL) transfer to the navicular bone to replace the diseased posterior tibial tendon (PTT) is part of the surgical armamentarium, as primarily described by Goldner et al.[15]. However, the fact that the FDL is physiologically weaker than the PTT[16] is a cause of concern. Interestingly, some studies have demonstrated an absence of fallen arch in patients with neurological damage who underwent dorsal transposition of the PTT to strengthen ankle dorsiflexion[17,18]. The absence of this expected deformity was credited to the fact that these patients have no peroneus brevis muscle function due to their neurological injury, demonstrating that hindfoot valgus deformity and arch fallen is due to muscle imbalance rather than PTT insufficiency[19-21]. Based on the principle of muscle balance, the authors hypothesized that peroneus brevis-to-longus transfer would be beneficial in patients with PTT dysfunction, rebalancing forces in the hindfoot, reducing valgus and abduction stress, increasing plantarflexion of the first ray, improving the medial longitudinal arch, and correcting forefoot supination[22,23]. Initially used by the authors to correct flexible forefoot supination, peroneus brevis-to-longus transfer (tenodesis) is now routinely used in patients with PTT dysfunction and flexible deformity to rebalance tendon forces and improve correction of the deformity[23].

In this context, the present study evaluated the clinical outcomes of patients who underwent correction of flexible progressive collapsing foot deformity through calcaneal osteotomy, FDL transfer to the navicular bone, and peroneus brevis-to-longus tenodesis. Subjective clinical analysis was performed by comparing pre- vs postoperative AOFAS scores and Visual Analog Scale pain scores. Radiographic analysis of deformity correction was performed by comparing pre- vs postoperative measures of Meary's angle and calcaneal pitch (Figure 1A-B). Our hypothesis was that adding peroneus brevis-to-longus transfer to conventional surgical flatfoot correction would contribute to muscle rebalancing at the level of the hindfoot and ankle, with subsequent improvement in clinical and radiographic parameters.

Methods

The study was approved by the hospital's institutional research ethics committee. We included patients with progressive collapsing foot deformity and PTT dysfunction who underwent FDL transfer to the navicular bone, calcaneal osteotomy, and peroneus brevis-to-longus tenodesis between May 2016 and March 2020. Twenty-two patients were included in the study and were assessed using a functional pain Visual Analog Scale and the American Orthopedic Foot and Ankle Society (AOFAS) scale before surgery and at the last clinical assessment. Radiographic correction, assessed by comparing pre- and postoperative Meary's angle and calcaneal pitch angles (Figure 1A-B), was possible in 16 (73%) of the 22 patients. The mean patient age at the time of surgery was 62.7 years. The mean duration of follow-up was 32 months (minimum 12 months).

Fifteen of the 22 patients underwent additional procedures during the surgical stage. Directly related to the valgus deformity, a pants-over-vest suture of the spring ligament lesion was performed in 5 patients, while proximal release of the medial gastrocnemius was performed in 6 patients who had positive Silfverskiöld test results in preoperative evaluation. In patients with more significant shortening of the posterior chain (3 cases), percutaneous Achilles tendon lengthening was performed. In 1 other case, a Strayer procedure was performed. Other procedures performed concurrently but not directly related to the pes planovalgus deformity included hallux valgus correction (5 cases), correction of claw deformity of the lesser toes (1 case), intermetatarsal neuroma removal (2 cases), and tarsometatarsal arthrodesis of the central rays (1 case).

Operative technique

After spinal anesthesia, epidural anesthesia, or popliteal blockade with sedation, an Esmarch bandage and tourniquet was placed on the thigh or above the ankle, depending on the anesthetic technique. All patients received antibiotic prophylaxis with cephalosporin for 24 hours, with the first dose given 1 hour before the procedure.

With the patient in the supine position, a medial incision was made above the longitudinal arch that extended approximately 5 cm proximally to the level of insertion of the PTT in the navicular bone. The flexor retinaculum was opened longitudinally, exposing the PTT, which was inspected for degenerati-

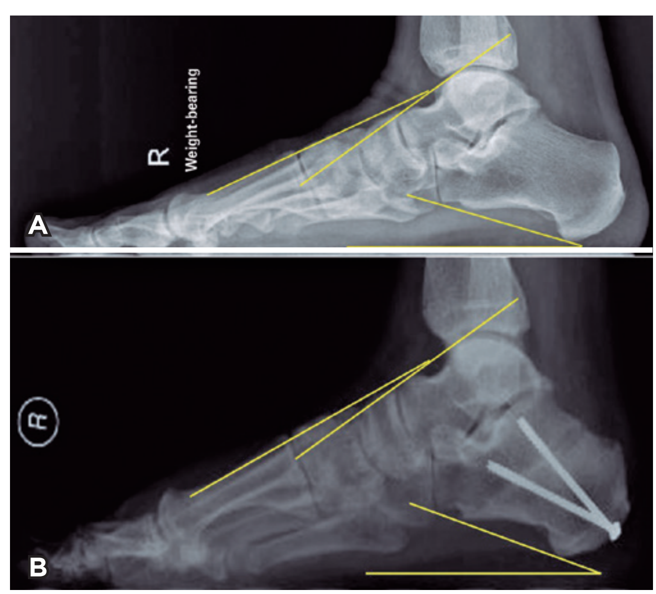


Figure 1. A-B. Pre- and postoperative x-ray with measurement of Meary's angle and calcaneal pitch.

ve changes and displaced plantarly to allow inspection of the spring ligament. Regardless of the degree of involvement, the PTT was not sutured; repairable spring ligament tears were prepared for direct suturing at the end of the procedure. The FDL was approached deep below the navicular bone, taking care to preserve local neurovascular structures, and was sectioned as distally as possible. The posterior region of the PTT sheath in the medial retromalleolar region was opened, exposing the FDL. A tag suture was made at the end of the FDL with 2-0 Vicryl and a transverse tunnel was drilled with a 4.5 mm bit in a dorsal to plantar direction in the medial portion of the navicular bone for subsequent fixation of the FDL.

Before FDL transfer, the calcaneus was accessed through a mini-L-shaped lateral approach to the hindfoot, leaving the skin, subcutaneous tissue, and sural nerve in a dorsal flap. An osteotomy was performed and the tuberosity was displaced 10 mm medially and fixated with 3 cannulated screws (diameter 4.5 mm, length 45–60 mm). After correct positioning of the screws was confirmed through control radiographs, the calcaneus incision was closed with 2-0 Vicryl, 3-0 Vicryl, and 4-0 Vicryl Rapid.

Through a 2 cm-long lateral retromalleolar longitudinal incision at the ankle joint level, the peroneal retinaculum was opened, exposing the peroneal tendons. A tag suture was made on the peroneus brevis (Figure 2A), which was then tenotomized immediately distal to this suture, advanced distally 10 mm, and sutured onto the peroneus longus tendon immediately behind it (Figure 2B). The retinaculum and subcutaneous tissue were closed with 3-0 Vicryl, while the skin was closed with 4-0 Vicryl Rapid. Finally, the spring ligament was sutured when possible, the FDL was passed through the plantar-to-dorsal tunnel in the navicular bone and was sutured to itself and onto the distal insertional portion of the PTT. This third incision was closed in layers (retinaculum, subcutaneous tissue, and skin), with 2-0 Vicryl, 3-0 Vicryl, and 4-0 Vicryl Rapid, respectively. The leg was then immobilized with a plaster splint in a slight equinovarus position.

Postoperative protocol

All patients were discharged the day after surgery, with no weight-bearing on the affected limb until the first postoperative visit at 10-14 days, when the splint was replaced with a synthetic cast with the foot in the plantigrade position, with weight-bearing allowed as tolerated by the patient. Six weeks after surgery, the cast was removed, and the patient was referred for rehabilitation.

Statistical analysis

The data are presented as frequency and percentage, mean ± standard deviation, median (interquartile range) or mean (95% confidence interval). The normality of the distribution was assessed with the Shapiro-Wilk test. Continuous variables were compared with the Wilcoxon test. In all cases, $P<0.05$ was considered statistically significant. All statistical analyses were performed in SPSS version 22 (IBM, Chicago, IL, USA).

Results

The mean Visual Analog Scale pain score decreased from 7.1 at baseline to 1.6 at follow-up, while the mean AOFAS score was 45.3 preoperatively and 86.3 in follow-up.

Pre-and postoperative radiographic comparison was not possible in 6 of 22 patients due to lack of preoperative (3 patients), postoperative (2 patients), or any radiographs (1 patient). In the remaining 16 patients, for whom adequate image documentation was available, Meary's angle and calcaneal pitch improved from preoperative means of 10.3° and

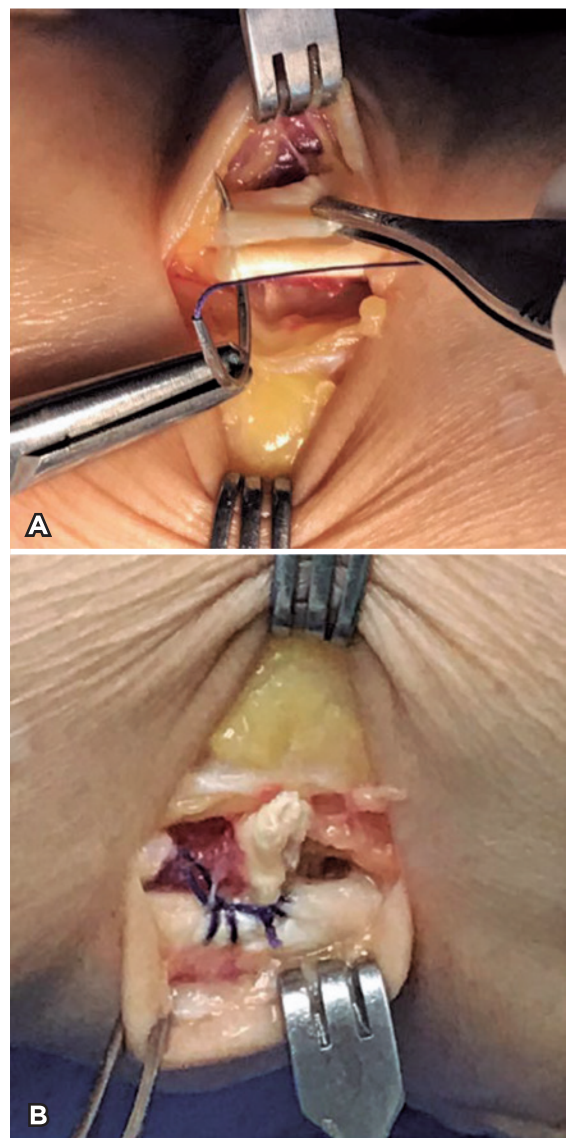


Figure 2. Transoperative image of peroneus brevis-to--longus transfer. A) tag suture of the peroneus brevis. B) peroneus brevis-to-longus tenodesis after distal traction of 10 mm.

11.7° to postoperative means of 6.9° and 17.2°, respectively, at follow-up, an improvement of 3.4° and 5.5°, respectively. Of the 22 patients, 15 were fully satisfied with the outcome, 6 were satisfied with some reservations, and 1 was dissatisfied. The dissatisfied patient had the shortest follow-up (12 months) and had not undergone any rehabilitation due to the COVID-19 pandemic, which may have contributed to the unsatisfactory clinical outcome, especially because the radiographic correction was considered adequate. In this patient, Meary's angle and the calcaneal pitch were 24° and 5° preoperatively and 19° and 9° at follow-up, respectively.

No patient complained about the peroneus brevis area, such as pain at the incision site, sural nerve injury, or reports of ankle sprain during the follow-up period. There were no cases of infection, deep vein thrombosis, or need for reintervention of any kind.

Discussion

The most common surgical treatment to correct progressive collapsing foot deformity involves calcaneus osteotomy and FDL transfer to the navicular bone[24]. Myerson et al.[20] reported pain relief in 97% of 129 patients who underwent correction of grade II PTT dysfunction through this technique; radiologically, a mean improvement of 12° in Meary's angle was observed. Marks et al.[25] observed a mean improvement of 1° in Meary's angle and 5° in calcaneal pitch in 14 patients who underwent calcaneal osteotomy and FDL tendon transfer after a mean follow-up of 23 months. Niki et al.[26] also observed improvement in Meary's angle, which had a mean of 23.7° preoperatively and 14° at the first weight-bearing radiograph (3 months after surgery). The mean calcaneal pitch was 13.3° preoperatively and 16.9° at the first weight-bearing radiograph, a difference the authors considered non-significant[26]. In a study of 48 patients, Chadwick et al.[27] observed mean AOFAS score improvement from 48.4 preoperatively to 90.3 after a minimum follow-up of 11 years. The Visual Analog Scale pain scores improved from a mean of 7.3 preoperatively to 1.3 at follow-up; 87% of patients were pain-free at final assessment.

Peroneus brevis-to-longus transfer was initially recommended to correct flexible forefoot varus, seeking to eliminate the bone procedure on the first ray, more specifically, first metatarsal osteotomies or medial column arthrodesis[4,12]. First-ray procedures are associated with a risk of nonunion or malunion (up to 12%) or complications involving the presence of the hardware itself (approximately 10%)[28,29].

Peroneus brevis transfer to treat flatfoot has already been described, but only as reinforcement in cases where the FDL or the flexor hallucis longus tendon were considered insufficient, too thin, or required revision surgery[30]. Peroneus longus-to-brevis transfer to elevate the first metatarsal has been described in cavovarus foot treatment[30,31]. Analogous to this procedure, peroneus brevis-to-longus transfer aims to relieve hindfoot valgus tension and forefoot abduction and verticalize the first ray, thus enhancing the medial longitudinal arch. The technique has been described in combination with lateral column lengthening in the treatment of child flatfoot and in adult diabetic patients undergoing transmetatarsal amputation to correct midfoot supination[32,33]. Hansen described peroneus brevis-to-longus tenodesis to treat flatfoot, but did not describe the results[34]. Geaney et al.[35] described this technique as an adjuvant to flatfoot treatment as well, also without reporting clinical or radiographic outcomes. Because one of the main actions of the peroneus longus is plantarflexion of the first ray, reinforcement of this structure by peroneus brevis tenodesis aims to enhance its function, increasing first ray plantarflexion, increasing the medial longitudinal arch, and correcting forefoot varus[36].

Sanhudo[23] described a peroneal tenodesis technique to correct the forefoot varus component of flatfoot deformities. The technique eliminates the risk of nonunion, malunion, or irritation due to the presence of hardware, all of which are associated with medial column osteotomy and first ray arthrodesis[37]. Mizel et al.[4] reported that patients with peroneal nerve palsy who undergo PTT transfer to the dorsum of the foot did not develop the typical deformities associated with loss of PTT function because they also lacked functioning peroneal tendons. They suggested that procedures which weaken the hindfoot valgus and midfoot abduction forces theoretically limit flatfoot progression and might relieve demand on the repaired or replaced PTT[4]. As hypothetical advantages, peroneus brevis release decreases midfoot abduction and valgus tension on the hindfoot, protecting the FDL transfer, while the peroneus brevis-to-longus tenodesis decreases abduction forces on the forefoot and strengthens the plantarflexion force of the first ray, thus helping correct forefoot varus and hindfoot valgus[23].

In all patients in the present series, the peroneal tendons were approached through an additional incision, with calcaneus osteotomy performed through a mini-L-shaped incision[38]. The peroneal tendons can be accessed with this same approach when transverse incision is used, although the sural nerve would be at higher risk of lesion.

This is the first study to evaluate the clinical and radiographic outcomes of patients who underwent correction of PTT dysfunction that included peroneal tenodesis. Study limitations include the small number of patients, the possibility of intraobserver error in radiographic parameter measurement, the short duration of follow-up, and the absence of a control group. Longer follow-up in a larger sample is needed for a more accurate assessment of the intervention's long-term utility for these patients.

Conclusion

Combining calcaneal osteotomy, FDL transfer, and peroneus brevis-to-longus tenodesis promoted significant clinical and radiographic improvement in the parameters of interest, with no need for reintervention due to loss of correction or persistent symptoms.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JAVS *(https://orcid.org/000-0002-4259-0358) Conceived and planned the activities that led to the study, clinical examination, survey of the medical records and approved the final version; GMC *(https://orcid.org/0000-0002-2712-9491) Participated in the review process, bibliographic review and formatting of the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID).

References

1. Myerson MS, Thordarson DB, Johnson JE, Hintermann B, Sangeorzan BJ, Deland JT, et al. Classification and nomenclature: progressive collapsing foot deformity. Foot Ankle Int. 2020; 41(10):1271-6.
2. Smyth NA, Aiyer AA, Kaplan JR, Carmody CA, Kadakia AR. Adult-acquired flatfoot deformity. Eur J Orthop Surg Traumatol. 2017;27(4):433-9.
3. Gomes MDR, Pinto AP, Fabian AA, Gomes TJM, Navarro A, Oliva XM. Insertional anatomy of peroneal brevis and longus tendon - A cadaveric study. Foot Ankle Surg. 2019;25(5):636-9.
4. Mizel MS, Temple HT, Scranton PE Jr, Gellman RE, Hecht PJ, Horton GA, et al. Role of the peroneal tendons in the production of the deformed foot with posterior tibial tendon deficiency. Foot Ankle Int. 1999;20(5):285-9.
5. Abousayed MM, Tartaglione JP, Rosenbaum AJ, Dipreta JA. Classifications in brief: Johnson and Strom classification of adult-acquired flatfoot deformity. Clin Orthop Relat Res. 2016;474(2): 588-93.
6. de Cesar Netto C, Roberts L, Kunas G, Marinescu A, Soukup D, Ellis S. Hindfoot alignment in stage ii adult acquired flatfoot deformity: can clinical evaluation predict radiographic measurements? Foot Ankle Orthop. 2018;3:2473011418S00205.
7. Shibuya N, Kitterman RT, LaFontaine J, Jupiter DC. Demographic, physical, and radiographic factors associated with functional flatfoot deformity. J Foot Ankle Surg. 2014;53(2):168-72.
8. Sensiba PR, Coffey MJ, Williams NE, Mariscalco M, Laughlin RT. Inter- and intraobserver reliability in the radiographic evaluation of adult flatfoot deformity. Foot Ankle Int. 2010;31(2):141-5.
9. Aronow MS. Tendon transfer options in managing the adult flexible flatfoot. Foot Ankle Clin. 2012;17(2):205-26.
10. Piraino JA, Theodoulou MH, Ortiz J, Peterson K, Lundquist A, Hollawell S, et al. American College of Foot and Ankle Surgeons Clinical Consensus Statement: appropriate clinical management of adult-acquired flatfoot deformity. J Foot Ankle Surg. 2020; 59(2):347-55.
11. Deland JT. Adult-acquired flatfoot deformity. J Am Acad Orthop Surg. 2008;16(7):399-406.
12. Alvarez RG, Marini A, Schmitt C, Saltzman CL. Stage I and II posterior tibial tendon dysfunction treated by a structured nonoperative management protocol: an orthosis and exercise program. Foot Ankle Int. 2006;27(1):2-8.
13. Zanolli DH, Glisson RR, Nunley JA 2nd, Easley ME. Biomechanical assessment of flexible flatfoot correction: comparison of techniques in a cadaver model. J Bone Joint Surg Am. 2014;96(6):e45.
14. Backus JD, McCormick JJ. Tendon transfers in the treatment of the adult flatfoot. Foot Ankle Clin. 2014;19(1):29-48.
15. Goldner JL, Keats PK, Bassett FH 3rd, Clippinger FW. Progressive talipes equinovalgus due to trauma or degeneration of the posterior tibial tendon and medial plantar ligaments. Orthop Clin North Am. 1974;5(1):39-51.
16. Bluman EM, Dowd T. The basics and science of tendon transfers. Foot Ankle Clin. 2011;16(3):385-99.
17. Sturbois-Nachef N, Allart E, Grauwin MY, Rousseaux M, Thevenon A, Fontaine C. Tibialis posterior transfer for foot drop due to central causes: Long-term hindfoot alignment. Orthop Traumatol Surg Res. 2019;105(1):153-8.
18. Gasq D, Molinier F, Reina N, Dupui P, Chiron P, Marque P. Posterior tibial tendon transfer in the spastic brain-damaged adult does not lead to valgus flatfoot. Foot Ankle Surg. 2013;19(3):182-7.
19. Helliwell TR, Tynan M, Hayward M, Klenerman L, Whitehouse G, Edwards RH. The pathology of the lower leg muscles in pure forefoot pes cavus. Acta Neuropathol. 1995;89(6):552-9.
20. Myerson MS, Badekas A, Schon LC. Treatment of stage II posterior tibial tendon deficiency with flexor digitorum longus tendon transfer and calcaneal osteotomy. Foot Ankle Int. 2004;25(7):445-50.
21. Den Hartog BD. Flexor digitorum longus transfer with medial displacement calcaneal osteotomy. Biomechanical rationale. Foot Ankle Clin. 2001;6(1):67-76.
22. Akimau P, Flowers M. Medium term outcomes of planovalgus foot correction in children using a lateral column lengthening approach with additional procedures 'a la carte'. Foot Ankle Surg. 2014;20(1):26-9.
23. Sanhudo JAV. Dynamic correction for forefoot varus in stage II-A adult flatfoot: Technique tip. Foot Ankle Surg. 2019;25(5):698-700.
24. Hiller L, Pinney SJ. Surgical treatment of acquired flatfoot deformity: what is the state of practice among academic foot and ankle surgeons in 2002? Foot Ankle Int. 2003;24(9):701-5.
25. Marks RM, Long JT, Ness ME, Khazzam M, Harris GF. Surgical reconstruction of posterior tibial tendon dysfunction: prospective comparison of flexor digitorum longus substitution combined with lateral column lengthening or medial displacement calcaneal osteotomy. Gait Posture. 2009;29(1):17-22.
26. Niki H, Hirano T, Okada H, Beppu M. Outcome of medial displacement calcaneal osteotomy for correction of adult-acquired flatfoot. Foot Ankle Int. 2012;33(11):940-6.
27. Chadwick C, Whitehouse SL, Saxby TS. Long-term follow-up of flexor digitorum longus transfer and calcaneal osteotomy for stage II posterior tibial tendon dysfunction. Bone Joint J. 2015;97-B(3):346-52.
28. Boffeli TJ, Schnell KR. Cotton osteotomy in flatfoot reconstruction: a review of consecutive cases. J Foot Ankle Surg. 2017;56(5):990-5.
29. Choi JY, Cha SM, Yeom JW, Suh JS. Effect of the additional first ray osteotomy on hindfoot alignment after calcaneal osteotomy for the correction of mild-to-moderate adult type pes plano-valgus. J Orthop Surg (Hong Kong). 2017;25(1):2309499016684747.
30. Song SJ, Deland JT. Outcome following addition of peroneus brevis tendon transfer to treatment of acquired posterior tibial tendon insufficiency. Foot Ankle Int. 2001;22(4):301-4.

31. Boffeli TJ, Abben KW. Complete fifth ray amputation with peroneal tendon transfer--a staged surgical protocol. J Foot Ankle Surg. 2012;51(5):696-701.
32. Hamel J. [Corrective procedures and indications for cavovarus foot deformities in children and adolescents]. Oper Orthop Traumatol. 2017;29(6):473-82.
33. Schweinberger MH, Roukis TS. Balancing of the transmetatarsal amputation with peroneus brevis to peroneus longus tendon transfer. J Foot Ankle Surg. 2007;46(6):510-4.
34. Cohen JC, de Freitas Cabral E. Peroneus longus transfer for drop foot in Hansen disease. Foot Ankle Clin. 2012;17(3):425-36.
35. Geaney LE, Myerson MS. Management of posterior tibial tendon rupture with allograft reconstruction, osteotomy, and peroneus brevis-to-longus transfer. Tech Foot Ankle Surg. 2015;14:112-9.
36. Otis JC, Deland JT, Lee S, Gordon J. Peroneus brevis is a more effective evertor than peroneus longus. Foot Ankle Int. 2004; 25(4):242-6.
37. Ajis A, Geary N. Surgical technique, fusion rates, and planovalgus foot deformity correction with naviculocuneiform fusion. Foot Ankle Int. 2014;35(3):232-7.
38. Sanhudo JA. Mini L-shaped incision for calcaneal osteotomy: clinical tip. Foot Ankle Int. 2006;27(5):380-1.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1630

Original Article

Weight-bearing CT Hounsfield unit algorithm assessment of calcaneal osteotomy healing. A prospective study comparing metallic and bio-integrative screws

Nacime Salomão Barbachan Mansur[1,2], Tutku Tazegul[1], Kepler Alencar Mendes de Carvalho[1], Ki Chu Kim[1,3], Kevin Dibbern[1], Matthieu Lalevee[1,4], César de César Netto[1]

1. Department of Orthopaedics and Rehabilitation, University of Iowa, Carver College of Medicine,Iowa City, IA, USA.
2. Federal University of Sao Paulo, Department of Orthopedics and Traumatology, Sao Paulo, SP, Brazil.
3. Seoul Medical Center, Seoul, South Korea.
4. Department of Orthopedic Surgery, Rouen University Hospital, Rouen, France.

Abstract

Objective: To investigate the capability of biointegrative screws to achieve similar radiographical healing outcomes to metallic screws, measured using Hounsfield Unit (HU) algorithms, in medial displacement calcaneus osteotomies (MDCO). Our main hypothesis is that both implant methods would demonstrate comparable results.

Methods: In this prospective comparative study, patients undergoing MDCO were allocated to either a biointegrative or a metallic group. Surgeon, primary diagnosis, technique, and displacement were the same for both groups. Patients were assessed using weight-bearing computed tomography preoperatively and at weeks 2, 6, and 12 postoperatively. A 40x40x40 mm cube was centered on the osteotomy site, defining a volume of interest (VOI). Image intensity (Hounsfield Units) profiles along lines perpendicular to the osteotomy line and crossing it were recorded. Graphical plots of the HU distributions were generated for each line and then used to calculate the HU contrast.

Results: Three patients were allocated to the metallic group (age: 50.66; BMI: 27.78) and three to the biointegrative group (age: 47.33; BMI: 39.35). At two weeks, mean HU intensity was lower in the metallic group on the center (403.25 vs. 416.28; p=0.312) and superior lines (438.97 vs. 497.92), but not on the inferior line (513.24 vs. 386.57; p<0.001). At six weeks, the mean HU intensity was higher in the biointegrative group on the center line (p<0.001) and the superior line (p=0.018). At 12 weeks, the metallic group presented lower HU values on the center (p<0.001) and inferior (p<0.001) lines, but higher values on the superior line (p=0.010). Contrast was higher in the metallic group patients in the second (p=0.034) and 12th weeks (p=0.049).

Conclusion: Bone healing radiographical status results were similar for metallic and bio-integrative screws. Maximum HU values were equivalent, indicating comparable results at the osteotomy sites. However, the biointegrative group had lower contrast, portraying lower variability of bone density over the area.

Level of Evidence II; Prospective Comparative Study.

Keywords: Absorbable implants; Biocompatible materials; Calcaneus; Fracture healing; Orthopedic fixation devices; Osteotomy.

Study performed at the Department of Orthopaedics and Rehabilitation, University of Iowa, Iowa City, IA, USA.

Correspondence: Nacime Salomao Barbachan Mansur. Department of Orthopedics and Rehabilitation, University of Iowa. 200 Hawkins Dr, John Pappajohn Pavillion (JPP). Room 01066, Lower Level. Iowa City, IA, 52242. United States. **E-mail:** nacime-mansur@uiowa.edu. **Conflicts of Interest: Nacime Salomao Barbachan Mansur:** Brazilian Foot and Ankle Society: Board or committee member. American Orthopaedic Foot and Ankle Society: Board or committee member. **César de César Netto:** American Orthopaedic Foot and Ankle Society: Board or committee member. Editor in Chief Foot and Ankle Clinics. CurveBeam: Paid consultant; Stock or stock Options. Foot and Ankle International: Editorial or governing board. Nextremity: Paid consultant. Ossio: Paid consultant. Paragon 28: IP royalties; Paid consultant.Weightbearing CT International Study Group: Board or committee member. Zimmer: Paid consultant. **Source of funding:** none. **Date received:** April 19, 2022. **Date accepted:** April 20, 2022. **Online:** April 30, 2022.

How to cite this article: Mansur NSB, Tazegul T, Carvalho KAM, Kim KC, Dibbern K, Lalevee M, et al. Weight-bearing CT Hounsfield unit algorithm assessment of calcaneal osteotomy healing. A prospective study comparing metallic and bio-integrative screws. J Foot Ankle. 2022;16(1):52-8.

Introduction

Use of biointegrative implants in orthopedic surgery is increasing exponentially[1-3] due to prospective benefits such as adequate bone healing, lower rates of removal, and diminished implant-related artifacts in imaging studies when compared to metallic implants[4,5]. While many biomechanical and histological studies have been able to demonstrate their structural and biological properties, few reports are available to support their potential clinical advantages[1,6,7]. Evolution of material priorities over the last years have aimed at total product integration and reduction of possible complications such as cysts, foreign body reaction, and breakage[2,4]. Still, there is no direct comparison between the gold-standard metallic and the new biointegrative implants.

Data from weight-bearing computed tomography (WBCT) imaging can provide an objective assessment of bone density and joint space width[8,9]. A numerical calculation of the bone density within specific volumetric regions can be performed using imaging data measured in Hounsfield Units (HU)[8]. This method might be helpful for identifying stages of bone healing in specific regions more objectively than the current assessment, which relies on subjective evaluation of bone interfaces on non weight-bearing computed tomography (CT)[10,11]. For the current assessment, readers must come up with a consolidation percentage using a trabecular crossing estimate based on observations in multiple CT slices[12,13]. This evaluation can be drastically hampered by imaging artifacts from implants such as plates or screws[8]. Various thresholds have been proposed for determining bone healing (from 25 to 70%), but an appropriate number has not yet been defined[13,14].

Calcaneal osteotomies are one of the most common procedures in orthopedic surgery, demonstrating high healing rates and few complications[15,16]. Since many of the external variables can be controlled when assessing displacement calcaneal osteotomies, they constitute suitable procedures for comparison of implants or techniques. Therefore, this study aims to use HU data from WBCT to compare radiographic outcomes associated with healing of medial displacement calcaneal osteotomies (MDCO) using biointegrative or metallic screws. Our hypothesis is that both types of implants would present similar radiographic results.

Methods

Design

This was a prospective comparative study conducted at a single center, the Orthopedic Functional Imaging Research Laboratory at the University of Iowa. The research complied with the Declaration of Helsinki and the Health Insurance Portability and Accountability Act (HIPAA). It was approved by the Institutional Review Board (#201912144) before initiation and did not receive any financial support for its execution.

Sample

Adult patients (18 to 75 years old) with a clinical and radiographic diagnosis of Progressive Collapsing Foot Deformity (PCFD) undergoing an MDCO between September 2021 and January 2022 were recruited. Patients were excluded if they were found to have a rigid deformity at physical examination, any prior PCFD surgery, or metallic implants in the foot or ankle. Patients with non-traditional calcaneus osteotomies or wedge calcaneus resection, patients with history or documented evidence of peripheral neuropathy, patients with systemic inflammatory disease, and patients unwilling or unable to sign the informed consent form were also excluded.

Allocation

Patients were allocated to metallic or biointegrative groups at a 1:1 ratio in a sequential, non-randomized, and unblinded fashion. The first patient was placed in the metallic group and the second in the biointegrative group. Subsequent patients were then placed in alternating groups appropriately. Subjects were evaluated independently. The intervention was the same for both groups, with identical arrangements and screw positionings, only diverging in the type of screw used. They were assessed at pre-intervention, then at 2, 6, and 12 weeks after the surgery.

Interventions

All surgeries were performed by a single fellowship-trained orthopedic foot and ankle surgeon with more than 10 years of experience. Patients in both groups were operated with the same technique and put on the same postoperative protocol, only diverging in the screw material implanted. A traditional MDCO was performed[17,18].

Patients were placed in a supine position after general anesthesia and peripheral block. A 5cm oblique lateral incision was performed over the posterior calcaneus tuberosity, centered on the bone safe zone. Dissection was accomplished, avoiding injury to the sural nerve and the peroneal tendons. After proper saw placement (confirmed by fluoroscopy), a perpendicular cut to the lateral wall of the calcaneus was executed until the far cortex was completely freed up[19]. A 10 mm translation of the posterior tuberosity was carried and stabilized with two 1.5 mm Kirschner wires. The wires crossed the osteotomy perpendicular to the cut, one dorsal and the other plantar to the center of the calcaneus. Proper displacement and guide-wire placement was confirmed with fluoroscopy. A 3.2 mm drill was used through the guides, and a 4 mm tap with countersink completed tunnel preparations.

Patients in the metallic group received two metallic headless 4.0 mm titanium cannulated screws (Paragon28®, Denver, CO, USA). Patients in the biointegrative group received two 4.0 mm fiber cannulated screws (Ossio®, Caesarea, Israel). The implants were inserted using hand screwdrivers until entirely inside the bone. Corrections and positions were checked using fluoroscopy. The incision was then sutured in layers, and the patients were placed in a below-knee postoperative splint. They remained non-weight-bearing for six weeks and then were transitioned to a walking boot. The boot was worn until the eighth week, and sports activities were allowed three months after surgery.

Outcomes

Bone healing was assessed using HU imaging data on WBCT recorded preoperatively, then at 2, 6, and 12 weeks postoperatively[8]. WBCT scans were performed with a cone-beam CT lower extremity scanner (HiRise; CurveBeam, LLC, Warrington, PA, USA). Raw multiplanar data were converted into sagittal, coronal, and axial plane images. Using dedicated software (CurveBeam LLC, Warrington, PA, USA), a 40x40x40 mm cube was centered on the osteotomy site, defining a volume of interest (VOI) (Figure 1). Within the VOI, initial computational analysis focused on image intensity (Hounsfield Units) profiles along lines perpendicular to the osteotomy line and to the osteotomy screws, crossing the osteotomy line and spanning approximately 8 mm on either side. Three perpendicular lines were placed for each ankle, with one located directly between the osteotomy screws, one superior to both screws, and one inferior to both screws. The HU intensity profiles were recorded and graphical plots of the HU distributions were generated for each line (Figure 1). The plots were then used to assess the mean, minimum, and maximum HU intensity values for each line, and trends over time for each ankle. The HU contrast, a proxy for bone healing at the osteotomy site, was also calculated.

Statistical Analysis

Normality of distribution was tested for continuous variables using the Kolmogorov-Smirnov test. Comparisons were performed using paired *t* tests and chi-square tests. Cohen's d and Hedges corrections were utilized. Analyses were performed with SPSS® V20 and Minitab® 16 software. The level of statistical significance was set at 5%, with a 95% confidence interval.

Results

After assessment of 10 subjects between September 2021 and January 2022, 6 patients were found eligible, included in the study, and allocated. Three patients were assigned to the metallic group (mean age: 50.66, max 65, min 29; mean BMI: 27.78, SD: 6.18) and three were assigned to the biointegrative group (mean age: 47.33, min 26, max 61; mean BMI: 39.35, SD: 7.74). No patients were excluded during follow-up. The groups were similar in age ($p=0.66$), but not in body mass index (BMI) ($p<0.05$).

Preoperative HU calcaneus assessment mean values were different between groups for center (metal: -45.78, SD 108.68 vs bio: 149.54, SD 180.85; $p<0.001$), inferior (metal: -51.30, SD 133.60 vs. bio: 190.64, SD 159.17; $p<0.001$), and superior (metal: 136.61, SD 154.51 vs. bio: 281.53, SD 240.73; $p<0.001$) lines. The minimum and maximum HU values were similar (Table 1). At 2 weeks, mean HU intensities in the metallic and bio-integrative were respectively 403.25 (SD: 398.06) and 416.28 (SD:176.78) at the center line ($p=0.312$), 513.24 (SD: 250.62) and 386.57 (SD: 151.86) at the inferior line ($p<0.001$), and 438.97 (SD: 338.95) and 497.92 (SD: 226.05) at the superior line ($p=0.020$).

Evaluation at 6 weeks demonstrated mean HU intensities of 318.40 (SD: 281.03) and 414.22 (186.12) at the center ($p<0.001$), 340.41 (SD: 212.98) and 356.86 (179.82) ($p=0.315$) at the inferior, and 401.72 (SD: 225.55) and 449.88 (SD: 236.87) at the superior ($p=0.018$) lines. At 12 weeks, HU intensities of -85.01

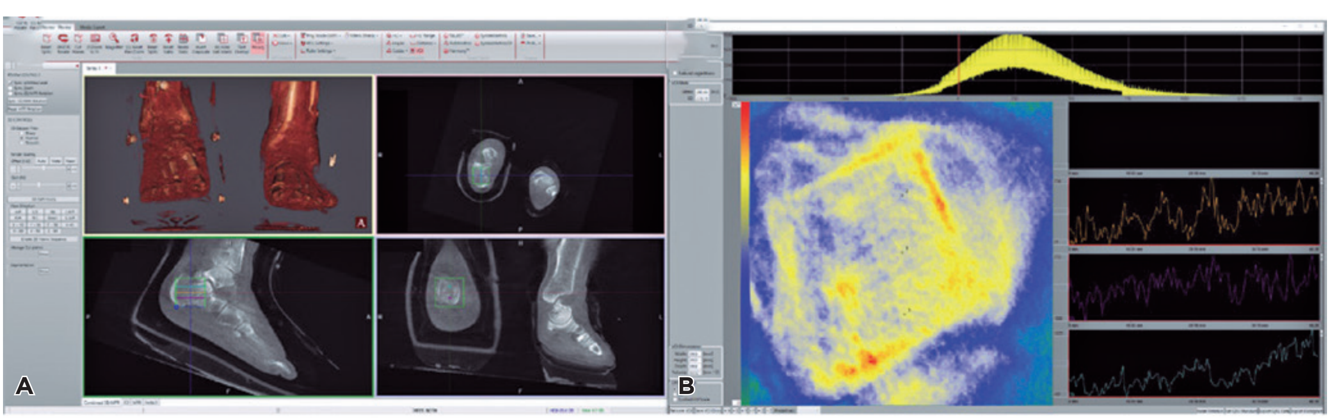


Figure 1. Hounsfield Unit (HU) assessment method for bone intensity. Using the dedicated software (A), the 40x40x40 mm cube was placed centralized on the calcaneal osteotomy in all planes, utilizing the rotation tools. Three 16 mm (8 mm either side of the osteotomy) lines were created. The first line (1) was centered between the two screws, the second (2) inferior to the plantar screw and the third (3) superior to the dorsal screw. Graphical plots (B) of the HU distributions were generated for each line. The plots were then used to calculate the HU contrast, a representation of bone healing at the osteotomy site.

Table 1. Values obtained for all variables assessed over the study timeline

Statistics	preop_ metal_ inter	preop_ bio_ inter	preop_ metal_ inf	preop_ bio_inf	preop_ metal_ sup	preop_ bio_sup	metal_2 weeks_inter	bio_2 weeks_inter	metal_2 weeks_inf	bio_2 weeks_inf	metal_2 weeks_sup	bio_2 weeks_sup
N	3	3	3	3	3	3	3	3	3	3	3	3
Mean	-45,784	149,546	-51,303	190,647	136,619	281,537	403,235	416,683	513,243	386,571	438,246	497,925
SD	108,683	180,853	133,606	159,172	154,520	240,734	398,069	176,789	250,624	151,863	338,954	226,052
Range	795	949	855	944	1068	1300	2025	973	1292	1002	1864	1283
Minimum	-254	-277	-319	-143	-126	-163	-294	-39	-19	-55	-215	-33
Maximum	541	672	536	801	942	1137	1731	934	1273	947	1649	1250

	metal_6 weeks_ inter	bio_6 weeks_ inter	metal_6 weeks_ inf	bio_6 weeks_ inf	metal_6 weeks_sup	bio_6 weeks_ sup	metal_12 weeks_ inter	bio_12 weeks_ inter	metal_12 weeks_ inf	bio_12 weeks_inf	metal_12 weeks_ sup	bio_12 weeks_ sup
N	3	3	3	3	3	3	3	3	3	3	3	3
Mean	318,5	414,228	340,414	356,862	401,728	449,881	-85,014	64,592	-111,367	139,193	225,959	166,055
SD	281,033	186,129	212,988	179,825	222,553	236,873	192,209	142,775	172,773	173,762	209,459	215,689
Range	1309	894	1085	1062	1191	1394	793	624	1085	1048	918	1076
Minimum	-129	-17	-144	-268	-95	-113	-458	-216	-422	-310	-140	-283
Maximum	1180	877	941	794	1096	1281	335	408	663	738	778	793

N: number of patients. SD: standard deviation. Metal: metallic group. Bio: biointegrative group. Inter: intermediate line. Inf: inferior line. Sup: superior line.

(SD: 192.20) and 64.59 (SD: 142.77) were found at the center ($p<0.001$), -111.36 (SD: 172.77) and 139.19 (SD: 173.76) at the inferior ($p<0.001$), and 225.95 (209.45) and 166.05 (215.68) at the superior lines respectively ($p=0.010$) (Table 2). Overall, HU units decreased from the second to the 12th week in both groups ($p<0.001$) (Figure 2). Considering all lines traced, contrast was higher in the metallic patients in the second week (0.42 to 0.25; $p=0.034$) and in the 12th week (1.06 to 0.45; $p=0.049$), but not in the sixth postoperative week (0.48 to 0.30; $p=0.064$).

Discussion

This study intended to compare radiographic bone healing in calcaneal osteotomies performed with metallic or biointegrative implants using HU imaging data. We found higher overall mean HU values in the biointegrative group for most variables and similar maximum HU values between implants. These results could be translated as similar bone intensity signals when comparing groups. Lower contrast was also observed in the biointegrative group, showing lower signal variability with this implant. The data presented suggest that our primary outcomes support our main hypothesis.

Use of HU values to assess bone quality is not original and has been described as a valuable tool when studying bony architecture[20,21]. Soft tissues and air present lower and negative Hounsfield Units while bone, particularly cortical bone, has higher values[22]. Positive correlations between HU values and bone density scans have also been reported, supporting their use in clinical practice[20]. However, it wasn't until recently that algorithms to predict joint width space and bone healing were created using data from WBCT[8,23]. By incorporating the same rationale, we were able to attest higher bone intensity values in our study when comparing biointegrative and metallic implants ($p<0.01$) in most of the crossed lines. Intensities were similar at the intermediate line at 2 weeks ($p=0.312$) and at the inferior line at 6 weeks. The metallic group had higher HU intensities at the inferior line at 2 weeks ($p<0.001$) and at the superior line at 6 weeks ($p<0.005$). The fact that the metallic screws were not superior to the biointegrative screws suggests that both implants have similar capacity to produce bone intensity signals compatible with healing. Previous studies, using different type of implants, have tried to compare bone healing in unique scenarios. Plaass et al.[6] compared magnesium absorbable screws with metallic screws for hallux valgus osteotomies. Using magnetic resonance imaging, these authors could not find differences in bone healing with a 3-year follow-up[6]. Leno et al.[24] also observed no dissimilarities between absorbable and titanium plates for mandibular fracture union. On the other hand, Noh et al.[25] compared metallic and biodegradable plates for ankle fractures, demonstrating shorter time to healing in the metallic group (15.8 vs. 17.6 weeks).

Contrast measures differences in image intensity and, when applied to HU, can translate the variability of a specific anatomical area, such as an articular space or bone-to-bone interface. Our study was able to demonstrate lower mean contrast values for the biointegrative group at the second (0.42 to 0.25; $p=0.034$) and 12th weeks (1.06 to 0.45; $p=0.049$) by evaluating all three lines together. Since this variable is deter-

Table 2. Pairwise comparisons of groups along specific timelines. Positive mean difference indicates a higher mean value in the metallic group. Negative mean difference indicates a higher mean value in the biointegrative group. Significant differences are highlighted in bold

		Paired Differences				
		Mean	SD	95% CI Lower	95% CI Upper	p value
Pair 1	preop_metallic_inter - preop_bio_int	-195,33028	201,65913	-222,24975	-168,4108	**<.001**
Pair 2	preop_metal_inf - preop_bio_inf	-241,94954	182,14296	-266,26381	-217,63528	**<.001**
Pair 3	preop_metal_sup - preop_bio_sup	-144,91743	288,80731	-183,47032	-106,36454	**<.001**
Pair 4	metal_2weeks_inter - bio_2weeks_inter	-13,44776	449,7527	-67,53908	40,64355	0,312
Pair 5	metal_2weeks_inf - bio_2weeks_inf	126,67164	327,58123	87,27377	166,06951	**<.001**
Pair 6	metal_2weeks_sup - bio_2weeks_sup	-59,6791	416,33452	-109,75125	-9,60696	**0,01**
Pair 7	metal_6weeks_inter - bio_6weeks_inter	-95,72761	311,08541	-133,14155	-58,31368	**<.001**
Pair 8	metal_6weeks_inf - bio_6weeks_inf	-16,44776	267,39959	-48,60765	15,71212	0,157
Pair 9	metal_6weeks_sup - bio_6weeks_sup	-48,15299	330,41255	-87,89138	-8,41459	**0,009**
Pair 10	metal_12weeks_inter - bio_12weeks_inter	-149,6055	265,8428	-185,09286	-114,11815	**<.001**
Pair 11	metal_12weeks_inf - bio_12weeks_inf	-250,55963	245,26333	-283,29984	-217,81943	**<.001**
Pair 12	metal_12weeks_sup - bio_12weeks_sup	59,90367	341,44234	14,32453	105,48281	**0,005**

SD: standard deviation. 95%CI: confidence interval of 95%. Metal: metallic group. Bio: biointegrative group. Inter: intermediate line. Inf: inferior line. Sup: superior line.

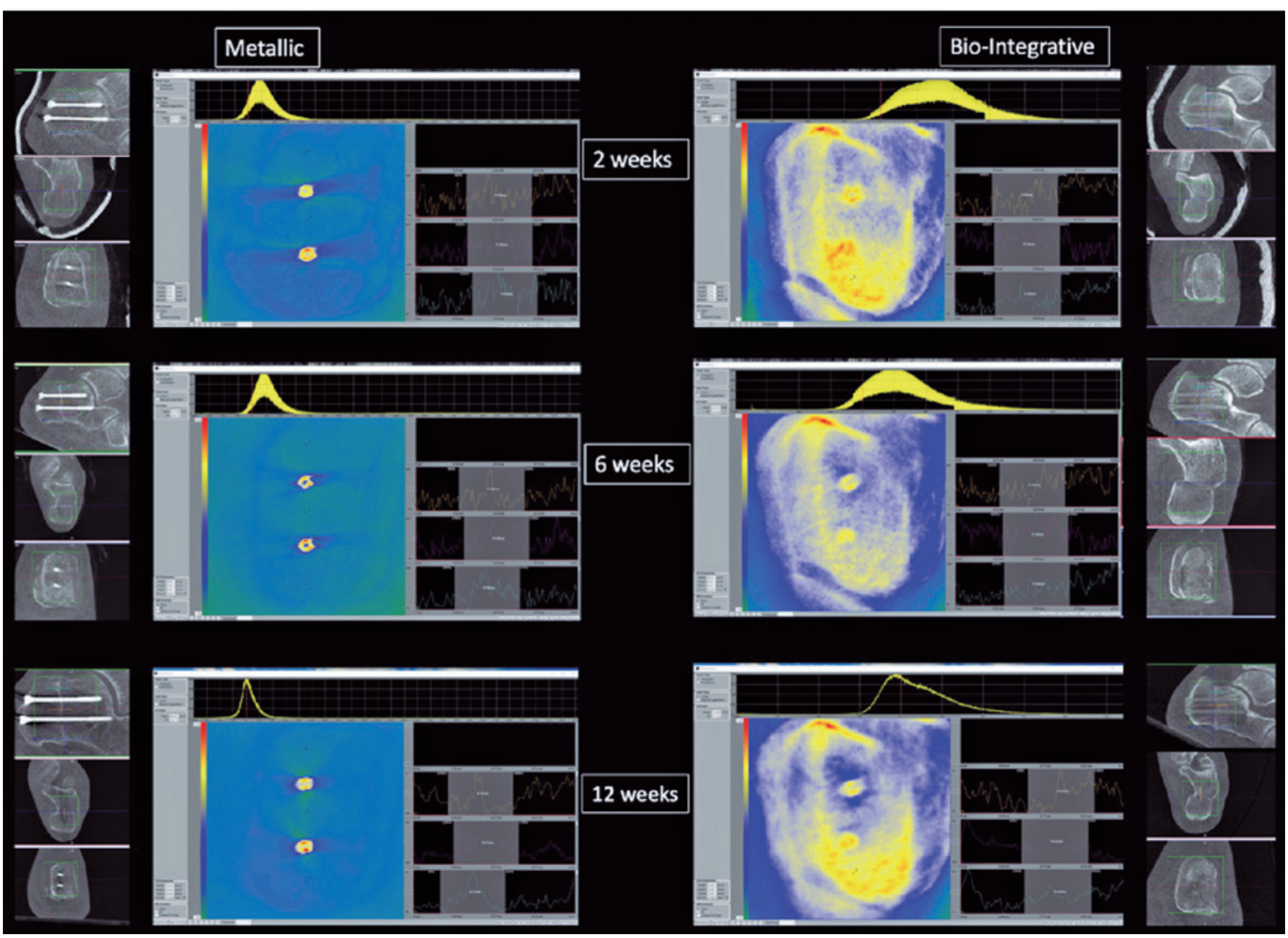


Figure 2. Representation of the analysis over time for one patient from the metallic screw group and one from the biointegrative group. Plots and slices on the left represent the metallic example and those on the right represent the biointegrative example.

mined by the ratio of the difference in maximum and background intensities to the background intensity, lower contrast values may suggest more uniform bone formation (smaller increase in signal over background). Decreased HU (air, soft tissue, or poor bone density) could also be attributed to degenerative joint disease with a diminished articular space or to a higher bone and bone interface compatible with bone healing. Since the sixth week evaluation showed no differences (0.48 to 0.30; p=0.064) between groups, we can state that the biointegrative implant was not inferior to the metallic implant when considering bone healing by HU contrast. Moreover, absence of valleys on the graphical plots at 2 weeks postoperatively, which would indicate presence of contiguous low HU values, could be a direct sign of osteotomy compression (Figure 2).

The increased contrast and the abundant presence of negative HU values in some areas of the metallic group (especially the center lines) might be due to a shielding effect associated with metallic screws. A beam hardening effect concentrates HU contiguous to metal, shielding the adjacent cancellous bone[8]. This might jeopardize assessment in the daily clinical scenario, requiring artifact reduction sequences that may not normalize the findings completely[26,27]. This would be a major confounding factor in our study had the lines not been placed in different locations and assessed independently. Another interesting finding was the diminished overall HU intensity over time during the study, potentially demonstrating the negative effect of the non-weight bearing regime on bone density.

There are several limitations to this study that need to be discussed. First, baseline characteristics differed for BMI, which might explain the disparities in overall HU values on preoperative WBCT scans. Further, bone healing was only evaluated using one novel imaging method, with no clinical or other radiographical assessment for comparison. No sample calculation or power analysis was performed. We evaluated a small number of subjects over a short follow-up period. Nevertheless, this pilot study was intended to attest the noninferiority of one group in relation to another by utilizing an objective and measurable tool to evaluate bone healing. The same surgeon performed all the surgeries and only one type of metallic and one type of biointegrative screw was used, which could undermine reproducibility of the methods. Finally, the HU algorithm is a novel technique that might not be universally accessible.

Conclusion

Comparison of bone healing between metallic and bio-integrative screws using our HU algorithm found similar results. Maximum HU intensity values were similar, indicating equivalent results at the osteotomy sites, a finding compatible with consolidation. Contrast was lower in the biointegrative group, indicating lower variability of bone density across the topography studied. Presence of metallic implants across the osteotomy site hampered evaluation of both HU intensity and contrast, presenting a challenge when calculating bone healing through indirect and direct assessments. Larger prospective comparative studies with longer follow-up are needed to endorse these results.

Authors' contributions: Each author contributed individually and significantly to the development of this article: NSBM *(https://orcid.org/0000-0003-1067-727X) Conceived and planned the activity that led to the study, data collection, interpreted the results of the study, bibliographic review, formatting of the article, wrote the article; TT *(https://orcid.org/0000-0002-3802-3422) Bibliographic review, wrote the article, data collection, conceived and planned the activity that led to the study; KAMC *(https://orcid.org/0000-0003-1082-6490) Bibliographic review, wrote the article; KCK *(https://orcid.org/0000-0002-3731-8448) Bibliographic review, wrote the article; KD *(https://orcid.org/0000-0001-5404-2132) Bibliographic review, wrote the article; ML *(https://orcid.org/ 0000-0001-5058-8867) Data collection, wrote the article; CCN *(https://orcid.org/0000-0001-6037-0685) Bibliographic review, wrote the article, formatting of the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Partio N, Mattila VM, Mäenpää H. Bioabsorbable vs. titanium screws for first tarsometatarsal joint arthrodesis: an in-vitro study. J Clin Orthop Trauma. 2020;11(3):448-52.
2. Daghino W, Bistolfi A, Aprato A, Massè A. Bioabsorbable implants in foot trauma surgery. Injury. 2019;50 Suppl 4:S47-s55.
3. Debieux P, Franciozi CE, Lenza M, Tamaoki MJ, Magnussen RA, Faloppa F, et al. Bioabsorbable versus metallic interference screws for graft fixation in anterior cruciate ligament reconstruction. Cochrane Database Syst Rev. 2016;7(7):Cd009772.
4. Clanton TO, Betech AA, Bott AM, Matheny LM, Hartline B, Hanson TW, et al. Complications after tendon transfers in the foot and ankle using bioabsorbable screws. Foot Ankle Int. 2013;34(4):486-90.
5. Cicchinelli LD, Štalc J, Richter M, Miller S. Prospective, multicenter, clinical and radiographic evaluation of a biointegrative, fiber-reinforced implant for proximal interphalangeal joint arthrodesis. Foot Ankle Orthop. 2020;5(4):247301142096631.
6. Plaass C, von Falck C, Ettinger S, Sonnow L, Calderone F, Weizbauer A, et al. Bioabsorbable magnesium versus standard titanium compression screws for fixation of distal metatarsal osteotomies - 3 year results of a randomized clinical trial. J Orthop Sci. 2018;23(2):321-7.
7. Park S, Kim JH, Kim IH, Lee M, Heo S, Kim H, et al. Evaluation of poly(lactic-co-glycolic acid) plate and screw system for bone fixation. J Craniofac Surg. 2013;24(3):1021-5.

8. Vandelune C, Tazegul T, J Ahrenholz S, Iehl C, Vivtcharenko V, Schmidt E, et al. Implant-related artifacts around metallic and bio-integrative screws: a CT scan 3D Hounsfield unit assessment. J Foot Ankle. 2021;15(2):95-9.
9. Panchbhavi VK, Boutris N, Patel K, Molina D, Andersen CR. CT density analysis of the medial cuneiform. Foot Ankle Int. 2013;34(11):1596-9.
10. Coughlin MJ, Grimes JS, Traughber PD, Jones CP. Comparison of radiographs and ct scans in the prospective evaluation of the fusion of hindfoot arthrodesis. Foot Ankle Int. 2006;27(10):780-7.
11. Cerrato RA, Aiyer AA, Campbell J, Jeng CL, Myerson MS. Reproducibility of computed tomography to evaluate ankle and hindfoot fusions. Foot Ankle Int. 2014;35(11):1176-80.
12. Jones CP, Coughlin MJ, Shurnas PS. Prospective CT scan evaluation of hindfoot nonunions treated with revision surgery and low-intensity ultrasound stimulation. Foot Ankle Int. 2006;27(4):229-35.
13. Glazebrook M, Beasley W, Daniels T, Evangelista PT, Donahue R, Younger A, et al. Establishing the relationship between clinical outcome and extent of osseous bridging between computed tomography assessment in isolated hindfoot and ankle fusions. Foot Ankle Int. 2013;34(12):1612-8.
14. Dorsey ML, Liu PT, Roberts CC, Kile TA. Correlation of arthrodesis stability with degree of joint fusion on MDCT. Am J Roentgenol. 2009;192(2):496-9.
15. Schon LC, de Cesar Netto C, Day J, Deland JT, Hintermann B, Johnson JE, et al. Consensus for the indication of a medializing displacement calcaneal osteotomy in the treatment of progressive collapsing foot deformity. Foot Ankle Int. 2020;41(10):1282-5.
16. Kendal AR, Khalid A, Ball T, Rogers M, Cooke P, Sharp R. Complications of minimally invasive calcaneal osteotomy versus open osteotomy. Foot Ankle Int. 2015;36(6):685-90.
17. Guha AR, Perera AM. Calcaneal osteotomy in the treatment of adult acquired flatfoot deformity. Foot Ankle Clin. 2012;17(2):247-58.
18. Talusan PG, Cata E, Tan EW, Parks BG, Guyton GP. Safe zone for neural structures in medial displacement calcaneal osteotomy: a cadaveric and radiographic investigation. Foot Ankle Int. 2015;36(12):1493-8.
19. Sherman TI, Guyton GP. Minimal Incision/Minimally Invasive medializing displacement calcaneal osteotomy. Foot Ankle Int. 2018;39(1):119-28.
20. Han K, You ST, Lee HJ, Kim IS, Hong JT, Sung JH. Hounsfield unit measurement method and related factors that most appropriately reflect bone mineral density on cervical spine computed tomography. Skeletal Radiol. 2022. doi: 10.1007/s00256-022-04050-4.
21. Silva IMDCC, Freitas DQD, Ambrosano GMB, Bóscolo FN, Almeida SM. Bone density: comparative evaluation of Hounsfield units in multislice and cone-beam computed tomography. Braz Oral Res. 2012;26(6):550-6.
22. Willner M, Fior G, Marschner M, Birnbacher L, Schock J, Braun C, et al. Phase-contrast hounsfield units of fixated and non-fixated soft-tissue samples. PLOS ONE. 2015;10(8):e0137016.
23. Lintz F, Welck MJ, Buedts K, Fernando C, Netto CDC, Bernasconi A. Distribution of bone mineral density in the ankle joint: correlation with hindfoot alignment. Foot Ankle Orthop. 2022;7(1):2473011421S0032.
24. Leno MB, Liu SY, Chen C-T, Liao HT. Comparison of functional outcomes and patient-reported satisfaction between titanium and absorbable plates and screws for fixation of mandibular fractures: a one-year prospective study. J Craniomaxillofac Surg. 2017;45(5):704-9.
25. Noh JH, Roh YH, Yang BG, Kim SW, Lee JS, Oh MK. Outcomes of operative treatment of unstable ankle fractures: a comparison of metallic and biodegradable implants. J Bone Joint Surg Am. 2012;94(22):e166.
26. Bolstad K, Flatabø S, Aadnevik D, Dalehaug I, Vetti N. Metal artifact reduction in CT, a phantom study: subjective and objective evaluation of four commercial metal artifact reduction algorithms when used on three different orthopedic metal implants. Acta Radiol. 2018;59(9):1110-8.
27. Giantsoudi D, De Man B, Verburg J, Trofimov A, Jin Y, Wang G, et al. Metal artifacts in computed tomography for radiation therapy planning: dosimetric effects and impact of metal artifact reduction. Phys Med Biol. 2017;62(8):R49-R80.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1619

Original Article

Intra-articular pressure measurement of the first metatarsophalangeal joint of the foot

Jorge Luis Alberto Castellini[1]

1. Dr. Jorge Castellini Clinic, Buenos Aires, Argentina.

Abstract

Objective: To measure the metatarsophalangeal (MTP) intra-articular pressure of the first ray before surgical intervention for hallux valgus (HV), recurrent HV, and hallux rigidus (HR).

Methods: This is a cross-sectional study including a consecutive sample of patients obtained from 1/1/2009 and 8/30/2015 in a center in Argentina. Measurements were made with a Stryker® pressure gauge, and results were expressed in mmHg. Descriptive and comparative statistics (Mann-Whitney test) were performed.

Results: A total of 166 feet were included, 120 cases with HV, 20 with HR, and 26 with recurrent HV; the sample consisted of men and women aged 15 to 90 years. The greater HV deformity, the higher intra-articular pressure at rest and during maximal dorsiflexion and maximal plantar flexion. Conversely, an inverse situation is observed in HR: the greater the deformity, the lower intra-articular pressure. Median resting intra-articular pressure of the first MTP joint of the foot was 3 mmHg in mild HV, compared to 23 mmHg in early-stage HR (p=0.001).

Conclusions: The measurement of intra-articular pressure could be a useful tool to differentiate early stages of joint diseases of the first ray of the foot.

Level of Evidence II; Prognostic Studies; Retrospective Study.

Keywords: Hallux valgus; Hallux rigidus; Osteoarthritis; Recurrence.

Introduction

Medical consultations due to or first metatarsophalangeal joint (MTPJ) pain deformity is very frequent in foot and ankle specialists' offices, requiring an accurate differential disease diagnosis. The conduct will be different whether it is a valgus hallux deformity known as hallux valgus (HV) or a disease presenting with restricted joint movement and deformity mainly at the dorsal level, known as hallux rigidus (HR) or Dorsal bunion[1].

The prevalence varies according to deformity and age. HV is more prevalent in women (2.3:1) and older adults. Nix et al.[2], in a systematic review that included 78 studies with 500,000 cases, estimated a prevalence of 7.8% in juveniles, 23% in adults from 18-65 years, and 35.7% in those older than 65 years. Senga et al.[3] found a prevalence of 26.7% for HR among 607 feet in Japan.

Several studies about the pathogenesis of HR have been conducted[4-6]. Lambrinudi[4] describes a flexion contracture of the metatarsophalangeal of the first ray and consider it a possible etiopathogenic factor of HR, which could explain the difference in the height of the first metatarsal relative to the second metatarsal in weight-bearing profile radiographs.

Several studies were conducted aiming to differentiate HV from HR using radiographic measures[1,7-9]. Bouaicha et al.[9] in 2010 and Usuelli et al.[1] in 2011 propose that metatarsus primus elevatus (MPE) is constant in HR and not in HV; whereas Horton and Meyer did not find conclusive results, because they observed MPE in both diseases[6,7].

With regard to HR, the biological plausibility of this first metatarsal elevation could be a consequence of reduced excursion of the flexor hallucis longus (FHL) tendon, either due to muscle contracture, plantar plate adherences, or dorsal

Study performed at the Dr. Jorge Castellini Clinic, Buenos Aires, Argentina.

Correspondence: Jorge Luis Alberto Castellini. Riobamba 972 3°C, CP 1116, Ciudad Autónoma de Buenos Aires, Argentina. **E-mail:** jorgecastellini@gmail.com.
Conflicts of interest: none. **Source of funding:** none. **Date received:** March 12, 2022. **Date accepted:** March 23, 2022. **Online:** April 30, 2022.

How to cite this article: Castellini JLA. Intra-articular pressure measurement of the first metatarsophalangeal joint of the foot. J Foot Ankle. 2022;16(1):59-63.

osteophytosis[10]. This proximal displacement of the FHL could increase tendon strength, causing increased loading on the first MTPJ and first metatarsal, and progressive fibrosis in the musculotendinous junction could result from increased loading or pressure on the MTPJ.

The most currently used surgical techniques consider MPE as the cause of HR and aim to descend the first metatarsal head and shorten the first metatarsal to achieve normal MTPJ range of motion[11-14]. Voss[15] proposed that joint decompression tenotomies would reduce primary and idiopathic increase in intra-articular pressure on hip joint. In a cadaveric study, Kim et al.[16] compared intra-articular pressure, measured with digital sensors (in kg/cm^2), before and after phalangeal osteotomy, and did not find changes in pressure of the first metatarsal head. However, this work has been questioned due to the absence of FHL during measurements of the cadaveric specimens.

Although there are objective standards to define advanced HV and HR, differentiation in early stages has not been cleared yet, these last account for nearly 90% of cases of HR, with mild deformity or without radiographic signs[3].

In light of the foregoing, I hypothesize that HR would present with a primary or idiopathic increase in intra-articular pressure, whereas HV would not. The aim of the present study is to measure intra-articular pressure of the MTPJ of the first ray in a group of patients with different stages of HV and HR, before undergoing surgical intervention.

Methods

This study, which was approved by my institution's ethics committee.

A cross-sectional study was conducted with a consecutive sample obtained from 1/1/2009 to 8/30/2015 and consisting of patients with HV, HR and/or recurrent HV who underwent surgical intervention with techniques performed according to baseline disease. Informed consent was provided by each study participant.

Radiographic classification of HV was based on values of metatarsophalangeal and intermetatarsal angles on frontal or anteroposterior radiograph, and HV was classified into mild, moderate, and severe[17,18].

Radiographic classification of HR considered parameters such as joint impingement, development of osteophytes, subchondral sclerosis at the first metatarsal base, and osteochondral lesions of the first metatarsal head and the base of phalanx. I used the classification proposed by Hattrup and Johnson[19], which classifies HR into Grades 1, 2, and 3.

Horton index is measured in weight-bearing profile radiograph of the foot. It is the distance in mm from the cortical dorsal surface of the first metatarsal (M1) to the cortical dorsal surface of the second metatarsal (M2), at the neck of the metatarsal, which is nearly 15 mm proximal to the joint surface. This measurement was conducted in all cases, and Horton index was considered high when there was 3 or more mm of difference between M1 and M2[6].

Cases of recurrent HV were considered those in which the metatarsophalangeal angle is above 20° on weight-bearing anteroposterior radiograph[20].

Patients with neurological or arterial vascular diseases, arthritis rheumatoid, hallux varus were excluded, as well as those with missing measurement data.

Technique for measuring intra-articular pressure

Measurement of intra-articular pressure of first MTPJ was made using a Stryker® pressure gauge, which is usually used to diagnose compartment syndrome in crush injuries of peripheral limbs (upper and lower).

Once regional anesthetic blockade was performed on the ankle, an ultrathin needle is placed on the dorsal MTPJ of the first ray, immediately medial to the extensor hallucis longus tendon, in order to prevent injuries to the dorsomedial collateral branch. This needle is connected to a catheter that is then attached to the pressure gauge.

In the first cases, a fluoroscope was used to ensure intra-articular position, but soon later it was not necessary, due to ease of the procedure with the needle.

Three consecutive measures were taken before surgical intervention. The first one was obtained with the patient in the supine position and the joint in a joint position, in order to assess the so-called baseline or resting pressure. For the second measure, a maximal passive dorsiflexion maneuver was performed, and pressure is shown on the display of the gauge held by an assistant (the pressure gauge is not sterile). Finally, a third measure was obtained placing the hallux in maximal passive plantar flexion (Figures 1, 2, 3 and 4).

Figure 1. Image obtained before hallux valgus surgery on the left foot and focusing on the insertion site of the needle to assess pressure of the metatarsophalangeal joint of the first ray.

Statistical analysis

For descriptive analysis, continuous variables were expressed as mean and standard deviation (SD) for normally distributed variables and as median and interquartile range (IQR) for abnormally distributed ones. Categorical and ordinal variables were presented as absolute and relative frequencies.

Comparative analysis between mild HV and early-stage HR was performed using the Mann-Whitney test for comparison of medians. Statistical significance was set a p-value of <0.05.

Figure 2. Image showing resting pressure in mmHg before hallux valgus surgery on the left foot.

Figure 3. Image showing pressure during maximal passive dorsiflexion measured in mmHg before hallux valgus surgery on the left foot.

Figure 4. Image showing pressure during maximal passive plantar flexion measured in mmHg before hallux valgus surgery on the left foot.

Results

During the study period, 166 feet were included, 120 cases with HV, 20 with HR, and 26 with recurrent HV; consisting of men and women aged 15 to 90 years (Table 1).

Of the 120 cases with HV, 55 (45.83%) presented with radiographic signs of arthrosis (4 mild, 24 moderate, and 27 severe)[21].

Pressures values measured in the different groups, dividing the cases of HV into 2 subgroups (with and without signs of arthrosis), recurrent HV, and HR are shown in Table 2.

Pressure values in millimeters of mercury (mmHg) in the different groups divided by disease severity into mild, moderate, and severe HV, Grade 1, 2, and 3 HR, and cases of recurrent HV are presented in Table 3.

Median resting intra-articular pressure in mild HV was significantly lower than that observed in grade 1 HR (3 mmHg vs 23 mmHg respectively; p=0.001).

Discussion

Results showed a statistically significant difference in resting intra-articular pressure between HV and early-stage HR. The greater HV deformity, the higher intra-articular pressure at rest and during maximal dorsiflexion and maximal plantar flexion. Conversely, an inverse situation was observed in HR: the greater deformity, the lower intra-articular pressure. The group of patients with recurrent HV presented with values similar to those of moderate and severe HV.

With regard to the etiopathogenic factor for HR described by Lambrinudi[4], early stage would present with higher pressure, either primary or secondary, and mobility is reduced as deformity increases, which could explain the reduction in intra-articular pressure observed in our study.

Due to the lack of reports in the literature expressing joint pressure in millimeters of mercury, it was not possible to compare our findings with those of other authors. However, the hypothesis of primary and idiopathic hyperpressure of hip joint has been present since 1956[15]. In Germany, Voss[15] proposed a treatment consisting of tenotomy of all tendons that cross the hip joint and finally insert into the proximal femur, an operation that he named "floating hip". In 1963 comparative results of these surgeries to reduce hip joint pressure were published, showing 80% of good clinical results, with a 6-month follow-up[22].

With regard to foot surgery, in a congress of the specialty held in early 2000, Fernando Troilo, a surgeon of *Sociedad Argentina de Medicina y Cirugía de Pie y de Pierna* (SAMECIPP) and *Asociación Argentina de Ortopedia y Traumatología* (AAOT), presented a technique to measure intra-articular pressure with a sphygmomanometer similar to that used to measure arterial tension, in patients with recurrent HV, reporting that they presented with an increase in such pressure. Several years later, a French surgeon, during a presentation at a congress of the specialty, stated that the aim of his surgery of first metatarsal shortening osteotomy was reducing pain,

Table 1. Description of demographic characteristics of samples according to diagnostic group

	Hallux valgus (n=120)	Hallux rigidus (n=20)	Recurrent hallux valgus (n=26)
Female sex	115 (95%)	15 (75%)	25 (96.15%)
Age (years)*	54.67±15	53.61±14	58.57±20
High Horton index	80/111 (72.07%)	19/20 (95%)	16/23 (69.57%)
Classification	Mild 15 (12.50%) Moderate 63 (52.50%) Severe 42 (35%)	Grade 1 5 (25%) Grade 2 11 (55%) Grade 3 4 (20%)	.....

*Mean (standard deviation)

Table 2. Pressure values in the different groups, with cases of hallux valgus (HV) divided into 2 subgroups (with and without signs of arthrosis). Values expressed in millimeters of mercury (mmHg)

	HV without arthrosis# (n=65)	HV with arthrosis# (n=55)	Recurrent HV (n=26)	HR (n=20)
At rest (mmHg)*	5 (-4 to 43)	7 (-5 to 73)	8 (-2 to 38)	20 (0 to 70)
Passive dorsiflexion*	37.5 (-2 to 196)	46 (-2 to 162)	38.5 (0 to 185)	40 (-2 to 196)
Passive plantar flexion*	24.5 (-4 to 193)	26 (-6 to 178)	23.5 (-6 to 181)	46 (-1 to188)

*median (percentile 1% - percentile 99%) #Kellgren-Lawrence classification

Table 3. Pressure values in millimeters of mercury (mmHg) in the different groups: mild, moderate, and severe hallux valgus (HV), Grade 1, 2, and 3 hallux rigidus (HR), and cases of recurrent HV

	At rest*	Passive dorsiflexion*	Passive plantar flexion*
Mild HV (n=15)	3 (-1 to 38)	31 (0 to 163)	28 (-2 to 115)
Moderate HV (n=63)	5 (-4 to 43)	40 (-2 to 196)	21 (-4 to 193)
Severe HV (n=42)	8 (-5 to 73)	41 (0 to 145)	34 (-6 to 178)
Recurrent HV (n=26)	8 (-2 to 38)	38.5 (0 to 185)	23.5 (-6 to 181)
Grade 1 HR (n=5)	23 (0 to 26)	110 (12 to 189)	63 (32 to 130)
Grade 2 HR (n=11)	21 (3 to 70)	83.5 (4 to 199)	39.5 (0 to 188)
Grade 3 HR (n=4)	16.5 (11 to 20)	40 (15 to 53)	23.5 (-1 to 66)

*median (percentile 1% - percentile 99%)

which would derive from increased joint pressure. Although the author did not aim to measure this pressure, he observed that such decompression was able to regenerate damaged joint cartilage in long-term radiographic controls.

In my experience, it was not possible to measure postoperative intra-articular pressure, because patients did not accept a new measurement in the long-term follow-up, except for cases of recurrent or persistent pain. Only in one case, on the surgery on the contralateral foot (after informed consent), I was able to measure intra-articular pressure of the osteotomized (shortened) metatarsal and observed a lower value compared to the first measure (taken prior to the first intervention), and pain had disappeared. Although M1 shortening seemed exaggerated on the radiograph of this foot patient, she wanted to have the same treatment on the other foot. Other limitation to mention is the number of patients, which prevented the exploration for ages or the stratification of severity subgroups, which could have been interesting, but it was not feasible (reduced sample size would lead to lack of statistical power). Furthermore, since it is a measurement involving an intervention, there is risk of information bias when placing the needle and exerting pressure to perform of dorsal and plantar flexion maneuvers (operator dependent).

It is worth highlighting that, although these findings may be interpreted from a mainly mechanical perspective, biological factors that would interfere with joint degenerative phenomena should also be considered. However, the findings of the present study make it possible to consider measurement of joint pressure as a possible diagnostic tool, particularly in early stages of HR or HV requiring surgical treatment. Objective measures are needed with regard to the surgical technique used (both in soft tissues and in bone tissue) to solve HV and HR, in order to objectively analyze its efficacy and effectiveness. Therefore, new prospective studies are necessary, which include measurement of pressure and long-term results to answer to these questions.

Conclusions

I observed that, the greater HV deformity, the higher intra-articular pressure at rest and during maximal dorsiflexion and maximal plantar flexion. Conversely, an inverse situation was observed in HR: the greater deformity, the lower intra-articular pressure.

A statistically significant difference was found between HV and early-stage HR in rest intra-articular pressure of the first MTPJ of the foot: 3 mmHg vs 23 mmHg respectively (p=0.001).

Thus, measurement of intra-articular pressure could be a useful tool to differentiate early stages of diseases of the first ray of the foot.

Acknowledgment

I especially thank Dr. María Florencia Grande Ratti for conducting statistical analysis and collaborating in the writing of the final report.

Author's contributuions: JLAC *(https://orcid.org/0000-0002-5665-480X) Conceived and planned the activities that led to the study, interpreted the results of the study, performed the surgeries, data collection, clinical examination, bibliographic review and approved the final version. The author read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Usuelli F, Palmucci M, Montrasio UA, Malerba F. Radiographic considerations of hallux valgus versus hallux rigidus. Foot Ankle Int. 2011;32(8):782-8.
2. Nix S, Smith M, Vicenzino B. Prevalence of hallux valgus in the general population: a systematic review and meta-analysis. J Foot Ankle Res. 2010;3:21.
3. Senga Y, Nishimura A, Ito N, Kitaura Y, Sudo A. Prevalence of and risk factors for hallux rigidus: a cross-sectional study in Japan. BMC Musculoskelet Disord. 2021;22(1):786.
4. Lambrinudi C. Metatarsus Primus Elevatus. Proc R Soc Med. 1938; 31(11):1273.
5. McMaster MJ. The pathogenesis of hallux rigidus. J Bone Joint Surg Br. 1978;60(1):82-7.
6. Horton GA, Park YW, Myerson MS. Role of metatarsus primus elevatus in the pathogenesis of hallux rigidus. Foot Ankle Int. 1999;20(12):777-80.
7. Meyer JO, Nishon LR, Weiss L, Docks G. Metatarsus primus elevatus and the etiology of hallux rigidus. J Foot Surg. 1987;26(3):237-41.
8. Bryant A, Tinley P, Singer K. A comparison of radiographic measurements in normal, hallux valgus, and hallux limitus feet. J Foot Ankle Surg. 2000;39(1):39-43.
9. Bouaicha S, Ehrmann C, Moor BK, Maquieira GJ, Espinosa N. Radiographic analysis of metatarsus primus elevatus and hallux rigidus. Foot Ankle Int. 2010;31(9):807-14.
10. Kirane YM, Michelson JD, Sharkey NA. Contribution of the flexor hallucis longus to loading of the first metatarsal and first metatarsophalangeal joint. Foot Ankle Int. 2008;29(4):367-77.
11. Pittman SR, Burns DE. The Wilson bunion procedure modified for improved clinical results. J Foot Surg. 1984;23(4):314-20.
12. Youngswick FD. Modifications of the Austin bunionectomy for treatment of metatarsus primus elevatus associated with hallux limitus. J Foot Surg. 1982;21(2):114-6.
13. Davies GF. Plantarflexory base wedge osteotomy in the treatment of functional and structural metatarsus primus elevatus. Clin Podiatr Med Surg. 1989;6(1):93-102.
14. Feldman KA. The Green-Watermann procedure: geometric analysis and preoperative radiographic template technique. J Foot Surg. 1992;31(2):182-5.
15. Voss C. [The importance of operative conservation of joint function in bilateral hip processes]. Minerva Ortop. 1962;13:534-5.
16. Kim PH, Chen X, Hillstrom H, Ellis SJ, Baxter JR, Deland JT. Moberg osteotomy shifts contact pressure plantarly in the first metatarsophalangeal joint in a biomechanical model. Foot Ankle Int. 2016;37(1):96-101.
17. Smith RW, Reynolds JC, Stewart MJ. Hallux valgus assessment: report of research committee of American Orthopaedic Foot and Ankle Society. Foot Ankle. 1984;5(2):92-103.
18. Coughlin MJ, Freund E. Roger A. Mann Award . The reliability of angular measurements in hallux valgus deformities. Foot Ankle Int. 2001;22(5):369-79.
19. Hattrup SJ, Johnson KA. Subjective results of hallux rigidus following treatment with cheilectomy. Clin Orthop Relat Res. 1988;(226):182-91.
20. Aiyer A, Shub J, Shariff R, Ying L, Myerson M. Radiographic recurrence of deformity after hallux valgus surgery in patients with metatarsus adductus. Foot Ankle Int. 2016;37(2):165-71.
21. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis. 1957;16(4):494-502.
22. Kollberg G, Lundholm G. The Voss operation in osteoarthritis of the hip. Acta Orthop Scand. 1965;36:82–8.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1613

Original Article

Reliability of intraoperative radiographic visual assessment of the hallux interphalangeal angle after hallux valgus correction

Paulo Norberto Faria Ferrao[1,2], **Nikiforos Pandelis Saragas**[1,2], **Mohammadali Khademi**[1]

1. University of the Witwatersrand, Johannesburg, South Africa.
2. Orthopaedic foot and ankle unit, Linksfield, South Africa.

Abstract

Objective: The aim of this study was to evaluate the reliability and reproducibility of visual estimation of the hallux interphalangeal angle (IPA). As a secondary aim we assessed for change in the IPA before and after hallux valgus (HV) correction.

Methods: A total of 50 surgically treated HV deformities were included in the study. Two surgeons visually estimated the IPA on intraoperative fluoroscopy after correcting HV. The fellow then measured the IPA formally on a printout of the fluoroscopic image. Pre-and intraoperative HVI angles were compared to assess for change after HV correction.

Results: The researchers found the interobserver reliability of radiographic visual assessment of the IPA to be 78% and intraobserver reliability to be 76% and 80% for surgeon 1 and 2, respectively. It was found that the preoperative IPA is on average 5.5 degrees less than IPA after HV correction.

Conclusion: Radiographic visual assessment of the IPA of the hallux was found to be reliable intraoperatively, thus aiding in the amount of correction required by Akin osteotomy. HVI can be masked by hallux pronation in HV deformity and should be assessed intraoperatively after HV correction.

Level of Evidence II; Therapeutic Studies; Prospective Comparative Study.

Keywords: Hallux valgus; Akin; Interphalangeal angle; Visual assessment.

Introduction

Lateral deviation of the interphalangeal joint of the hallux was investigated for the first time by Daw[1] in 1935, who coined the term hallux valgus interphalangeus (HVI). The method of assessing HVI was described by Burry in 1957[2]. The pathophysiology of HVI was first described by Sorto and Balding[3]. They suggested that this deformity is due to phalangeal condyle hypoplasia. There is no other study to support this theory[3-8].

Strydom et al.[9] reported that the interphalangeal angle (IPA) correlates inversely with the other angular measurements for hallux valgus (HV). Therefore, the more severe HV deformity, the smaller the IPA. These findings may be due to pronation of the hallux in HV deformities, which then masks true HVI. The more severe the HV deformity, the greater the hallux pronation, leading thus to a perceived decrease in measured IPA. Strydom et al.[9] also defined accurate reference points for the distal phalanx to standardize the method of measurement of the IPA.

The radiographic measurement of the IPA is measured as the angle between the long axes of the proximal and distal phalanges. The normal angulation in the axial plane between these two bones is less than 10 degrees[3]. The IPA is used to assess the severity of HVI deformity[3,10-13] (Figure 1).

The magnitude of the surgical procedure required to correct HVI deformity is based on the IPA on weight-bearing radiographs[12,14]. Akin osteotomy is primarily indicated for

Study performed at the University of the Witwatersrand, Johannesburg, South Africa.

Correspondence: Paulo Norberto Faria Ferrao. Suite 303 Linksfield Hospital, 24 12th Avenue, Linksfield West, 2192, South Africa. **E-mail:** paulo@cybersmart.co.za. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** February 26, 2022. **Date accepted:** March 18, 2022. **Online:** April 30, 2022.

How to cite this article: Ferrao PNF, Saragas NP, Khademi M. Reliability of intraoperative radiographic visual assessment of the hallux interphalangeal angle after hallux valgus correction. J Foot Ankle. 2022;16(1):64-8.

correction of HVI deformity and was first described in 1925[15]. In conjunction with the other osteotomies for HV correction, Akin osteotomy can assist with total HV deformity correction. Shannak et al.[16] found that for a 15-degrees correction, an osteotomy with a 3-mm base is needed. Akin osteotomy is also used to correct any residual pronation of the hallux[14].

Since the preoperative IPA can be underestimated in moderate to severe HV deformities due to hallux pronation (Figure 2A-B), the surgeon reassesses the IPA intraoperatively after correcting HV. As it is not practical to formally measure the IPA intraoperatively, the surgeon visually estimates the IPA using fluoroscopy, while simulating weight-bearing. The size of wedge resection for Akin osteotomy is dependent on accurate assessment of the IPA. Surgeon's estimation intraoperatively needs to be reasonably accurate and reproducible.

The aim of the study was to evaluate the reliability and reproducibility of visually estimating the IPA after correction of HV deformity by comparing it with the formal measurement. As a secondary aim, the authors hypothesized that preoperative HVI deformity can be underestimated due to hallux pronation and surgical correction of HV deformity can unmask true HVI.

Methods

Ethics approval was given by the Human Ethics Committee of the university. The study included 50 consecutive feet of 39 patients who underwent surgical correction of a HV deformity by two foot and ankle surgeons. Of the 39 patients, 11 had bilateral surgery. Exclusion criteria were patients under the age of 18 years and incomplete records. Hallux pronation was assessed clinically and documented by looking at the orientation of the nail (Figure 2A). All patients underwent

Figure 1. Reference points and method for measuring the interphalangeal angle.

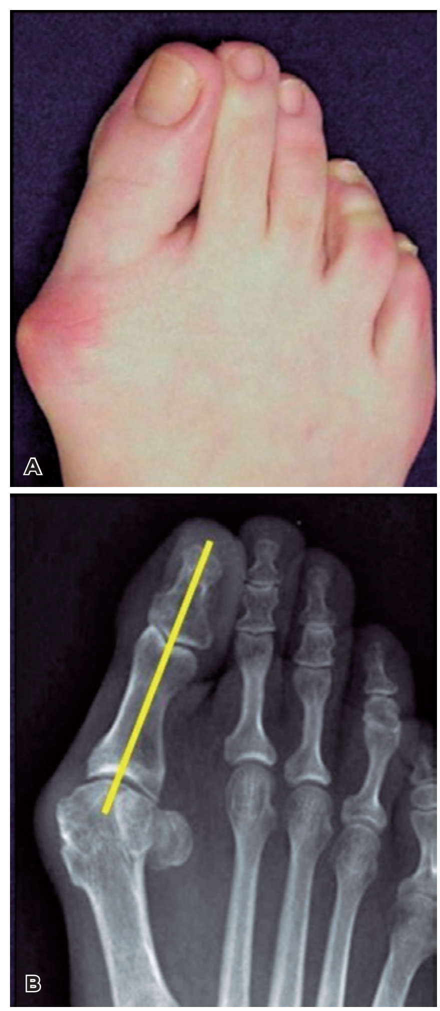


Figure 2. A) Clinical picture of Hallux valgus deformity with pronation. B) Radiographic measurement of the interphalangeal angle showing underestimation.

preoperative weight-bearing radiographs of their feet according to standard international guidelines. Preoperative radiographs were used to measure the HV angle, the intermetatarsal angle (IMA), and the IPA by a foot and ankle fellow.

HV deformity was corrected using the appropriate procedure according to the severity and cause of hallux pronation. If hallux pronation was related to first metatarsal pronation, a modified Lapidus procedure was performed to correct metatarsal pronation and HV deformity. All other deformities were corrected using the appropriate procedure which would correct the HV angle and cover the sesamoids, thereby correcting muscle imbalance (Table 1). Following HV correction with an appropriate osteotomy, the IPA angle was visually estimated using intraoperative fluoroscopy by the 2 senior authors (Observer 1 [NPS] and Observer 2 [PNF]. A mini-image intensifier was used to allow for simulated weight-bearing by pushing the foot up against the flat detector plate. The fluoroscopic image was printed, and formal IPA measured by the foot and ankle fellow, with the aid of a goniometer, using the standard measurement technique (Figure 3). Visually estimated and formally measured IPAs were assessed for reliability. Pre- and intraoperative IPAs were compared to assess for change after HV correction. Data was entered on an Excel spreadsheet and analyzed.

Statistical analysis

To measure the reliability of a test, the standard deviation of subject's true value and of measurement errors need to be calculated. Higher reliability shows smaller measurement errors of a test. Reliability values range between 0 and 1. A reliability value of 1 represents zero measurement error and vice versa[10,12]. To describe data on observers' measurement, mean and standard deviation (SD) were calculated. To determine interobserver agreement, a Pearson's correlation test was applied. All analyses were performed using STATA version 14.0. Statistical analyses were conducted at a significance level of 5% ($p<0.05$).

Results

The cohort consisted of 37 females and 2 males, with an average age of 48 (18-72) years. The mean preoperative IPA was 6.2 (0-18) degrees. The mean intraoperative (post HV correction) IPA was 11.7 (3-20) degrees. The mean difference between IPA before and after HV correction of 5.5 degrees was found to be statistically significant ($p=0.039$).

Visually estimated measurements by each observer and the formal measurements are reported in table 2. On average, Observer 2 had a higher mean measurement in comparison to Observer 1. Intraobserver reliability was 0.76 for Observer 1 and 0.80 for Observer 2. Interobserver reliability was 0.78. The Pearson's correlation test found a strong agreement between the two observers' visual measurements ($p<0.001$), as well as between observers' visual measurements and formal measurements ($p<0.001$).

Discussion

HVI is a three-dimensional deformity (pronation and valgus deformities). Treatment of HV deformity is based on physical and radiological examination. Various radiographic angles have been described for surgical planning, including IPA. These angles need to be reproducible and accurate to aid in surgical planning[6,17,18]. Coughlin et al.[3,10,12] reported that the techniques for measurement of the I-II IMA and the HV angle are reliable and reproducible.

The prevalence of HVI varies significantly in the literature. Strydom et al.[9] found a 62.1% prevalence of the HVI when they evaluated X-rays of patients with a HV deformity. They

Table 1. Summary of procedures performed to correct hallux valgus deformity

Procedure	Number
Chevron	11
Scarf	8
Proximal opening wedge	15
Modified Lapidus procedure	16

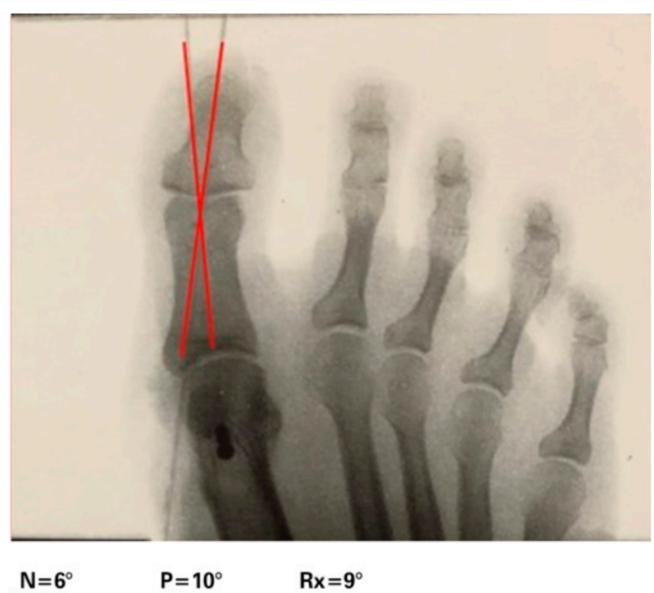


Figure 3. Intraoperative fluoroscopic image post hallux valgus correction for formal measurement of the interphalangeal angle.

Table 2. Summary of observers' visual estimations and formal measurements of the interphalangeal angle

Measured by	Mean (SD) (Degrees)	Min–Max (Degrees)
Observer 1	10.26° (3.89)	3° – 20°
Observer 2	11.42° (3.53)	4° – 18°
Formal measurement	11.68° (4.27)	3° - 20°

also concluded that the contribution of the IPA is 37.9% to the total valgus deformity of the hallux. Interestingly, HVI decreased as the severity of HV increased. We postulated that as the severity of HV worsens, the hallux tends to pronate more, thereby masking true HVI. Preoperative IPA is thus inaccurate and misleading.

Various causes have been described for hallux pronation in HV. In some studies, the flexor hallucis longus tendon has been implicated as a causative factor. This tendon will eccentrically pull the distal phalanx causing rotation of the hallux[3-6]. More recently, research on first metatarsal pronation in HV has become popular. First metatarsal pronation is not a novel idea and was reported by Eustace et al.[19] and Saltzman et al.[20]. Okuda et al.[21] found that correcting metatarsal pronation is an important component of HV surgical correction. Kim et al.[22] reported the incidence of first metatarsal pronation in HV to be as high as 87.3%. The advent of weight-bearing computed tomography has reinforced the incidence and amount of metatarsal pronation. Wagner et al.[23] has highlighted the importance of correcting first metatarsal pronation to prevent recurrence of HV deformity. Therefore, HV correction also corrects hallux pronation, revealing true HVI. We found that the IPA increased on average by 5.5 degrees after HV correction. This supports our theory that true HVI is masked in more severe HV deformity.

It is not practical to formally measure the IPA once true HVI has been identified intraoperatively. The importance of knowing the IPA is to guide the surgeon with regards to the required wedge size when performing Akin osteotomy. Shannak et al.[16] reported that a 1-mm increase in wedge size is necessary to correct for every 5-degree increase in IPA. The surgeon therefore often estimates the IPA using intraoperative fluoroscopy. Accuracy of visual estimation of angles by physicians has been reported in the literature for various measurements. Moran et al.[24] evaluated reproducibility and reliability of visual estimation of a series of angles by orthopaedic surgeons. They found that orthopaedic surgeons can visually estimate angles to within 10 degrees 93.1% of the time and to within 5 degrees 64.6% of the time. Repeat measurements 6 weeks later were within 5 degrees of their initial responses 82.2% of the time and within 10 degrees of the initial responses 94.5% of the time. Molony et al.[25] reported that orthopaedic surgeons can accurately estimate within 5 degrees acute angles less than 30 degrees. Abu-Rajab et al.[26] reported a 70.8% accuracy in estimating degrees of elbow flexion within 5 degrees amongst 116 observers. Higashi et al.[27] evaluated accuracy of visual estimation of the I-II IMA and reported that visual estimation differed from formal measurements by 3.28 +/-1.56. They also concluded that visual estimation of angles <10 degrees was more accurate.

The current study found intraobserver reliability of visually assessing the IPA to be 76% and 80% for each observer respectively, with a margin of error of 3 degrees or less. Interobserver reliability was found to be 78%. It is therefore viable for the surgeon to visually estimate the IPA intraoperatively after HV correction.

The limitation of this study is that only 2 observers were used to visually estimate the IPA. A future multi-surgeon study would be of benefit. Another limitation was that we compared the IPA in simulated weight-bearing using a mini-image intensifier to standard weight-bearing radiographs. Boffeli and Mahoney[28] reported that intraoperative simulated weight-bearing lateral foot imaging had a direct correlation to weight-bearing radiographs. Further research is required to assess the validity of comparing simulated weight-bearing images to standard weight-bearing radiographs.

Conclusion

Inter- and intraobserver visual assessment of the IPA of the hallux was found to be reliable intraoperatively, thus aiding in planning the amount of correction required by Akin osteotomy. Furthermore, the study suggested that HVI could be masked by the amount of preoperative hallux pronation from the HV deformity and should rather be assessed intraoperatively after HV correction.

Authors' contributions: Each author contributed individually and significantly to the development of this article: PNFF *(https://orcid.org/0000-0003-4639-0326) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, statistical analysis, formatting of the article and approved the final version. NPS *(https://orcid.org/0000-0002-5566-7588) Performed the surgeries, formatting of the article and approved the final version; MK *(https://orcid.org/0000-0003-3167-7797) Data collection, interpreted the results of the study and formatting of the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Daw SW. An unusual type of hallux valgus (two cases). Br Med J. 1935;2:580-1.
2. Burry HS. Effect of shoes on hallux valgus: a significant case study. Kettering: British boot, shoe and allied trades research association; 1957. (Satra Research Report R.R. 147).
3. Sorto LA Jr, Balding MG, Weil LS, Smith SD. Hallux abductus interphalangeus. Aetiology, x-ray evaluation and treatment. J Am Podiatr Med Assoc. 1992;82(2):85-97.
4. Coughlin MJ, Saltzman LC, Anderson BR. Mann's Surgery of the foot and ankle. 9th ed. Philadelphia: Elsevier Health Sciences; 2014.
5. Mann RA. Disorders of the first metatarsophalangeal joint. J Am Acad Orthop Surg. 1995;3(1):34-43.
6. Salleh R, Beischer A, Edwards WH. Disorders of the hallucal interphalangeal joint. Foot Ankle Clin. 2005;10(1):129-40.
7. Perera AM, Mason L, Stephens MM. The pathogenesis of hallux valgus. J Bone Joint Surg Am. 2011;93(17):1650-61.
8. Thomas S, Barrington R. Hallux valgus. Curr Orthop. 2003;17(4):299-307.
9. Strydom A, Saragas NP, Ferrao PN. A radiographic analysis of the contribution of hallux valgus interphalangeus to the total valgus deformity of the hallux. Foot Ankle Surg. 2017;23(1):27-31.
10. Coughlin MJ, Saltzman CL, Nunley JA 2nd. Angular measurements in the evaluation of hallux valgus deformities: a report of the ad hoc committee of the American Orthopaedic Foot & Ankle Society on angular measurements. Foot Ankle Int. 2002;23(1):68-74.
11. Condon F, Kaliszer M, Conhyea D, O' Donnell T, Shaju A, Masterson E. The first intermetatarsal angle in hallux valgus: an analysis of measurement reliability and the error involved. Foot Ankle Int. 2002;23(8):717-21.
12. Coughlin MJ, Freund E. Roger A. Mann Award. The reliability of angular measurements in hallux valgus deformities. Foot Ankle Int. 2001;22(5):369-79.
13. Bartlett JW, Frost C. Reliability, repeatability and reproducibility: analysis of measurement errors in continuous variables. Ultrasound Obstet Gynecol. 2008;31(4):466-75.
14. Frey C, Jahss M, Kummer FJ. The Akin Procedure: An analysis of results. Foot Ankle Int. 1991;12(1):1-6.
15. Akin OF. The treatment of hallux valgus: a new operative procedure and its results. Med Sentinel. 1925;33:678-9.
16. Shannak O, Sehat K, Dhar S. Analysis of the proximal phalanx size as a guide for an Akin closing wedge osteotomy. Foot Ankle Int. 2011;32(4):419-21.
17. Srivastava S, Chockalingam N, El Fakhri T. Radiographic measurements of hallux angles: a review of current techniques. Foot (Edinb). 2010;20(1):27-31.
18. Wilson DW. Treatment of hallux valgus and bunions. Br J Hosp Med. 1980;24(6):548-9.
19. Eustace S, O'Byrne J, Stack J, Stephens MM. Radiographic features that enable assessment of first metatarsal rotation: the role of pronation in hallux valgus. Skeletal Radiol. 1993;22(3):153-6.
20. Saltzman CL, Brandser EA, Anderson CM, Berbaum KS, Brown TD. Coronal plane rotation of the first metatarsal. Foot Ankle Int. 1996;17(3):157-61.
21. Okuda R, Yasuda T, Jotoku T, Shima H. Supination stress of the great toe for assessing intraoperative correction of hallux valgus. J Orthop Sci. 2012;17(2):129-35.
22. Kim Y, Kim JS, Young KW, Naraghi R, Cho HK, Lee SY. A New Measure of Tibial Sesamoid Position in Hallux Valgus in Relation to the Coronal Rotation of the First Metatarsal in CT Scans. Foot Ankle Int. 2015;36(8):944-52.
23. Wagner E, Wagner P. Metatarsal Pronation in Hallux Valgus Deformity: A Review. J Am Acad Orthop Surg Glob Res Rev. 2020; 4(6):e20.00091.
24. Moran KM, Ness K, Finkbeiner AA. Visual estimation of angles by orthopedic surgeons. Am J Orthop (Belle Mead NJ). 2000; 29(5):361-2
25. Molony DC, Sparkes J, Noonan J, McCormack D. The orthopaedic angle on angles: the accuracy of health care professionals in assessing angular displacement. Eur J Orthop Surg Traumatol. 2004;14(2):80–3.
26. Abu-Rajab RB, Marsh A, Young D, Rymaszewski L. Visual estimation of joint angles at the elbow. Eur J Orthop Surg Traumatol. 2010; 20(6):463–7.
27. Higashi M, Shofler D, Manji K, Penera K. Reliability of visual estimation of the first intermetatarsal angle. J Foot Ankle Surg. 2017;56(1):8-9.
28. Boffeli TJ, Mahoney KJ. Intraoperative simulated weightbearing lateral foot imaging: the clinical utility and ability to predict sagittal plane position of the first ray in lapidus fusion. J Foot Ankle Surg. 2016;55(6):1158-63.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1606

Original Article

Comminuted medial malleolar fractures – a series of 5 cases

Bruno Air Machado da Silva[1], **Paulo Victor de Souza Pereira**[1], **Murilo Friaça Tatibana**[1], **Daniel Pinheiro Lima**[1], **Andre Luiz Coelho Thomé**[1]

1. Hospital de Urgências de Aparecida de Goiânia, Aparecida de Goiânia, GO, Brazil.

Abstract

Objective: To demonstrate fixation options for comminuted fractures of the medial malleolus.

Methods: We retrospectively analyzed patients operated on for ankle fractures who had comminuted fractures of the medial malleolus between 2014 and 2018. Five patients were included in the study, 3 women and 2 men aged 19 to 37 years. Four cases were fixed with a tension-band wiring technique using Kirschner wires and cerclage, and 1 case with lag screws and buttress plate.

Results: Four cases progressed satisfactorily (AOFAS >70), and 1 case progressed to ankle arthrodesis.

Conclusion: Fixation with a tension-band wiring technique using Kirschner wires and cerclage may be an alternative to osteosynthesis in comminuted fractures of the medial malleolus with small fragments. Fixation with lag screws and buttress plate may be used in cases with larger fragments.

Level of Evidence IV; Therapeutic Studies; Cases Series.

Keywords: Ankle fractures; Ankle; Fractures, comminuted.

Introduction

Fractures of the medial malleolus can occur alone or in association with lateral malleolus or posterior pilon fractures, with an incidence of 187 per 100,000 person-years(1). Several methods have been used for fixation of medial malleolar fractures, but the technique traditionally used is osteosynthesis with 2 partially threaded screws perpendicular to the fracture line(2).

The AO group recommends the use of lag screws or tension-band wiring for transverse fractures of the medial malleolus, while a buttress plate or lag screws should be used for oblique fractures. However, there are no clear recommendations for the fixation of comminuted fractures of the medial malleolus(3).

The aim of this study is to present a case series demonstrating fixation options for comminuted fractures of the medial malleolus.

Methods

This study was approved by the Research Ethics Committee (approval number: CAAE 37116020.9.0000.0033).

We retrospectively analyzed patients operated on for ankle fractures who had comminuted fractures of the medial malleolus between 2014 and 2018. Patients with a follow-up <18 months, patients without preoperative and postoperative radiographs and those aged <18 years were excluded.

Of 12 patients evaluated, 7 were excluded: 2 for follow-up <18 months, 4 for absence of radiographs, and 1 patient younger than 18 years.

Results

Five patients were included in the study, 3 women and 2 men aged 19 to 37 years (Table 1).

Study performed at the Hospital de Urgências de Aparecida de Goiânia, Aparecida de Goiânia, GO, Brazil.

Correspondence: Bruno Air Machado da Silva. Avenida Diamante, Setor Conde dos Arcos, 74969-210, Aparecida de Goiânia, GO, Brazil. **Email:** bruno.silva@igh.org.br/drbrunoair@hotmail.com. **Conflicts of interest**: none. **Source of funding:** none. **Date received:** January 24, 2022. **Date accepted:** March 3, 2022. **Online:** April 30, 2022.

How to cite this article: Silva BAM, Pereira PVS, Tatibana MF, Lima DP, Thomé ALC. Comminuted medial malleolar fractures – a series of 5 cases. J Foot Ankle. 2022;16(1):69-71.

Case 1

A female patient presented with an open bimalleolar ankle fracture with comminution of the medial malleolus. For treatment of the medial malleolar fracture, a tension-band wiring technique was used, with Kirschner wires and cerclage, in addition to mini- and microplates for distal fibular fixation (Figure 1). The patient had an American Orthopaedic Foot and Ankle Society (AOFAS) score of 92.

Case 2

A male patient had a motorcycle accident resulting in a bimalleolar ankle fracture. The medial malleolus showed comminution with displacement. Emergency treatment included a temporary external fixator until definitive surgery. In the second procedure, tension-band wire fixation was chosen for the medial and lateral malleoli. After 14 months, the patient developed post-traumatic arthritis (AOFAS 56) and underwent ankle arthrodesis.

Case 3

A male patient presented with an injury in the medial malleolar region due to a gunshot wound, with a comminuted fracture and loss of bone mass. The fragments were fixed using a tension-band wiring technique and cancellous bone grafting. The patient had an AOFAS score of 75.

Case 4

A female patient presented with a bimalleolar ankle fracture, with comminution of the medial malleolus and oblique fracture of the fibula. For treatment of the comminuted fracture of the medial malleolus, a tension-band wiring technique was used, with Kirschner wires and cerclage, and a T-plate was placed to fix the fibula. After 1 year, the patient required hardware removal due to medial discomfort. She had an AOFAS score of 88.

Table 1. Cases evaluated in this study

Patient	AOFAS	Fixation method	Complications
Case 1	92	Tension band	None
Case 2	56	Tension band	Post-traumatic arthritis
Case 3	75	Tension band	None
Case 4	88	Plate and screws	Plate-related discomfort
Case 5	94	Plate and screws	None

AOFAS, American Orthopaedic Foot and Ankle Society.

Case 5

A female patient presented with a bimalleolar ankle fracture with a shear line in the medial malleolus and comminution. The medial malleolus was fixed with lag screws and buttress plate (Figure 2). She had an AOFAS score of 94.

Discussion

Ankle fractures are common and can be classified as unimalleolar, bimalleolar, or trimalleolar. Approximately 87% of these fractures require surgical treatment. In this setting, isolated fractures of the medial malleolus are less common than other ankle fractures and present greater stability due to the deltoid ligament complex. Therefore, they can be treated conservatively when not displaced[1].

Displaced fractures require surgical treatment. Osteosynthesis can be performed using several fixation methods described in the literature, such as cortical or cancellous screws, plates, and Kirschner tension-band wiring, among others. The fixation method recommended by the AO group for medial malleolar fractures is the use of a 4-mm partially threaded cancellous screw. This screw should have an average length of 40mm in order to reach the dense part of the cancellous bone in the metaphyseal region of the distal tibia[3].

For comminuted fractures of the medial malleolus, there are no studies in the literature showing a better method than osteosynthesis. A comparative study between tension-band fixation and lag screws in comminuted fractures of the medial malleolus showed a higher rate of union, better AOFAS score, and lower rate of revision surgery for fractures treated with lag screws, but the difference was not statistically significant due to the small sample size. According to the authors, comminuted fractures have poor outcomes regardless of the fixation

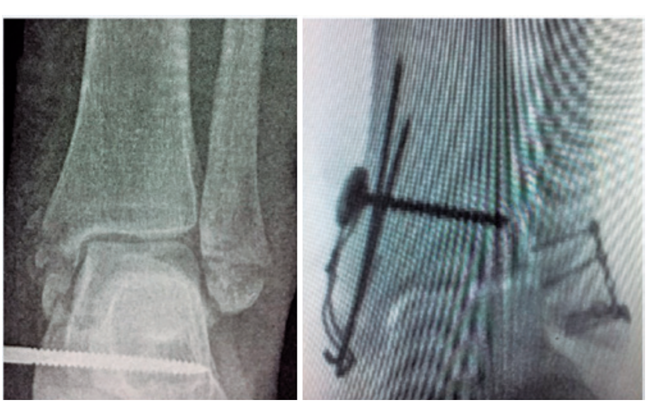


Figure 1. Preoperative and postoperative radiographs.

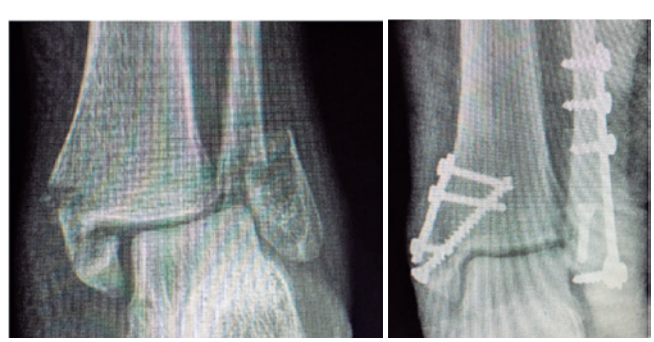


Figure 2. Preoperative and postoperative radiographs.

method[4]. In our case series, fixation methods were not compared, but all cases achieved union, with only 1 case associated with an unfavorable outcome requiring revision surgery. This poor outcome may be explained by the fact that it was an open fracture, with joint bone healing failure after reduction.

Of the 5 cases presented here, 4 were fixed from the medial malleolus using the 8-fold tension-band wiring technique with 2 Kirschner wires and stainless-steel cerclage wire. A tension-band wiring technique was used in 4 of our cases because they showed great comminution with very small fragments for screw osteosynthesis. Fixation with Kirschner wires and cerclage allowed anatomic reduction and fixation of the fragments.

A study comparing cancellous bone screw fixation vs tension-band fixation of medial malleolar fractures with 2-mm and 4-mm fragments in cadavers concluded that cancellous screws showed only 47.16% (60.98 N) of the strength of tension-band fixation (129.30 N), indicating that tension-band fixation provides greater resistance against displacement and local fracture protection[5]. It is possible that the resistance and strength generated by tension-band fixation provide better stability to comminuted fractures, thus reducing the likelihood of loss of reduction and allowing early rehabilitation.

All cases presented here exhibited a marked degree of comminution, only Case 5 showed a larger distal fragment despite comminution of the medial wall. This was the only case in which fixation was possible with lag screws and buttress plating.

Fracture union was achieved in all of our cases. Only 1 patient had postoperative wound infection, treated with oral antibiotics and subsequent hardware removal. This patient developed early post-traumatic arthritis and, therefore, underwent ankle arthrodesis. This unfavorable outcome may be explained by the joint bone healing failure after reduction and postoperative infection.

A limitation of this study is that it is a case series with a small sample size. Also, we did not compare the fixation methods used for comminuted fractures of the medial malleolus.

Conclusion

Fixation with a tension-band wiring technique using Kirschner wires and cerclage may be an alternative to osteosynthesis in comminuted fractures of the medial malleolus with small fragments, but it has shown less favorable outcomes in previous published studies and also in the present case series (only 1 tension-band patient had an AOFAS score of 92), most probably due to the nature of the fracture rather than the internal fixation method. Fixation with lag screws and buttress plate may be used in cases with larger fragments.

Authors' contributions: Each author contributed individually and significantly to the development of this article: BAMS *(https://orcid.org/0000-0002-3008-460X) Wrote the paper, interpreted the results of the study; conceived and planned the activities that led to the study, approved the final version; PVSP *(https://orcid.org/0000-0002-9538-8479) Wrote the paper, participated in the reviewing process; MFT *(https://orcid.org/0000-0001-9688-4389) Interpreted the results of the study; wrote the paper; DPL *(https://orcid.org/0000-0001-8000-7234) Wrote the paper, participated in the reviewing process; ALCT *(https://orcid.org/0000-0002-9045-959X) Wrote the paper, participated in the reviewing process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Daly PJ, Fitzgerald RH Jr, Melton LJ, Ilstrup DM. Epidemiology of ankle fractures in Rochester, Minnesota. Acta Orthop Scand. 1987;58(5):539-44.
2. King CM, Cobb M, Collman DR, Lagaay PM, Pollard JD. Bicortical fixation of medial malleolar fractures: a review of 23 cases at risk for complicated bone healing. J Foot Ankle Surg. 2012;51(1):39-44.
3. Barbosa P, Bonnaire F, Kojima K, Demmer P. Malleoli reduction and fixation. AO Foundation. 2006. Available from: https://www2.aofoundation.org/wps/portal/surgery?showPage=diagnosis&bone=Tibia&segment=Malleoli
4. Ebraheim NA, Ludwig T, Weston JT, Carroll T, Liu J. Comparison of surgical techniques of 111 medial malleolar fractures classified by fracture geometry. Foot Ankle Int. 2014;35(5):471-7.
5. Johnson BA, Fallat LM. Comparison of tension band wire and cancellous bone screw fixation for medial malleolar fractures. J Foot Ankle Surg. 1997;36(4):284-9.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1631

Original Article

Agreement between semiautomatic and manual measurement of selected parameters on weight-bearing computed tomography images in total ankle replacement: a retrospective study

Vineel Mallavarapu[1], Ryan Jasper[1], Matthew Jones[1], Christian VandeLune[1], Kepler Alencar Mendes de Carvalho[1], Ki Chun Kim[1,3], Nacime Salomão Barbachan Mansur[1,2], Kevin Dibbern[1], César de César Netto[1]

1. Department of Orthopaedics and Rehabilitation, University of Iowa, Carver College of Medicine,Iowa City, IA, USA.
2. Federal University of Sao Paulo, Department of Orthopedics and Traumatology, Sao Paulo, SP, Brazil.
3. Seoul Medical Center, Seoul, South Korea.

Abstract

Objective: To assess the agreement between semiautomatic 3D measurements and manual measurements derived from WBCT images in patients with end-stage ankle osteoarthritis (AO) who underwent total ankle replacement (TAR).

Methods: In this retrospective, IRB-approved study (ID #201904825), we evaluated patients who underwent TAR via the lateral trans-fibular approach for end-stage ankle OA. The study included 14 ankles from 14 patients. Raw multiplanar data were analyzed using CubeVue® software. Lateral talar station (LTS) was obtained in the sagittal plane, while hindfoot moment arm (HMA) and talar tilt angle (TTA) were calculated in the coronal view. Semiautomatic 3D measurements were performed using Disior® software. Intra-rater reliabilities were analyzed using the intraclass correlation coefficient (ICC). Agreement between methods was tested with Bland-Altman plots. Each measurement was assessed using the Wilcoxon signed-rank test. Alpha risk was set to 5% (α=0.05). P-values of $\leq$0.05 were considered significant.

Results: ICC-measured reliabilities ranged from moderate to almost perfect for manual and semiautomatic WBCT measurements in the preoperative and postoperative groups for HMA and LTS. There was high correlation between parameters calculated from manual and semiautomatic measurements, and strong agreement between the readers and software in both groups.

Conclusions: Manual (M) and semiautomatic (SA) 3D measurements expressed excellent agreement for pre- and postoperative groups, indicating a high correlation between the parameters calculated and strong agreement between the readers and the software in both groups.

Level of Evidence III; Therapeutic Studies; Comparative Retrospective Study.

Keywords: Ankle; Osteoarthritis; Arthroplasty, replacement, ankle; Tomography, x-ray computed; Weight-bearing.

Study performed at the Department of Orthopaedics and Rehabilitation, University of Iowa, Iowa City, IA, USA.

Correspondence: Kepler Alencar Mendes de Carvalho. Department of Orthopedics and Rehabilitation, University of Iowa. 200 Hawkins Dr, John Pappajohn Pavillion (JPP). Room 01066, Lower Level. Iowa City, IA, 52242. United States. **E-mail:** kepler-carvalho@uiowa.edu. **Conflicts of Interest: Christian VandeLune:** Brazilian Foot and Ankle Society: Board or committee member. **Ki Chun Kim:** Brazilian Foot and Ankle Society: Board or committee member. **Nacime Salomao Barbachan Mansur:** Brazilian Foot and Ankle Society: Board or committee member. American Orthopaedic Foot and Ankle Society: Board or committee member. **César de César Netto:** American Orthopaedic Foot and Ankle Society: Board or committee member. Editor in Chief Foot and Ankle Clinics. CurveBeam: Paid consultant; Stock or stock Options. Foot and Ankle International: Editorial or governing board. Nextremity: Paid consultant. Ossio: Paid consultant. Paragon 28: IP royalties; Paid consultant. Weightbearing CT International Study Group: Board or committee member. Zimmer: Paid consultant. **Source of funding:** none. **Date received:** April 19, 2022. **Date accepted:** April 20, 2022. **Online:** April 30, 2022.

How to cite this article: Mallavarapu V, Jasper R, Jones M, VandeLune C, Carvalho KAM, Kim KC, et al. Agreement between semiautomatic and manual measurement of selected parameters on weight-bearing computed tomography images in total ankle replacement: a retrospective study. J Foot Ankle. 2022;16(1):72-8.

Introduction

Ankle osteoarthritis (AO) is a chronic joint disease associated with discomfort, mobility issues, and reduced quality of life[1,2]. Approximately 1% of the population worldwide is affected by AO[3]. Unlike in other joints, primary or idiopathic AO is rare. A post-traumatic etiology is most common[4,5], with rotational ankle fractures and ligamentous injuries comprising the most common traumatic causes[6-8]. Total ankle replacement (TAR) has been advocated over ankle arthrodesis to correct AO, with evolving strategies and revisions each year to reduce complication rates[9-11]. However, bony overlap in conventional radiographs poses a challenge in the 3D evaluation of the ankle, and axial alignment of the ankle joint can be difficult to evaluate in the intraoperative management of AO[12]. Weight-bearing computed tomography (WBCT) has been increasingly adopted as a method well- equipped to assess the rotational elements of the ankle joint in the axial plane, addressing a limitation of standard radiographic evaluation[13-15]. Radiographic parameters obtained from these images can be valuable in the preoperative assessment and postoperative analysis of TAR for AO; thus, improvement in the acquisition, reliability, and accuracy of these measurements can influence treatment approaches and impact patient outcomes after deformity correction[16-19].

The use of semiautomated 3D measurements in WBCT images has recently been demonstrated to be reliable in assessing midfoot and hindfoot disorders[20-23], suggesting the potential for a method to characterize 3D joint morphology quickly and comprehensively. Compared to 2D measurements in weight-bearing radiographs, semiautomatic 3D measurements have proven more reliable in assessing foot and ankle alignment[13]. Kvarda et al.[20] showed that auto-generated 3D measurements using WBCT images of the midfoot and hindfoot were reliable in evaluating healthy individuals and patients with post-traumatic end-stage AO. Further, Lintz et al.[21], in a study on the development of periprosthetic cysts after TAR utilizing 3D multiplanar reconstruction, proposed the potential for 3D biometrics in the improvement of malalignment characterization in the foot and ankle.

No studies have examined the reliability of semiautomatic 3D measurements derived from WBCT in assessing patients who underwent TAR for end-stage AO. Validation of semiautomatic 3D measurements in this analysis may reveal a time-efficient and cost-efficient method to assess and treat patients with end-stage AO, and lay the groundwork for an AI-based evaluation in the future. In this study, we applied semiautomatic 3D measurement software to WBCT images of patients with end-stage AO who underwent TAR. Our aim was to assess the agreement between manual and semiautomatic 3D measurements derived from WBCT images, with the hypothesis that semiautomatic measurement would be as reliable and accurate as measurements performed manually in this setting.

Methods

A retrospective comparative study was performed, which analyzed existing data recorded as part of routine clinical care. The study was approved by the Institutional Review Board (ID #201904825) in accordance with the Health Insurance Portability and Accountability Act (HIPAA) and the provisions of the Declaration of Helsinki.

Subjects included were patients greater than 18 years of age who underwent TAR via a lateral trans-fibular approach for end-stage ankle OA, with at least 5° of coronal and/or sagittal plane deformity, and who underwent preoperative and postoperative WBCT. WBCT was used to assess each patient's ankle as a diagnostic standard. Exclusion criteria included patients who underwent TAR via an anterior ankle approach, patients with no ankle deformity in the coronal or sagittal planes, and patients with less than 9 months of clinical follow-up. The study included a total of 14 ankles (5 right and 9 left) in 14 patients, and the average age and BMI were 63.9 years (range, 43-83) and 32.7 kg/m^2 (standard deviation, 7.5).

Conventional Surgical Procedure

All surgical procedures were performed by a single fellowship-trained foot and ankle orthopedic surgeon with more than 10 years of experience. All patients received the Zimmer-Biomet® (Warsaw, Indiana, US) Trabecular Metal™ TAR (Figure 1).

Imaging acquisitions

WBCT scans were performed utilizing a cone-beam lower extremity CT scanner (pedCAT® Model, CurveBeam®, Warrington, FL, USA). Patients entered the scanner in a bipedal standing position and were instructed to bear weight equally between their lower limbs with their feet shoulder-width apart. Images were taken at 120 kVp and 5 mA with a maximum exposure of 10s. The volume was reconstructed with a 0.37-mm isotopic voxel.

Manual WBCT measurements

A single fellowship-trained foot and ankle orthopedic surgeon performed all WBCT measurements. De-identified, raw multiplanar data were translated into sagittal, coronal, and axial plane images and evaluated utilizing CubeVue® software (CurveBeam, LLC, Warrington PA, USA). Lateral talar station (LTS) was obtained using sagittal plane views, whereas hindfoot moment arm (HMA) and talar tilt angle (TTA) were calculated in the coronal plane (Figure 2).

Semiautomatic 3D WBCT measurements

Semiautomatic 3D measurements were performed utilizing the Disior® Bonelogic® Ortho Foot and Ankle Software (version 2.0; Helsinki, Finland). First, a file is selected in DICOM format for analysis, and the software automatically constructs a 3D isosurface of the bone tissue. Bone segmentation is performed by placing at least one marker point on each visible bone in the rendered image for analysis. Deformable shape models were applied to obtain a patient-specific shape. Longitudinal axis estimates were generated for each patient-specific model by finding the center of the specific bones and analyzing cross-sections at different locations. The software applied vigorous line-fitting techniques to select the straight-line representative for the center of the bone. Subsequently, the software automatically registered a mathematical model of the foot and ankle on the image and computed the location of measurement landmarks and longitudinal axes of the bones of interest (Figure 3).

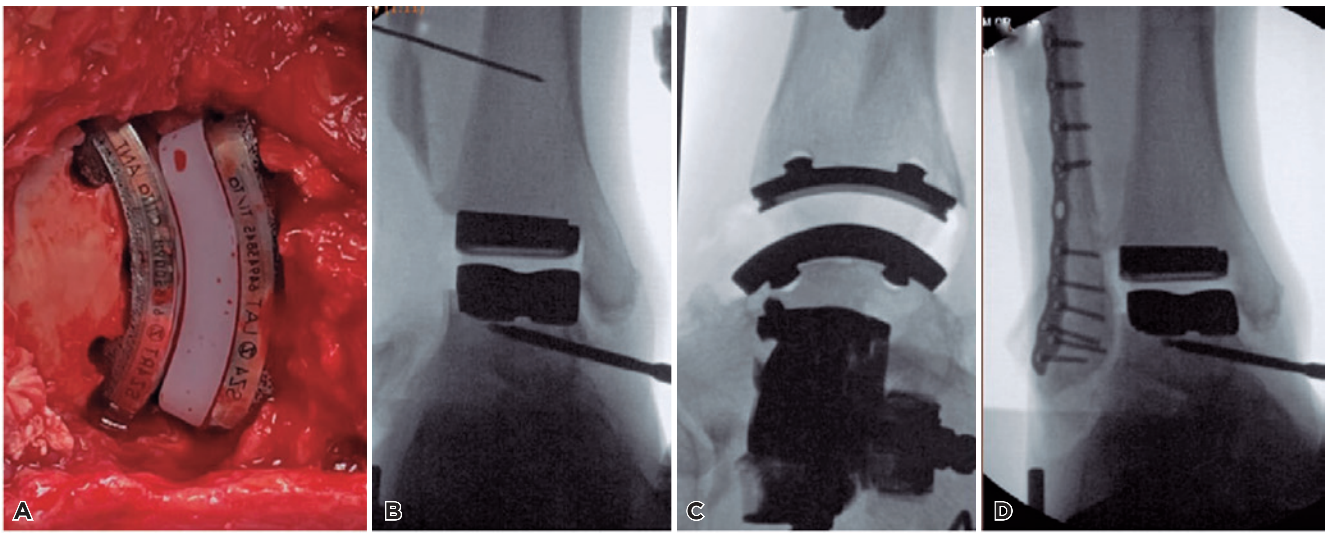


Figure 1. Lateral trans-fibular total ankle replacement. Final implant in place (A), and final positioning checked on the anteroposterior (B) and lateral (C) views. Final view: the fibula was reduced, and bone osteosynthesis was executed (D).

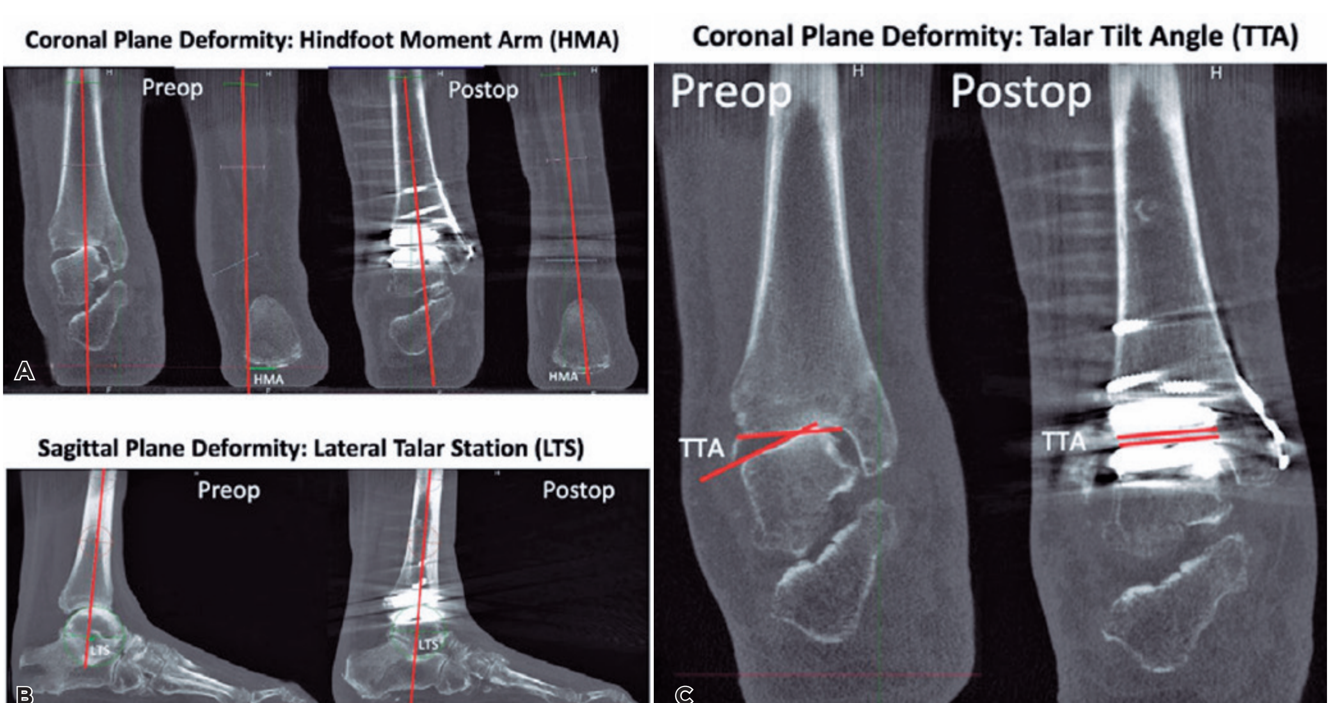


Figure 2. Manual measurements in preoperative and postoperative WBCT images: A) Hindfoot moment arm (HMA), B) Lateral talar station (LTS), and C) Talar tilt angle (TTA).

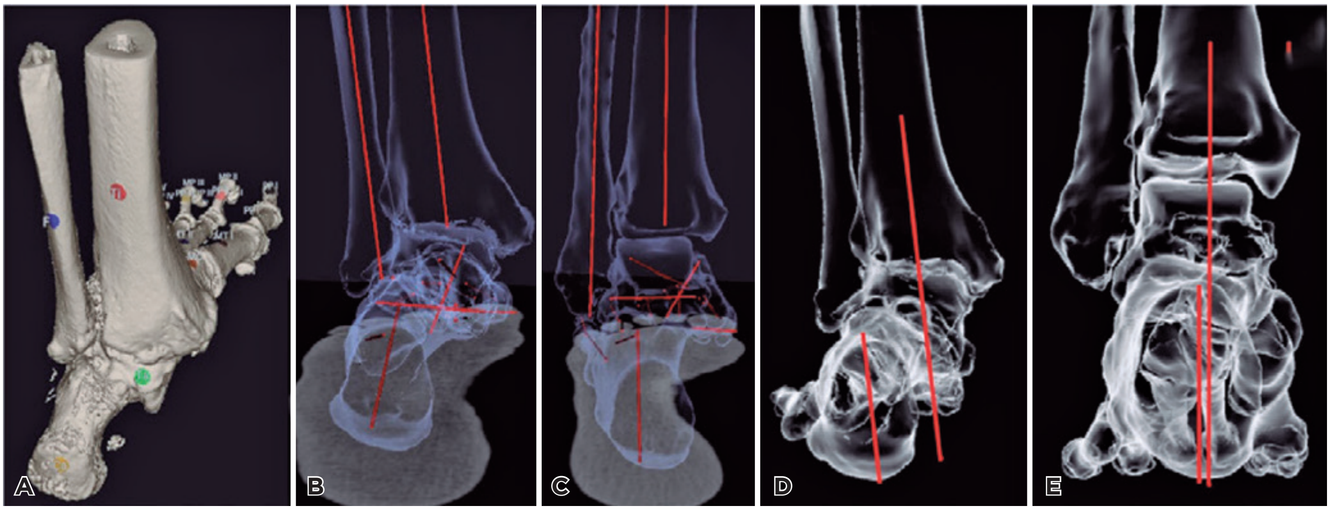


Figure 3. Raw multiplanar nonidentified data were converted into sagittal, coronal, and axial images and evaluated using dedicated software (CubeVue™). Bone segmentation performed using the DISIOR Bonelogic F&A Software (A). The software automatically registered a mathematical model of the foot and ankle on the image and computed the location of measurement landmarks and longitudinal axes of bones of interest producing semiautomatic 3D measurements; preoperative (ankle osteoarthritis) (B) and postoperative (after total ankle replacement) (C). Hindfoot Moment Arm (HMA) measured semiautomatically, in preoperative (D) and postoperative (E) images.

Statistical analysis

Each measurement was evaluated for normality using the Wilcoxon test, and descriptive statistics were obtained (mean and 95% confidence interval values). Intra-rater reliabilities for continuous data were analyzed using intraclass correlation coefficients (ICC).

A Pearson correlation coefficient was utilized to evaluate the linear relationship between the semiautomatic WBCT and manually performed WBCT measurements. Alpha risk was set to 5% (α=0.05). Agreement between manual (M) and semiautomatic (SA) methods was evaluated using Bland-Altman plots. P-values of $\leq$0.05 were considered significant.

Results

ICC-measured reliability ranged from moderate to almost perfect for manual and semiautomatic WBCT measurements in the preop and postop groups for HMA and LTS (Table 1).

Mean manual and semiautomatic measurements of HMA, LTS, and TTA showed, as expected, a decrease in value when comparing the preoperative group with the postoperative group, and presented a statistically significant difference for HMA in manual and semiautomatic measurements (Tables 2 and 3).

According to Pearson coefficients, there was a high positive linear correlation between semiautomatic and measurements performed manually in the preoperative group for the two parameters evaluated (HMA, r=0.93, p<0.001; LTS, r=0.64, p=0.01). There was no significant positive linear correlation between the semiautomatic and manual measurements performed for TTA (r=0.01; p=0.936). The same phenomenon occurred in the postoperative group, with a high, positive linear correlation for HMA (r=0.84; p<0.001) and LTS (r=0.66; p=0.01). There was no significant positive linear correlation between the semiautomatic and manual measurements for TTA (r=0.22; p=0.448).

Agreement between manual (M) and semiautomatic (SA) methods was tested for HMA, LTS, and TTA using Bland-Altman plots. This method expressed excellent agreement between manual and semiautomatic segmentation for the preoperative and postoperative groups. In the preoperative group, the plot shows that the mean difference between measurements for HMA was 0.48 degrees, with a 95% confidence interval of -6.81 to 5.86; for LTS, 2.64 mm, with a 95%CI of -5.58 to 10.85; and for TTA, 1.4 degrees, with a 95%CI of -30.83 to 28.03. In the postoperative group, the mean difference between measurements for HMA was 2.9 degrees, with a 95% confidence interval of -11.11 to 5.3; for LTS, it was 3.12 mm, with a 95%CI of -0.43 to 6.68; and for TTA it was 2.62 degrees, with a 95%CI of -12.69 to 17.91. These results indicated a high correlation between the parameters calculated from the manual and semiautomatic measurements, and strong agreement between the readers and the software in both groups (Figure 4).

Discussion

Our study revealed that computer-assisted semiautomatic WBCT image measurements in end-stage OA patients undergoing TAR are reliable and expressed excellent agreement between manual and semiautomatic segmentation for the

Table 1. Intraobserver Agreement and Consistency of Manual vs. Semi-Automatic Measurements Assessed by ICC[a]

	Pre-op			Post-op		
	Agreement (95% CI)	Consistency (95% CI)	P value	Agreement (95% CI)	Consistency (95% CI)	P value
HINDFOOT MOMENT ARM	0.697 (0.143-0.896)	0.706 (0.123-0.901)	0.014*	0.877 (0.522-0.963)	0.91 (0.719-0.971)	<0.001*
LATERAL TALAR STATION	0.725 (0.185-0.908)	0.778 (0.339-0.925)	0.004*	0.496 (0.235-0.842)	0.793 (0.335-0.933)	0.004*
TALAR TILT ANGLE	0.27 (0.00-0.686)	0.26 (0.00-0.673)	0.481	0.229 (0.00-0.596)	0.241 (0.00-0.602)	0.648

M, Manual measurement; SA, semi-automatic measurement.
[a] P values are based on F tests calculated using function icc() of *R* package irr.
*Statistical significance, P<.05.

Table 2. Comparison between Preop vs. Postop group using Manual measurement

	Preop Mean	Postop Mean	Mean difference	P value
HINDFOOT MOMENT ARM	10,61	5,98	4,63	<0.001*
LATERAL TALAR STATION	4,66	3,58	1,08	0,1
TALAR TILT ANGLE	2,87	0,37	2,5	0,176

aP values are based on Wilcoxon test.
*Statistical significance, P<.05.

Table 3. Comparison between Preop vs. Postop group using Semi-automatic measurement

	Preop Mean	Postop Mean	Mean difference	P value
HINDFOOT MOMENT ARM	11,28	8,19	3,09	0.006*
LATERAL TALAR STATION	3,78	1,49	2,29	0,07
TALAR TILT ANGLE	2,99	0,63	2,36	0,231

aP values are based on Wilcoxon test.
*Statistical significance, P < .05.

pre- and postoperative groups. We validated a high positive linear relationship between semiautomatic and manual measurements for HMA and LTS. However, no significant positive linear correlation was found for TTA in either group. This stands in contrast to previous studies, which have only focused on 3D measurements concerning end-stage posttraumatic AO or the assessment of foot and ankle alignment, not on how these measurements can be applied to evaluate a surgical approach[13, 20,21].

This study used semiautomatic WBCT measurements to evaluate patients with end-stage AO who underwent a lateral trans-fibular TAR. Previous studies have illustrated the superiority of WBCT over conventional radiography for assessing the foot and ankle[24,25], suggesting that this imaging method can more accurately characterize 3D joint morphology in comparison to 2D radiographs. It has been demonstrated that hindfoot alignment can be poorly evaluated in the clinic[26] and that 2D radiographs have poor reproducibility[27,28]. Further, a study performed by de Cesar Netto and Richter[14] suggested that WBCT can mitigate certain flaws inherent to 2D imaging, such as errors in patient positioning, overlapping structures, and operator-related bias. These critiques are supported by others[13-15,22].

Bernasconi et al.[23] evaluated semiautomatic 3D measurements of WBCT images to assess hindfoot alignment in pes cavovarus, and found high intra- and inter-observer reliability regarding these measurements.

In a recent study, Kvarda et al.[13] examined 3D measurements generated from WBCT images of the midfoot and hindfoot by semiautomated software and assessed the reliability of these measurements in patients with posttraumatic end-stage AO. They concluded that this technique provided an accurate assessment of the hindfoot and midfoot, irrespective of the observer, and found that the automatically generated 3D measurements were reliable both in healthy patients and in patients with posttraumatic end-stage AO. They suggested that acquiring these measurements can impact patient outcomes and provider decision-making.

These studies confirmed our impression that semiautomatic 3D WBCT measurements expressed high intra-rater reliability in assessing foot and ankle hindfoot deformities.

While our study yielded significant findings, some limitations must be addressed: (1) we used a retrospective design; (2) while the software utilized to collect semiautomatic measurements calculates the parameters automatically, selection of the bone structures within the interface was done manually; (3) we did not measure image acquisition time, a software parameter subject to variability depending on the computer, and this must be accounted for; (4) this software is currently limited to select research institutions, and is still under development. Thus, there are some barriers to improving access to this novel technology.

Further research will need to be conducted for this technology to be integrated into clinical practice as a tool that can improve the time efficiency and accuracy of diagnosis, treatment planning, and decision-making by orthopedic surgeons.

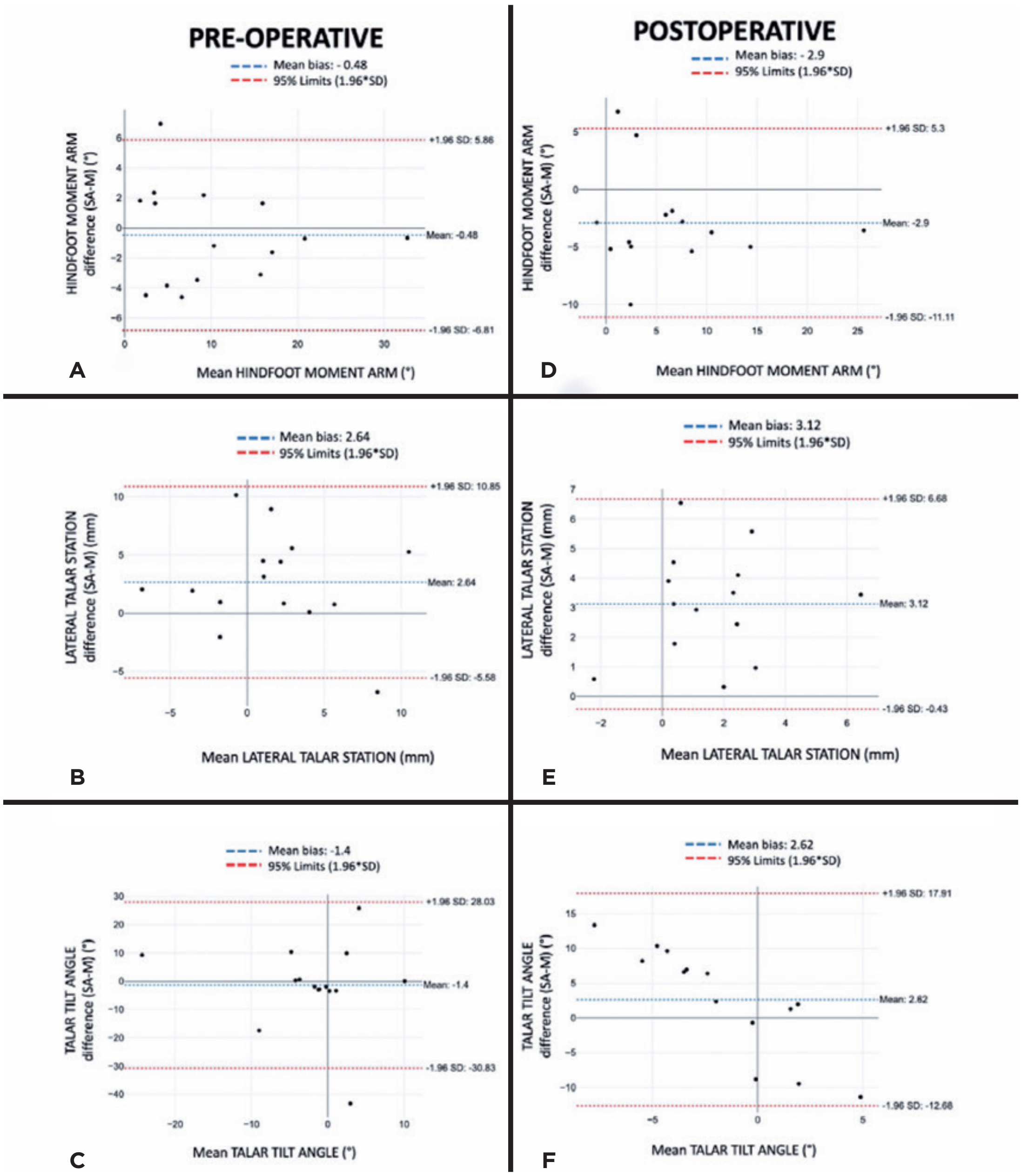


Figure 4. Bland-Altman plots for preoperative group: A) hindfoot moment arm, B) lateral talar station, and C) talar tilt angle; and for postoperative group: D) hindfoot moment arm, E) lateral talar station, and F) talar tilt angle. The mean for each pair of semiautomatic (SA) and manual (M) measurements is shown on the x-axis. The corresponding difference (bias) between each SA and M measurement (SA minus M) is shown on the y-axis. Dashed blue line represents the mean difference. Dashed red lines represent 95% limits of agreement (mean difference ± 1.96 standard deviation [SD] of the difference).

Conclusion

Our hypothesis that semiautomatic measurement in the setting of patients with end-stage AO who underwent TAR would be as reliable and accurate as measurements performed manually was confirmed. Manual (M) and semiautomatic (SA) 3D measurements expressed excellent agreement for pre-and postoperative groups, indicating a high correlation between the calculated parameters, and strong agreement between the readers and the software in both groups.

Authors' contributions: Each author contributed individually and significantly to the development of this article: VM *(https://orcid.org/0000-0002-8612-5941) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process and approved the final version; RJ *(https://orcid.org/0000-0003-3448-1300) Data collection and interpreted the results of the study; MJ *(https://orcid.org/0000-0003-0773-7286) Data collection and interpreted the results of the study; CV *(https://orcid.org/0000-0002-7797-6111) Data collection and interpreted the results of the study; KAMC *(https://orcid.org/0000-0003-1082-6490) Interpreted the results of the study, participated in the review process and approved the final version; KCK *(https://orcid.org/0000-0002-3731-8448) Data collection and interpreted the results of the study; NSBM *(https://orcid.org/0000-0003-1067-727X) Interpreted the results of the study and approved the final version; KD *(https://orcid.org/0000-0002-8061-4453) Interpreted the results of the study and approved the final version; CCN *(https://orcid.org/0000-0001-6037-0685) Interpreted the results of the study and approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID).

References

1. Barg A, Pagenstert GI, Hügle T, Gloyer M, Wiewiorski M, Henninger HB, et al. Ankle osteoarthritis: etiology, diagnostics, and classification. Foot Ankle Clin. 2013;18(3):411-26.
2. Glazebrook M, Daniels T, Younger A, Foote CJ, Penner M, Wing K, et al. Comparison of health-related quality of life between patients with end-stage ankle and hip arthrosis. J Bone Joint Surg Am. 2008;90(3):499-505.
3. Valderrabano V, Horisberger M, Russell I, Dougall H, Hintermann B. Etiology of ankle osteoarthritis. Clin Orthop Relat Res. 2009;467(7):1800-6.
4. Herrera-Pérez M, González-Martín D, Vallejo-Márquez M, Godoy-Santos AL, Valderrabano V, Tejero S. Ankle osteoarthritis aetiology. J Clin Med. 2021;10(19):4489.
5. Nwankwo EC Jr, Labaran LA, Athas V, Olson S, Adams SB. Pathogenesis of posttraumatic osteoarthritis of the ankle. Orthop Clin North Am. 2019;50(4):529-37.
6. Saltzman CL, Salamon ML, Blanchard GM, Huff T, Hayes A, Buckwalter JA, et al. Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopaedic center. Iowa Orthop J. 2005;25:44-6.
7. Demetriades L, Strauss E, Gallina J. Osteoarthritis of the ankle. Clin Orthop Relat Res. 1998;(349):28-42.
8. Wyss C, Zollinger H. The causes of subsequent arthrodesis of the ankle joint. Acta Orthop Belg. 1991;57 Suppl 1:22-7.
9. Saito GH, Sanders AE, de Cesar Netto C, O'Malley MJ, Ellis SJ, Demetracopoulos CA. Short-Term complications, reoperations, and radiographic outcomes of a new fixed-bearing total ankle arthroplasty. Foot Ankle Int. 2018;39(7):787-94.
10. Norvell DC, Ledoux WR, Shofer JB, Hansen ST, Davitt J, Anderson JG, et al. Effectiveness and safety of ankle arthrodesis versus arthroplasty: a prospective multicenter study. J Bone Joint Surg Am. 2019 Aug 21;101(16):1485-94.
11. Veljkovic AN, Daniels TR, Glazebrook MA, Dryden PJ, Penner MJ, Wing KJ, et al. Outcomes of total ankle replacement, arthroscopic ankle arthrodesis, and open ankle arthrodesis for isolated non-deformed end-stage ankle arthritis. J Bone Joint Surg Am. 2019; 101(17):1523-9.
12. Flury A, Viehöfer AF, Hoch A, Vlachopoulos L, Wirth SH, Imhoff FB. Talar neck angle correlates with tibial torsion-Guidance for 3D and 2D measurements in total ankle replacement. J Orthop Res. 2021;39(4):788-96.
13. Kvarda P, Krähenbühl N, Susdorf R, Burssens A, Ruiz R, Barg A, et al. High reliability for semiautomated 3D measurements based on weightbearing CT scans. Foot Ankle Int. 2022;43(1):91-95.
14. de Cesar Netto C, Richter M. Use of advanced weightbearing imaging in evaluation of hallux valgus. Foot Ankle Clin. 2020; 25(1):31-45.
15. Day MA, Ho M, Dibbern K, Rao K, An Q, Anderson DD, et al. Correlation of 3D joint space width from weightbearing CT with outcomes after intra-articular calcaneal fracture. Foot Ankle Int. 2020;41(9):1106-16.
16. Stufkens SA, Barg A, Bolliger L, Stucinskas J, Knupp M, Hintermann B. Measurement of the medial distal tibial angle. Foot Ankle Int. 2011;32(3):288-93.
17. Tochigi Y, Suh JS, Amendola A, Pedersen DR, Saltzman CL. Ankle alignment on lateral radiographs. Part 1: sensitivity of measures to perturbations of ankle positioning. Foot Ankle Int. 2006;27(2):82-7.
18. Escudero MI, Le V, Barahona M, Symes M, Wing K, Younger A, et al. Total ankle arthroplasty survival and risk factors for failure. Foot Ankle Int. 2019;40(9):997-1006.
19. Escudero MI, Le V, Bemenderfer TB, Barahona M, Anderson RB, Davis H, et al. Total ankle arthroplasty radiographic alignment comparison between patient-specific instrumentation and standard instrumentation. Foot Ankle Int. 2021;42(7):851-8.
20. Kvarda P, Heisler L, Krähenbühl N, Steiner CS, Ruiz R, Susdorf R, et al. 3D assessment in posttraumatic ankle osteoarthritis. Foot Ankle Int. 2021;42(2):200-14.
21. Lintz F, Mast J, Bernasconi A, Mehdi N, de Cesar Netto C, Fernando C. 3D, weightbearing topographical study of periprosthetic cysts and alignment in total ankle replacement. Foot Ankle Int. 2020;41(1):1-9.
22. de Carvalho KAM, Walt JS, Ehret A, Tazegul TE, Dibbern K, Mansur NSB, et al. Comparison between Weightbearing-CT semiautomatic and manual measurements in Hallux Valgus. Foot Ankle Surg. 2022:S1268-7731(22)00043-1.
23. Bernasconi A, Cooper L, Lyle S, Patel S, Cullen N, Singh D, et al. Intraobserver and interobserver reliability of cone beam weightbearing semi-automatic three-dimensional measurements in symptomatic pes cavovarus. Foot Ankle Surg. 2020;26(5):564-72.
24. Richter M, Seidl B, Zech S, Hahn S. PedCAT for 3D-imaging in standing position allows for more accurate bone position (angle) measurement than radiographs or CT. Foot Ankle Surg. 2014;20(3):201-7.
25. Hamard M, Neroladaki A, Bagetakos I, Dubois-Ferrière V, Montet X, Boudabbous S. Accuracy of cone-beam computed tomography for syndesmosis injury diagnosis compared to conventional computed tomography. Foot Ankle Surg. 2020;26(3):265-72.
26. Baverel L, Brilhault J, Odri G, Boissard M, Lintz F. Influence of lower limb rotation on hindfoot alignment using a conventional two-dimensional radiographic technique. Foot Ankle Surg. 2017;23(1):44-49.
27. Barg A, Bailey T, Richter M, de Cesar Netto C, Lintz F, Burssens A, et al. Weightbearing computed tomography of the foot and ankle: emerging technology topical review. Foot Ankle Int. 2018;39(3):376-86.
28. de Cesar Netto C, Bernasconi A, Roberts L, Pontin PA, Lintz F, Saito GH, et al. Foot alignment in symptomatic National Basketball Association players using weightbearing cone beam computed tomography. Orthop J Sports Med. 2019;7(2):2325967119826081.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1610

Original Article

Stress fracture of the fifth metatarsal in professional soccer players treated with intramedullary fixation: is a return to sports safe?

Carlos Augusto Zazueta-Arnaud[1], Luis Gómez-Carlín[1], Luis Felipe Radillo-Ubando[1], Victor Jonathan Ramírez-Gómez[1], Elsa Viridiana Sánchez-Hernández[1]

1. Medyarthros Clinic, Guadalajara, Jalisco, Mexico.

Abstract

Objective: To evaluate the clinical and functional outcomes of professional soccer players with zone 3 fractures of the fifth metatarsal treated with intramedullary fixation; and to determine a safe return time to sports.

Methods: This study included professional Mexican soccer players with fractures in zone 3 of the fifth metatarsal treated with intramedullary fixation. The clinical and functional status were evaluated with the VAS and Foot and Ankle Ability Measure (FAAM-Sp) Sport Subscale Score.

Results: Twenty-two professional soccer players (average age: 20.13 ± 2.85 years) were included. The average postoperative follow-up time was 23.54 ± 15.26 months. Fracture consolidation was demonstrated at 12-week follow-up in all 22 (100%) subjects. The FAAM-Sp Sport Subscale Score was 91.45 ± 8.84 postoperatively; the safe time to return to sports was 12.04 ± 2.21 weeks, when normal or close to normal function was observed in 21 (95%) players.

Conclusion: A safe return to sports at 12 weeks, at the same performance level demonstrated prior to injury, was achieved in 95% of professional soccer players in this sample. To our knowledge, this is the first study to explicitly define a time for safe return to sports activities that is related to the critical time required to allow fracture union.

Level of Evidence III; Therapeutic Studies; Retrospective Cohort Study.

Keywords: Activities of daily living; Fractures, stress; Soccer.

Introduction

Fractures of the fifth metatarsal in professional soccer players account for 0.5% of all sport injuries[1]. This lesion frequently occurs in zones 1 and 2, whereas a lesion in zone 3, known as a stress fracture, is less frequent and is a result of repetitive loading that occurs during training and competitions. Intrinsic and extrinsic risk factors have been described, such as being a young athlete and participating in intense preseason training[2,3]. Recently, an abnormality in the mean malleolar glide angle of the ankle has been shown to be a risk factor for stress fractures in the fifth metatarsal[4].

A conservative treatment approach is not effective for athletes; immobilization to manage stress fractures can be catastrophic and associated with delayed consolidation, pseudoarthrosis, and a prolonged recovery time[5-8]. Currently, the consensus is that intramedullary fixation of stress fractures is indicated specifically in subjects with high physical demands, such as professional soccer players[1,9]. Surgical management offers the greatest safety for bone union, with advantages that include its technical simplicity and its minimally invasive nature[10], ideal for patients with high levels of physical activity. In 1975, for the first time, Dameron[6] suggested that athletes should be operated on early to accelerate bone union.

Study performed at the Medyarthros Clinic, Guadalajara, Jalisco, Mexico.

Correspondence: Luis Felipe Radillo-Ubando. Av. Ignacio L. Vallarta 3060, Ladrón de Guevara, 44690. **E-mail:** radillo_lf09@hotmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** February 17, 2022. **Date accepted:** February 26, 2022. **Online:** April 30, 2022.

How to cite this article: Zazueta-Arnaud CA, Gómez-Carlín L, Radillo-Ubando LF, Ramírez-Gómez VJ, Sánchez-Hernández EV. Stress fracture of the fifth metatarsal in professional soccer players treated with intramedullary fixation: is a return to sports safe? J Foot Ankle. 2022;16(1):79-84.

There are few reports of stress fractures in zone 3 of the fifth metatarsal[1,3,11]. Moreover, to our knowledge, no studies have determined the clinical and functional progression of this injury with valid and reproducible scales of surgical results and their relation to the time of return to professional sports at the same performance level reached prior to the injury. Therefore, the objectives of our study were 1) to evaluate clinical and functional outcomes on a visual analog scale (VAS) and the Sport Subscale Score of the Foot and Ankle Ability Measure-Spanish (FAAM-Sp) in professional soccer players with fractures in zone 3 of the fifth metatarsal treated with intramedullary fixation, 2) to determine a safe time for these players to return to play, and 3) to ascertain whether the players reached the same performance level at which they played prior to injury.

Methods

After a full review, the study was approved by the Ethics Committee of the Jalisco Institute of Clinical Research (No. 14-CEI-005-20170427- No. 1066).

A retrospective cohort study was conducted from July 2013 to February 2018; participants were enrolled consecutively. Players from the Mexican professional soccer league with a primary fracture in zone 3 of the fifth metatarsal that was treated with intramedullary fixation within the first 10 days of injury were eligible and included in the study. Patients who had experienced traumatic events and fractures in zone 1 and/or 2 of the fifth metatarsal were not included. Patients who agreed to participate gave verbal informed consent.

Study Description

The following variables were included: age, sex, dominant foot, fractured foot, preseason injury, postoperative temporal progression, time until return to the professional sporting level the player had reached prior to injury (weeks), and radiographs at 4-, 8-, and 12-week postoperative follow-up time points to identify whether union, nonunion, or a delay of consolidation and complications occurred. Union required complete bone bridging across the fracture site with or without normal density on radiographs and no tenderness at the zone fracture. The period of inability to participate in sport at the player's preinjury professional level was recorded.

Evaluation Scales

The clinical and functional status of the fifth metatarsal stress fracture, as well as postoperative outcomes, were evaluated with the VAS and FAAM-Sp Sport Subscale Score[12,13].

FAAM-Sp Sport Subscale Score

The sports subscale comprises eight elements of high-level activities, such as those required for athletes. The capacity to respond, validity, reliability, and reproducibility of this scale, including the Spanish version[12], were previously verified[14]. Tools for assessment, such as self-reporting surveys, use the patient's response to measure his performance: the survey is useful to evaluate the efficacy of the treatment. The maximum score, 100, corresponds to an ability to perform the sporting activity with the patient's normal technique and participate in the sporting activity for as long as necessary. The minimum score, 20, corresponds to an inability to perform or participate in the sporting activity. Similarly, the current level of function defined by the players was evaluated during sporting activities by a range of scores from 0 to 100 (100 corresponded to their level of function prior to the fracture and 0 corresponded to an inability to perform any of their usual daily activities). In relation to the question, "How do you classify your current function level?" the parameters evaluated were normal, close to normal, abnormal, and severely abnormal.

Operative Technique

All patients were operated on in the supine position using regional anesthesia and a tourniquet. Patients received prophylactic antibiotics. During the surgical procedure, fluoroscopic monitoring was used. A cannulated drill and a guide wire were used; every surgical procedure was performed via the "high and inside" surgical technique.

Postoperative Management

Patients received general wound care and minimal handling of the surgical site. They went into non-weight-bearing immobilization in a walker boot for 2 weeks. Subsequently, progressive weight-bearing in regular shoes was indicated as tolerated. In case of any functional limitation, strength-training exercises were prescribed. Between 6 and 10 weeks after surgery, elliptical training and jogging were authorized. The intensity of these activities was decided based on the patient's recovery status. Between 10 and 12 weeks after surgery, patients joined their team for regular training. Our criteria for return to sport were pain relief at the affected zone, adequate physical function, and complete trabecular bridging across the fracture site on radiographs.

Statistical Analysis

Data were recorded in Excel (Microsoft™, Seattle, WA). Student's t test was performed to compare pre-and postoperative VAS scores. A p-value of <0.05 was considered statistically significant.

Results

Twenty-two professional male players with diagnosis of primary fracture in zone 3 of the fifth metatarsal that was treated with intramedullary fixation were included in the study (Figure 1). The age of the patients ranged from 17 to 29 years, with an average age of 20.13 ± 2.85 years (Table 1). The patients were clinically and radiographically evaluated within the first 10 days after the injury. A widening of the fracture line and evidence of intramedullary sclerosis were shown in the radiographs (Figure 2A-B). Stress fracture occurred during the preseason training phase for 15 (68%) of the 22 players, while it occurred during the competition season for 7 (32%) players.

The average duration of follow-up after intramedullary fixation was 23.54 ± 15.26 months (Table 1); 21 (95%) of 22 players were treated with a 4.5 mm cannulated compression screw and only one patient was managed with a 4.0 mm cannulation screw. Consolidation of the fracture, demonstrated with radiographic images in the 12-week follow-up, occurred in the 22 (100%) players included in the study; good trabeculation across the fracture was shown on radiographs, although some patients still had some visualization of the original fracture line (Figure 2C-D). Delayed consolidation or nonunion was not observed in any player. The average time elapsed between the surgical intervention and return to professional sporting activity was 12.04 ± 2.21 weeks. Only one complication was reported in a patient, a refracture that occurred at 8 weeks postoperatively and was unrelated to sports activities or rehabilitation; the injury occurred when going down a step by the forced inversion mechanism.

There were no more refractures and the patients were able to return to their previous sports activities without reporting pain in the following (24-month) follow-up.

No delay was observed in consolidation of the fractures in any of the patients.

The VAS in the preoperative evaluation revealed an average score of 8.81 ± 0.90; at postoperative follow-up after return to sporting activity, the VAS score was 1.68 ± 1.52 ($p<0.05$) (Table 1).

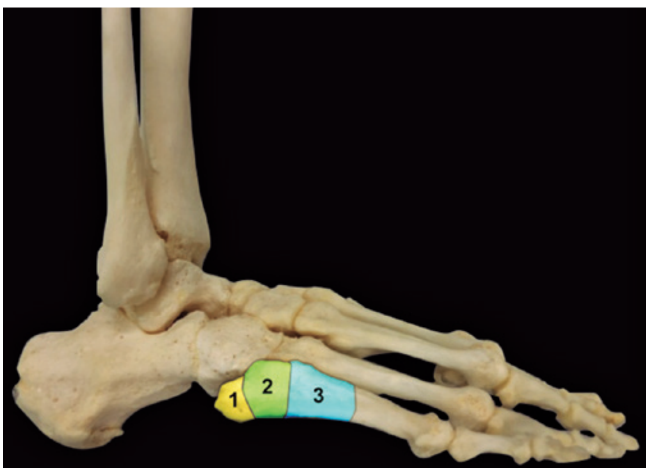


Figure 1. Three types of proximal fifth metatarsal fracture by zone: 1) tuberosity avulsion; 2) metaphyseal-diaphyseal union (Jones fracture); 3) diaphyseal stress fracture.

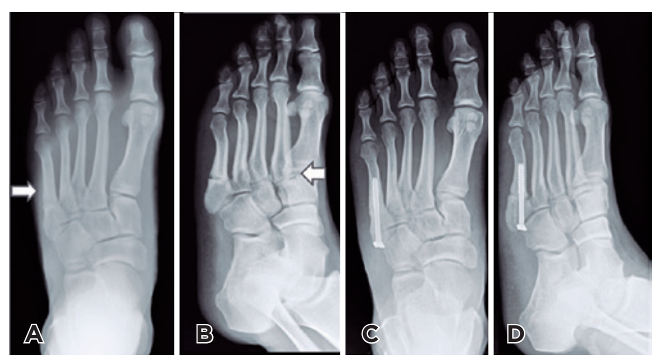


Figure 2. A-B) Anteroposterior and oblique radiographs of the proximal fifth metatarsal demonstrating a wide fracture line. This fracture extends into zone 3 and involves both cortices, with partial obliteration of the medullary canal by sclerosis at the site of fracture. C-D) Anteroposterior and oblique radiographs of the left foot taken at 12 weeks postoperatively. The orientation of a 4.5-mm diameter cannulated screw with washer is seen in both projections, as well as consolidation with evidence of trabeculation through the fracture but without full normal density.

Table 1. Characteristics of professional soccer players with a zone 3 fracture in the fifth metatarsal that was treated with intramedullary fixation (N=22)

Years of age (mean ± SD)	20.13 ± 2.85
Sex (male)	22 (100%)
Dominant foot (left/right)	3/19
Fractured foot (left/right)	13/9
Preseason injury (yes/no)	15/7
100% fracture consolidation	22
Postoperative follow-up (months) (mean ± SD)	23.54 ± 15.26
Time to return to professional sporting activity (weeks) (mean ± SD)	12.04 ± 2.21
Complications	1[a]
VAS preoperative score [b] (mean ± SD)	8.81 ± 0.90
VAS postoperative score after return to sporting activity (mean ± SD)	1.68 ± 1.52[c]

[a] Only 1 patient presented with a refracture, which was unrelated to professional sporting activity and diagnosed at the 8-week postsurgical follow-up; the injury was induced by the forced inversion mechanism when descending a stair.
[b] VAS: visual analog scale.
[c] $p<0.05$.

Table 2. Average FAAM-Sp Sport Subscale Score[a] in the postoperative period of professional soccer players with a zone 3 fracture that was treated by intramedullary fixation (N=22)

	Mean ± SD	Minimum	Maximum
Sport Subscale Score	91.45 ± 8.84	72	100

[a] FAAM-Sp[12,13].

The average score of the FAAM-Sp Sport Subscale Score was 91.45 ± 8.84 (ranging from 72 to 100) (Table 2) in the postoperative period. In Figure 3, the average score obtained by the athletes is shown in relation to the following specific maneuvers: running, jumping, landing, starting and stopping quickly, cutting and lateral movements, and low impact activities. Among the 22 professional soccer players included in the study, 14 (64%) players had a score between 90 and 100.

During postoperative follow-up, the level of functional activity related to the sport was determined by the FAAM-Sp Sport Subscale Score upon the player's return to sporting activity. The average score was 91.13 ± 10.11 (Table 3); in 17 (77%) of the 22 players, a score between 90 and 100 was reported. The players' functional level upon return to the sporting activity was evaluated with the question *"How do you classify your current function level?"*; among the 22 players, 21 (95%) classified themselves as having a normal or close to normal functional level, and only one player reported an abnormal functional level.

Discussion

In our study, a safe return to sports for professional soccer players was demonstrated to be possible 12 weeks after the intramedullary fixation of a stress fracture in the fifth metatarsal; at that time, performance was normal or close to normal in 95% of the athletes (FAAM-Sp Sports Subscale Score). To our knowledge, this is the first study in the literature to define the timing for safe return to sporting activities in terms of the critical time required to allow fracture consolidation.

For professional soccer players, a stress fracture in the fifth metatarsal could mean the end of their participation in the sport[1]. The decreased time to return to sports and the reliability of healing are the main reasons for pursuing operative fixation[15]. The functional prognosis of a player's return to the sport following the intramedullary fixation of a stress fracture in the fifth metatarsal had not been defined. In a recent study of professional soccer players with stress fractures who were treated with intramedullary fixation, Miller et al.[9] found that an early return (8 weeks) to professional sporting activity was associated with a radiological delay of fracture union in 9 (24%) of the 37 cases, suggesting that, in the absence of symptoms, this radiological finding did not limit the players' time of return to sports activity. In contrast, another study reported that return to full activity before complete radiological union was predictive of failure[16]; surgeons must be cognizant of the risk of refracture, particularly in dealing with high-demand populations, and avoid the temptation to return patients to high-impact activities before radiographic union[17].

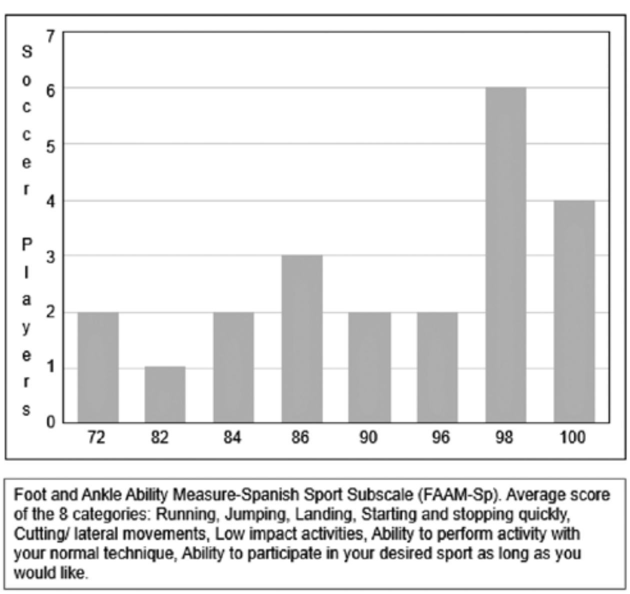


Figure 3. FAAM-Sp Sport Subscale in the postoperative period. The average score obtained by the athletes is shown in relation to the following specific maneuvers: running, jumping, landing, starting and stopping quickly, cutting and lateral movements, and low-impact activities.

Table 3. Function level scores[a] during sport-related activities in soccer players with the diagnosis of a zone 3 fracture that was treated with intramedullary fixation (N=22)

Case no.	Current level of function during sport-related activities[b]	In general, how do you classify your current level of function?[c]
1	100	Normal
2	100	Normal
3	95	Normal
4	95	Close to normal
5	85	Close to normal
6	100	Close to normal
7	90	Close to normal
8	90	Close to normal
9	90	Close to normal
10	95	Normal
11	100	Normal
12	100	Normal
13	95	Normal
14	90	Close to normal
15	100	Normal
16	90	Close to normal
17	100	Normal
18	75	Close to normal
19	95	Normal
20	80	Close to normal
21	60	Abnormal
22	80	Close to normal

[a] FAAM-Sp Sport Subscale Score[12,13].
[b] The score of 100 corresponds to the level of function prior to the injury, and the score of 0 corresponds to the inability to perform any of the usual daily activities.
[c] Normal, close to normal, abnormal, or severely abnormal

Bucknam et al.[17] reported 32 patients with fifth metatarsal fractures of zone 2 or 3.

They included both zones under eponymous Jones fractures because current data suggest a similar vascular watershed and a subsequent impaired healing response within zone 3; the mean follow-up was 24.2 (SD, 21.2) months. All patients (100%) achieved osseous union at a mean of 10.8 weeks, with return to restriction-free activities at an average 13.0 weeks (to include high-impact activities). There were no refractures or nonunions, and overall patient-reported satisfaction was 100% at a mean follow-up of just over 2 years. In our study, the average time of return to sporting activity was 12 weeks after surgery, which was related to consolidation of the fracture, and the level of function was normal or close to normal in 21 (95%) of the 22 professional soccer players with primary stress fracture. Our results are comparable to those reported by Ekstrand and Torstveit[3], which included an average time of 12 weeks for professional soccer players with a stress fracture in the fifth metatarsal to return to normal sport activities. We believe a return to sport after 12 weeks is safe and that consolidation of the fracture in the fifth metatarsal in professional soccer players is currently predictable.

Stress fractures, unlike traumatic injuries, have an insidious course that is related to overuse. In a biomechanical analysis of stress fractures, Orendurff et al.[18] showed that the highest flexion moments during acceleration are applied to the fifth metatarsal; this moment is characterized by the forward inclination of the torso, forefoot contact, and a relatively large propulsive force from the lower extremities. The metatarsal pressure incurred during acceleration is twice as large as the pressure incurred during cutting maneuvers, lateral movements, and jumping, landing, and running actions at a constant speed in a straight line. Therefore, acceleration exerts the largest load on the fifth metatarsal compared with other maneuvers performed on courts and sports fields. The highest frequency of fractures in zone 3 of the fifth metatarsal was related to the preseason period due to the repetitive stresses incurred during intense physical training; in our study of Mexican soccer players, 15 (68%) of the 22 players incurred a stress fracture during the preseason period. The repetition of stress on the lateral-plantar region of the fifth metatarsal is a risk factor for fracture in zone 3[4,19]; in contrast, fractures in zones 1 and 2 are related to acute traumatic injuries, mainly during the competition period. It is important to understand this concept and apply it in a preventative manner in training strategies to reduce the frequency of stress fractures in the fifth metatarsal during the preseason period[1].

Advances in technology have made cannulated screws available, which may ease the difficulty of insertion into the fifth metatarsal; the recommendation is to use the largest screw possible and be cautious with the use of screws less than 4 mm in diameter[20]. On the other hand, in one study, the biomechanical stiffness of a 4.5-mm solid malleolar screw and a 4.5-mm cannulated screw was examined in a cadaveric fifth metatarsal model[21]; the force to displacement was not different between the two screws. The authors noted that the choice of screws from a biomechanical standpoint was at the surgeon's discretion. In our study, all cannulated screw diameters were 4.5 mm except in one patient, with a diameter of 4.0 mm. We considered the intramedullary fixation of a stress fracture in the fifth metatarsal with a 4.5-mm cannulated screw to be reliable for achieving effective healing in fifth metatarsal stress fractures, both clinically and radiographically[22].

It is currently argued that solid screws have a higher resistance to bending fatigue, as published by Nunley et al.[23]; however, potential bias should be considered since this research was funded by the company that develops the screws under study. In most published series, there are no statistically significant differences observed between the use of solid or cannulated screws; however, there also seems to be a consensus about using screws of the largest possible diameter and the necessary length for the distal threads of the intramedullary screw to generate axial compression to the fracture line[24].

In 2005, Porter et al.[22] reported on 23 athletes treated with intramedullary fixation with 4.5-mm cannulated screws. The authors concluded that 100% of the patients returned to their sporting activities after an average of 7 weeks.

A strength of this study is the clinical and functional evaluation with the FAAM-Sp Sports Subscale Score, which has been validated to determine the results of the surgical procedure; the reliability and reproducibility of the Spanish version have also been verified[14]. Another strength of the study is the homogeneity of the patients, a group of professional soccer players who had stress fractures in the fifth metatarsal and underwent the same surgical procedure of intramedullary fixation at a specialized Foot and Ankle Clinic that sees patients from throughout the country. On the other hand, limitations include the retrospective design and the fact that biomechanical evaluations were not performed.

Conclusion

In conclusion, our study demonstrated safe return of professional soccer players to sporting activity with normal or close to normal performance in 95% of the athletes (FAAM-Sp Sports Subscale Score) at 12 weeks after intramedullary fixation of a stress fracture in the fifth metatarsal; this procedure achieved fracture consolidation in all cases with excellent clinical and functional outcomes. Based on the results of our study, it is possible to predict the safe return of professional soccer players to sporting activity 12 weeks after surgery. Future prospective studies to validate this recommendation are warranted.

Acknowledgment

The authors thank Dr. Ana María Contreras-Navarro of the Unidad de Investigación y Desarrollo Tecnológico (UNIDET) Medyarthros for her advice when drafting this article.

Authors' contributions: The authors contributed individually and significantly to the development of this article: CAZA *(https://orcid.org/0000-0002-4135-3748) Conceived and planned the activities that led to the study, interpreted the results of the study, wrote the article; LCA *(https://orcid.org/0000-0002-0812-2497) Conceived and planned the activities that led to the study, interpreted the results of the study, wrote the article; LFRU *(https://orcid.org/0000-0002-5000-1592) Wrote the article and tables; VJRG *(https://orcid.org/0000-0002-7384-7080) Wrote the article, approved the final version; EVSH *(https://orcid.org/0000-0001-8238-2353) Wrote the article, approved the final version; The authors read and approved the final manuscript. ORCID (Open Researcher and Contributor ID) iD.

References

1. Ekstrand J, van Dijk CN. Fifth metatarsal fractures among male professional footballers: a potential career-ending disease. Br J Sports Med. 2013;47(12):754-8.
2. Brockwell J, Yeung Y, Griffith JF. Stress fractures of the foot and ankle. Sports Med Arthrosc Rev. 2009;17(3):149-59.
3. Ekstrand J, Torstveit MK. Stress fractures in elite male football players. Scand J Med Sci Sports. 2012;22(3):341-6.
4. Kizaki K, Yamashita F, Mori D, Funakoshi N. Ankle structures of professional soccer (football) players with proximal diaphyseal stress fractures of the fifth metatarsal. J Foot Ankle Surg. 2019;58(3):489-91.
5. Dameron TB Jr. Fractures of the proximal fifth metatarsal: selecting the best treatment option. J Am Acad Orthop Surg. 1995;3(2):110-4.
6. Dameron TB Jr. Fractures and anatomical variations of the proximal portion of the fifth metatarsal. J Bone Joint Surg Am. 1975;57(6):788-92.
7. Gómez-Carlín LA, Ortiz-Garza JI, Gutiérrez-Parada CA. Stress fractures in the athlete: epidemiology and management. Orthotips. 2016;12(1):12-22.
8. Lee KT, Park YU, Young KW, Kim JS, Kim JB. Surgical results of 5th metatarsal stress fracture using modified tension band wiring. Knee Surg Sports Traumatol Arthrosc. 2011;19(5):853-7.
9. Miller D, Marsland D, Jones M, Calder J. Early return to playing professional football following fixation of 5th metatarsal stress fractures may lead to delayed union but does not increase the risk of long-term non-union. Knee Surg Sports Traumatol Arthrosc. 2019;27(9):2796-801.
10. Sauer S. Intramedullary screw fixation of a proximal fifth metatarsal stress fracture in an elite athlete: a case report. Surg J (N Y). 2017;3(1):e6-e8.
11. Larsson D, Ekstrand J, Karlsson MK. Fracture epidemiology in male elite football players from 2001 to 2013: 'How long will this fracture keep me out?'. Br J Sports Med. 2016;50(12):759-63.
12. Cervera-Garvi P, Ortega-Avila AB, Morales-Asencio JM, Cervera-Marin JA, Martin RR, Gijon-Nogueron G. Cross-cultural adaptation and validation of Spanish version of The Foot and Ankle Ability Measures (FAAM-Sp). J Foot Ankle Res. 2017;10:39.
13. Martin RL, Irrgang JJ, Burdett RG, Conti SF, Van Swearingen JM. Evidence of validity for the Foot and Ankle Ability Measure (FAAM). Foot Ankle Int. 2005;26(11):968-83.
14. Shazadeh Safavi P, Janney C, Jupiter D, Kunzler D, Bui R, Panchbhavi VK. A systematic review of the outcome evaluation tools for the foot and ankle. Foot Ankle Spec. 2019;12(5):461-70.
15. Chuckpaiwong B, Queen RM, Easley ME, Nunley JA. Distinguishing Jones and proximal diaphyseal fractures of the fifth metatarsal. Clin Orthop Relat Res. 2008;466(8):1966-70.
16. Larson CM, Almekinders LC, Taft TN, Garrett WE. Intramedullary screw fixation of Jones fractures. Analysis of failure. Am J Sports Med. 2002;30(1):55-60.
17. Bucknam RB, Scanaliato JP, Kusnezov NA, Heida KA Jr, Dunn JC, Orr JD. Return to weightbearing and high-impact activities following Jones fracture intramedullary screw fixation. Foot Ankle Int. 2020;41(4):379-86.
18. Orendurff MS, Rohr ES, Segal AD, Medley JW, Green JR 3rd, Kadel NJ. Biomechanical analysis of stresses to the fifth metatarsal bone during sports maneuvers: implications for fifth metatarsal fractures. Phys Sportsmed. 2009;37(2):87-92.
19. Thevendran G, Deol RS, Calder JD. Fifth metatarsal fractures in the athlete: evidence for management. Foot Ankle Clin. 2013; 18(2):237-54.
20. Reese K, Litsky A, Kaeding C, Pedroza A, Shah N. Cannulated screw fixation of Jones fractures: a clinical and biomechanical study. Am J Sports Med. 2004;32(7):1736-42.
21. Pietropaoli MP, Wnorowski DC, Werner FW, Fortino MD. Intramedullary screw fixation of Jones fractures: a biomechanical study. Foot Ankle Int. 1999;20(9):560-3.
22. Porter DA, Duncan M, Meyer SJ. Fifth metatarsal Jones fracture fixation with a 4.5-mm cannulated stainless steel screw in the competitive and recreational athlete: a clinical and radiographic evaluation. Am J Sports Med. 2005;33(5):726-33.
23. Nunley JA, Glisson RR. A new option for intramedullary fixation of Jones fractures: the Charlotte Carolina Jones Fracture System. Foot Ankle Int. 2008;29(12):1216-21.
24. Ruta DJ, Parker D. Jones fracture management in athletes. Orthop Clin North Am. 2020;51(4):541-53.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1605

Case Report

Posterior osteochondroma of the talus as posterior ankle impingement syndrome: a case report

Eli Ávila Souza Júnior[1]

1. Universidade Federal de Alfenas, Alfenas, Minas Gerais, Brazil.

Abstract

Posterior ankle impingement syndrome is a common cause of ankle pain. Posterior osteochondroma of the talus is very rare and scarcely described in the literature, although it should always be considered an etiological hypothesis of posterior impingement. As for surgical treatment, both endoscopic and open approaches are reported as therapeutic options. The endoscopic approach, however, provides advantages over open procedures. Although little data has been published, it is believed that the former has more advantages. I report a rare case of posterior osteochondroma of the talus in a young man, clinically manifested as posterior ankle impingement syndrome and treated endoscopically.

Level of Evidence V; Diagnostic Studies; Expert Opinion.

Keywords: Ankle joint; Arthroscopy; Osteochondroma.

Introduction

Posterior ankle impingement syndrome is a common cause of ankle pain. Symptoms include pain, hyperesthesia in the posterior aspect of the ankle, and limited range of motion for plantar flexion[1] . An os trigonum is a major etiological hypothesis, as it originates from a stress fracture of the Stieda process or failed fusion of the secondary ossification center of the lateral tubercle of the talus[1].

Osteochondroma is a very common bone tumor, accounting for 20-50% of all benign bone tumors, and 10-15% of all bone tumors[2]. However, posterior talus osteochondroma is particularly rare and poorly described in the literature[3]. Fuselier et al.[4] first described it in 1984.

I report a rare case of posterior osteochondroma of the talus manifested as posterior ankle impingement syndrome.

Case description

This case report was approved by the Research Ethics Committee linked to the Plataforma Brasil of the institution.

A 30-year-old man with hypertension, working as an automotive mechanic, reported pain and discomfort in the posterolateral region of the right ankle for 1 year in 2017. He rated his pain as 8 out of 10 on a visual analog scale (VAS). He had no history of trauma or incidents. The patient reported that the pain increased with walking, standing upright, and applying manual pressure on the posterolateral region of the ankle. Six months earlier, he had noticed a small mass in the posterolateral region with occasional instances of inflammation at the site, when he made his first appointment to see an orthopedist. He received medical treatment from other orthopedists for 6 months, including physiotherapeutic measures, immobilization, and the use of nonsteroidal anti-inflammatory drugs, with no improvement.

Clinical evaluation showed a normal gait pattern without claudication and no foot deformity with weight-bearing. Physical examination revealed edema in the posterolateral region of the right ankle. No mass lesion was palpated on the ankle, but his pain increased with palpation of the posterolateral margin of the tibiotarsal joint. Regarding mobility, a 10-degree restriction of ankle plantar-flexion was observed, with increased pain with forced flexion of the ankle. Neurovascular examination was unremarkable.

Study performed at the School of Medicine, Universidade Federal de Alfenas, Alfenas, Minas Gerais, Brazil.

Correspondence: Eli Ávila Souza Júnior. Alameda Libânio, 72, Jardim da Colina, Alfenas, 37133-624, MG, Brazil. **E-mail:** elijr42@yahoo.com.br. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** January 18, 2022. **Date accepted:** March 04, 2022. **Online:** April 30, 2022.

How to cite this article: Souza Júnior EA. Posterior osteochondroma of the talus as posterior ankle impingement syndrome: a case report. J Foot Ankle. 2022;16(1):85-8.

Ankle radiographs showed a well-defined, extra-articular, radiopaque mass in the posterior aspect of the ankle (Figure 1). Magnetic resonance imaging (MRI) showed a well-defined mass with a characteristic bone signal surrounded by a lamina seen as a cartilage-like signal, with adjacent T2-weighted hypersignal typical of inflammatory fluid (Figure 2).

Given the clinical and imaging suspicion of posterior ankle impingement syndrome due to a benign-looking tumor with evident mass effect of unknown etiology, a posterior endoscopic approach was recommended for simultaneous diagnostic and therapeutic applications.

In May 2021, the patient underwent posterior endoscopy of the right ankle using the standard posterolateral and posteromedial portals, as described by van Dijk et al.[5] (Figure 3). An extensive extra-articular inflammatory process was visible in the posterior aspect of the ankle, in addition to a well-defined bone mass surrounded by cartilage and adjacent to the posterolateral process of the talus.

Extensive extra-articular debridement of the posterior aspect of the ankle was performed. The bone mass was fragmented to 2 small fragments and 1 main segment for removal. The resected material was sent for histopathological examination in a laboratory (Figure 4).

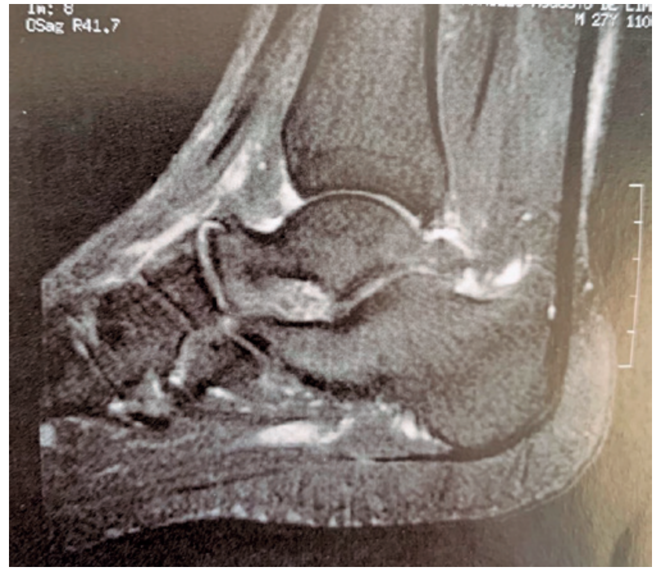


Figure 2. T2-weighted sagittal MRI scan showing a mass with a signal compatible with bone surrounded by cartilage and inflammatory fluid.

Figure 1. Lateral radiograph of the right ankle showing a well-defined, extra-articular, radiopaque mass in the posterior aspect of the ankle.

Figure 3. Two-portal (posterolateral and posteromedial) endoscopic approach of the ankle.

One week later, at the first follow-up visit, the patient reported improvement in pain and satisfaction with reduced hypersensitivity of the posterior ankle. At the 3-week follow-up visit, histopathology revealed 3 fragments of mature neoplastic mesenchymal cells with proliferation of trabecular bone covered with hyaline cartilage cap, measuring 2.0 x 2.0 x 0.5cm. There was no evidence of malignancy, and the findings were compatible with osteochondroma. Three months later, after physical therapy, the patient had significant improvement of the impingement syndrome symptoms, with no significant pain or functional complaints, with a VAS pain score of 1 out of 10. There was complete recovery of range of motion, which was symmetric to the contralateral side. An ankle radiograph showed no evidence of tumor recurrence (Figure 5).

Discussion

Posterior ankle impingement syndrome is a common cause of chronic ankle pain. It results from compression of osseous structures or soft tissues during plantar flexion. The causes and anatomical and pathological conditions are heterogeneous, as several pathological conditions can cause posterior impingement syndrome. Os trigonum, malunion of posterior malleolus fractures, increased posterior tibial slope, and talocalcaneal coalition are some of these causes[1]. This case report shows that, although rare, a benign bone tumor of the talus should be considered an etiological hypothesis.

Most osteochondromas are asymptomatic and often diagnosed incidentally. In general, they are more common in the knee, but when located in the talus, they occur more frequently in the dorsal region[6]. As reported here, in the posterior region, they can manifest as posterior ankle impingement syndrome causing pain, edema, and hypersensitivity, which worsen with prolonged standing and maximal forced plantar flexion. In 1984, Fuselier et al.[4] published the first case report of osteochondroma of the talus and conducted a review of cases with symptoms similar to those reported in this case.

An os trigonum is undoubtedly one of the most prevalent etiological hypotheses of posterior impingement syndrome. Radiographic studies of normal feet and ankles have shown a prevalence of os trigonum of 14% to 25% in the general population[1]. The clinical and imaging features of os trigonum and posterior talus osteochondroma may be very much alike; however, to date, no study has explored their differences, especially in terms of anatomy and pathology. An os trigonum can be seen on MRI as fibrous, fibrocartilaginous, or cartilaginous tissue, connected or not to the talus[1]. As described in the present case, the osteochondroma was histopathologically classified as a mature mesenchymal neoplasm characterized by proliferation of trabecular bone covered with hyaline cartilage cap, with no evidence of malignancy.

The reported incidence of malignant transformation of solitary osteochondromas ranges from 1% to 2%[7]. There are no reports of malignant transformation of solitary osteochondromas of the talus. In the case reported by Kulkarni[8], because there was no evidence of increase in pain or local swelling,

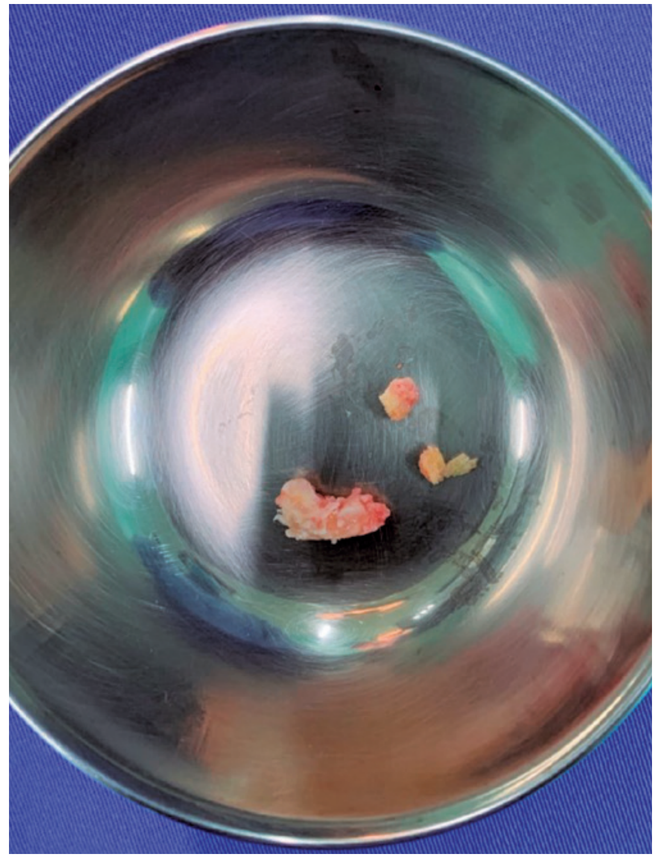


Figure 4. Bone specimens collected during endoscopy for histopathological examination.

Figure 5. Lateral radiograph of the ankle with no evidence of tumor recurrence.

skin changes, or malignancy on radiographs and MRI, total excision of the lesion was planned, requiring no previous biopsy. In the present report, following the same reasoning, total excision was planned for both diagnostic and therapeutic purposes.

Open surgery for the treatment of posterior ankle osteochondroma has been described in the literature(9). However, endoscopic approaches have gained popularity in recent decades due to advantages such as better visualization of anatomical structures, lower risk of complications, minimal postoperative pain, less dissection, and the possibility of earlier return to daily activities(5). In a series of 36 patients treated with hindfoot endoscopy for symptomatic os trigonum and osteophytes, VAS pain scores improved significantly from 7.2 to 1.3, although paresthesia in the sural nerve territory was reported in 2 cases(10). In the present report, pain relief was also significant, improving from 8/10 to 1/10 after the endoscopic approach, with no complications associated with the technique. Consistent with this finding, in another series of 16 posterior ankle endoscopic procedures performed at 32-month follow-up, all patients had good to excellent results in their postoperative quality of life(11).

Conclusion

Osteochondroma is a rare neoplastic condition in the talus, and even more uncommon in its posterior portion. Therefore, it should always be considered an etiological hypothesis of posterior ankle impingement syndrome.

Author's contributions: The author contributed individually and significantly to the development of this article: EASJ *(https://orcid.org/0000-0002-5054-874X) conceived and planned the activities that led to the study, wrote the article, participated in the review process, approved the final version. The author read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Giannini S, Buda R, Mosca M, Parma A, Di Caprio F. Posterior ankle impingement. Foot Ankle Int. 2013;34(3):459-65.
2. Murphey MD, Choi JJ, Kransdorf MJ, Flemming DJ, Gannon FH. Imaging of osteochondroma: variants and complications with radiologic-pathologic correlation. Radiographics. 2000;20(5):1407-34.
3. Kulkarni AG, Kulkarni GK. Paraarticular osteochondroma of talocalcaneal joint: a case report. Foot 2004;14:210–3.
4. Fuselier CO, Binning T, Kushner D, Kirchwehm WW, Rice JR, Hetherington V, et al. Solitary osteochondroma of the foot: an in-depth study with case reports. J Foot Surg. 1984;23(1):3-24.
5. van Dijk CN, Scholten PE, Krips R. A 2-portal endoscopic approach for diagnosis and treatment of posterior ankle pathology. Arthroscopy. 2000;16(8):871-6.
6. Atik OS, Sarikaya B, Kunat C, Muradi R, Ocaktan B, Topçu H. Osteochondroma of the talus. Eklem Hastalik Cerrahisi. 2010; 21(2):116-7.
7. Bottner F, Rodl R, Kordish I, Winklemann W, Gosheger G, Lindner N. Surgical treatment of symptomatic osteochondroma. A three-to eight-year follow-up study. J Bone Joint Surg Br. 2003;85(8):1161-5.
8. Kulkarni U, Kulkarni A. Posterior talus osteochondroma a rare location, treated by posterior ankle arthroscopy. Foot Ankle Surg. 2015;21(3):e51-4.
9. Song MH, Cheon JE, Moon KC, Lee DY, Choi IH. Secondary synovial osteochondromatosis of the ankle in a child. Pediatr Radiol. 2013; 43(12):1642-6.
10. Galla M, Lobenhoffer P. Technique and results of arthroscopic treatment of posterior ankle impingement. Foot Ankle Surg. 2011; 17(2):79-84.
11. Willits K, Sonneveld H, Amendola A, Giffin JR, Griffin S, Fowler PJ. Outcome of posterior ankle arthroscopy for hindfoot impingement. Arthroscopy. 2008;24(2):196-202.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1604

Systematic Review

A comparison of arthrodesis and arthroplasty for hemophilic arthropathy of the ankle: a systematic review

Rubens Américo Fontoura de Sousa Pinto[1], Mauro César Mattos Dinato[1], Caio Vinicius de Andrade Gouvea[1], Rodrigo Gonçalves Pagnano[1]

1. Department of Orthopedics, Rheumatology and Traumatology, Faculdade de Ciências Médicas, Universidade Estadual de Campinas - UNICAMP, Campinas, SP, Brazil.
2. Instituto Vita, São Paulo, SP, Brazil.

Abstract

Objective: To conduct a systematic review of the literature on surgical treatment for end-stage hemophilic arthropathy of the ankle joint, describing the results for arthroplasty and arthrodesis.

Methods: We conducted a systematic literature review according to Cochrane (Cochrane Handbook for Systematic Reviews of Interventions version 6.1, 2020) and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations. The primary outcome was clinical improvement in pain and function of the affected limb. Secondary outcomes included adverse effects and complications from the surgical procedures.

Results: After reviewing 514 studies, 10 were included for data extraction and qualitative analysis (180 patients: 100 arthroplasties and 117 arthrodeses).

Conclusions: Both methods showed low overall complication rates and effectively reduced pain and improved function, allowing a return to work, activities of daily living and, in some cases, sports. One procedure was not clearly better than the other: the choice must be based on the patient's characteristics and clinical judgment.

Level of Evidence III; Therapeutic Studies; Systematic Review of Level III Studies.

Keywords: Ankle; Arthrodesis; Arthropathy; Arthroplasty; Hemophilia.

Introduction

Hemophilic arthropathy (HA) occurs after multiple episodes of hemarthrosis. Its onset is during childhood[1] and its pathophysiology is characterized by progressive proteolytic cartilage degeneration and synovial hypertrophy, in addition to vascular damage to bones in joint regions and reduced joint space[2]. In advanced stages, it can lead to joint deformity, chronic pain, and range of motion loss in the involved joint, resulting in lower quality of life[3].

The ankle is one of the most affected joints in HA[1] and its treatment, especially in advanced cases, has given rise to much discussion[4]. When the ankle joint does not show major signs of degeneration, there are several surgical options for preserving the joint, including arthroscopic debridement, synovectomy, and supramalleolar osteotomies[3]. In more advanced cases of ankle arthropathy, non-joint-sparing procedures (arthrodesis and arthroplasty) are performed[3,5].

In arthrodesis, there is concern about functional limitations and potential overload in other lower limb joints after the procedure, as well as the risk of non-consolidation[6,7]. Total ankle arthroplasty, an alternative to arthrodesis, presents good functional results and pain relief while preserving joint mobility, which improves patient quality of life[7]. However, some studies on hip and knee replacement in patients with hemophilia have reported higher rates of aseptic loosening and deep infection.

Study performed at the Department of Orthopedics, Rheumatology and Traumatology, Faculdade de Ciências Médicas, Universidade Estadual de Campinas - UNICAMP, Campinas, SP, Brazil.

Correspondence: Rodrigo Gonçalves Pagnano. Rua Tessália Vieira de Camargo, 126 - Cidade Universitária Zeferino Vaz, Campinas - SP, Brazil. CEP: 13083-887. **E-mail:** rpagnano@unicamp.br. **Conflicts of Interest:** none. **Source of funding:** none. **Date received:** December 31, 2021. **Date accepted:** February 14, 2022. **Online:** April 30, 2022.

How to cite this article: Pinto RAFS, Dinato MCM, Gouvea CVA, Pagnano RG. A comparison of arthrodesis and arthroplasty for hemophilic arthropathy of the ankle: a systematic review. J Foot Ankle. 2022;16(1):89-95.

The aim of the present study was to conduct a systematic review of the literature on the surgical treatment of terminal HA of the ankle, comparing the results of arthroplasty and arthrodesis.

Methods

We conducted a systematic review of the literature according to Cochrane (*Cochrane Handbook for Systematic Reviews of Interventions*, version 6.1, 2020) and PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) recommendations.

The PICO methodology was used to define the review's clinical question and search for evidence, with "P" representing the population included in the studies (hemophilic patients with ankle joint disorders), "I" representing the intervention to be investigated (arthroplasty), "C" representing comparison with standard treatment (arthrodesis), and "O" representing the investigated outcome (conclusions about the intervention and pain, function, and complication outcomes), is arthroplasty better than arthrodesis in patients with hemophilia? Are ankle arthroplasty outcomes comparable to those of ankle arthrodesis in patients with hemophilia? Table 1 shows how the PICO methodology was used in the present review.

Randomized and non-randomized clinical trials were included in this review, in addition to controlled observational studies and case series, without restrictions on year of publication or language. The population of interest included hemophilia patients with joint disorders (hemophilic arthropathy), without age or sex restrictions. Participants could either have been undergoing regular treatment for their underlying disease or not. The included intervention types were arthroplasty or arthrodesis to treat ankle arthropathy. Comparative groups could include no intervention (previous patient status), previous surgical approaches, or arthrodesis in studies assessing arthroplasty and vice versa.

The condition or domain under investigation was the presence of HA and joint disorders in patients with hemophilia. The following article types were excluded: animal and in vitro studies, literature reviews, case reports, duplicate articles, studies that did not assess arthroplasty or arthrodesis to treat hemophilic arthropathy, and articles not published in full.

Table 1. Structured research construction strategy through the PICO strategy

Acronym	Component	Description
P	Population	Patients with hemophilic arthropathy of the ankle
I	Intervention	Arthroplasty
C	Comparison	Arthrodesis
O	Outcome	Clinical outcomes (pain, function, and complications)

Source: The authors.

Primary outcomes included clinical improvement in pain and function of the affected limb. Clinical evaluation included patient satisfaction and results based on specific criteria and questionnaires: the Visual Analog Pain Scale, the American Orthopedic Foot and Ankle Society (AOFAS), Ankle and Hindfoot Score, and the 36-item Short Form Health Survey (SF-36). Secondary outcomes included adverse outcomes and surgical complications.

The studies were identified through systematic searches of electronic databases and search portals, as well as the reference lists of articles. The searches were conducted in the following including eight databases: PubMed (September 1, 2021 to September 9, 2021), PubMed Central (September 9, 2021), VHL/BIREME (September 9, 2021), EBSCOHost (September 9, 2021), Scopus (September 9, 2021), Web of Science (September 9, 2021), EMBASE (September 1, 2021 to September 9, 2021), the Cochrane Library (September 9, 2021), and PROQUEST (until April 2020; conducted on September 9, 2021).

The search strategy involved the following keywords (medical subject headings and free terms): ("Hemophilia A" OR "Hemophilia B") AND (("Joint Diseases" AND Ankle) OR "Ankle Joint") AND ("Arthroplasty, Replacement, Ankle" AND Arthrodesis)).

A total of 514 articles were retrieved, which were exported to the Rayyan reference management program, with titles, abstracts, references and the database of origin. Duplicate studies were automatically removed by the program (280 articles), resulting in a total of 234 articles for analysis and study selection according to the eligibility assessment. In the initial step of the study selection process, the titles and abstracts were independently evaluated by two reviewers (RAFSP and RGP). The full text of each study considered relevant was retrieved and fully reviewed independently by two reviewers (RAFSP and RGP). Each reviewer created a list of studies that met pre-established inclusion and exclusion criteria. The lists were compared, and disagreements were resolved by discussion and consensus.

One author extracted and analyzed the data from the articles, evaluating their eligibility and comparing the results. Information was collected on each study (title, authors, journal name, year of publication, volume, and study type), the participants (total number, age, sex, body mass index, clotting disorder, high titer inhibitor, prophylaxis, hemophilia severity, comorbidities, pain assessment, function, inclusion and exclusion criteria, allocation procedure, blinding, and the number of randomized participants), the interventions (description of the intervention, the methods, other concurrent treatments, and follow-up duration), and outcome measures (description of the measurements, including pain level and quality of life through validated scales).

The risk of bias was assessed by both reviewers, who evaluated adequate randomization (allocation sequence generation), guaranteed allocation concealment, the blinding methods (participants, research team, outcome evaluators), intention-to-treat analysis, follow-up losses, as well as other sources of bias, such as early discontinuation of the study. Disagreements among the authors were resolved by consensus.

Results

A total of 10 studies were included in this systematic review. Barg et al.[8] was prospective, while all the others were retrospective. All of the studies evaluated the results of arthroplasty or arthrodesis in the ankle joint of patients with hemophilia; only Ahn et al.[4] compared the two procedures in the same study.

The 10 articles included a total of 180 patients (100 arthroplasties and 117 arthrodesis), and the same patient may have undergone more than one procedure in a study, since ankle HA can occur bilaterally. The mean patient age at the time of surgery was reported, and in 9 of the 10 studies it was >39 years; the study in which it was lower was aimed at children and adolescents[9].

The mean follow-up length was reported in all articles (Table 2)[4,6,8,10-16], being 5.7 and 9.3 years in arthroplasty and arthrodesis studies, respectively.

In all of the studies, the patients underwent replacement and strict regulation of clotting factors throughout the perioperative period, being jointly followed up with the hematology teams of the respective centers.

Although the surgical procedures were indicated according to different criteria, pain was the main symptom. Degenerative changes in the ankle joint were evaluated in different ways: range of motion, functional scores, and radiographic alterations.

The main methods for radiographic evaluation of HA were the Pettersson score[17], which was used in 4 studies, and the Kellgren-Lawrence scale[18], which was used in 2 studies.

Generally speaking, the surgeries were performed using a tourniquet, and antibiotic prophylaxis with first-generation cephalosporins was also performed, in addition to joint follow-up with a hematology team and strict control of clotting factors. The selected articles were then discussed according to surgical procedure: arthroplasty or arthrodesis.

Of the 10 selected studies, 6 involved arthroplasty procedures, the results of which are described in Table 3[4,8,10-13], and 5 involved arthrodesis, the results of which are described in table 4[4,6,14-16].

Although the included studies used different methods to evaluate the functional results of the procedures, the main results evaluated were: pain assessment, functional capacity, and quality of life (Table 5)[4,6,8,10-16].

Seven of the studies assessed pain with the Visual Analogue Scale, and in all studies that used this criterion, improvement was found after the procedures. The mean overall Visual Analogue Scale score was 7.14 before the intervention. Ahn et al.[4] had the the lowest reported value before the procedure (5.5) and Preis et al.[12] had the highest (8.5). When comparing the two interventions, the mean score decrease was 7.35 to 1.34 for arthroplasties and 5.75 to 1.28 for arthrodesis.

Six of the 10 studies used the AOFAS score to assess patient functional capacity. Three of these, whose object was arthroplasty[11,12,14], showed significant improvement in AOFAS scores, with pre-and post-intervention means of 30.9 and 78.4, respectively, which indicates significantly lower ankle pain in these cases. However, among arthrodesis studies, only Wang et al.[16] found significant improvement in AOFAS scores, which increased from 37.9 to 81.4. Among arthrodesis studies, the mean AOFAS score increased from 29.9 to 80.95.

Patient quality of life was assessed with the SF-36 in 4 of the 10 studies. Among arthroplasty studies, statistically important results were found in Barg et al.[8] and Preis et al.[12], with mean increases from 34.25 to 80.25 and 54.15 to 80.85 in physical and mental assessment values, respectively. Wang et al.[16], another arthrodesis study, found mean increases from 10 to 82.9 and 59.2 to 72 in physical and mental assessment values, respectively ($p<0.05$).

The complications observed in the 10 studies are described in Table 6[4,6,8,10-16].

Table 2. Number of procedures, mean age when they were performed, and mean follow-up period

Authors/data	Technique	Sample	Age	Follow-up
Barg et al.[8]	Arthroplasty	10 procedures in 8 patients	43.3 years	5.6 years
Strauss et al.[10]	Arthroplasty	11 procedures in 10 patients	49 years	3 years
Asencio et al.[11]	Arthroplasty	32 procedures in 21 patients	43.6 years	4.4 years
Preis et al.[12]	Arthroplasty	14 procedures in 14 patients	51.4 years	5.8 years
Eckers et al.[13]	Arthroplasty	17 procedures in 14 patients	43 years	9.6 years
Bluth et al.[6]	Arthrodesis	57 procedures in 45 patients	56.7 years	6.6 years
Eichler et al.[14]	Arthrodesis	11 procedures in 8 patients	39 years	8 years
de l'Escalopier et al.[15]	Arthrodesis	22 procedures in 17 patients	15.5 years	19.7 years
Wang et al.[16]	Arthrodesis	14 patients	40.7 years	3 years
Ahn et al.[4]	Both	29 patients, (16 arthroplasty and 13 arthrodesis)	44.1 years	6.8 years

Source: Data collected by the authors.

Discussion

We conducted a systematic review on the two main surgical procedures for advanced HA of the ankle. After the selection process, 10 articles were analyzed, totaling 180 patients who underwent 217 procedures (100 arthroplasties and 117 arthrodeses).

Only Ahn et al.[4] compared the results of arthroplasty and arthrodesis in patients with hemophilia. The included studies were mostly retrospective or case series without comparison or control groups, which demonstrates the need for studies with higher levels of evidence on the subject.

The mean patient age was 42.6 years at the time of the procedure, although it was >60 years in Kim et al.[19], which could indicate that these patients were operated on earlier, probably due to the clinical course of HA, in which recurrent hemarthrosis attacks the ankle joint beginning in childhood and adolescence[1,3].

Table 3. Results of articles in the arthroplasty category

Author/data	Sample	Results
Barg et al.[8]	10 procedures in 8 patients	Non-constrained prostheses were performed, with Achilles tendon stretching necessary in 5 cases. There were no cases of loosening or revision, and arthrofibrosis occurred in only 1 case. The patients reported physical and mental improvements. The procedure was safe and had high success rates, allowing a return to work and sports activities.
Strauss et al.[10]	11 procedures in 10 patients	There were two cases of prosthesis infection. In 8 patients, the mean AOFAS score increased from 21.5 to 68. On the pain scale, the score decreased from 7.6 to 1.9. Among patients without complications, satisfaction was high, making it a reliable option for patients with osteoarthritis due to hemophilia.
Asencio et al.[11]	32 procedures in 21 patients	The mean AOFAS score increased from 40.2 to 85.3, functional scores increased from 23.6 to 35.9, and dorsiflexion scores increased from 0.8 to 10.38. Two patients underwent subsequent arthrodesis. The components were stable upon radiographic examination. There were 2 cases each of perioperative and orthopedic complications. Limiting pain was reported by 18 patients before surgery and 0 after surgery.
Preis et al.[12]	14 procedures in 14 patients	There were 4 complications, pain reduction (8.5 to 1.3), and functional improvement. The patients' physical and mental conditions improved.
Eckers et al.[13]	17 procedures in 14 patients	Implant survival was 95% at 10 years and 70% at 15 years. Patient satisfaction was 76%, the mean pain scale score was 2, and range of motion increased. The mean AOFAS score was 81 points and there were 10 complications.
Ahn et al.[4]	16 patients	Pain scores improved for all patients, and the total range of motion increased from 30.8º to 37.3º at the final follow-up. Three cases of osteolysis and 1 case of heterotopic ossification occurred.

Table 4. Results of articles in the arthrodesis category

Author/data	Sample	Results
Bluth et al.[6]	57 procedures in 45 patients	A total of 33 isolated tibiotalar, 15 tibiotalar and subtalar, and 9 isolated subtalar arthrodeses were performed. Nonunion occurred in 10.4% of tibiotalar procedures and 8.3% of subtalar procedures; new surgical techniques helped reduce these percentages. Pain was eliminated in 75% of the cases; 25% reported moderate pain. The procedure was effective and patient functional capacity improved considerably.
Eichler et al.[14]	11 procedures in 8 patients	All arthrodesis were tibiotalar. Mean AOFAS scores increased from 28 to 69. Fusion was achieved in all 11 ankles after an average of 3.5 months.
de l'Escalopier et al.[15]	22 procedures in 17 patients	Tibiotalar arthrodesis was performed in children and adolescents (mean age 15.5 years). Mean follow-up was 19.7 years, with 86% of the results considered good or excellent.
Wang et al.[16]	14 patients	Bone fusion occurred in all cases after a median of 12.9 weeks. Two cases of superficial infection and 1 case of subtalar arthritis occurred. AOFAS and VAS scores increased, as did physical and mental components. All patients reported satisfaction.
Ahn et al.[4]	13 patients	Good union and significant pain improvement occurred in all cases. There was 1 case each of synthesis material breakdown and worsening talonavicular degeneration.
Ahn et al.[4]	16 patients	Pain scores improved for all patients, and the total range of motion increased from 30.8º to 37.3º at the final follow-up. Three cases of osteolysis and 1 case of heterotopic ossification occurred.

In all analyzed articles, follow-up was performed jointly with the hematology team, with careful control of the patients' clotting factors. The articles also mentioned intraoperative procedures to control bleeding (eg, tourniquets were used in all 10 articles). There was also consensus about the use of first--generation cephalosporins for antibiotic prophylaxis, which could be continued for 24 to 48 hours after the procedure.

Regarding functional results, both arthrodesis and arthroplasty had favorable outcomes, especially for pain control. The most common scale used to measure this variable was the Visual Analog Pain Scale, and the mean scores for arthroplasty decreased from 7.35 preoperatively to 1.34 at the end of the follow-up, while for arthrodesis they decreased from 5.75 to 1.28, similar to the results of patients without hemophelia[19,20].

Table 5. Comparison of study outcomes

Study	Technique	VAS		AOFAS		SF-36			
						Before		After	
		Before	After	Before	After	Physical	Mental	Physical	Mental
Barg et al.[8]	Arthroplasty	7.1	0.8	38	81	30.4	56.9	83.4	82.8
Strauss et al.[10]	Arthroplasty	7.6	1.9	21.5	68	-	-	-	-
Asencio et al.[11]	Arthroplasty	-	-	40.2	85.3	-	-	-	-
Preis et al.[12]	Arthroplasty	8.5	1.3	23.9	76.6	38.1	51.4	77.7	78.9
Eckers et al.[13]	Arthroplasty	-	1.9	-	81	-	-	47	57
Bluth et al.[6]	Arthrodesis	-	0.75	-	90.4	-	-	-	-
Eichler et al.[14]	Arthrodesis	-	-	22	69	-	-	-	-
de l'Escalopier et al.[15]	Arthrodesis	-	-	-	83	-	-	-	-
Wang et al.[16]	Arthrodesis	7.0	1.4	37.9	81.4	10	59.2	82.9	72
Ahn et al.[4]	Both	5.5	0.9	-	-				
	Arthroplasty	4.5	6.2						
	Arthrodesis	0.7	0.8						

Source: Data collected by the authors.
AOFAS: American Orthopedic Foot and Ankle Society - Ankle and Hindfoot Scale; SF-36: 36-item Short Form Health Survey; VAS: Visual Analog Scale

Table 6. Comparison of complications in the included studies

Authors/data	Technique	Sample	Complications
Barg et al.[8]	Arthroplasty	10 procedures in 8 patients	1 case of arthrofibrosis
Strauss et al.[10]	Arthroplasty	11 procedures in 10 patients	2 cases of early prosthetic infection
Asencio et al.[11]	Arthroplasty	32 procedures in 21 patients	2 cases of progressively worsening pain; 1 case of bleeding associated with anticoagulant use
Preis et al.[12]	Arthroplasty	14 procedures in 14 patients	1 case of medial malleolus fracture; 2 cases of delayed healing; 2 patients had painful arthrofibrosis
Eckers et al.[13]	Arthroplasty	17 procedures in 14 patients	1 case of lateral malleolus fracture; 1 case of medial malleolus fracture with medial plantar nerve injury; 1 case of hematoma; 1 case of stress fracture of the calcaneus and 1st metatarsal; 2 cases of lost range of motion; 3 cases of loosening of prosthetic components
Bluth et al.[6]	Arthrodesis	57 procedures in 45 patients	5 cases of synthesis material removal due to local pain; 3 cases of adjacent joint degeneration; 1 case of transtibial amputation due to osteomyelitis
Eichler et al.[14]	Arthrodesis	11 procedures in 8 patients	2 cases of adjacent joint degeneration
de l'Escalopier et al.[15]	Arthrodesis	22 procedures in 17 patients	2 cases of adjacent joint degeneration; 3 cases of synthesis material removal due to local pain
Wang et al.[16]	Arthrodesis	14 patients	1 case of adjacent joint degeneration; 2 cases of superficial infection of the external fixator pin path
Ahn et al.[4]	Both	16 arthroplasties	2 cases of intra-articular hematoma; 1 case of heterotopic ossification; 3 cases of osteolysis of the tibial component
		13 arthrodeses	1 case of degenerated adjacent joints; 1 case of breakage of the synthesis material

Other functional indicators also showed positive results, comparable to those reported in the literature. Zaid et al.[9] performed a systematic review on ankle arthroplasty, finding an increase in AOFAS scores from 40 to 80 points after the procedure, whereas in the present review, the mean AOFAS score increased from 30.9 to 78.4.

Regarding arthrodesis, the results of the present review are also similar to those of the literature for patients with advanced arthrosis of the ankle joint. Van den Heuvel et al.[20] performed a systematic review of different access routes for arthrodesis, observing a mean postoperative AOFAS score of 74.9, whereas that of the present review was 80.9.

Finally, low rates of postoperative complications were observed for both procedure types. In this review, a total of 47 complications were reported in 217 procedures (21.6%), and most were resolved with conservative (non-surgical) treatment. Only one case of transtibial amputation after osteomyelitis was reported[17].

The most common complication for arthroplasty was arthrofibrosis or lost range of motion associated or not with local pain (5 cases), the majority being treated with soft tissue repair[13,15]. Three cases of prosthesis component loosening and 2 cases of prosthesis infection were reported, which are the most feared complications of total ankle arthroplasty[20].

The most common complication of arthrodesis was the need to remove synthesis material due to local pain (8 cases), followed by adjacent joint degeneration (7 cases). Both complications are described in the literature, and adjacent joint degeneration is one of the main causes of pain in patients undergoing arthrodesis of the ankle joint[19,21].

Overall, surgery was required more often for arthrodesis complications than arthroplasty complications, which were treated more conservatively. One possible explanation for this would be the shorter mean follow-up time in the arthroplasty studies (5.7 vs 9.3 years). The arthroplasty study reporting the highest number of complications also had the longest mean follow-up time (9.6 years)[15].

One limitation of the included studies was that 9 out of 10 were observational retrospective analyses, which could involve selection and recall bias. However, this reflects the current lack of prospective studies on this subject with high evidence levels.

For advanced HA, total ankle arthroplasty is a viable treatment approach with favorable mid- and long-term clinical outcomes. Ten-year implant survival is similar to that of inflammatory diseases in the general population. Preserving ankle mobility can be an advantage in terms of patient comfort and adjacent joint disease. Although the clinical results are encouraging, follow-up radiographs show component loosening and periprosthetic radiolucency in most cases[16].

In cases of severe HA, more cases and data are available for ankle arthrodesis. The greater technical reproducibility and the consistency of good long-term results make ankle joint fusion surgery a viable treatment choice, especially due to the lack of consistent data about later complications of arthroplasty[4,7,13].

Conclusions

Total ankle arthroplasty and arthrodesis are currently indicated for HA of the ankle. In the studies included in this review, these procedures had low complication rates, were effective in reducing pain and increasing functional capacity, and allowed a return to daily work activities, resulting in a better quality of life for patients with hemophilia. It cannot be said that one procedure is better than the other; the choice must be based on the patient's characteristics and the professional's technical aptitude.

In addition, studies with larger samples and longer follow-up are needed to adequately assess the possible complications of these surgical procedures in the medium and long term, in addition to further prospective and controlled studies to compare the techniques.

Authors' contributions: Each author contributed individually and significantly to the development of this article: RAFSP *(https://orcid.org/0000-0002-7610-0724) Conceived and planned the activities that led to the study, performed the surgeries, data collection, approved the final version; MCMD *(https://orcid.org/0000-0001-6572-1771) Conceived and planned the activities that led to the study, performed the surgeries, data collection, approved the final version; CVAG *(https://orcid.org/0000-0002-4481-8301) Conceived and planned the activities that led to the study, performed the surgeries, data collection, approved the final version; RGP *(https://orcid.org/0000-0002-6064-2027) Conceived and planned the activities that led to the study, performed the surgeries, data collection, approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Shopnick RI, Brettler DB. Hemostasis: a practical review of conservative and operative care. Clin Orthop Relat Res. 1996(328):34-8.
2. Barg A, Morris SC, Schneider SW, Phisitkul P, Saltzman CL. Surgical procedures in patients with haemophilic arthropathy of the ankle. Haemophilia. 2016;22(3):e156-76.
3. Melchiorre D, Manetti M, Matucci-Cerinic M. Pathophysiology of Hemophilic Arthropathy. J Clin Med. 2017;6(7):63.
4. Ahn J, Yoo MC, Seo J, Park M, Jeong BO. Comparison of Total Ankle Arthroplasty and Ankle Arthrodesis in End-Stage Hemophilic Arthropathy. Foot Ankle Int. 2020;41(8):937-44.
5. Pasta G, Forsyth A, Merchan CR, Mortazavi SM, Silva M, Mulder K, et al. Orthopaedic management of haemophilia arthropathy of the ankle. Haemophilia. 2008;14 Suppl 3:170-6.
6. Bluth BE, Fong YJ, Houman JJ, Silva M, Luck JV Jr. Ankle fusion in patients with haemophilia. Haemophilia. 2013;19(3):432-7.
7. Sackstein P, Cooper P, Kessler C. The role of total ankle replacement in patients with haemophilia and end-stage ankle arthropathy: A review. Haemophilia. 2021;27(2):184-91.
8. Barg A, Elsner A, Hefti D, Hintermann B. Haemophilic arthropathy of the ankle treated by total ankle replacement: a case series. Haemophilia. 2010;16(4):647-55.
9. Zaidi R, Cro S, Gurusamy K, Siva N, Macgregor A, Henricson A, et al. The outcome of total ankle replacement: a systematic review and meta-analysis. Bone Joint J. 2013;95-b(11):1500-7.
10. Strauss AC, Goldmann G, Wessling M, Gravius S, Müller MC, Wimmer MD, et al. Total ankle replacement in patients with haemophilia and virus infections--a safe alternative to ankle arthrodesis? Haemophilia. 2014;20(5):702-8.
11. Asencio JG, Leonardi C, Biron-Andreani C, Schved JF. Short-term and mid-term outcome of total ankle replacement in haemophilic patients. Foot Ankle Surg. 2014;20(4):285-92.
12. Preis M, Bailey T, Jacxsens M, Barg A. Total ankle replacement in patients with haemophilic arthropathy: primary arthroplasty and conversion of painful ankle arthrodesis to arthroplasty. Haemophilia. 2017; 23(4):e301-9.
13. Eckers F, Bauer DE, Hingsammer A, Sutter R, Brand B, Viehöfer A, et al. Mid- to long-term results of total ankle replacement in patients with haemophilic arthropathy: A 10-year follow-up. Haemophilia. 2018;24(2):307-15.
14. Eichler D, Ehlinger M, D'Ambrosio A, Desprez D, Bierry G, Adam P, et al. Ankle fusion in hemophilic patients. Orthop Traumatol Surg Res. 2017;103(8):1205-9.
15. de l'Escalopier N, Badina A, Padovani JP, Harroche A, Frenzel L, Wicart P, et al. Long-term results of ankle arthrodesis in children and adolescents with haemophilia. Int Orthop. 2017;41(8):1579-84.
16. Wang S, Li Q, Zhang Z, Wang W, Li J, Liu L. Ankle arthrodesis for end-stage haemophilic ankle arthropathy using a Ilizarov method. Int Orthop. 2020;44(5): 995-1001.
17. Pettersson H, Ahlberg A, Nilsson IM. A radiologic classification of hemophilic arthropathy. Clin Orthop Relat Res. 1980;(149):153-9.
18. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis. 1957;16(4):494-502.
19. Kim HJ, Suh DH, Yang JH, Lee JW, Kim HJ, Ahn HS, et al. Total ankle arthroplasty versus ankle arthrodesis for the treatment of end-stage ankle arthritis: a metaanalysis of comparative studies. Int Orthop. 2017;41(1):101-9.
20. van den Heuvel SBM, Doorgakant A, Birnie MFN, Blundell CM, Schepers T. Open ankle arthrodesis: a systematic review of approaches and fixation methods. Foot Ankle Surg. 2021;27(3): 339-47.
21. Muir DC, Amendola A, Saltzman CL. Long-term outcome of ankle arthrodesis. Foot Ankle Clin. 2002;7(4):703-8.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1608

Technical Tips

One-stage correction of combined hindfoot, forefoot, and knee deformities: Joint preserving surgery

Ricardo Ummen de Almeida Tenório Villar[1], Talissa Oliveira Generoso[1], Fábio Correa Paiva Fonseca[2], Eduardo Araújo Pires[2], Luis Eduardo Passarelli Tirico[1,2], Alexandre Leme Godoy-Santos[1,2]

1. Hospital Israelita Albert Einstein, São Paulo, SP, Brazil.
2. Lab. Prof. Manlio Mario Marco Napoli, Hospital das Clínicas, Faculdade de Medicina, Universidade de São Paulo, SP, Brazil.

Abstract

Combined angular deformities of the knee and foot are challenging clinical presentations for the orthopedic surgeon. We describe a surgical technique used in a 58-year-old man diagnosed with genu varum associated with progressive collapsing foot deformity and severe hallux valgus. The surgical team and the patient decided to perform a one-stage correction of all deformities. The procedure included corrective osteotomies with bone grafting and soft tissue reconstruction. The varus knee, hindfoot valgus, and hallux valgus were properly corrected intraoperatively with the surgical techniques described here. Satisfactory functional outcomes and excellent maintenance of the realignment were achieved at short-term follow-up.

Level of Evidence V; Therapeutic Studies; Expert Opinion.

Keywords: Foot deformities; Joint dislocations; Forefoot; Genu varum; Knee joint.

Introduction

Angular deformities of lower limb joints, such as the knee and foot, are a common clinical presentation in orthopedic practice. When deformities are combined, they determine the alignment of the lower limb as a whole and may lead to compensatory deformities in other joints of the lower limb[(1)]. There is solid evidence of the functional outcomes of surgical correction of deformities alone. However, scientific data on surgical correction of severe combined deformities, such as varus knee associated with progressive collapsing foot deformity and hallux valgus, are scarce.

In this article, we present a one-stage surgical technique used in the treatment of combined angular deformities of the knee, hindfoot, and forefoot in a 58-year-old patient.

Clinical and radiological findings

A 58-year-old businessman and former motorcycle racer complained of chronic pain in the left lower limb, mainly in the knee and foot, associated with difficulties to move around daily. The patient reported a left knee sprain with ligament injury 20 years ago and a right femur fracture 8 years ago, treated with a locked intramedullary nail. Physical examination showed bilateral varus knee deformity, more severe on the left side, associated with pain in the medial joint line, anterior instability, asymmetric left hindfoot valgus, valgus deviation, and pronation of the left hallux. Inspection showed loss of the medial longitudinal arch of the left foot (Figure 1A-H). Weight-bearing radiographs of the knees, ankles, and feet as well as a panoramic radiograph of the lower limbs were obtained. Radiographic evaluation of the left lower limb revealed severe varus knee, hindfoot valgus, presence of accessory navicular bone, loss of adequate talonavicular joint coverage, severe hallux valgus deformity, a break in Meary's line, and decreased calcaneal pitch (Figure 2A-H). Magnetic resonance imaging (MRI) of the knee showed a chronic anterior cruciate ligament (ACL) injury, moderate medial compartment knee osteoarthritis, and a degenerative medial meniscal tear. MRI of the hindfoot showed posterior tibial tendon dysfunction and extensive partial spring ligament tear.

Study performed at the Hospital Israelita Albert Einstein, São Paulo, SP, Brazil.

Correspondence: Ricardo Ummen de Almeida Tenório Villar. Hospital Israelita Albert Einstein - Av. Albert Einstein, 627 - Jardim Leonor, 05652-900, São Paulo - SP, Brazil. **E-mail:** ricardovillar_@hotmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received**: February 8, 2022. **Date accepted:** March 4, 2022. **Online:** April 30, 2022

How to cite this article: Villar RUAT, Generoso TO, Fonseca FCP, Pires EA, Tirico LEP, Godoy-Santos AL. One-stage correction of combined hindfoot, forefoot, and knee deformities: Joint preserving surgery. J Foot Ankle. 2022;16(1):96-102

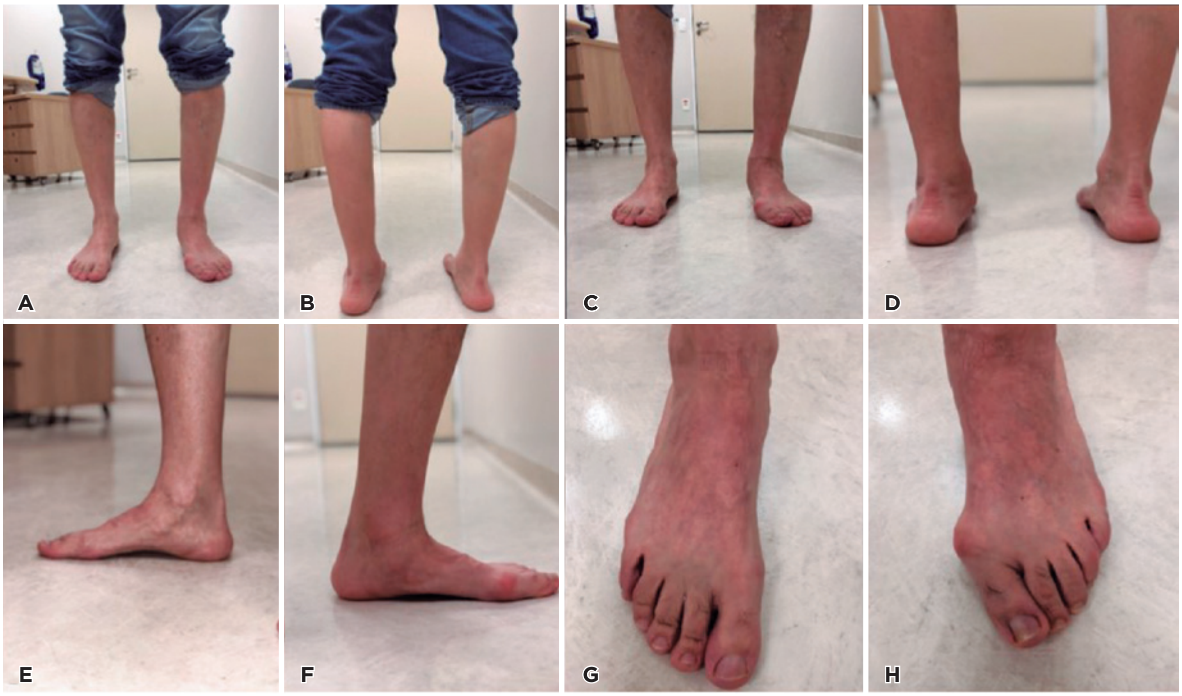


Figure 1. Clinical evaluation of a patient with bilateral genu varum, more severe on the left side, associated with hindfoot valgus, longitudinal arch collapse, and hallux valgus of the left foot.

Figure 2. Preoperative weight-bearing radiographs showing severe varus left knee, loss of adequate talonavicular joint coverage, severe hallux valgus, a break in Meary's line, and decreased left calcaneal pitch.

Technical tip

With the patient in the supine position under spinal anesthesia with a pneumatic tourniquet at the root of the limb, the knee joint was initially approached through an anteromedial incision at the level of the proximal medial tibia, and the gracilis and semitendinosus tendons were removed for ACL reconstruction. The 8-mm thickness grafts were prepared in a quadruple arrangement. After graft removal, anteromedial and anterolateral portals were created for the knee arthroscopy. The following injuries were found in the joint inventory: grade III chondral injury in the femoral trochlea and patellar apex, medial meniscal extrusion, and radial tear in the body of the medial meniscus, associated with a small flap in the meniscal body. These lesions were treated with debridement of the chondral injury in the femoral trochlea and partial medial meniscectomy. The femoral tunnel was created in anatomic position with an 8-mm FlipCutter (Arthrex®). Subsequently, biplane medial opening-wedge high tibial osteotomy was performed with the creation of a 12-mm opening wedge guided by radioscopy as planned preoperatively. The osteotomy was fixed with a Tomofix® plate with cortical locking screws. Iliac bone grafting was performed using tricortical grafts and a cancellous autologous bone graft. The tibial tunnel was then created with an 8-mm drill and the flexor tendon graft was advanced through it, fixed with an ACL TightRope (Arthrex®) in the femur and an interference screw (Arthrex®) in the tibia. The incisions were closed in layers.

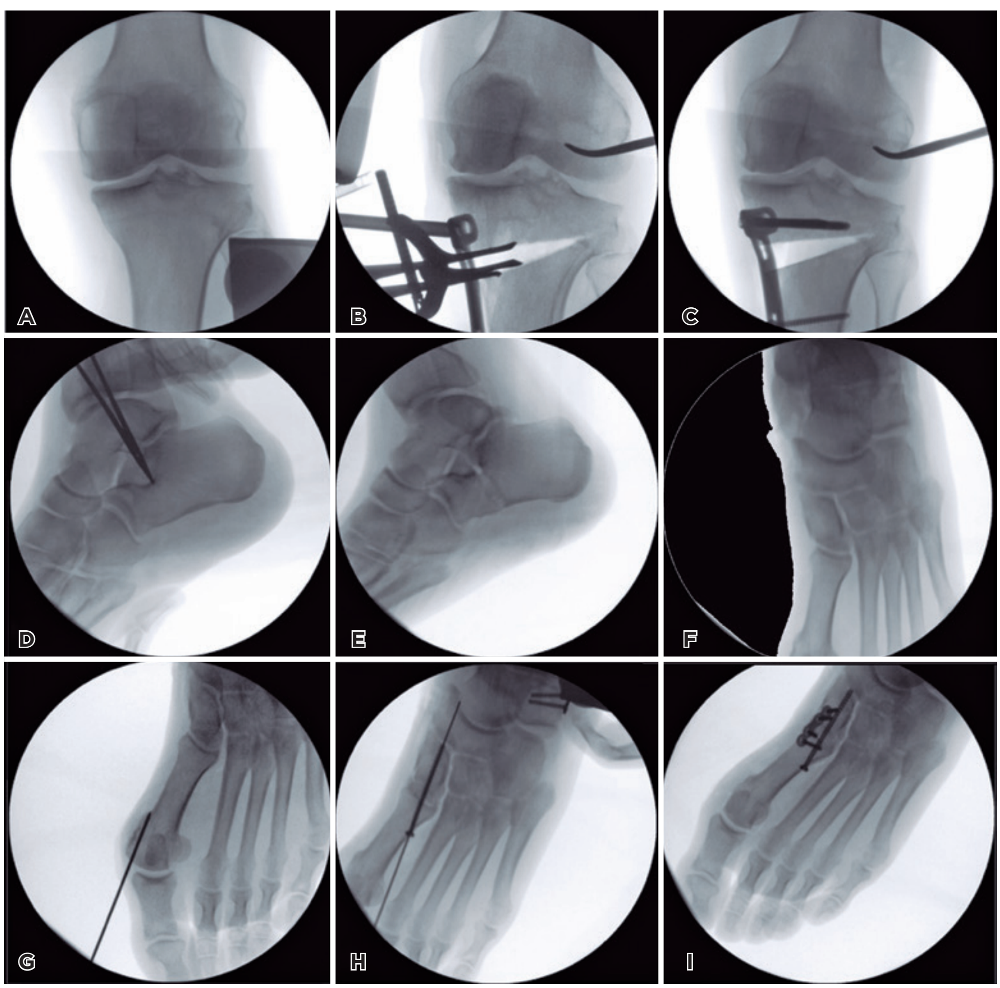


Figure 3. Intraoperative radioscopic images: A-C) Biplane medial opening-wedge high tibial osteotomy and fixation with a Tomofix® plate, with associated bone grafting. D-F) Lateral column lengthening following the technique described by Hintermann, showing adequate talonavicular joint coverage. The homologous bone graft is placed and fixed with an Aptus Foot locking plate (Medartis®). G-I) Approach to hallux valgus with bunionectomy and Lapicotton arthrodesis[2] using a bone bank graft and fixation with a 4-mm compression screw (Depuy-Synthes®) and an Aptus Foot dorsal locking plate (Medartis®).

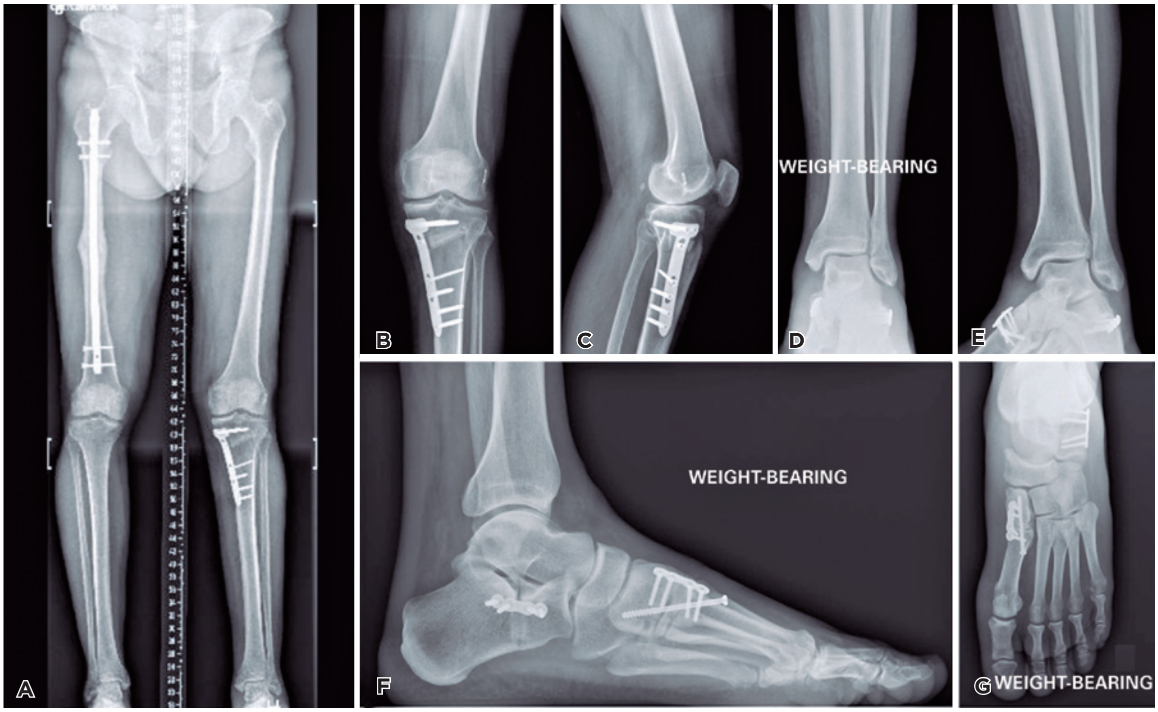


Figure 4. Postoperative weight-bearing radiographs showing successful correction of the mechanical axis of the left lower limb, with correction of the varus left knee and left ankle valgus, restoration of Meary's angle and left calcaneal pitch, and correction of the hallux valgus.

Figure 5. Postoperative CT scan. A-D) Proper correction of the posterior and medial subtalar joint and talonavicular joint congruence, and adequate talonavicular joint coverage. E-F) Union of the osteotomy of the anterior process of the calcaneus and the Lapicotton arthrodesis.

After 1 hour and 30 minutes, the knee deformities had been treated and the pneumatic tourniquet was deflated. After limb reperfusion, the tourniquet was reinflated. We then initiated the correction of flatfoot by lengthening the gastrocnemius fascia using the Strayer procedure. Subsequently, a medial incision was made along the posterior tibial tendon with resection of the accessory navicular bone, retensioning of the spring and deltoid ligaments, tenoplasty of the posterior tibial tendon with flexor digitorum longus tendon transfer, and reinsertion of this set into the navicular. A lateral hindfoot incision was made and lateral column lengthening was performed following the technique described by Hintermann. A spreader was used to open the osteotomy site, and adequate talonavicular joint coverage was observed with the aid of radioscopy. We then measured the size of the graft (7 mm) needed for apposition in the opening-wedge osteotomy. In this case, we used a bone bank graft and fixed the osteotomy with a locking plate using four 2.8 mm Aptus Foot screws (Medartis®). Finally, the forefoot deformity was approached through a medial incision at the hallux for bunionectomy and capsuloplasty. The correction of metatarsus primus varus and forefoot rotation was performed through a dorsal incision at the level of the first metatarsal-medial cuneiform joint, with joint decortication and Lapicotton arthrodesis as described by de Cesar Netto et al.[2] We used a bone bank graft and fixed the arthrodesis with a 4 mm compression screw (Depuy-Synthes®). A dorsal plate was locked with four 2.8 mm Aptus Foot screws (Medartis®) for neutralization (Figure 3A-I). The incisions were closed in layers. The pneumatic tourniquet was deflated after 1 hour and 40 minutes, and a soft-padded bandage was applied.

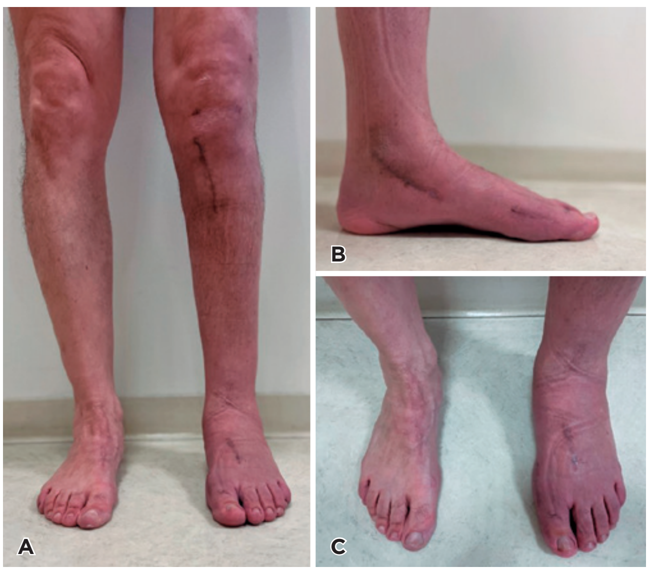


Figure 6. Postoperative clinical evaluation showing improved alignment of the left knee, ankle, and foot, with adequate surgical wound healing.

Postoperative protocol

Postoperative care included knee and foot immobilization in a flexible stance-control knee-ankle-foot orthosis and a rigid ankle-foot orthosis. The patient remained non-weight-bearing

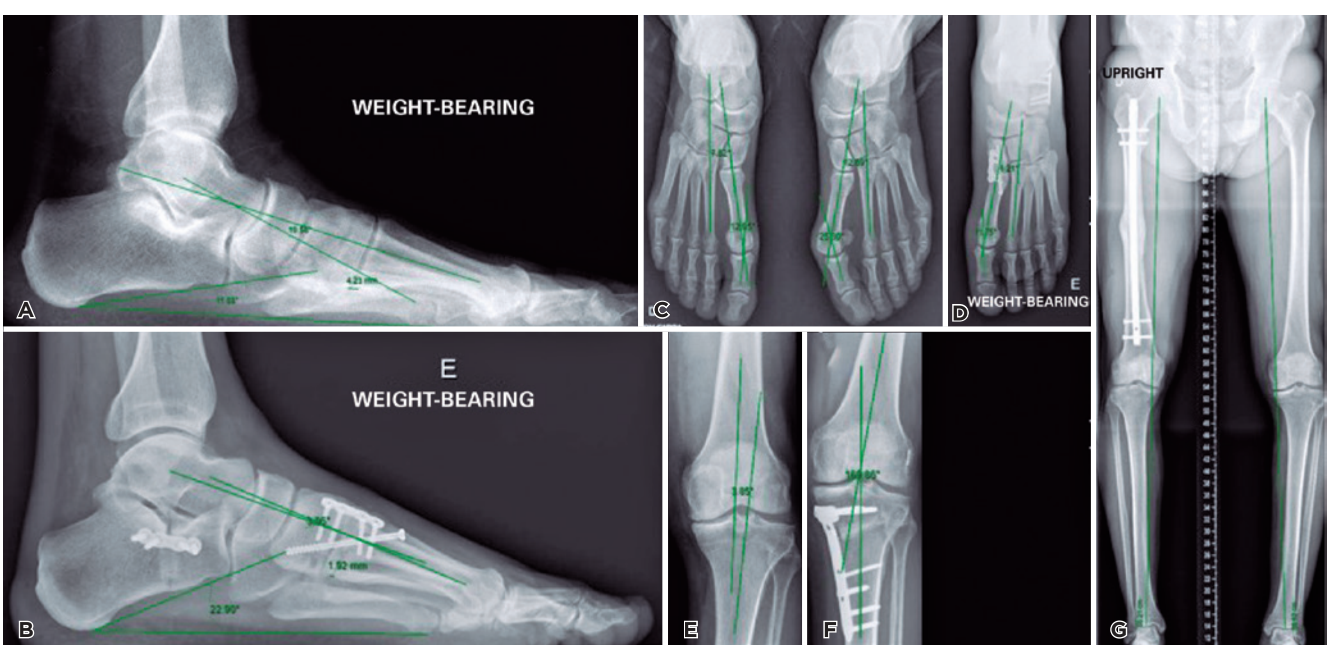


Figure 7. Preoperative and postoperative weight-bearing radiographic measurements.

for 4 weeks, with progressive partial weight-bearing with crutches from weeks 5 to 8. The protocol included encouragement of progressive return of the knee, ankle, and foot range of motion from the beginning of the postoperative course, with full range of motion of these joints being achieved after 8 weeks.

Clinical and radiographic evaluation

The evaluation of clinical and imaging outcomes was recorded at the 3-month follow-up visit.

The patient presented with excellent clinical alignment and no pain at the surgical wound sites (Figures 4-6).

Radiographic parameters showed normal angles with healing of the tibial and calcaneal osteotomies and the Lapicotton arthrodesis.

- Preoperative and postoperative ankle and hindfoot (Figure 7A-B)
  - Meary's angle: 10.58°/3.06°
  - Calcaneal inclination angle (calcaneal pitch): 11.88°/22.90°
  - Plantar gapping in the first tarsometatarsal joint: 4.23 mm/ 1.92 mm
- Preoperative and postoperative hallux valgus (Figure 7C-D)
  - Intermetatarsal angle (IMA): 12.69°/6.21°
  - Hallux valgus angle (HVA): 25.30°/11.75°
- Preoperative and postoperative knee (Figure 7E-F)
  - Anterior talofibular ligament (ATFL): 176.15°/169.86°

Discussion

The varus knee is a condition characterized by medial deviation of the mechanical axis of the lower limb from the center of the knee, resulting in an overload of the medial compartment, which is more prone to the development of degenerative changes. Studies indicate that knee misalignment significantly influences the ankle alignment, especially in patients with varus knee deformity, causing compensatory changes in ankle and hindfoot valgus, possibly accelerating the degenerative process of these joints[3-5].

For young patients with symptomatic degeneration of the medial compartment of the knee, valgus high tibial osteotomy is a validated surgical option aimed at laterally displacing the mechanical axis of the lower limb, transferring the load to the preserved lateral compartment, thus sparing the affected medial compartment, with improvements in knee pain and function[6], although it may also affect the ankle alignment[7].

Progressive collapsing foot deformity comprises a wide spectrum of tendon and ligament changes, especially of the posterior tibial tendon and spring ligament, which result in decreased plantar arch and associated ankle valgus[8,9]. It is a common condition affecting more than 10% of the population over 65 years of age. There is a broad spectrum of therapeutic approaches, from non-surgical treatment for milder cases, including changes in daily activities, physical therapy, and orthoses, to surgical treatment for more severe cases, with different techniques according to the underlying cause but often including medializing calcaneal osteotomy, lateral column lengthening, and spring ligament reconstruction[8].

Hallux valgus is also a common condition, affecting 2%-4% of the population, which has a multifactorial etiology and may be associated with flatfoot. It typically presents with valgus deviation, pronation of the hallux, and varus deviation of the first metatarsal and is a major reason for orthopedic medical consultation. Several bone and soft tissue procedures have been described for surgical treatment, according to the level of deformity.

Despite the high prevalence of these conditions alone, there is a lack of data on their simultaneous occurrence and therapeutic approaches for combined deformities. Questions could be raised about the optimal sequence to treat these deformities; whether all joint deformities should be treated surgically; the ability to redirect associated compensatory deformities after surgical correction of any of them; whether treatment should be performed in one or more surgical stages; and how different approaches may affect each other. Given the paucity of evidence and in the search for answers to these questions in order to find a safe and effective combined treatment option, we described here a surgical technique used in the simultaneous treatment of varus knee, ankle valgus, adult-acquired flatfoot, and hallux valgus in one patient treated at a tertiary care hospital in Brazil. The technique showed excellent results and can be a valuable alternative in specific cases.

Authors' contributions: Each author contributed individually and significantly to the velopment of this article: RUATV *(https://orcid.org/0000-0002-4563-5726) Conceived and planned the activities that led to the study, data collection, formatting of the article; TOG *(https://orcid.org/0000-0001-9277-7746) Conceived and planned the activities that led to the study, data collection, formatting of the article; FCPF *(https://orcid.org/0000-0002-8907-0472) Interpreted the results of the study, participated in the review process; EAP *(https://orcid.org/0000-0001-6008-8671) Interpreted the results of the study, participated in the review process; LEPT *(https://orcid.org/0000-0003-4067-319X) Performed the surgeries, approved the final version, participated in the review process; ALGS *(https://orcid.org/0000-0002-6672-1869) Performed the surgeries, approved the final version, participated in the review process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Lee OS, Lee SH, Lee YS. Does Coronal Knee and Ankle Alignment Affect Recurrence of the Varus Deformity after High Tibial Osteotomy? Knee Surg Relat Res. 2018;30(4):311–8.
2. de Cesar Netto C, Ahrenholz S, Iehl C, Vivtcharenko V, Schmidt E, Lee HY, et al. Lapicotton technique in the treatment of progressive collapsing foot deformity. J Foot Ankle. 2020; 14(3):301–8.
3. Gao F, Ma J, Sun W, Guo W, Li Z, Wang W. The influence of knee malalignment on the ankle alignment in varus and valgus gonarthrosis based on radiographic measurement. Eur J Radiol. 2016;85(1):228-32.
4. Xie K, Han X, Jiang X, Ai S, Dai K, Yu Z, et al. The effect of varus knee deformities on the ankle alignment in patients with knee osteoarthritis. J Orthop Surg Res. 2019;14(1):134.
5. Norton AA, Callaghan JJ, Amendola A, Phisitkul P, Wongsak S, Liu SS, et al. Correlation of knee and hindfoot deformities in advanced knee OA: compensatory hindfoot alignment and where it occurs. Clin Orthop Relat Res. 2015;473(1):166-74.
6. Kfuri M, Lobenhoffer P. High Tibial Osteotomy for the Correction of Varus Knee Deformity. J Knee Surg. 2017;30(5):409-20.
7. Takeuchi R, Saito T, Koshino T. Clinical results of a valgus high tibial osteotomy for the treatment of osteoarthritis of the knee and the ipsilateral ankle. Knee. 2008;15(3):196-200.
8. Henry JK, Shakked R, Ellis SJ. Adult-Acquired Flatfoot Deformity. Foot Ankle Orthop. 2019;4(1): 1-17.
9. Deland JT, de Asla RJ, Sung I-H, Ernberg LA, Potter HG. Posterior Tibial Tendon Insufficiency: Which Ligaments are Involved? Foot Ankle Int 2005;26(6):427–35.

DOI: https://doi.org/10.30795/jfootankle.2022.v16.1609

Technical Tips

Comminuted navicular fracture treated with an internal fixation plate – Technical Tip

Henrique Mansur[1,2], Landweherle de Lucena da Silva[2], Daniel Augusto Maranho[3]

1. Department of Orthopaedics Surgery, Hospital Santa Helena, Brasília, DF, Brazil.
2. Department of Orthopaedics Surgery Hospital Regional do Gama, Gama, DF, Brazil.
3. Department of Orthopaedics Surgery, Hospital Sírio-Libanês, Brasília, DF, Brazil.

Abstract

Fractures of the navicular are relatively uncommon lesions. Comminuted fractures of the navicular body may be associated with focal bone collapse and loss of integrity of the medial column of the midfoot with gross instability, leading to deformities and potential early osteoarthritis. The treatment is challenging due to the difficulties to maintain the length and stability of the midfoot medial column and restoring the anatomy without damaging the vascular supply. Here we present an option for the surgical treatment of comminuted fractures of the navicular using a low-profile locking plate with the "bridge" principle as a temporary internal fixator. The technique consists of restoring the navicular anatomy by fixing the larger fragments with screws and applying indirect reduction of minor fragments. The bone length is maintained by a bridge-plating system with screws inserted into the talus and the medial cuneiform, crossing the talonavicular and naviculocuneiform joints. Implants are removed after fracture healing.

Level of Evidence V; Therapeutic Study; Expert Opinion.

Keywords: Tarsal bones; Fractures, bone; Foot injuries; Diagnostic techniques, surgical.

Introduction

Fractures of the navicular are relatively uncommon lesions resulting from acute injuries or chronic overloading[1]. The talus and the midfoot cuneiform bones compress the navicular with a combination of forces that may result in transverse fractures towards the plantar navicular aspect and superior displacement of the dorsal fragment[2]. The fractures of the navicular body with comminution or joint displacement may be associated with bone collapse and/or loss of integrity of the medial midfoot column. Moreover, they are frequently associated with gross instability, progressing to potentially severe deformities with flattening of the midfoot arch[1,3]. Even following adequate treatment, patients may experience chronic pain, disability, early osteoarthritis, and loss of quality of life[1-5].

Surgical treatment is recommended for the displaced and comminuted fractures of the navicular to restore the articular surface, the length of the medial column, and the anatomical relationship between the hindfoot and the forefoot[1-5]. The decision-making criteria include articular displacement >2 mm, shortening of the medial column >3 mm, subluxation or dislocation, open fracture, compartment syndrome, and risk of skin lesion due to an overlying bone fragment[1,5,6]. Simple and noncomminuted displaced fractures may be treated with open or closed reduction followed by fixation with isolated screws or plate and screw systems. However, comminuted fractures are challenging, requiring additional stability to maintain the length of the medial column, including external or internal fixation, Kirschner wires, and, in some cases, bone grafting[1,2,5]. As these lesions are uncommon, the literature reporting treatment details is relatively scarce.

This study aims to present an option for the surgical treatment of comminuted fractures of the navicular based on the use of a low-profile locking plate with the "bridge" principle as a temporary internal fixator. The technique consists of (1) restoring the navicular morphology by open reduction, (2) fixing the larger articular fragments with lag screws, and (3) positioning a plate that crosses the talonavicular and naviculocuneiform joints, with proximal screws inserted into the talus and distal screws into the medial cuneiform.

Study performed at the Hospital Santa Helena, Brasilia, DF, Brazil.

Correspondence: Henrique Mansur. SMHN Quadra 2 - Centro Clínico Cléo Octávio - Asa Norte, 70710-146, Brasília, DF, Brazil. **E-mail:** drhenriquemansur@gmail.com.
Conflicts of Interest: none. **Source of funding:** none. **Date received:** February 08, 2022. **Date accepted:** March 23, 2022. **Online:** April 30, 2022.

How to cite this article: Mansur H, Silva LL, Maranho DA. Comminuted navicular fracture treated with an internal fixator plate – Technical Tip. J Foot Ankle. 2022;16(1):103-7.

Case presentation

The technique is indicated for comminuted and displaced fractures of the navicular body (type 3 in the classification of Sangeorzan et al.[7]) with subluxation of the dorsal fragment of the navicular or comminution of the plantar fragment resulting in loss of integrity of the medial column.

To illustrate the technique, we describe a case of a patient who had a motorcycle fall injury and sustained a comminuted and displaced fracture of the navicular. The dorsomedial fragment was displaced dorsally, with impaction of the dorsomedial articular surface of the talonavicular joint. The plantar-lateral fragment of the navicular was displaced with shortening of the medial column of the midfoot (Figures 1 and 2). The surgical strategy was to reduce major fragments through a direct dorsomedial approach, restoring articular talonavicular and naviculocuneiform surfaces with interfragmentary compression screws. Subsequently, a dorsal bridge plate crossing the navicular fracture was inserted to maintain the length of the medial column and indirectly reduce the comminuted fragments (Figures 3 and 4).

Surgical technique

1. The surgical procedure was performed with the patient in the supine position under spinal anesthesia in combination with peripheral sciatic and popliteal nerve block;

2. A pneumatic tourniquet was positioned proximally at the thigh and inflated to the pressure of 300 mm Hg (after Esmarch exsanguination);

3. A direct dorsomedial straight incision of 8 cm was performed from the talus neck to the medial cuneiform;

Figure 1. Initial radiographs of the foot and the ankle showing comminuted and displaced fracture of the navicular.

4. The anterior tibial tendon was identified and retracted medially, while the extensor hallucis longus tendon was retracted laterally (Figure 3A);

5. The articular capsules were partially disrupted, and their dorsal aspect was sectioned to widely expose the talonavicular and naviculocuneiform joints (Figure 3B);

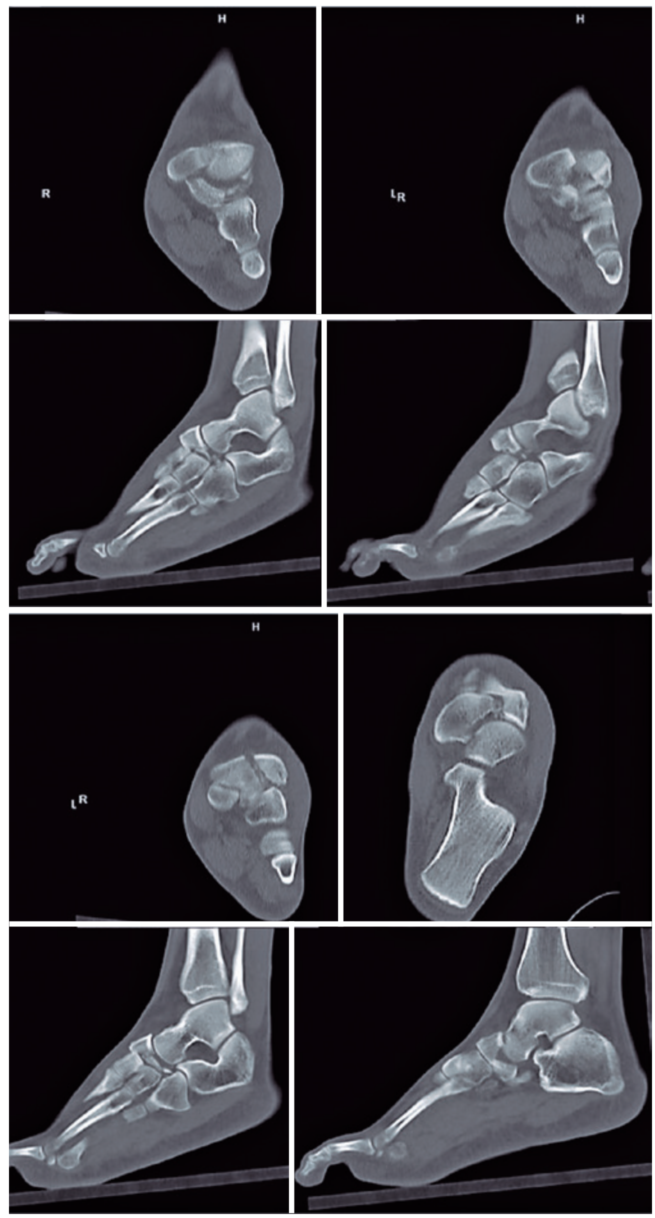


Figure 2. Computed tomography scans on the coronal, axial, and sagittal views showing the dorsomedial fragment displaced dorsally, with impaction of the dorsomedial articular surface of the talonavicular joint, and the plantar-lateral fragment comminuted and displaced, with shortening of the medial column of the midfoot.

6. The fracture of the navicular was noted with the presence of two major fragments, one dorsomedial, and the anatomical reduction of the articular surfaces. Such fragments were fixed with two 3.0 mm HCS™ lag screws (DePuy Synthes, J&J Company, USA) (Figure 3C);

7. Appropriate length of the medial column of the foot was restored and confirmed by radioscopy, and a 2.7-mm low-profile locking plate (Medartis AG, Switzerland) was positioned at the dorsal aspect of the midfoot. Then, 2.7-mm locking screws were inserted proximally into the talus head and distally into the medial cuneiform, sparing the navicular and maintaining the anatomy of the medial longitudinal arch (Figure 3D);

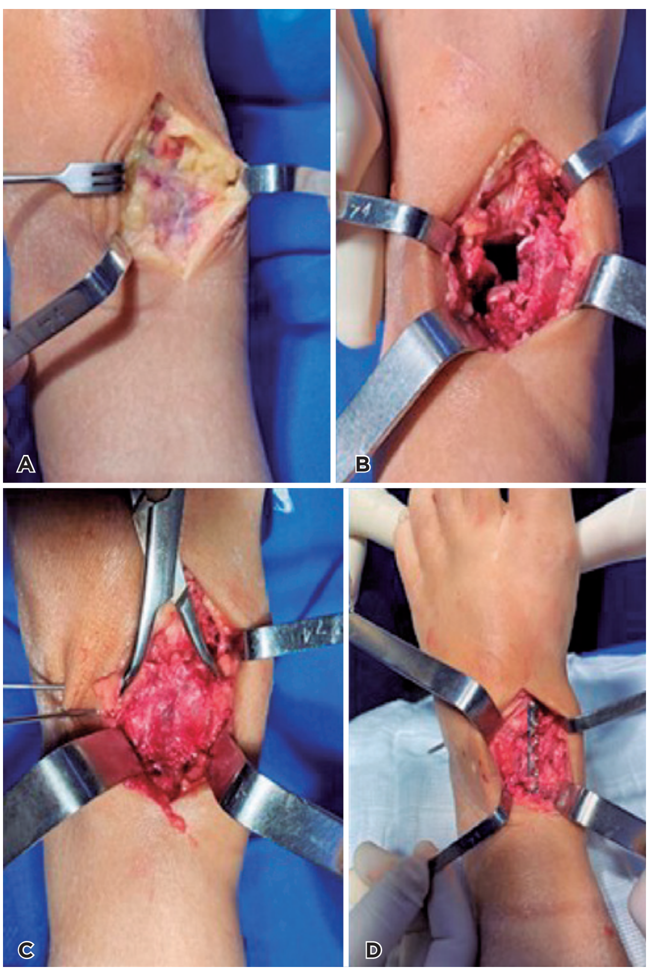


Figure 3. A) Dorsomedial incision from the talus neck to the medial cuneiform, with retraction of the anterior tibial and extensor hallucis longus tendons. B) Intraoperative image of the fracture of the navicular with the presence of two major fragments, one dorsomedial and the other plantar-lateral, and naviculocuneiform joint luxation. C) Reduction of the main articular fragments. D) Positioning of the bridge plate at the dorsal aspect of the midfoot after screw fixation of the main fragments.

Figure 4. Postoperative radiographs with navicular fracture reduction and restoration of the talonavicular and naviculocuneiform joint congruence and medial column length.

Figure 5. Radiographic views of the foot 10 months following the injury, 6 months after plate removal.

Figure 6. Clinical aspect of the feet and ankle 10 months following the initial trauma and surgery.

8. After the correct positioning of the implants and the reduction of the fracture and joints were confirmed with radioscopy, the wound was irrigated with 0.9% saline and sutured with 2.0 absorbable sutures subcutaneously and 4.0 mononylon sutures on the skin;

9. An occlusive dressing was applied with sterile gauze protecting the surgical incision. The pneumatic tourniquet was released with consequent restoration of normal peripheral perfusion.

10. The limb was immobilized with a removable ankle/foot orthopedic orthosis for 3 weeks, when the suture was removed.

During the first 6 weeks, we recommended avoiding bearing weight on the affected foot, allowing only toe-touch weight-bearing. Stiffness of the talonavicular joint is expected while the bridge plate is present. After week 6, the patient was recommended to progressively bear weight with the orthosis until week 9, when the orthosis was discontinued. At week 16, we confirmed by clinical and radiographic evaluation the presence of fracture healing (Figure 4), preservation of the medial longitudinal arch and joint congruence, and maintenance of the length of the medial column of the foot. At that moment, the patient underwent a second surgical procedure, and the bridge plate was removed. Ten months following the fracture, new radiographs showed a healed navicular fracture with joint congruence and without avascular necrosis. The patient presented with a range of motion similar to the contralateral side, had no complaints of pain, and had resumed sports activities (Figures 5 and 6).

Discussion

Fractures of the tarsal navicular bone are uncommon. Only 5% of foot fractures affect the midfoot, and 35% of those affect the navicular(5). The most serious fractures may progress with midfoot collapse and/or early osteoarthritis, causing important functional limitations(1,5,6,8).

In 1989, Sangeorzan et al.(7) classified fractures of the navicular body into (1) fractures with coronal line without angulation, with dorsal or tuberosity avulsion; (2) body fractures with dorsolateral to plantar-medial line with loss of the medial arch (most common type); and (3) navicular body fractures with central or lateral comminution. The classification system was based on the direction of the fracture line, the direction of displacement of the foot, and the pattern of disruption of the surrounding joints, and was intended to assist in the surgical treatment of fractures(1,7). Type 3 fractures are challenging injuries because a large amount of energy usually promotes joint fragmentation and displacement. The treatment aims to restore the medial longitudinal arch and the anatomical relationship between the hindfoot and the forefoot, promoting stability of the midfoot(1). In this injury pattern with small-sized comminuted fragments, conventional fixation techniques may not be feasible or sufficiently stable(1,3,5,9). Kirschner wires may not provide sufficient stability to maintain the length and shape of the medial midfoot arch, and plate and screw systems may cause excessive vascular damage(9-11). Furthermore, late complications and poor outcomes have been associated with comminuted navicular fractures, including avascular necrosis, delayed union, osteoarthritis, joint stiffness, and chronic pain, especially when the medial column is not restored(3,10,11). Therefore, some authors recommend the association of an external fixator with primary osteosynthesis or primary arthrodesis as a salvage procedure(1,5,12).

For comminuted fracture patterns, surgical attempts to obtain optimal open anatomical reduction and compression fixation may be counterproductive if the vascular bone supply is not respected and when multiple small fragments are present. Important fundaments are to carefully plan surgical approaches, use indirect reduction techniques when possible, and consider biologic fixation(6). For example, in a series(11) of 10 types 2 and 3 navicular fractures treated with a navicular locking plate, the authors reported the presence of healed fractures in all patients and overall good functional outcomes of the feet after 20 months of follow-up. However, one patient had a compartment syndrome requiring fasciotomy, and another developed partial necrosis of the navicular(11).

Bridge plating has been used more recently in traumatic foot injuries, mainly in severe and comminuted fractures associated with subluxation and bone shortening or impaction. Biomechanical cadaveric studies(13) and case series studies(14) have suggested that outcomes following surgical Lisfranc joint injuries might be superior when fixed with dorsal bridge plating compared with screw fixation only. A previous study(10) reported the outcomes of 7 patients with comminuted and displaced type 3 fractures of the navicular treated surgically with bridge plating. The authors used a 2.7-mm reconstruction plate with 8 to 10 holes at the medial column of the foot, from the talus to the first metatarsal. The 2 proximal and 2 distal holes were fixed with screws, the distal ones being long enough to reach the lateral column[15]. Apostle and Younger[15] described a technique consisting of double bridge plating to the medial and middle cuneiforms. In the current technical report, we performed bridge plating fixation using a 2.7 mm locking plate, inserting two screws into the talus and the medial cuneiform. Therefore, in addition to a single and smaller incision, the Lisfranc joint and the bones of the lateral column were not included in the fixation, avoiding joint stiffness and symptoms in the lateral column.

In our opinion, the bridge plating technique is indicated for severely comminuted navicular fracture–dislocations. In these fractures, the forefoot assumes an abducted position, and comminution of the medial midfoot results in shortening of the medial column, which may lead to a midfoot collapse[1]. Direct open reduction and fixation of small bony fragments may not be achieved, in addition to leading to excessive vascular damage. Furthermore, medial column instability may require the addition of an external fixator. In the technique described, the small fragments, especially the plantar ones, which are difficult to achieve, are reduced by ligamentotaxis, and the medial column is stabilized by the bridge plate, ruling out the need for external fixators and avoiding complications and multiple incisions. A disadvantage of the technique is the need for a new surgery to remove the plate. Previous authors[10,15] have recommended removal after 4–9 months to allow restoration of function in the transverse tarsal and subtalar joints. Because of the possibility of delaying early osteoarthritis and arthrodesis, we consider the present technique to be a good alternative in selected cases. The case presented to illustrate this technical tip was followed up only for 10 months, which is an important limitation. Therefore, mid- and long-term follow-up studies are warranted to evaluate the maintenance of anatomical alignment, functional scores, and development of post-traumatic osteoarthritis.

In sum, the technique described herein has the following advantages: (a) maintenance of the medial longitudinal column in comminuted navicular fractures; (b) indirect reduction of the small bone fragments; (c) maintenance of the congruence of the talonavicular and naviculocuneiform joints; (d) longer protection in potential cases of vascular damage of the bone tissue or delayed union; and (e) lower morbidity with limited surgical incisions, saving the Lisfranc joint and the lateral column of the foot.

Authors' contributions: Each author contributed individually and significantly to the development of this article: HM *(https://orcid.org/0000-0001-7527-969X) Data collection, interpreted the results of the study, wrote the article; LLS *(https://orcid.org/0000-0003-3006-7831) Wrote the article; DAM *(https://orcid.org/0000-0002-3893-0292) Wrote the article, participated in the review process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

References

1. Ramadorai MU, Beuchel MW, Sangeorzan BJ. Fractures and dislocations of the tarsal navicular. J Am Acad Orthop Surg. 2016;24(6):379-89.
2. Burne SG, Mahoney CM, Forster BB, Koehle MS, Taunton JE, Khan KM. Tarsal navicular stress injury: long-term outcome and clinicoradiological correlation using both computed tomography and magnetic resonance imaging. Am J Sports Med 2005;33(12):1875-81.
3. Schmid T, Krause F, Gebel P, Weber M. Operative treatment of acute fractures of the tarsal navicular body: midterm results with a new classification. Foot Ankle Int. 2016;37(5):501-7.
4. Pinney SJ, Sangeorzan BJ. Fractures of the tarsal bones. Orthop Clin North Am. 2001;32(1):21-33.
5. Marshall D, MacFarlane RJ, Molloy A, Mason L. A review of the management and outcomes of tarsal navicular fracture. Foot Ankle Surg. 2020;26(5):480-6.
6. DiGiovanni CW. Fractures of the navicular. Foot Ankle Clin. 2004;9(1):25-63.
7. Sangeorzan BJ, Benirschke SK, Mosca V, Mayo KA, Hansen ST Jr. Displaced intra-articular fractures of the tarsal navicular. J Bone Joint Surg Am. 1989;71(10):1504-10.
8. Coulibaly MO, Jones CB, Sietsema DL, Schildhauer TA. Results and complications of operative and non-operative navicular fracture treatment. Injury. 2015;46(8):1669-77.
9. Karmali S, Ramos JT, Almeida J, Barros A, Campos P, Costa DS. Tarsal navicular fracture in a parkour practitioner, a rare injury – Case report and literature review. Rev Bras Ortop. 2019;54(6):739-45.
10. Schildhauer TA, Nork SE, Sangeorzan BJ. Temporary bridge plating of the medial column in severe midfoot injuries. J Orthop Trauma 2003;17(7):513-20.
11. Cronier P, Frin JM, Steiger V, Bigorre N, Talha A. Internal fixation of complex fractures of the tarsal navicular with locking plates. A report of 10 cases. Orthop Traumatol Surg Res. 2013;99(4 Suppl):S241-9.
12. Moreira ET, Andrade CA, Maluf Neto J, Lovisotto LA. Navicular bone comminuted fracture: medial plate fixation. Case report and literature review. Rev ABTPé. 2014;8(1):39-44.
13. Alberta FG, Aronow MS, Barrero M, Diaz-Doran V, Sullivan RJ, Adams DJ. Ligamentous Lisfranc joint injuries: a biomechanical comparison of dorsal plate and transarticular screw fixation. Foot Ankle Int. 2005;26(6):462-73.
14. Hu SJ, Chang SM, Li XH, Yu GR. Outcome comparison of Lisfranc injuries treated through dorsal plate fixation versus screw fixation. Acta Ortop Bras. 2014;22(6):315-20.
15. Apostle KL, Younger AS. Technique tip: open reduction internal fixation of comminuted fractures of the navicular with bridge plating to the medial and middle cuneiforms. Foot Ankle Int. 2008;29(7):739-41.