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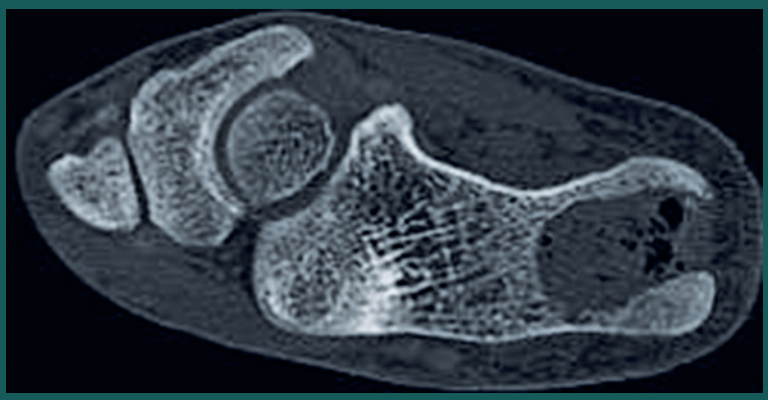

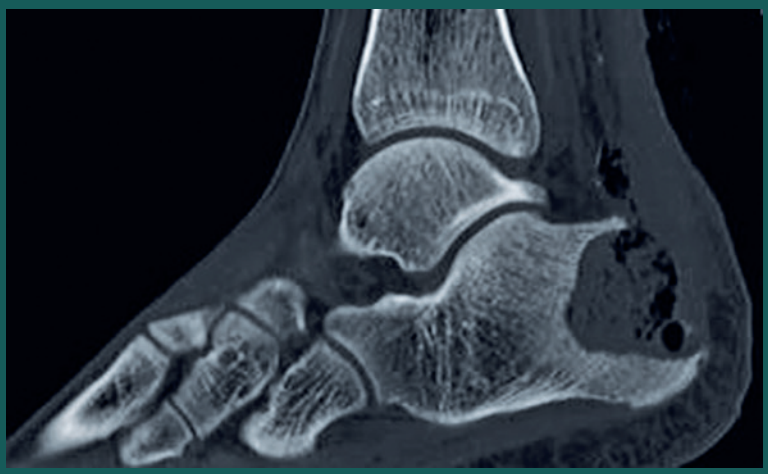

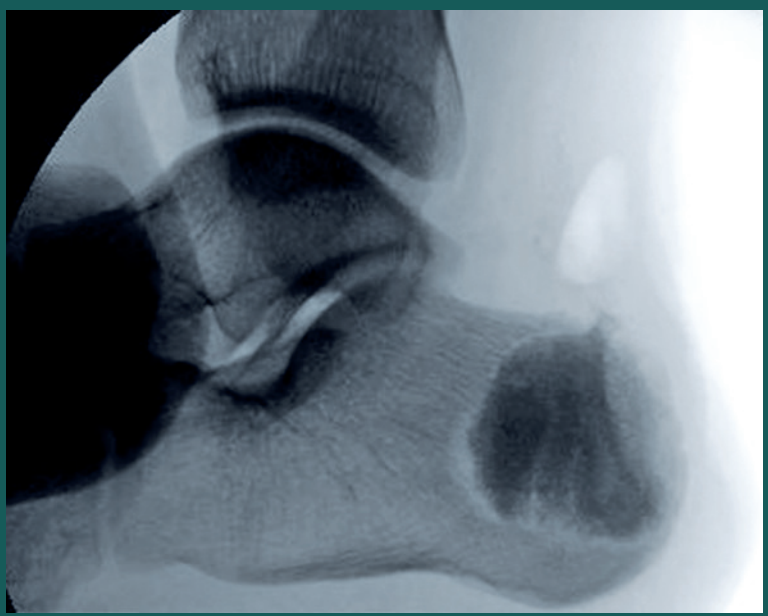

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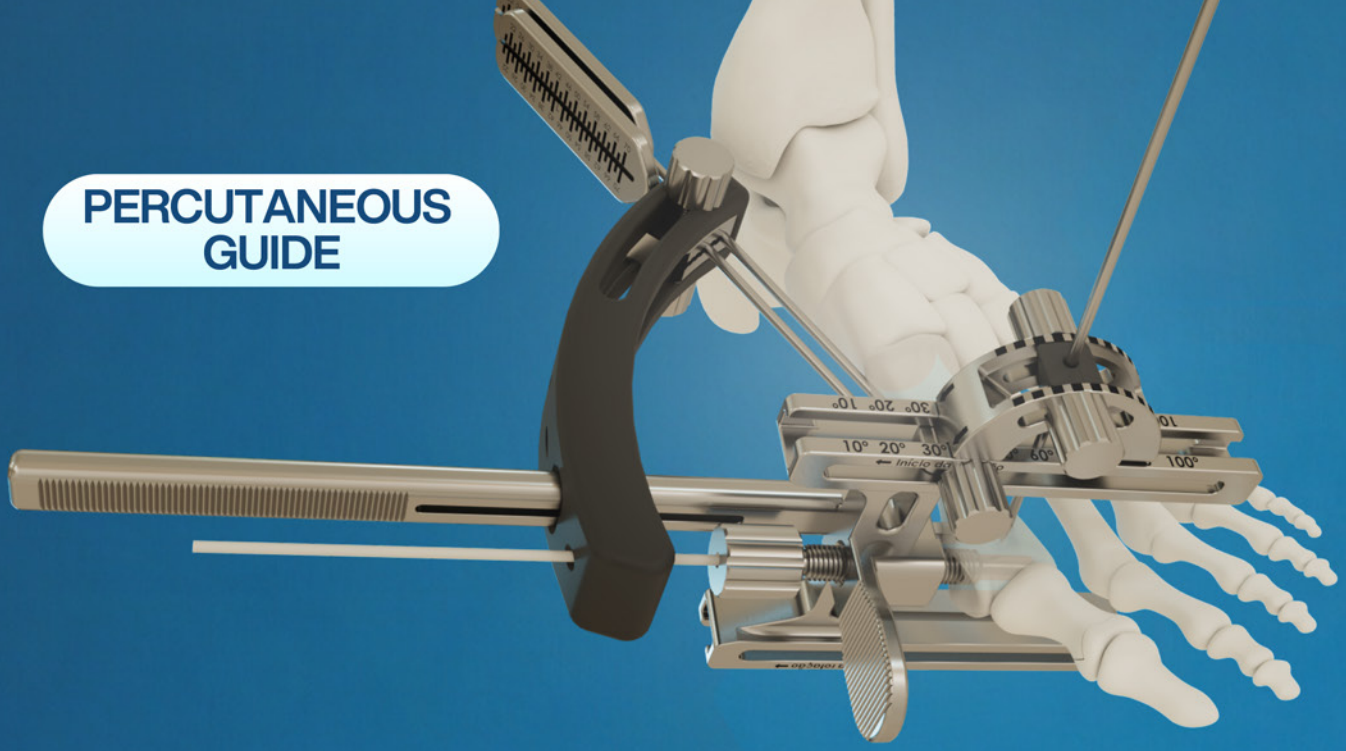

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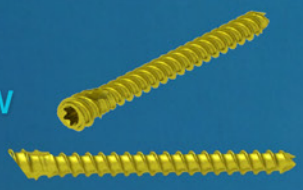

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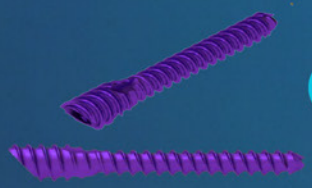

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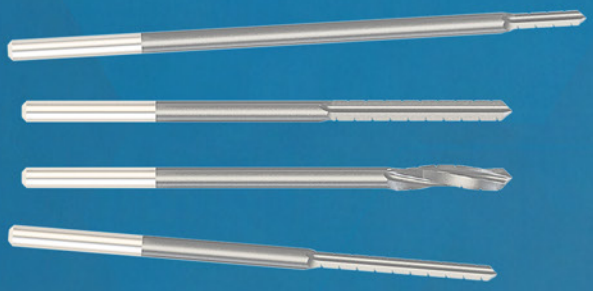

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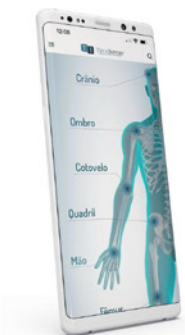

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ALEXANDRE LEME GODOY-SANTOS

(UNIVERSIDADE DE SÃO PAULO, AND HOSPITAL ISRAELITA ALBERT EINSTEIN, SÃO PAULO, SP, BRAZIL)

Welcome to the new Editor-in-Chief

With great enthusiasm, we welcome the new Editor-in-Chief of the Journal of the Foot and Ankle, Prof. Dr. Caio Nery. On behalf of the entire editorial team and the scientific community, we would like to express our sincere joy at having him in such an important position.

His nomination as Editor-in-Chief is undoubtedly a reflection of his outstanding career and significant contributions to medicine and foot and ankle specialty. His vast knowledge and experience, combined with his passion for scientific research, will certainly further strengthen the reputation and impact of our prestigious journal.

We hope his leadership will bring new perspectives and opportunities to the Journal of the Foot and Ankle, further enriching its content and promoting the dissemination of high-quality scientific information.

ABTPé is committed to supporting him in all his initiatives and working together to maintain the high standards of excellence for which our journal is known.

Once again, welcome, Prof. Dr. Caio Nery. We are sure that your leadership will be inspiring and that we will continue to advance towards the indexing of our journal.

Best regards,

Alexandre Leme Godoy-Santos
Elected President ABTPé (2024–2025)
Emeritus Editor of the Journal of the Foot and Ankle

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Systematic Review

Foot and ankle COVID-19 clinical manifestation: an integrative review

Victor Hugo Morais Ruela[1], Gabriela Silva Bochi[1], Eli Ávila Souza Júnior[1]

1. Universidade Federal de Alfenas – UNIFAL, Alfenas, MG, Brazil.

Abstract

Objective: Review the literature to obtain evidence of whether COVID-19 causes or exacerbates signs and symptoms in the foot and ankle.

Methods: This is an integrative literature review. Articles from the Scielo and PubMed platforms, published between January 2020 and April 2023, were selected and obtained by combining the descriptors "COVID-19", "Signs and Symptoms", "Joints", "Foot", and "Ankle", which answered the question guide: "What are the signs and symptoms in feet and ankles presented by patients affected by COVID-19?"

Results: Twenty-one articles were included, and data related to COVID-19 manifestation in the feet and ankles were extracted. The findings were grouped into dermatological, neurological, vascular, and musculoskeletal manifestations. The most prevalent dermatological manifestation was a chilblain-like lesion. The vascular manifestations include arterial thrombosis, vasculitis, and subacute arterial ischemia. Regarding the neurological findings, mononeuropathies and polyneuropathies were cited, including paresthesia and paresis in the feet and deep ankle areflexia. Among the musculoskeletal findings are reactive arthritis (with arthralgia in the ankle and foot, Achilles tendon enthesitis, redness, and edema), dactylitis, and heterotopic ossification in the ankle.

Conclusion: COVID-19 causes or exacerbates dermatological, neurological, vascular, and musculoskeletal signs and symptoms in the feet and ankles.

Level of Evidence IV; Diagnostic Studies; Integrative review.

Keywords: COVID-19; Signs and symptoms; Ankle; Foot; Toes.

Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), responsible for the pandemic that emerged in late 2019 in Wuhan, China, is a determinant of a wide spectrum of systemic manifestations that define COVID-19[1]. Respiratory signs and symptoms are the most prominent indicators of infectious pneumonia onset, ranging from mild dyspnea to severe acute respiratory syndrome (SARS). Additional extra-pulmonary manifestations, including anosmia, hyposmia, ageusia, and gastrointestinal symptoms, contribute to the overall clinical manifestation. While less prevalent, these manifestations are important in defining the comprehensive clinical profile[2]. However, although frequently reported by patients, musculoskeletal manifestations need to be better explored to corroborate the suspicion and diagnosis of the infection.

Some less reported changes have been described in the literature throughout the further investigation of the disease. Signs and symptoms in the feet and ankles are some extra-pulmonary COVID-19 manifestations that should be valued for determining the correct diagnosis and properly managing COVID-19[3].

The scarcity of publications on the symptomatology caused or aggravated by COVID-19 in the feet and ankles

Study performed at the Universidade Federal de Alfenas – UNIFAL, Alfenas, MG, Brazil.

Correspondence: Victor Hugo Morais Ruela. Alameda Libânio, 72, Jardim da Colina, Alfenas, MG, Brazil. **Email:** Elijr42@yahoo.com.br. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** August 31, 2023. **Date accepted:** October 25, 2023. **Online:** December 20, 2023.

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is remarkable. The explanation for this phenomenon is that publications focus on signs and symptoms more involved with mortality, especially the respiratory system. The objective of this study is to review the literature to obtain evidence of whether COVID-19 causes or exacerbates signs and symptoms in the foot and ankle and to corroborate the suspicion and diagnosis of such a condition in medical practice.

Methods

Our study was designed according to the necessary steps for elaborating an integrative review[4]. A theme was defined, the descriptors were established, the inclusion and exclusion criteria were defined, and a literature search was performed based on the descriptors. The studies were selected based on the specified criteria, and from them, the data were extracted, analyzed, and presented descriptively.

The literature search was based on the guiding question: "What are the signs and symptoms in the feet and ankles presented by patients affected by COVID-19?".The descriptors were defined based on the controlled vocabulary in the DeCS/MeSH, namely: "COVID-19", "Signs and Symptoms", "Joints", "Foot", and "Ankle". The Boolean operator used in the search was AND.

The search was conducted on the Scielo and PubMed platforms, and the inclusion criteria were publications between January 2020 and April 2023 in Portuguese, English, and Spanish, addressing signs and symptoms in the feet and/or ankles caused or exacerbated by COVID-19 and are available for full reading.

The criteria used to exclude articles were publications that did not address signs and symptoms in the feet and ankles, managed unconfirmed cases of COVID-19, addressed signs and symptoms arising from adverse effects of immunization, reported consequences of the pandemic caused by SARS-CoV-2.

The search was conducted in April 2023, resulting in 1611 studies, and 29 were selected. After a full-text read, 21 studies were included. The study followed The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and is summarized in Figure 1.

Data extraction was performed using a validated data collection instrument[5]. The article selection and data extraction were performed independently by two researchers with experience in the subject, using similar research criteria previously agreed upon, with subsequent comparison of the results; this method was performed to reduce possible interpretation biases. Articles were synthesized, and hierarchical classification was conducted regarding the level of scientific evidence, as proposed by the Agency of Healthcare Research and Quality (AHRQ).

Results

This study included 21 articles; seven were published in 2020, ten in 2021, and four in 2022. Regarding the countries

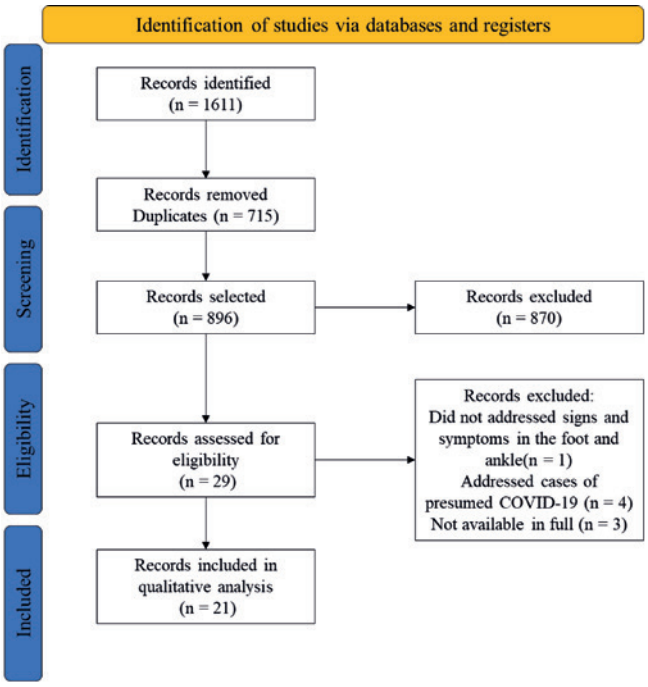

Figure 1. PRISMA flowchart, representing the search in the literature and the studies selection.

of origin of the studies, 23.80% were performed in Spain (n = 5), 19.04% in the United States of America (n = 4), 9.52% in Argentina (n = 2), 9.52% in Italy (n = 2), 4.55% in Germany (n = 1), 4.76% in Belgium (n = 1), 4.76% in Egypt (n = 1), 4.76% in Iran (n = 1), 4.76% in Japan (n = 1), 4.76% in Pakistan (n = 1), 4.76% in Portugal (n = 1), and 4.76% in the United Kingdom (n = 1). Regarding the methodologies of the publications, most articles were case reports, representing 66.66% (n = 14); the remaining were 14.28% literature reviews (n = 3), 4.76% cohort study (n = 1), 4.76% cross-sectional study (n = 1), 4.76% update article (n = 1); and 4.76% prospective study (n = 1).

The selected studies analysis showed various foot and ankle manifestations caused or exacerbated by COVID-19. Thus, the findings were grouped into four major groups according to the affected systems: dermatological, neurological, vascular, and musculoskeletal manifestations. Signs and symptoms simultaneously affected more than one system; in these cases, they were allocated to the group referring to the etiology of the manifestation or to the group in which the symptomatology was more evident in cases of etiology not completely clarified.

Dermatological manifestations were reported in nine articles, with the perniosis-type lesion, also known as Covid toes, being the most cited. This manifestation has been described as a lesion with a varied appearance of erythema, papules, or macules, most often located on the toes, and may be associated with blisters, edema, pain, and pruritus. The

second most reported manifestation in the dermatological group was the necrotic lesion of the toes or soles of the feet, known as acroischemia. It was written as cyanosis, hemorrhagic blisters, and dry gangrene. Desquamation of the distal phalanges of the fingers and toes, also known as acral peeling, was another dermatological manifestation reported. Acral peeling was described as mild erythema followed by desquamation of the distal phalanges of the fingers and/or toes. Other dermatological manifestations found were acral papulo-vesicular eruption, acral urticarial lesion, acral non-inflammatory purpura and skin necrosis, acral vasculitis, acral erythema multiforme lesion, acral lesions associated with multisystem inflammatory syndrome in children and red half-moon nail sign.

Regarding peripheral neurological manifestations, three studies reported peripheral axonal mononeuropathies, two reported peripheral axonal polyneuropathies, and one reported cases of worsening pre-existing diabetic foot conditions. Among the mononeuropathies are deep knee and ankle areflexia, hypoparesis, or paresis in the knee, ankle, and foot. The manifestations of polyneuropathies were hypoparesis of ankle dorsiflexion, painless paresthesia, abnormalities in the deep knee and ankle reflexes, deep knee and ankle areflexia, abnormality of the calcaneal tendon reflex, Guillain-Barré syndrome (manifested in the ankle with hypoparesis and deep areflexia). The aggravation of the diabetic foot was evidenced by acute pain, pain at rest, and coldness sensation in the affected foot.

Regarding vascular manifestations, three studies addressed arterial thromboembolism due to COVID-19, and one study showed venous thromboembolism concomitant. The manifestations reported were discoloration of the feet, coldness sensation, claudication of small distances, subacute arterial ischemia, distal necrosis of the toes, vasculitis (Kawasaki disease), and deep vein thrombosis.

The most reported musculoskeletal manifestation in three publications was acute reactive arthritis, mainly as arthralgia that most frequently affected the metatarsophalangeal joint and ankle. In one of the cases of acute reactive arthritis after COVID-19, there was an association of Achilles tendon enthesitis. One of the publications reported dactylitis with edema and pain in the fourth and fifth toes. Another manifestation with only one report was heterotopic ossification, which affected several joints, including both ankles.

The results were compiled and presented descriptively in Table 1[6-25].

Discussion

Among the 1611 studies found, 29 were selected, and only 21 met the inclusion and exclusion criteria and were included in the qualitative analysis. A bias in selection could affect the results.

Dermatological manifestations were the most evident in the review, with the perniosis-type lesion being the most frequently reported. Perniosis is an inflammatory vasculopathy in the toes induced by an abnormal response to cold. It can be idiopathic, hereditary, or associated with diseases such as leukemia, viral infections, and rheumatoid arthritis. The perniosis-like lesions observed in COVID-19 cases are clinically and histopathologically similar to perniosis, except for the definition of its triggering by cold[26].

A possible explanation for the perniosis-like lesions are more prevalent in young, healthy patients with mild symptoms of COVID-19 or asymptomatic patients is that these patients have an exuberant immune reaction mediated by interferon I, containing the infection early and favorably[27]. The skin capillaries' lesion mechanism, which generates the lesion characteristics, involves an immune response directed to the cutaneous vessels or a direct invasion of the SARS-CoV-2 infection into the endothelium[21].

Acroischemia occurs in states where SARS-CoV-2 activates the complement system in capillaries and interacts with coagulation pathways, predisposing to thrombotic microvascular damage[21]. This dermatological manifestation is often present in cases where innate and adaptive immunity fail to contain virus infection, resulting in a cytokine storm[11].

The involvement of the central nervous system has not yet been completely elucidated. Dos Anjos et al.[28] proposed hypotheses of direct and indirect mechanisms for neuronal involvement. Viral neuroinvasiveness was presented as a direct mechanism. Another hypothesis would be hematogenous dissemination, where infected leukocytes cross the blood-brain barrier, infecting the central nervous system. The hypothesis centered on the indirect mechanism refers to the destruction of neuron support cells, namely oligodendrocytes and astrocytes, which occur due to the cytokine storm triggered by the release of pro-inflammatory cytokines by leukocytes.

A range of neurological manifestations of COVID-19 are described in the literature; the most common are anosmia, ageusia, nausea, vomiting, headache, dizziness, confusion, and myalgia. COVID-19 is also related to the incidence of neurological diseases or complications, such as ischemic stroke, hemorrhagic stroke, cerebral venous sinus thrombosis, encephalopathy, encephalitis, oculomotor nerve paralysis, Miller-Fisher syndrome and Guillain-Barré syndrome[29].

Peripheral neuropathy is a rare neurological manifestation of SARS-CoV-2 infection, but it generates a limiting motor deficit. Oaklander et al.[30] showed that peripheral nerve involvement is related to patients with prolonged disease time and mild symptomatology. Peripheral neurological symptoms usually started one month after the COVID-19 onset and were often disabling. Finsterer et al. [31] corroborates the hypothesis of immune dysregulation in peripheral neuropathy.

According to Roberts et al.[32] the vascular impairment of COVID-19 is hypothetically caused by the overlap of an endothelial dysfunction combined with a coagulopathy with high levels of D-dimer and fibrinogens. The mechanisms proposed to explain these phenomena vary. It includes the invasion of vascular tissue by the virus through binding to

Table 1. Results extracted from the studies included in the integrative review

Authors	Study design	Level of evidence	Sample	Comorbidities	Manifestation in the foot and ankle
Aguilar-Shea et al.[6]	Case Report	5	1 participant 96 years old Male	Pulmonary bibrosis	Arterial thrombosis with 10-day evolution with pain and change of color of the right foot
Acharya et al.[7]	Case Report	5	1 participant 34 years Female	SAH, sleep apnea, and morbid obesity	Neuropathy of the left sciatic nerve. Hypoparesis and hypoesthesia in the right lower limb.
Andina-Martíne et al.[8]	Case Report	5	6 participants 5–13 years 4 Male 2 Female	Asthma, atopic dermatitis, and allergic rhinitis	Desquamative and erythematous acral lesions on hands and feet, which were the only manifestations of COVID-19
Brance et al.[9]	Case Report	5	1 participant 54 years old Male	None	Heterotopic ossification in several joints, including the ankle, adjacent to soft tissue edema and reduced mobility
Carro et al.[10]	Case Report	5	3 participants 50–62 years 2 Male 1 Female	Type 2 DM, SAH, obesity, dyslipidemia, pulmonary TB	Diabetic foot of atypical presentation with an extensive ischemic and infectious involvement of the feet
Dombret et al.[11]	Case Report	5	1 participant 30 years Female	None	Reactive arthritis, manifested as acute pain and erythema in the forefoot and left ankle
Farajzadeh et al.[12]	Scope Review	4	Not Reported	Not reported	Acral papulo-vesicular eruption, acral urticarial lesion, acral non-inflammatory purpura, and necrosis, acroischemia associated COVID-19, acral vasculitis, chilblain-like lesion (COVID Toe), acral erythema multiform like lesion, hand and foot skin lesions associated with multisystem inflammatory syndrome in children, acral peeling conditions and red half-moon nail sign
Jimenez-Cebrian et al.[3]	Integrative Review	3	1 systematic review 9 narrative reviews	Not reported	Perniosis-like lesion, Kawasaki disease, distal ischemia and necrosis, polyneuropathy, Guillain-Barré syndrome, isolated dermatological manifestations (desquamation, cysts, blisters, livedo reticularis and papules), recurrent herpes
Kolivras et al.[13]	Prospective Study	2	32 participants 10–70 years Male and female	Not reported	Perniosis-like lesion in the feet, manifested with erythema, edema, macules, blisters, erosions, ulcers, crusts, and purples
Kopacz et al.[14]	Case Report	5	1 participant 48 years Female	SAH, AF, antiphospholipid syndrome	Perniosis-like lesion and spasticity in the feet
Lee et al.[15]	Cohort study	2	1 participant 74 years old Male	Psoriasis and hypoacusis	Venous and arterial thrombosis, evolving with ischemia and amputation below the left knee and right transmetatarsal
Mahmood et al.[16]	Case Report	5	1 participant 61 years Male	SAH and type 2 DM	Lower limbs axonal mononeuropathy with reduced strength in the left ankle and no knee and plantar flexor reflexes bilaterally
Odriozola et al.[17]	Case Report	5	4 participants 57–73 years 3 Male 1 Female	Type 1 and 2 DM but no history of diabetic neuropathy	Neuropathy with paresthesia in the feet associated with changes in sensory quantification test
Ono et al.[18]	Case Report	5	1 participant 50 years old Male	Fatty Liver Disease	Acute reactive ankle arthritis and Achilles tendon enthesitis
Relvas et al.[19]	Narrative Review	5	267 articles	Not reported	Perniosis-like lesion and acroischemia in the feet

continue...

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Table 1. Results extracted from the studies included in the integrative review

Authors	Study design	Level of evidence	Sample	Comorbidities	Manifestation in the foot and ankle
Rose-Salud et al.[20]	Update article	5	Not Reported	Not reported	Perniosis-like lesion and Kawasaki disease (sole edema and erythema) affecting the feet
Rubin et al.[21]	Case Report	5	1 participant 27 years old Female	None	Perniosis-like lesion on toes manifested with edema, pruritus, and pain
Salvatierra et al.[22]	Case Report	5	1 participant 16 years Female	None	Feet dactylitis, manifested as edema in the second, fourth, and fifth toes, and associated with pain on palpation of the metatarsophalangeal joints
Taha et al.[23]	Cross-sectional study	3	100 participants 18–74 years 61 Male 39 Female	14 smokers, other comorbidities not reported	Reactive arthritis occurred in 37 participants, with arthralgia being the main manifestation
Tammaro et al.[24]	Case Report	5	1 participant 59 years Male	COPD, smoking	Necrotic acral lesion in left calcaneus surrounded by erythematous area
Tramonti et al.[25]	Case Report	5	1 participant 44 years old Male	Type 2 DM, obesity, and psychotic illness not specified	Axonal polyneuropathy with motor and sensory impairment, with bilateral strength deficit in ankle dorsiflexion and no deep tendon reflexes

SAH: Systemic Arterial Hypertension; DM: Diabetes Mellitus; TB: Tuberculosis; MS: Multiple Sclerosis; MIS-C: Multisystem Inflammatory Syndrome in Children; AF: Atrial Fibrillation; COPD: Chronic Obstructive Pulmonary Disease.

angiotensin-converting enzyme 2 (ACE2), cytokine storm, oxidative stress, and coagulation cascade dysfunction secondary to microcirculation dysfunction.

One of the most reported musculoskeletal manifestations in the reviewed publications was reactive arthritis, an oligoarthritis or monoarthritis that develops after one to four weeks of an infectious condition, usually urethritis or enteritis[10]. Taha et al.[23] demonstrated that post-COVID reactive arthritis is associated with hyperinflammation triggered by respiratory infection. This inflammation induces arthritis in post-COVID patients by its effect on the synovial membrane and articular cartilage. Inflammatory markers such as IL-6, erythrocyte sedimentation rate, and C-reactive protein measured six months after recovery are statistically associated with post-COVID arthritis.

An important limitation identified during the development of this study was the lack of comprehensive differential diagnoses for manifestations attributed to the virus infection. While articles addressing cases of symptom emergence or exacerbation in confirmed COVID-19 cases were included, not all rigorously provided a thorough exploration of alternative explanations for these manifestations.

Conclusion

COVID-19 causes or exacerbates dermatological, vascular, neurological, and musculoskeletal manifestations in the foot and ankle. While uncommon, these manifestations may occur as primary symptoms of the disease or the worsening of pre-existing conditions. Although infrequent, recognizing such signs and symptoms corroborates the assertiveness in the suspicion of SARS-CoV-2 diagnosis, especially when the systemic and respiratory symptoms are mild and nonspecific. However, new studies presenting a higher level of scientific evidence are necessary to affirm the causality between SARS-CoV-2 infection and manifestations in the feet and ankles.

Authors' contributions: Each author contributed individually and significantly to the development of this article: VHMR *(https://orcid.org/0000-0003-0154-7385) conceived and planned the activities that led to the study, approved the final version; GSB *(https://orcid.org/0000-0003-1753-2655) wrote the article EASJ *(https://orcid.org/0000-0002-5054-874X) participated in the review process. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID).

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Special Article

Surgical management for ankle arthropathy in patients with hemophilia and other congenital coagulation disorders

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Abstract

Objective: Compare the surgical treatment options available in our institution and the postoperative outcomes during follow-up. Additionally, assess patient's perception of their condition and its progression.

Methods: This descriptive observational study is a case series with a narrative literature review. All patients who met the inclusion and exclusion criteria and received surgical management for ankle arthropathy due to ankle hemarthrosis between 1999 and 2022 at Hospital San José in Bogotá were included. A perception survey was conducted via teleconsultation to evaluate pain control, functional impact, and capacity for daily activities.

Results: Fifteen patients were included in the study, 13 male (86.7%). The mean age at the time of surgical intervention was 33 years (range 25–68). Among the patients, eight (53.3%) were diagnosed with Hemophilia A, four (26.7%) with Hemophilia B, two with Von Willebrand disease (13.3%), and one (6.7%) with Factor VII deficiency. The most common surgical intervention was ankle arthroscopy, with nine cases (50%). No infectious or intraoperative complications were documented, but one case of Hemophilic Pseudotumor developed late. The mean follow-up time was 87.7 months (IQR 60–105, SD 56.17). All patients reported improved pain and resumed their daily activities after the surgical intervention.

Conclusion: Surgical management, regardless of the technique used (joint preservation or sacrifice), had a positive impact on patients by reducing pain after conservative management failure and allowing them to regain their daily activities, improving their quality of life.

Level of Evidence IV; Therapeutic studies - investigating the results of treatment; Case series.

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

Introduction

Congenital coagulation factor deficiencies constitute a group of pathologies in which the coagulation process cannot properly develop, leading to potential spontaneous bleeding[1-3]. Congenital coagulation factor deficiencies found in our patients, such as Hemophilia A and B, Von Willebrand disease, and rare coagulation defects like Factor VII deficiency, were included in our study.

Worldwide, the prevalence of Hemophilia A is 21 cases per 100,000 inhabitants, and Hemophilia B is 4 cases per 100,000 inhabitants[3]. In Colombia, there are specialized care pathways for orphan diseases, and thus far, there have been 2,262 cases of Hemophilia A, 507 cases of Hemophilia B, 1,868 cases of Von Willebrand disease, and 139 cases of Factor VII deficiency. Chronic arthropathy is the most common complication related to Hemophilia, with 37.5% in the national registry. This condition leads to limited mobility of the limbs, making it the leading cause of disability in patients with hemophilic arthropathy, accounting for 45.28%[4].

The tibiotalar joint is one of the most affected by these pathologies from an early age, and its dysfunction

Study performed at the Fundación Universitaria de Ciencias de la Salud - Hospital de San José, Bogotá, Colombia.

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significantly impacts gait biomechanics[5] and the quality of life of patients. However, surgical interventions to address joint-related clinical manifestations are rare in our country, considering the high cost of the procedure and the limited availability of specialized centers that can offer comprehensive management.

Considering that Hospital San José in Bogotá currently operates under the European Foundation for Quality Management (EFQM) model as a High-Performance Clinical Unit (UCAD) in the management of Hemophilia and other congenital coagulation factor deficiencies, the hospital is recognized as a national reference center for complex medical and surgical management of these patients[6]. It has a multidisciplinary team, coagulation factors, and other hemostatic agents that contribute to the success of surgical interventions and subsequent rehabilitation.

This study shows our experience in the surgical management of ankle arthropathy due to hemarthrosis, collecting institutional information from the past 24 years and comparing it with the current literature worldwide.

A narrative review of the available literature is conducted to compare the surgical treatment options available in our institution and the postoperative outcomes during follow-up. Additionally, a survey was administered to assess the patient's perception of their condition and its progression.

Methods

This descriptive observational study is a case series with a narrative literature review. All patients with congenital coagulation deficiencies such as Hemophilia A and B, Von Willebrand disease, and rare coagulation defects, submitted to surgical management for ankle hemarthrosis-related arthropathy and traumatic causes in patients with a history of coagulation factor deficiencies between 1999 and 2022 at Hospital San Jose in Bogotá were included. Information regarding the patient's demographic characteristics and outcomes was obtained from the review of medical records.

A perception survey was used to assess the current patient status and indirectly evaluate the surgical treatment outcome measured by functionality and pain control (Table 1). The questions were previously reviewed and endorsed by three experts, consisting of two orthopedists and one hematologist.

Selection criteria

Inclusion

- Patients diagnosed with Hemophilia A and B or other congenital coagulation deficiencies who received surgical management for ankle hemarthrosis-related arthropathy.
- Patients treated since 1999 with available follow-up medical records.

Exclusion

- Loss of follow-up.
- Patients under 18 years old.

Due to the nature of the study, a descriptive analysis of the patient's information was performed. For quantitative variables, measures of central tendency (mean, median), dispersion (standard deviation), and position (percentiles) were calculated. Frequency measures and tables with percentage distribution were generated for qualitative variables, including the data collected from the perception survey. The information was processed and analyzed using the statistical software STATA version 17 (FUCS license).

Furthermore, a narrative literature review was conducted in May 2023 on PubMed and Cochrane databases to find literature reporting surgical management outcomes for ankle hemarthrosis-related arthropathy. The following descriptors and Mesh terms were used: "ankle," "coagulopathy," "hemophilia," "von Willebrand," and "surgery," combined in the following search equations: ("Ankle" AND "Hemophilia" AND "von Willebrand" AND "surgery") (("Hemophilia A" OR "Hemophilia B") OR "von Willebrand Diseases" AND "Ankle" AND "Surgery"). Studies published up to that date were selected based on their title and abstract, documenting the performance of surgical management and its results measured in intraoperative bleeding, length of hospital stay, pain control, and patient satisfaction.

The strategy search resulted in 217 articles. In the first filter by abstract, 48 articles were selected for full-text review. Additionally, the references of interest were reviewed to find additional articles (3 articles), resulting in 51 articles included in the narrative review (Figure 1).

Systematic reviews, case series, cohort studies, or case reports that reported the abovementioned variables were considered. To facilitate evaluation, they were subdivided into categories depending on the evaluated surgical procedure (total ankle replacement, arthroscopy, arthrodesis, and joint distraction).

Results

Fifteen patients met the inclusion criteria, and the information was obtained from the medical records. Of

Table 1. Follow-up survey

Question	Answer Choices
Did you perceive improvement in pain with surgical treatment?	Got worse, Stayed the same, Improved
Do you need external support?	Yes, No
Do you require prescribed footwear or orthotic insoles?	Yes, No
Do you have difficulty walking on uneven ground?	Yes, No
Do you limp while walking?	Yes, No
Have you been able to resume your daily activities?	Yes, No
After your surgery, did you return to your previous work activity?	Yes, No
Are you able to exercise or participate in sports activities?	Yes, No

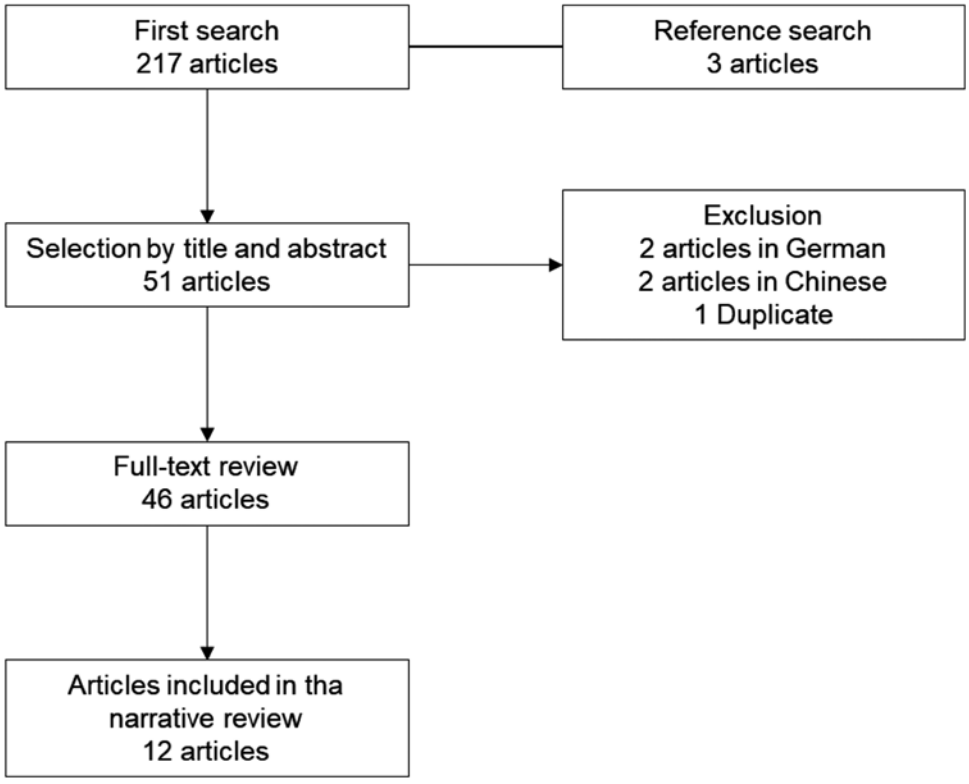

Figure 1. Flowchart of article selection.

these patients, two were women (13.3%), with a mean age at the time of surgical intervention of 33 years (range 25–68). Sociodemographic data are described in Table 1.

Among the patients, eight (53.3%) were diagnosed with Hemophilia A, four (26.7%) with Hemophilia B, two with Von Willebrand disease (13.3%), and one (6.7%) with Factor VII deficiency. Regarding the severity of Hemophilia, patients with severe Hemophilia accounted for 66.7% (n = 8), followed by moderate 16.7% (n = 2), and mild 16.7% (n = 2). Inhibitors in the preoperative were documented in three patients (27.27%): two with a low response and one with high-response inhibitors who required an immunotolerance management protocol with successful elimination of the inhibitor before the surgical intervention (Table 2).

The associated comorbidities were divided into four groups: 1) infectious, such as treated Hepatitis C; 2) one patient with cardiovascular disease (hypertension); 3) obesity, which was not recorded in any patient at the time of surgical procedure; and 4) other comorbidities included all active diseases being treated unrelated to increased risk during the perioperative period, such as kidney stones, benign prostatic hyperplasia, fatty liver, or gallstones (Table 2).

Regarding the surgical procedures, 19 surgeries in 15 patients were performed; three patients were submitted to bilateral surgery, and one patient initially submitted to ankle arthroscopy with synovectomy and osteophyte resection, but due to persistent pain, the patient ultimately was submitted to tibiotalocalcaneal (TTC) fusion. The most frequent surgical intervention was ankle arthroscopy with synovectomy and osteophyte resection in nine cases (47.37%), followed by ankle fusion in five cases (26.31%), all being TTC. The least performed procedures were ankle joint replacement in two cases (10.52%). The remaining were Achilles tendon lengthening in one case (5.26%), supramalleolar osteotomy in the context of tibiotalar ankylosis with angular deformity in one case (5.26%), lateral ligament reconstruction in one case (5.26%) (Figure 2). Pain management was the most frequent indication for surgery, accounting for 84.21% (n = 16) (Figure 3). One patient underwent surgical management due to chronic lateral instability secondary to trauma, and the main indication for surgery was instability control rather than hemarthrosis or intra-articular bleeding-related arthropathy. Also, it was observed if patients were submitted to surgeries in other joints due to the same arthropathy, four patients (26.67%) were operated on in other joints, all with severe Hemophilia. Figures 4, 5, and 6 show radiographs of the procedures performed.

Intraoperative bleeding was measured using surgical and anesthesiologist records. The mean bleeding for all procedures was 65 ml (median 50 ml, IQR 50–75 ml), and no cases required blood transfusion (Table 3).

Table 2. Demographic characteristics

Characteristics n = 15	
Mean age at the time of surgery	33 (25–68)
Sex, n (%)	
Men	13 (86.7%)
Women	2 (3.3%)
City of residence, n (%)	
Bogotá	8 (53.3%)
Facatativá	1 (6.67%)
Combita	1 (6.67%)
Manizales	1 (6.67%)
Cajamarca	1 (6.67%)
Santa Marta	1 (6.67%)
Turbaco	1 (6.67%)
Ciudad de México	1 (6.67%)
Socioeconomic stratum, n (%)	
1	1 (6.67%)
2	5 (33.33%)
3	5 (33.33%)
4	4 (26.67%)
5	0 (0.0)
6	0 (0.0)
Educational level, n (%)	
Elementary	1 (6.67%)
High School	6 (40%)
Technical	2 (13.33%)
University	4 (26.67%)
Postgraduate	2 (13.33%)
Occupation, n (%)	
Employee	7 (46.67%)
Student	2 (13.33%)
Unemployed	2 (13.33%)
Retire	4 (26.67%)
Type of coagulopathy, n (%)	
Hemophilia A	8 (53.3%)
Hemophilia B	4 (26.6%)
Von Willebrand type 1	1 (6.67%)
Von Willebrand type 3	1 (6.67%)
Factor VII deficiency	1 (6.67%)
Severity of hemophilia, n (%)	
Mild	2 (16.67%)
Moderate	2 (16.67%)
Severe	8 (66.67%)
Presurgical inhibitors, n (%)	
Yes	3 (25%)
No	9 (75%)
Comorbidities, n (%)	
Infectious	3 (20%)
Obesity	0 (0.0%)
Cardiovascular	1 (6.67%)
Other	5 (3.33%)
None	9 (60%)

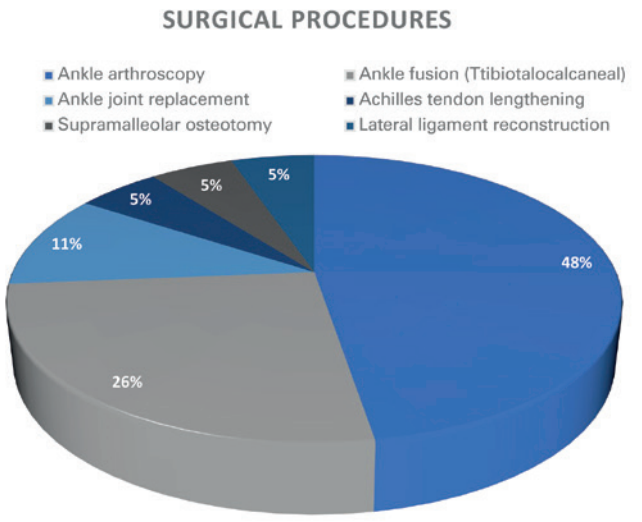

Figure 2. Surgical Procedures.

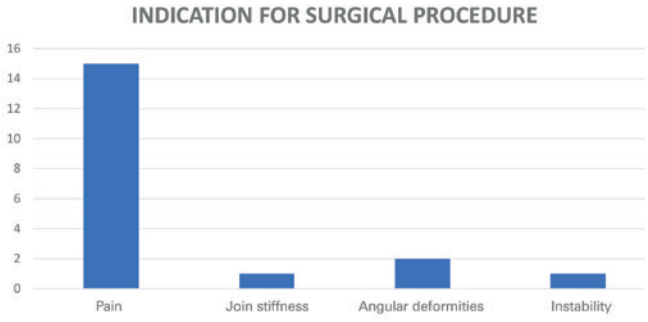

Figure 3. Indication for surgical procedure.

Length of hospital stay was measured in days from admission to postoperative discharge; the mean stay for all procedures was 13.25 days (median 11 days, IQR 9.5–14.5). One patient required a 31-day hospital stay due to ankle fusion and knee joint replacement performed in the same surgical procedure (Figure 7).

No surgical site infections were documented within the first 30 postoperative days for the 19 surgical procedures. However, a Hemophilic pseudotumor related to the arthroscopy portal was discovered four years after the intervention.

A perception survey was conducted with 15 patients, with a mean follow-up time of 87.7 months (IQR 60–105, SD 56.17). All patients reported improvement in pain after surgery. Only two patients (13.33%) needed orthotic devices or external support, and six (40%) reported difficulty walking on uneven surfaces or limping during walking. All patients resumed their daily activities, but three (20%) were unable to return to their previous work activity or engage in sports.

Regarding the narrative review, the search was conducted on PubMed and Cochrane databases, resulting in 217 articles. After an initial filter by title, abstract, and cross-references,

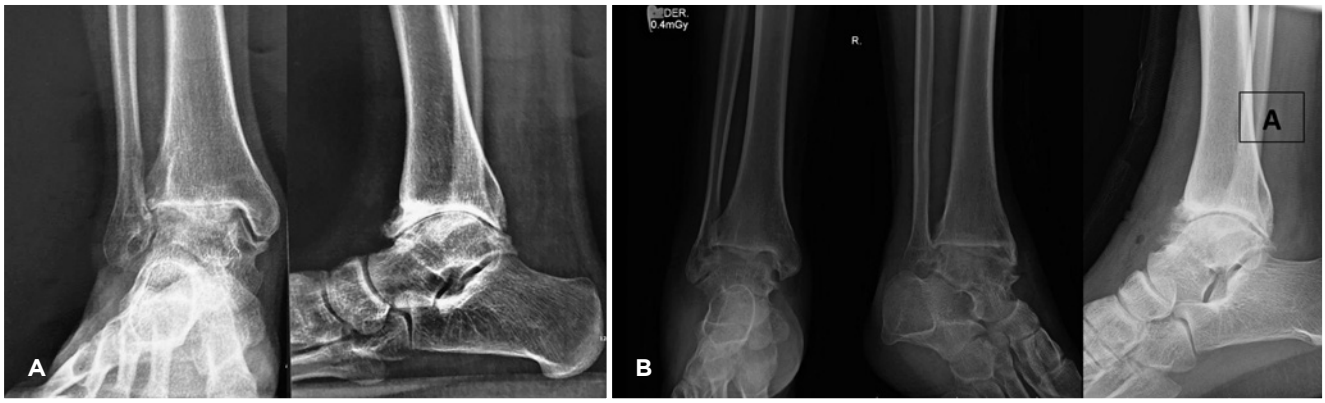

Figure 4. Right ankle arthroscopy (A) Preoperative AP and lateral radiographs of patients with Von Willebrand type 3 (B) Postoperative AP, oblique, and lateral radiograph.

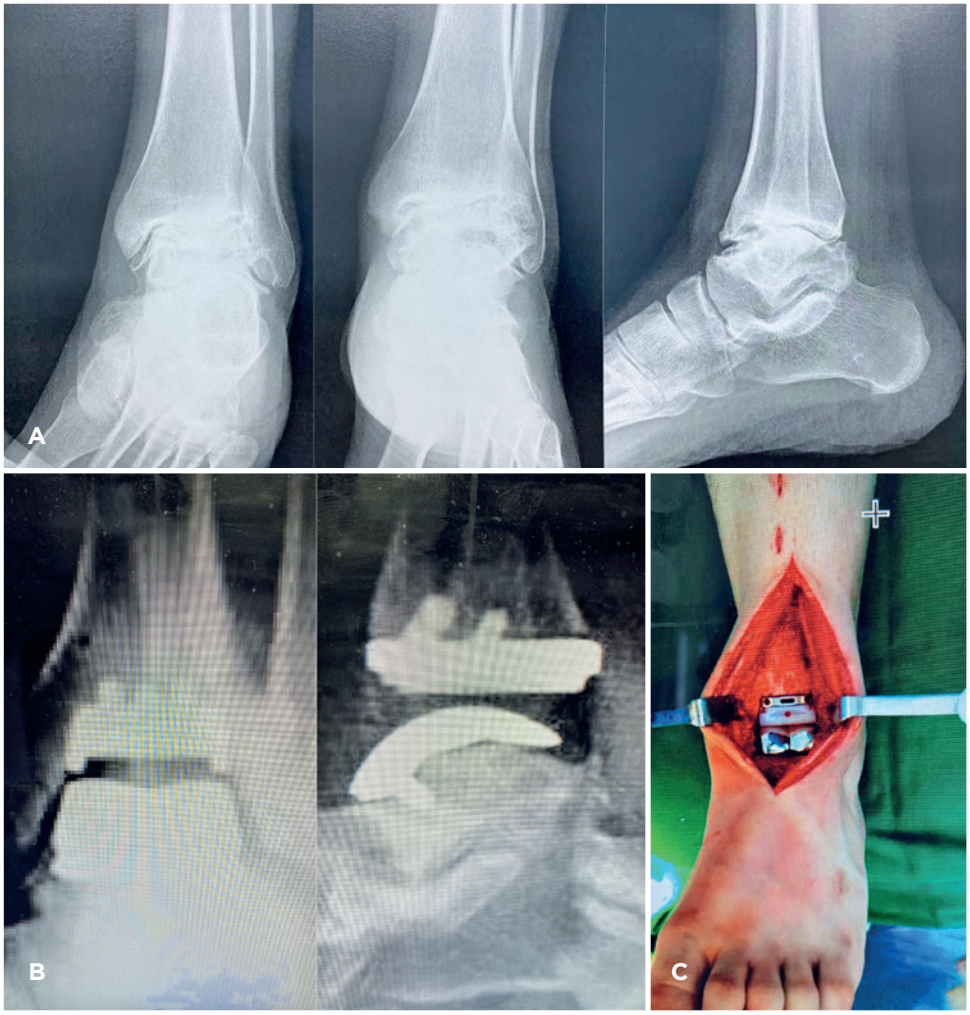

Figure 5. Right ankle arthroplasty in a patient with severe Hemophilia B. (A) Preoperative AP, oblique, and lateral radiographs. (B) Postoperative radiograph. (C) Intraoperative image.

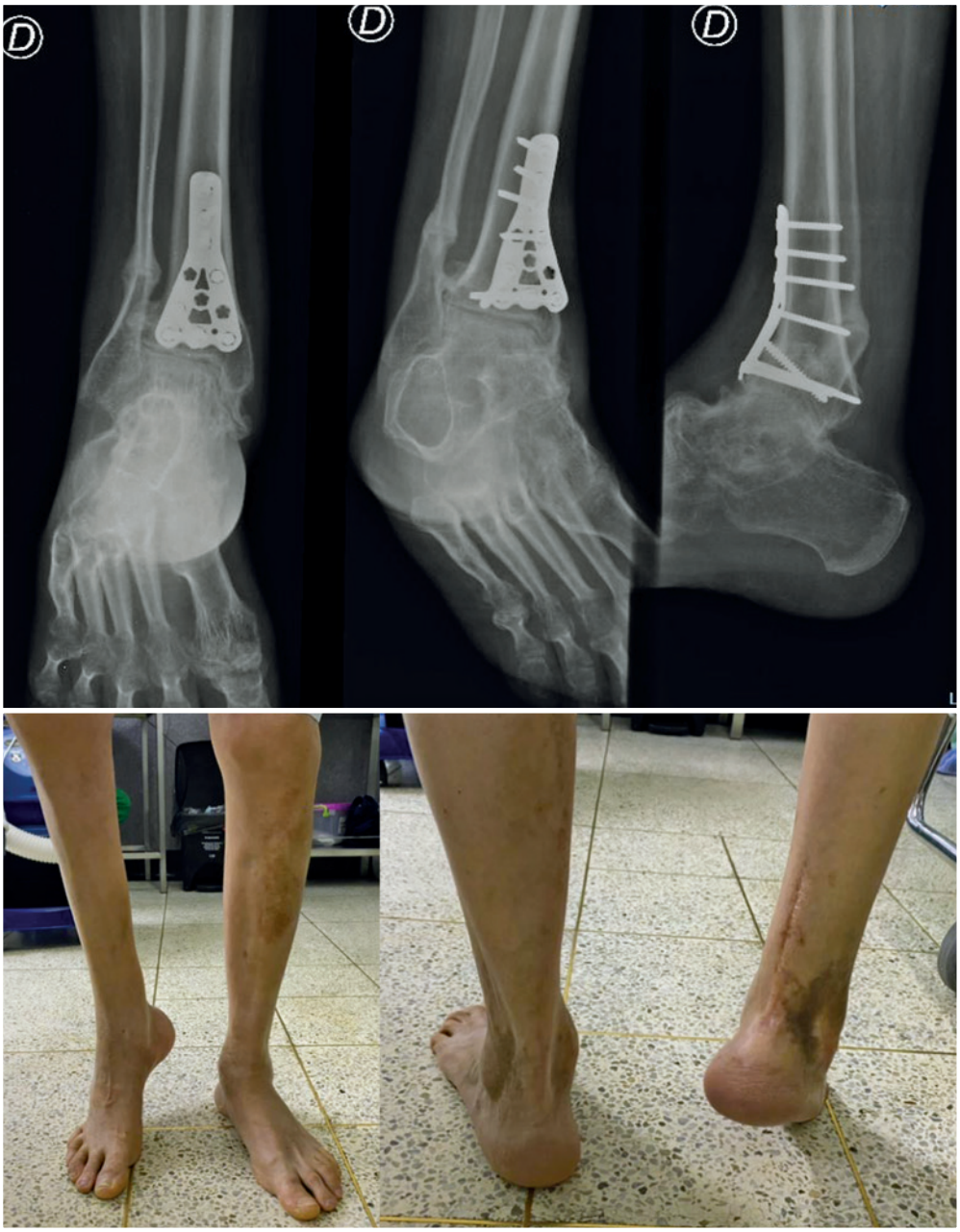

Figure 6. Left supramalleolar osteotomy in a patient with severe Hemophilia A with ankle ankylosis and proximal recurvatum deformity.

Table 3. Intraoperative bleeding (ml)

Surgical Procedures	Mean	SD	Median	IQR
Ankle arthroscopy	52.7	8.33	50	50–50
Ankle arthrodesis	87	24.39	100	75–100
Total ankle replacement	75	35.35	75	50–100
Lateral ligament reconstruction	75	-	75	75–75
Achilles tendon lengthening	50	-	50	50–50
Total	65.83	22.32	50	50–75

IQR: Interquartile range.

51 articles were obtained. In a second filter, four articles were excluded due to the language of publication (2 German, 2 Chinese) and one duplicate article, leaving 46 articles for full-text review. Finally, 12 articles that met the selection criteria were selected and used in this review.

In the literature, there are different case series with small cohorts for various surgical procedures, with ankle arthroplasty generating the most interest in functional outcomes (Table 4). Barg et al.[7] reported improvement in

Figure 7. Length of hospital stay by surgical procedure.

Table 4. Functional outcomes of each study

Author (year)	# Patient (# Surgeries)	Surgery	VAS pre and post	Surgical site infections	Hemostatic complications
Barg (2010)	8 (10)	Arthroplasty	7.1–0.8 (p < 0.001)	0	-
Kotela (2015)	3 (3)	Artrhoplasty	7.1–0.8	-	-
Barg (2015)	34 (36)	Arthroplasty	8.2–0.9 (p < 0.001)	-	-
Preis (2017)	14 (14)	Arthroplasty	8.5–1.3 (p < 0.001)	0	-
Bluth (2013)	45 (45)	Arthrodesis	-	1	-
Wang (2020)	14 (14)	Arthrodesis	7.0–1.4 (p < 0.001)	2	-
Ahn (2020)	29 (16 Arthroplasty – 13 Arthrodesis)	Arthroplasty vs. Arthrodesis	5.5–0.9 (p < 0.001)	-	2 (Intra-articular hematoma)
Mussawy (2021)	19 (10 Arthroplasty – 9 Arthrodesis)	Artrhoplasty vs Arthrodesis	Arthroplasty 7.6–2.5 Artrodesis 7.4–0.7	2 (Arthroplasty)	-
Rodriguez-Merchan (2014)	23 (24)	Arthroscopy	6.6–2.3	0	2 (Intra-articular hematoma)
Yasui (2017)	8 (8)	Arthroscopy	5.7–2.2	0	0
Pulles (2015)	3 (3)	Articular distraction	6.5–1.2	2	-
Wallny (2006)	23 (23)	Achilles tendon lengthening	-	-	-

VAS: Visual analog scale.

preoperative pain from 7.1 (range 4–9) to 0.8 (range 0–3) ($p < 0.001$) in eight patients (10 ankles) with a previous diagnosis of Hemophilia A, all satisfied with the surgical procedure, and no surgical site infections were reported. Kotela et al.[8], with a cohort series of three cases submitted to ankle joint replacement, reported a mean preoperative pain score of 7.1, which improved to 0.8 postoperatively. Once again, Barg et al.[9] included 34 patients (36 ankles), 20 patients with Von Willebrand disease, all patients were submitted to joint replacement. The mean preoperative pain score was 8.2 (range 7–10), which decreased to 0.9 (range 0–4) ($p < 0.001$) postoperatively. In 2017, Preis et al.[10] presented a series of 14 cases, including five patients submitted to conversion from arthrodesis to total ankle arthroplasty. They reported improvement in preoperative pain from 8.5 (range 8–10) to 1.3 postoperatively (range 0–6) ($p < 0.001$) and did not report deep infections.

Tibiotalocalcaneal or rearfoot fusion has been considered the gold standard treatment due to predictable long-term outcomes. Bluth et al.[11] included 45 patients over 39 years (1971–2010). All patients underwent surgical management with tibiotalar and/or subtalar fusion, with good results. Complete resolution of pain was achieved in 75% of patients, while the remaining experienced mild pain. Complications included deep infection (osteomyelitis) in one patient and non-union in 18.7% of cases. Another series reported by Wang et al.[12] included 14 patients, 12 with Hemophilia A and two with Hemophilia B, with a mean age of 40.7 years. The patients were submitted to ankle fusion with an Ilizarov external fixator. Preoperatively, the mean pain score was 7.0 (range 6–8), improving to 1.4 (range 0–3) ($p < 0.001$) postoperatively. Two cases experienced superficial infection at the pin insertion sites, but no deep infections were reported.

Comparisons have been made between ankle fusion and arthroplasty in patients with hemophilia, such as the case series reported by Ahn et al.[13] with 29 patients, where 16 were submitted to total ankle replacement and 13 fusion. In the replacement group, the mean preoperative pain score was 6.2 (range 3–10), with a postoperative improvement to 0.8 (range 0–5) ($p = 0.002$). For the fusion group, the preoperative mean pain score was 4.5 (range 2–10), improving to 0.7 (range 0–3) ($p = 0.005$) postoperatively. There were no statistically significant differences between the groups, as both improved pain in the postoperative outcome. For the management of end-stage joint disease, Mussawy et al.[14] presented nine patients submitted to fusion with a mean age of 35.7 years and ten patients submitted to total ankle arthroplasty with a mean age of 49.4 years. In the fusion group, pain decreased from 7.4 in the preoperative to 0.7 postoperatively ($p < 0.001$), and for the arthroplasty group, it was 7.6 in the preoperative to 2.5 postoperatively ($p < 0.001$); despite a statistically significant difference in favor of ankle arthrodesis ($p = 0.013$), clinically all patients expressed satisfaction with the results and proposed both therapeutic options. However, more complications were reported, such as deep infection, in the total ankle arthroplasty group ($n = 2$). For our cohort, in general, there was a decrease from 5.5 (range 2–10) in the preoperative to 0.9 (range 0–5) ($p < 0.001$) postoperatively.

On the other hand, arthroscopy is one of the most used tools nowadays due to its less invasive and joint preservation qualities and favorable results. An example is the cohort study by Rodriguez-Merchan et al.[15], with 23 patients submitted to 24 ankle arthroscopies for debridement and synovectomy with osteophyte resection. Of these patients, 22 had Hemophilia A, and one had Hemophilia B, with a mean age of 25.3 years (range 21–36). The mean preoperative pain was 6.6 (range 6–9), decreasing to 2.3 (range 1–3) postoperatively. Good clinical results and patient satisfaction were achieved in 22 cases (91.7%), while two patients experienced postoperative hemarthrosis requiring joint aspiration, and three patients required a second procedure with ankle arthrodesis due to persistent symptoms. Another more recent case series is described by Yasui et al.[16], with eight patients submitted to arthroscopic management, with a mean age of 29 years (range 18–54 years). The mean preoperative pain was 5.7, decreasing to 2.2 postoperatively. No hematological complications or surgical site infections were reported. In our experience, most patients were submitted to arthroscopic management, including synovectomy and osteophyte resection. In one patient, arthroscopy was used as a preparation method for ankle arthroscopic fusion, making it a useful therapeutic option for joint preservation or sacrifice.

Finally, alternative treatment options used less frequently have been described, such as joint distraction using the Ilizarov external fixator, reported by Van Vulpen et al.[17], showing their experience with three patients aged 22–33 years and followed up for 12 months. They observed a decrease in preoperative pain from 6.5 to a mean value of 1.2 at the end of the postoperative follow-up. Two patients experienced superficial infections successfully resolved with oral antibiotic therapy. Another procedure is Achilles tendon lengthening for the management of equinus deformities; Wallny et al.[18] presented 23 patients with a mean follow-up of 13 years (range 1–24), where 12 patients showed improvement in range of motion, ten remained unchanged, and one worsened. Therefore, they recommend reserving lengthening as a standalone procedure for equinus deformities less than 30°.

No postoperative hemorrhagic complications were documented, unlike some cohorts where postoperative intraarticular hemorrhages were reported. These results highlight the importance of joint management by hematology during the pre-and immediate postoperative period, multidisciplinary care, and the systematic use of a tourniquet during surgery. No surgical site infections were recorded in any patient.

The collected data from the selected articles are summarized in Figure 1.

Discussion

Congenital coagulation deficiencies such as Hemophilia A and B, Von Willebrand disease, and other rare coagulation defects like factor VII deficiency are uncommon pathologies

that, in severe cases, can lead to joint degeneration and functional limitation, primarily affecting the hip, knee, elbow, and ankle[19]. Numerous publications are on managing hip and knee arthropathy, but literature on the tibiotalar joint is scarce.

The number of available patients to evaluate the surgical management of ankle arthropathy due to hemarthrosis is limited. In our study, 15 patients were included, including patients with Hemophilia A and B, Von Willebrand disease, and factor VII deficiency, whose surgical management needs were determined over time based on radiological findings related to tibiotalar degenerative changes and clinical assessment, which involves not only pain qualities but also a range of motion and angular deformities. Therefore, one of the three available surgical management options (arthroscopy, arthrodesis, and arthroplasty) was chosen alone or combined with other procedures (ligament reconstruction, periarticular osteotomies, or Achilles tendon lengthening).

In our case series, those with severe pathologies may require surgical interventions in more than one joint, consistent with what has been described in the literature[19,20].

Despite the small number of patients, an improvement in pain and a return to daily activities were evident, similar to what has been reported in different cohorts found in the literature review, thus impacting the quality of life of a vulnerable population.

Conclusion

Regardless of the technique used, surgical management has a good clinical response, decreasing pain in patients after conservative management failure, translating into patient satisfaction. The most frequent surgical procedure was arthroscopy with synovectomy and osteophyte resection, in line with a trend towards joint preservation techniques, differing from more aggressive procedures such as joint replacement and arthrodesis for older patients. However, there is no consensus on the first-choice therapeutic option for each patient. Therefore, in young patients with a preserved range of motion and Takakura 0-I-II degenerative changes, the arthroscopic option would be considered after medical management failure, with osteophyte resection and synovectomy, possibly requiring additional soft tissue management and realignment osteotomies. But in cases where it is not possible to consider a conservative approach, we can consider arthrodesis in patients with Takakura III-IV tibiotalar arthritis with angular deformity of the hindfoot and loss of range of motion, while arthroplasty is considered in patients who preserve some tibiotalar mobility, in addition to maintaining alignment.

The main limitation of our study is the small sample, which makes it difficult to gather a more homogeneous group to determine if a certain surgical procedure is superior to others.

Further studies are also needed to objectively assess the impact of surgical intervention using pre-and postoperative functional scales.

More studies are necessary to reflect the impact of implementing public health policies, increased access and coverage of services, and primary prophylaxis, and whether these measures reduce sequelae in the adult population.

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Original Article

Suprapatellar nail – the gold standard in the treatment of tibia fractures

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Abstract

Objective: Demonstrate the experience of the team of leg and foot surgeons in tibia instrumentation by the suprapatellar approach for all tibia fractures that meet the indication of an endomedullary nail over three years.

Methods: Forty patients were operated on, and after applying inclusion and exclusion criteria, 14 were excluded, totaling 26 patients. The Olerud & Molander (0–100) and Lower Extremity Functional Scale (LEFS) (80/80, 100%) scores were used. Knee pain was evaluated by subdividing the knee into six quadrants to assess the anatomical location of the discomfort.

Results: The mean Olerud & Molander was 76.92, and the mean LEFS was 72.33. Five patients presented pain in the knee quadrant 3, reproducing this at maximum knee flexion, and one in quadrant 5, the site of the proximal locking nail, which resolved with its removal. None presented pain at the site of nail entry or femoropatellar pain.

Conclusion: Suprapatellar nail instrumentation for tibia fractures has become the gold standard in treating these fractures in the Cirujanos Especialistas en Piena e Pie due to its technical advantages and favorable postoperative evolution.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Bone nails; Fracture fixation, intramedullary; Tibial fractures.

Introduction

Fractures of the proximal and distal third of the tibia are a challenge for the trauma surgeon, especially when the indication of osteosynthesis is an endomedullary nail given its biological and mechanical advantages[1-3] and for having less incidence of material removal compared to osteosynthesis with plate[4]. To avoid traction of the patellar tendon on the proximal fragment of the tibia, in 1996, Tornetta[5] described the medial parapatellar approach, arthrotomy, and lateral patellar subluxation, with the patient in a semiextended position. In 2006, Dr. Dean Cole described the suprapatellar approach we know today as a modification to the grand approach of Sanders et al.[6]. Over time, the use of this technique gained popularity due to its advantages and its classic indication in extraarticular fractures of the proximal third, extended to the reduction and osteosynthesis of tibia fractures at all levels. The objective of this study was to demonstrate the experience of the Cirujanos Especialistas en Piena e Pie (CEPP) team (Specialist Surgeons in Leg and Foot) in suprapatellar approach for the placement of endomedullary nail to show that this technique is a less demanding and given the semiextended position it helps the reduction and control of the fragments, this being the main indication of endomedullary interlock in the CEPP team, leaving the trans or parapatellar approach with the knee in 90º as the second option.

Methods

The CEPP team operated on 40 patients at the Dupuytren Institute in Buenos Aires from July 2018 to December 2021. The inclusion criteria were patients with tibia fractures with indication of osteosynthesis with endomedullary nail

Study performed at the Instituto Dupuytren, CABA, Buenos Aires, Argentina.
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of suprapatellar approach (whether proximal, diaphyseal, or distal fractures) and follow-up greater than six months. All patients were operated on within ten days of the initial trauma. The exclusion criteria were patients with open physis and patients scheduled to have the procedure as a second surgery (review) for some complication. Among the operated patients, 14 were excluded due to not meeting the abovementioned criteria. Twenty-six patients were analyzed, and two patients had bilateral tibia fractures. The main cause of the fractures was a motorcycle accident. The patients were classified according to AO/OTA, and the Gustilo and Anderson classification was used for exposed fractures. A retrospective analysis of the postoperative outcomes of the included patients was performed. The Olerud and Molander Scores (0–100) and the Lower Extremity Functional Scale (LEFS)(80/80, 100%) were used[7,8]. The patient's knees were divided into six equal quadrants to evaluate postoperative pain; the patients were asked to point a finger in which quadrant the pain was located (Figure 1).

Surgical technique

During the physical examination, we recommend verifying the mobility of the patella in laterolateral and avoiding this approach in cases of ankylosis or very rigid patellofemoral space. Osteoarthritis is a relative contraindication; this approach can help remove osteophytes, and with the aid of anesthesia and poor muscle tone of older patients, the patella can be easily dislocated. The patient was placed in a dorsal decubitus position on a radiolucent surgical table, with the healthy contralateral limb unevenly downwards to avoid overlapping images in the profile view. An ipsilateral enhancement below the gluteus may be necessary to place the knee in a neutral position. We operated with a hemostatic cuff and a sterile support below the knee to give 10º–20º flexion (Figure 2). The incision was made from the upper part of the patella towards the proximal end, approximately 3 cm, through the skin, cellular tissue, and quadriceps tendon (Figure 3). We placed the index finger through the joint; if it was not tight and the patella could be easily maneuvered, we slid the protective sheath consisting of the outside inward of the protective handle with the outer sheath, the radiopaque metal protective sheath, and then the cannulated tip (Figure 4). To facilitate the entry, we used a blunt tool to push the patella forward (Figure 5). If the patellofemoral space was tight, we released tension by widening the approach of the quadriceps tendon below the skin; if this is not enough, we can perform a percutaneous release of the lateral facets of the patella and allow its dislocation. We placed the guide pin

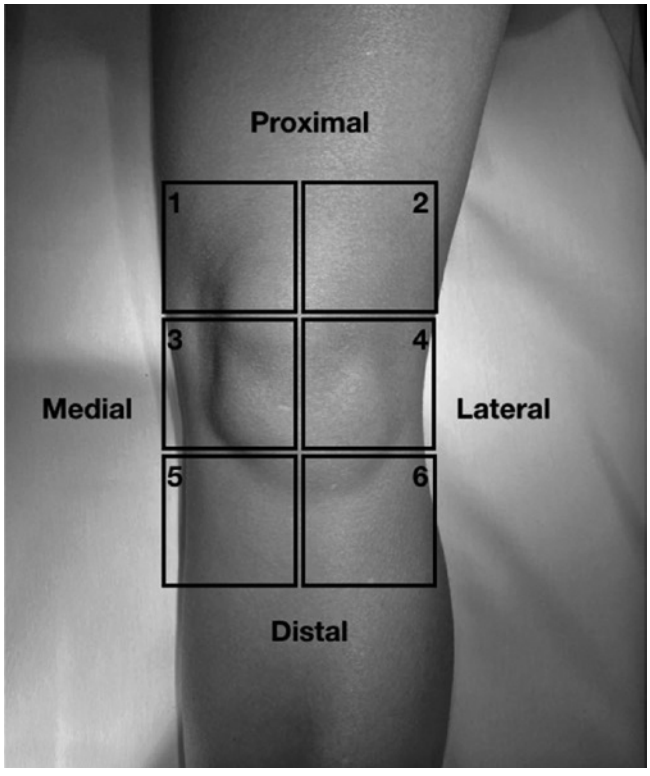

Figure 1. Division of the knee into 6 quadrants to identify areas of postoperative pain.
Source: Sanders et al. (2014)

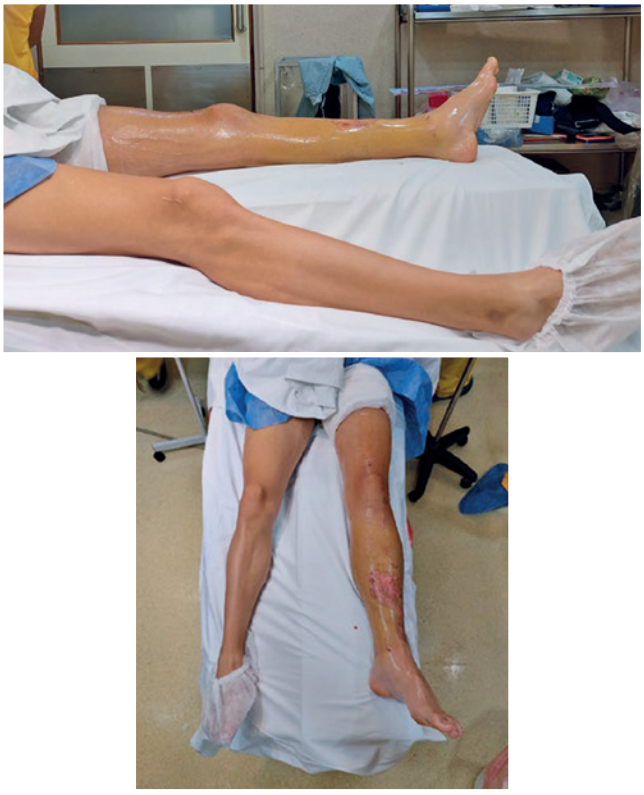

Figure 2. Patient in dorsal decubitus position with the healthy limb unevenly downward to avoid overlaps in the profile view.

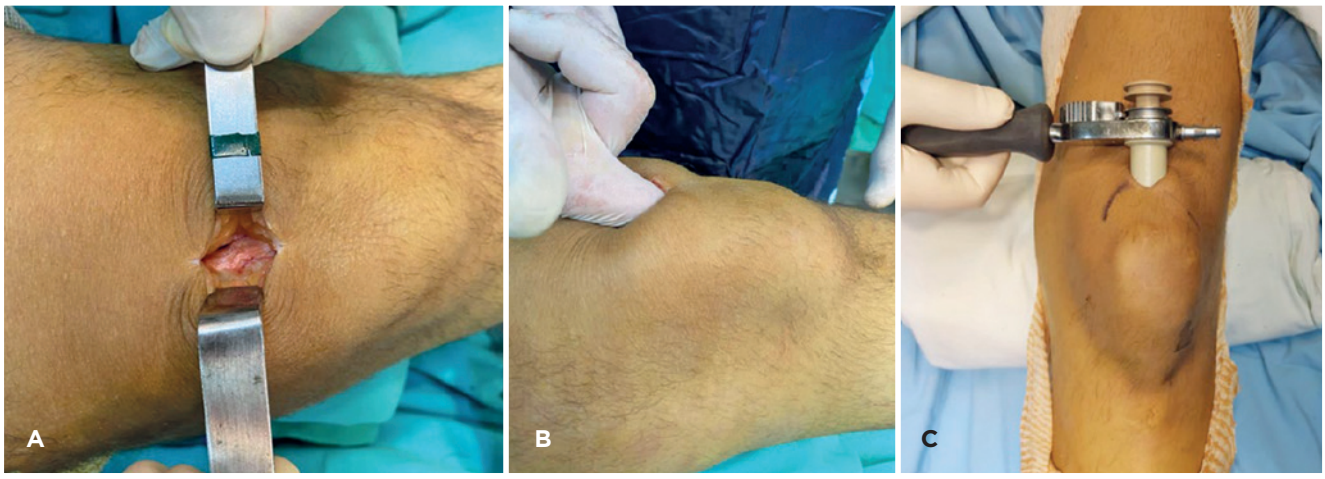

Figure 3. (A) suprapatellar approach; (B) index finger entering the patellofemoral space, indicating that the space may be instrumentable. (C) Instrumentation of the space with the protective sheaths.

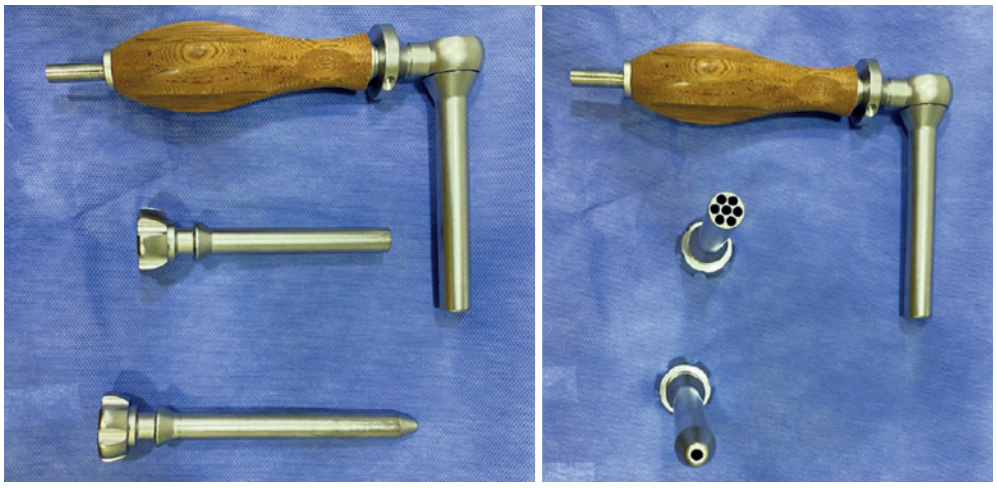

Figure 4. Protective sheaths, from top to bottom, external sheath with handle and adapter for suction; screened sheath for reorientation of the guide pin, and the internal sheath with a blunt cannulated tip.

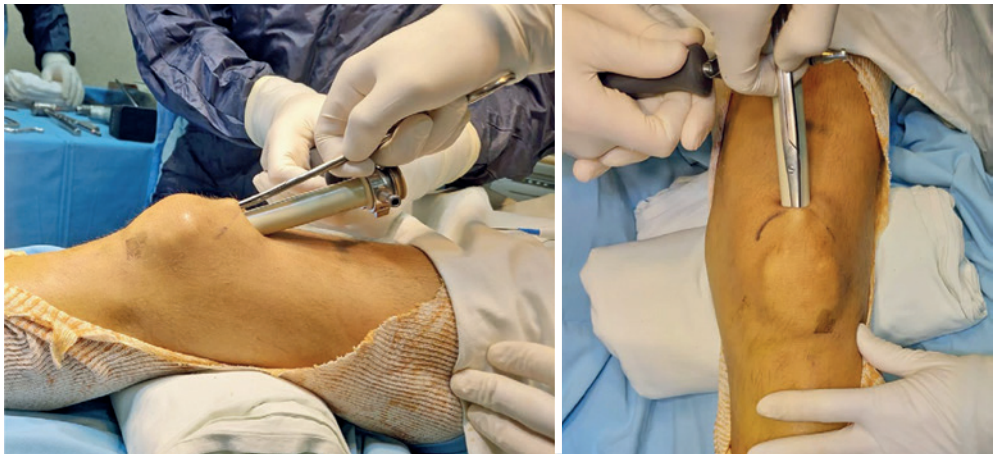

Figure 5. Profile and front view where, with a blunt tool, we pull the patella towards the front, gaining a few millimeters for the placement of the protective sheaths.

through the cannulated or screened tip at the insertion site, 2 mm medial to the lateral spine in line with the axis of the tibia in the front view and adjacent and anterior to the articular surface in profile view[9], controlling the direction of the guide pin from the handle of the protective sheaths, directing the tip of it towards the posterior cortical most parallel to the axis of the tibia. In a strict profile, the femoral condyles must be aligned, and in the front view, the external tibial plateau must cut the head of the fibula in the middle, and we have the spines of the tibia deployed and with good visualization. We advanced with the guide pin, removed the internal tip, and drilled the entry site with the cannulated starter drill (Figure 6). Afterward, we removed the guide pin, passed the olive-shaped endomedullary guide, slightly curved to connect the fragments, and placed the distal pole in the center of the ankle joint. Because the patient was in a semiextended position, the reduction of the fragments and the control of the axes was easily performed, as is the intraoperative radiological examination, since we did not have to flex the hip and knee in the 90º position. The drilling started with the front cutting cutter, which was 1 mm longer than the nail we would place. In case of segmental fractures, we hold the intermediate fragment with a tip clamp to prevent rotation and thus the detachment of soft tissue from it[10] (Figure 7). We measured the length of the nail using a radiopaque ruler under fluoroscopic guidance (from the ankle physis to the anterior edge of the tibial plateau). We must remove the radiopaque sheath before nail placement to avoid jamming. In case of proximal or distal fractures (41 or 43 according to AO/OTA classification), these fragments are first reduced either directly (plates, tip clamps, femoral distractor, or external tutor) (Figure 8) or prepared to be reduced when

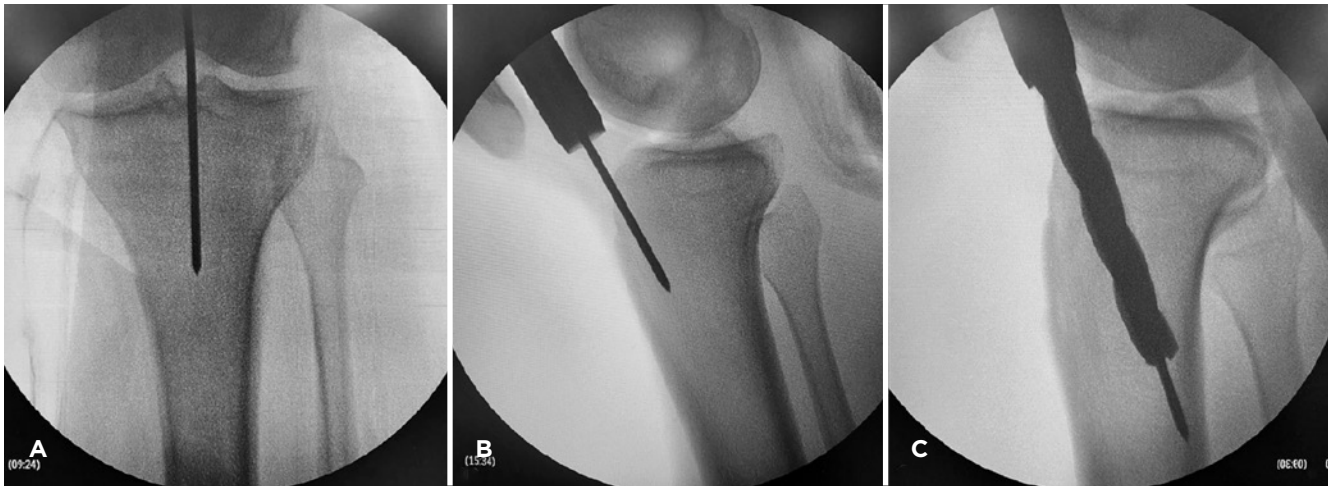

Figure 6. (A) front view where the guide pin is placed medial to the lateral spine. (B) profile view, the pin is positioned adjacent to the articular surface more parallel to the posterior cortex. (C) initial drilling to open the spinal portal.

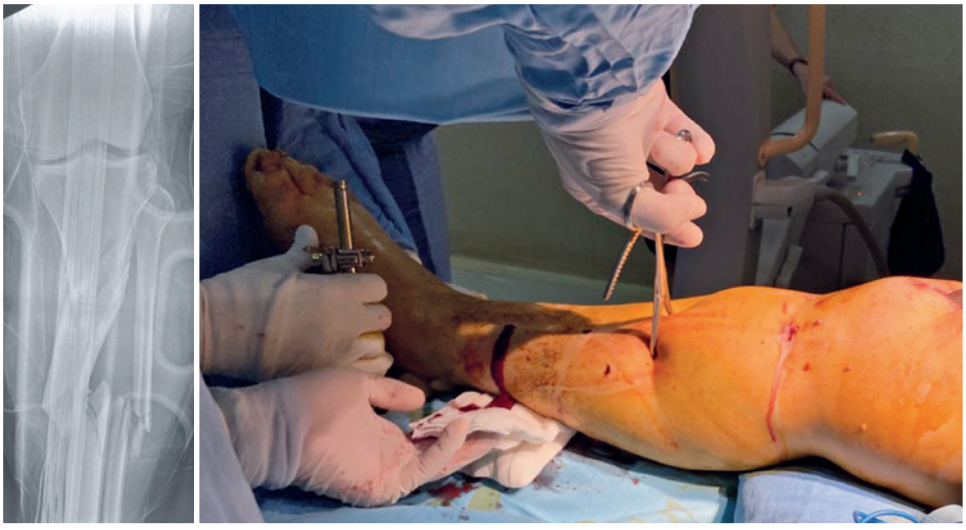

Figure 7. The intermediate fragment is secure during drilling to prevent its rotation.

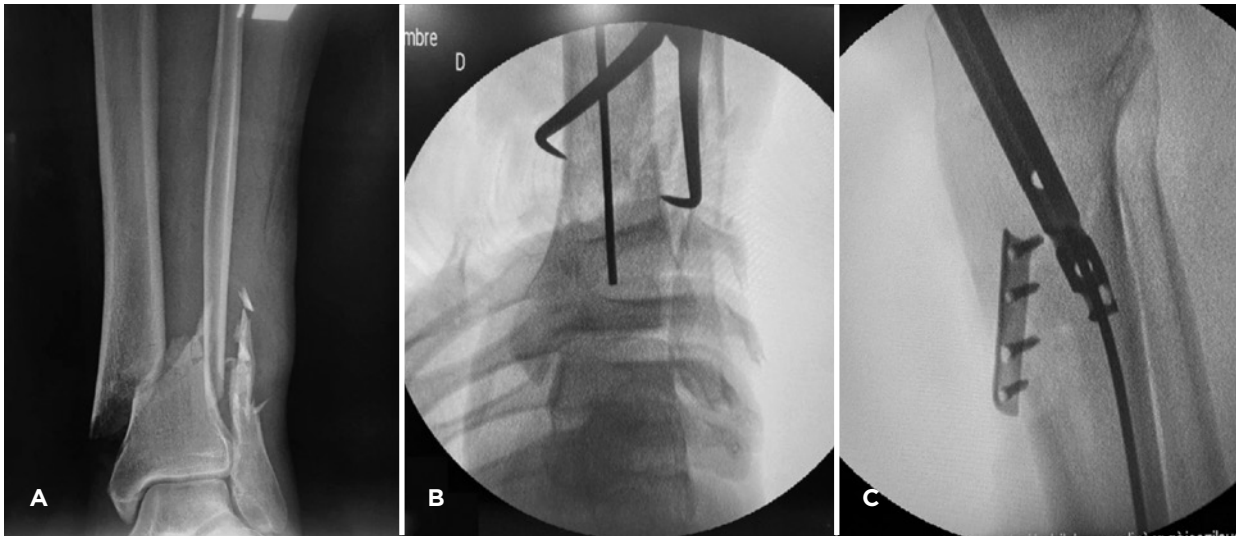

Figure 8. (A) Displaced distal tibia fracture. (B) Reduction with tip clamp and placement of intramedullary guide in the center of the ankle. (C) Reduced proximal third fracture with monocortical tube third plate.

the nail is placed with post screws or Steinmanns (which were then changed by screws when the nail was locked)[11], and one or more can be used (as a palisade method)[12] to mark the path of the nail and avoid misalignment in the different planes (Figure 9). Although the position of the patient helps in the reduction, especially for proximal fractures (since the tension of the patellar tendon is avoided), this does not prevent its displacement after the interlocking, no matter how appropriate the entry site may have been, so we must always start by reducing it (directly or indirectly). Once the tibia had been instrumented, we began by locking the distal end of the nail with a hands-free technique. Then, we finalized the reduction details directly by manipulating the nail using the insertion handle. The nail plug was placed through the patellofemoral space under fluoroscopic guidance.

To avoid injury to the patellofemoral space, we recommended preventing the protective sheaths from moving the place during drilling. Some marks allow the sheath handle to be fixed to the femur with a Steinmann, the external protective sheath should not be removed during nail placement, and the knee joint should not be extended during instrumentation[13]. Once the osteosynthesis is finished, we aspirate the joint with a physiological solution.

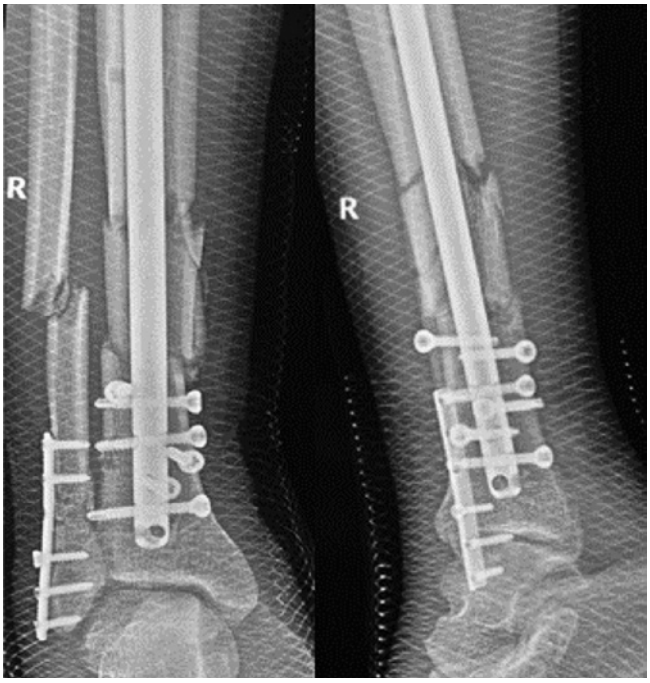

Figure 9. Distal tibia fracture where the post screws are visible in the different planes to avoid the deflection of the distal fragment.

Results

Forty patients were operated on, and 26 were included in the analysis, according to the inclusion criteria, followed by postoperative clinical and radiological assessment in December 2021. Among the patients, nine were women, 17 were men. The mean age was 41.5 (range 22–84). The mean follow-up was 17.69 (6–35 months).

The patients were classified according to AO/OTA tibia fractures, and the Gustilo and Anderson classification was used for exposed fractures. Regarding the distribution of the affected tibia region, three were from the proximal third, 13 from the medial third, and 13 from the distal third. Fourteen had exposed fractures, two Gustillo 1, six Gustillo 2, and six Gustillo 3.

Regarding the cause of the fractures, 14 suffered a motorcycle accident, six fell from their own height, four had car accidents, and two had sports trauma.

The Olerud & Molander mean was 76.92, and the mean LEFS was 72.33.

Five patients (19.23%) presented discomfort in the knee (quadrant 3) at the maximum flexion, a condition that did not generate limping, and one (3.84%) patient presented discomfort in the knee (quadrant 5), locking site, which resolved with its removal. None presented pain at the site of nail entry or femoropatellar pain.

Immediate postoperative complications: one (3.84%) patient to whom we released the lateral facets of the patella suffered postoperative hemarthrosis, and we had to perform arthroscopic debridement and due to lack of adherence to kinesiology evolved with knee stiffness that after mobilization under anesthesia and rehabilitation regain normal mobility. One (3.84%) patient had wound dehiscence, and another (3.84%) had skin necrosis at exposure sites, which was resolved by plastic surgery-total immediate complications 11.52%, which resolved without sequelae.

Isolated complications: two (7.69%) nail replacements, one due to lack of consolidation in a proximal tibia fracture (hypertrophic pseudoarthrosis) due to the lack of locks that stabilize the nail (it only had the dynamic lock) and the other patient due to chronic osteomyelitis (Table 1).

Discussion

Many studies have been published to compare the suprapatellar vs. infrapatellar approaches[14-16], demonstrating some advantages the former has over the latter (anterior knee pain, better fragments reduction, less radiation exposure time), even greater precision at the insertion site in the coronal plane[15,17]. Soft tissue would appear less exposed to trauma with the semiextended position[18]. No differences were found in the learning curve between these two techniques[19]. With the infrapatellar approach, whether transtendon or paratendon, anterior knee pain may exceed 70% of cases, affecting more the young population[16,20-22]. This condition may cause scarring of the patellar tendon, posterior shortening, or the iatrogenic incision of the infrapatellar branches of the internal saphenous nerve among others[23,24]. The percentage of misalignment in proximal fractures by the infrapatellar approach may reach 58%[25]. Although the patellofemoral instrumentation appeared aggressive, Sanders et al.[6] performed pre- and postoperative arthroscopy in 26 patients with 12-month follow-up, and only two presented with grade 2 chondromalacia but no anterior knee pain, there was no evidence of heterotopic ossifications around the debris of the intramedullary drilling. Fifteen cadaveric limbs

Table 1. Evaluation of patient

Patient	Age	Cause	AO + G&A	Follow-up (Months)	Olerud	Pain Status	LEFS
1	28	Motorbike	42B2 + GIIIB	23	100	No pain	93.8
2	34	Car	42B3B + GI	12	80	No pain	76.3
3	30	Car	43B2 + GII	8	80	3	66.3
4	53	Motorbike	423C + GI	30	75	No pain	76.3
5	42	Sports trauma	43B2	8	85	No pain	77.5
6	51	Motorbike	42C2	34	90	No pain	81.3
7	32	Motorbike	L – 43A2 + D – 43B2 GIIIB	9	80	No pain	76.3
8	49	Motorbike	L – 42A2 + D – 43C1	20	80	No pain	76.3
9	53	Car	42C3 GIIIB	23	75	No pain	72.5
10	23	Motorbike	43B2 + GIIIB	35	85	No pain	77.5
11	32	Fall from the own height	43A3	12	85	No pain	77.5
12	33	Motorbike	42C2 GIIIA	20	80	No pain	76.3
13	84	Fall from the own height	42A2	17	75	No pain	72.5
14	29	Sports trauma	42B2	33	85	No pain	77.5
15	29	Motorbike	42A2 + GII	15	85	No pain	81.3
16	43	Fall from the own height	43A1	12	85	No pain	72.5
17	34	Motorbike	42A2a + GII	24	80	No pain	76.3
18	25	Motorbike	42B2 + GII	19	100	3	86.3
19	84	Fall from the own height	41A2	15	20	No pain	28.7
20	34	Motorbike	42A2	7	55	6	53.8
21	43	Motorbike	43A1	10	90	No pain	81.3
22	49	Fall from the own height	43A2	8	60	No pain	63.7
23	42	Motorbike	42A3 + GI	24	100	3	93.8
24	22	Motorbike	42A3	6	60	3	56.3
25	79	Fall from the own height	42A1	20	35	3	26.3
26	27	Motorbike	41A2 GIIIB	15	75	No pain	72.5

were instrumented with a suprapatellar nail with a medial arthrotomy and lateral patella dislocation, finding injury to the internal meniscus in 6.7%, injury to the medial articular edge in 13% (damage of 1 mm to 2 mm), damage to the intermeniscal ligament in 20%, and abrasion of the patellar fat. These results cannot be clinically applied, and it is believed that medial arthrotomy leads to initiating the portal a little more medial than it should[26]. The pressure exerted by the protective sheaths on the patellofemoral space is 3.83 MPa compared to 1.26 (3 times more) exerted by the 90º position when we instrument the tibia in an infrapatellar approach[27], but for apoptosis to occur on the cartilage cells, a pressure of 4.5 MPa is needed as demonstrated in bovine cartilage[28].

The risk of knee sepsis after the suprapatellar approach, especially in exposed fractures, may be a consideration, but multicenter studies have shown that this is not the case[29,30].

In case of facet release, caution is advised regarding hemarthrosis. We believe this may be due to the arrangement of the vessels of the peripatellar ring around the patella susceptible to being injured with the incision. In our series, we had a patient who then underwent arthroscopic debridement and knee mobilization under anesthesia to regain mobility.

Due to lack of consolidation, two nails were removed, one due to lack of proximal stability in an unstable fracture since it only had the dynamic lock placed, and the other patient due to osteomyelitis after osteosynthesis in an exposed fracture. The same was removed conventionally from the transtendon and knee in 90º flexion without complications at the approach site. In our series, five patients presented residual pain at maximum knee flexion in quadrant 3 but without limping, and one in quadrant 5. Sperone et al.[31], in a series of six patients with proximal tibia fracture treated with suprapatellar placement endomedullary nail, divided the knee into three thirds (extraarticular proximal, purely articular, and extraarticular distal), and each of these thirds was subdivided into internal, middle and external. One patient had pain in the internal extraarticular distal third related to the proximal locking nail, and two patients in the middle distal extraarticular related to the fracture focus, the remaining quadrants reported no pain.

Conclusion

The semiextended position in which the patient is placed helps reduce fractured fragments and better control of the axes, whether in proximal, half-diaphyseal, or distal fractures. The advantages of suprapatellar vs. infrapatellar instrumentation have been demonstrated in different studies. In our series, no disadvantages were found except the possibility of hemarthrosis when we released the facet, and five patients had pain in quadrant 3 at maximum knee flexion. We had no residual pain in the suprapatellar incision because it is far from the infrapatellar nerve branches, it does not address the tendon, and the scar does not produce ailments either. There were no complications with the quadriceps tendon, with the placement of the endomedullary nail by the suprapatellar approach, the gold standard adopted by our team. This study is the first group of patients that we were able to evaluate, and we are committed to continuing incorporating patients to have a larger study population and not only compare it with the infrapatellar approach but with the medial and lateral parapatellar also to find answers to residual pain in quadrant 3.

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Original Article

Content validation of the progressive collapsing foot deformity classification

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Abstract

Objective: The aim of this study was to validate the content accuracy of the PCFD classification.

Methods: A survey-based study distributed through international foot and ankle programs among surgeons with vast experience in practice to analyze the terminology and interpretations used in the PCFD classification. A returned survey with completion of all questions filled out was considered a valid record. Descriptive statistical analysis was applied using SAS version 9.4 for data processing, statistical analysis, and visualization.

Results: Eighty-two valid returned surveys from surgeons in 22 countries with a mean of 16 years in clinical practice were included. Among them, 80.5% of the participants considered the PCFD classification helpful in guiding decision-making, 79.3% thought it helped facilitate diagnosis and documentation, 58.5% found it easy to use, 30.5% were unlikely to use the classification, and 29.3% noted that the interpretation of the classification was not clear. Regarding the accuracy, clarity, and clinical relevance of terminology, 42.7% had difficulty in using increased foot and ankle offset, 35.4% had difficulty in using increased hindfoot moment arm, 19.5% found peritalar subluxation not clear, 13.4% found the term sinus tarsi impingement an unclear description, and 8.5% found forefoot varus difficult to diagnose.

Conclusions: This international survey-based study provides readers with insights into the content of the PCFD classification. The findings indicate that some terminologies used in the PCFD classification are not universally understood. The authors recommend that modifications may be beneficial to enhance the accuracy and user-friendliness of the PCFD classification.

Level of Evidence II; Retrospective study.

Keywords: Adult; Data accuracy; Flatfoot; Foot deformities; Posterior tibial tendon dysfunction.

Introduction

The exact etiology of the adult-acquired flatfoot deformity (AAFD) remains unclear. However, it was initially described as a result of posterior tibial tendon failure, hence the original term posterior tibial tendon dysfunction[1-3]. Johnson and Strom were the first to classify this disease process as a 3-stage classification system[2], modified by Myerson[4] and subsequently by Bluman et al.[5]. To improve standardization of diagnosis and treatment, a consensus group recently introduced the terminology and classification of Progressive Collapsing Foot Deformity (PCFD). This classification includes two stages (stage 1 flexible deformity and stage 2 rigid deformity) and five classes (A = hindfoot valgus deformity; B = midfoot/forefoot abduction deformity; C

Study performed at the Department of Orthopedic Surgery, University of Colorado School of Medicine, Denver, CO, USA.

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= forefoot varus deformity/medial column instability; D = peritalar subluxation/dislocation; and E = ankle instability)[6].

The PCFD classification has been found to have moderate interobserver reliability, very good intraobserver agreement[7], and good diagnostic accuracy[8]. The aim of this study is to validate the content accuracy of the PCFD classification system, an important step when a newly introduced classification system is being widely adopted for clinical use.

Methods

Study design

This study was exempted from Institutional Review Board (IRB) review. An online survey was distributed through REDCap to foot and ankle fellowship training programs worldwide to analyze the terminology and interpretations associated with the PCFD classification (Appendix 1). Foot and ankle consultants from 22 countries who willingly agreed to participate in this study were included. The demographic data from the participants were collected, including practice country/region, years of clinical practice since fellowship, and surgical volume per month before the pandemic in treating foot/ankle and flatfoot deformities. All data was anonymous, and no personal information was collected (Figure 1).

Each participant was provided with detailed instructions on using the PCFD classification system with the original paper[6] (Figure 2), a video presentation, and one case example to demonstrate how to use the classification. Following the instructions, three clinical cases were presented with a combination of history, physical examination videos,

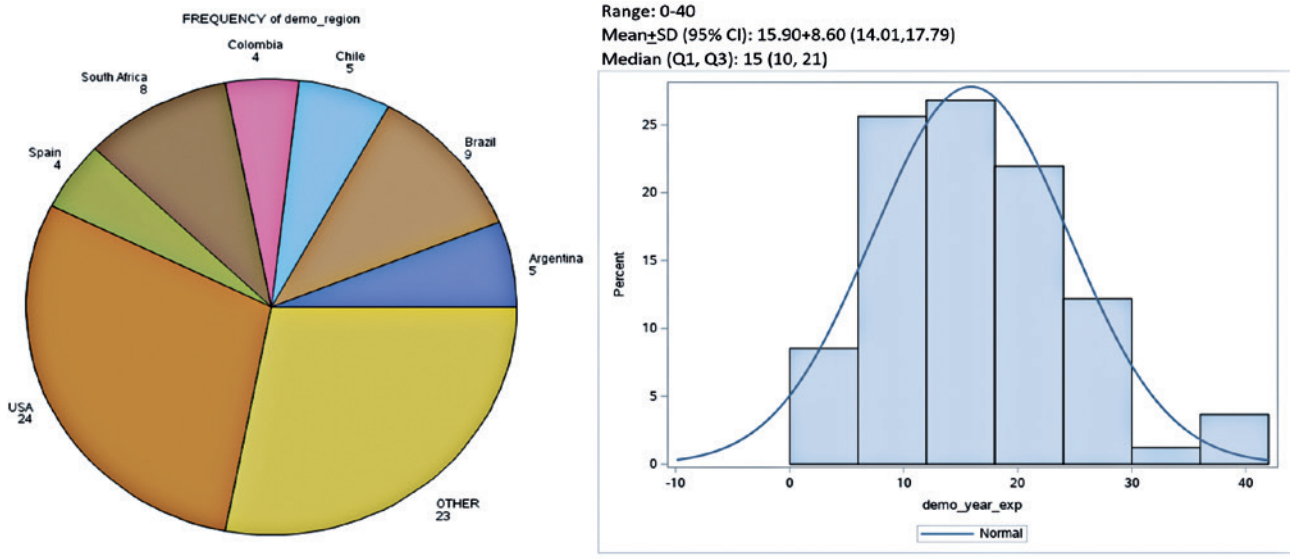

Figure 1. Demographic data of the surgeon's participant.

Stage I (flexible)		Stage II (rigid)
Types of deformity (classes – isolated or combined)		
	Deformity type/location	Consistent clinical/radiographic findings
Class A	Hindfoot valgus deformity	Hindfoot valgus alignment Increased hindfoot moment arm, hindfoot alignment angle, foot and ankle offset
Class B	Midfoot/forefoot abduction deformity	Decreased talar head coverage Increased talonavicular coverage angle Presence of sinus tarsi impingement
Class C	Forefoot varus deformity/medial column instability	Increased talus–first metatarsal angle Plantar gapping first TMT joint/NC joints Clinical forefoot varus
Class D	Peritalar subluxation/dislocation	Significant subtalar joint subluxation/subfibular impingement
Class E	Ankle instability	Valgus tilting of the ankle joint

Figure 2. The progressive collapsing foot deformity (PCFD) classification.
Source: Myerson et al. (2020).

photographs, and radiographic images[2] to test participants' understanding of the PCFD classification. The full survey was then provided to gain participants' feedback on the PCFD classification system, including each stage and class. For general opinions on the PCFD classification, the questions focused on necessity, applicability, and ease of use. For the content of each stage and class, questions focused on ease of use, accuracy, and clarity. A rating scale of 1–5 ("1" for strongly disagree, "2" for disagree, "3" for neutral, "4" for agree, and "5" for strongly agree) was provided to assess the degree to which a participant agreed or disagreed about an item, then multiple-answer questions followed to investigate the reasons for agreeing or disagreeing. Open-answer questions were also provided to collect subjective opinions not covered by answer options in the closed-ended questions.

Survey evaluation and data processing

Participants without foot and ankle fellowship training or uncompleted surveys missing information in one or more sections/questions were considered invalid responses. The online link for the survey was kept active for three months and then closed for data processing and evaluation. Invalid responses were excluded during the data cleaning process.

Statistical analysis

The SAS software version 9.4 (SAS Institute Inc., 100 SAS Campus Drive, Cary, North Carolina 27513, USA) was used for data processing, statistical analysis, and visualization. Descriptive statistical analysis was applied. Means with standard deviations (SDs) were used to describe numerical data. Bar charts were utilized to describe categorical data, and pie charts to describe proportional data. Each selection from multiple-answer questions was counted independently to reflect actual weight and option percentage. All numbers were accurate to one decimal place. Subjective opinions and evaluations were analyzed separately.

Results

Eighty-two valid anonymous surveys were received, meeting the recommended sample size for an e-survey. This number was considered statistically sufficient for inquiring into PCFD content[9]. The 82 surgeon participants had been in practice for a mean of 15.9 years, treating 17.5 cases of foot and ankle deformities, including 3.42 cases of flatfoot monthly (Table 1). Over 90% of the participants agreed with the importance of a classification system for the flatfoot for clinical and research purposes, 73.2% thought they did not need a classification system for diagnostic and treatment purposes, 69.5% would use the classification in their daily practice while 14.7% would not. The latter group would not use the PCFD classification; 66.7% found it difficult to use, 41.7% found it not advantageous, and 16.7% stated they had never used a classification system (Figure 3). Among the total, 58.5% found the PCFD classification easy to use, 26.8% had a neutral opinion, and 14.7% found it difficult to use. The reasons for difficulties were diagnosis criteria and interpretation (75%), the five classes (33.3%), concepts and terminology (16.7%), and the 2-stage system (8.3%) (Figure 4). Out of the total, 46.3% agreed that weight-bearing computed tomography (WBCT) would benefit their patients, 22% did not agree with using WBCT either due to lack of access or thought that WBCT was unsuitable for incorporation into clinical practice, and 29.3% thought it would be beneficial to have independent diagnostic criteria for flatfoot based on clinical and radiographic findings, and WBCT results depending on accessibility to these three types of examination, instead of mixing the different types of exams.

Regarding the five classes, for classes A, B, C, and E, over 90% of the participants were familiar with using it and comfortable incorporating it into their practice, while the familiarity and comfort in class D were 87.8% and 80.5%, respectively. Among the 19.5% who were not comfortable with using it in class D, 14.6% considered the definition (peritalar subluxation) unclear, 3.7% were uncomfortable with the concept, 1.2% had no idea what the term "peritalar subluxation" itself was, and 2.4% had no idea how to diagnose it (Figure 5).

Table 1. Demographic data of participant's clinical experience.

Variable	Sample Size	Range	SD	Mean (95%CI)	Median (Q1, Q3)
Years of clinical practice since fellowship	82	0-40	8.60	15.90 (14.01, 17.79)	15 (10, 21)
Flatfoot deformities/ Month	82	0-15	3.26	3.42 (2.71, 4.14)	2 (1, 4)
Foot & ankle deformities/ Month	81	1-60	14.09	17.57 (14.45, 20.68)	15 (5, 25)

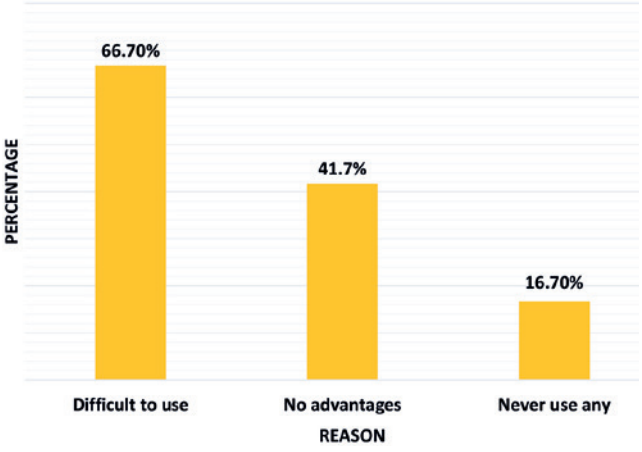

Figure 3. Reasons not to use the PDCF classification.

The ease of use for diagnosis criteria of each class was investigated, especially concerning accuracy, clarity, and relevance. Among the total, 35.4% reported that "increased hindfoot moment arm" in class A was difficult to use (19.5% considered the description unclear, 11% did not know how to diagnose it, 5% considered the term inaccurate, and 5% considered this concept was not suitable for clinical use), 42.7% reported that "increased foot and ankle offset" in class A was difficult to use (14.6% considered the description unclear, 13.4% did not know the term, 8.5% did not know how to diagnosis it, and 6.1% considered this concept was not suitable for clinical use) (Figure 6), 13.4% reported that the term "Sinus tarsi impingement" in class B was difficult to use (4.9% considered "sinus tarsi impingement" had an unclear description with a missing reference range for diagnosis, 4.9% did not know how to diagnose it, 3.7% considered the term inaccurate, and 1.2% were not familiar with the term itself) (Figure 7).

Discussion

Reliability (i.e., precision) and validity (i.e., accuracy) are required for a classification system to be able to guide users[10-12]. The precision of a classification system is generally evaluated by testing inter- and intra-observer reliabilities[10,13], while accuracy applies to the content of the classification, such as terminology and its interpretation. In other words, does the instrument measure what it is intended to do[14]? A good classification for clinical practice and research is expected to categorize and interpret the attribute of

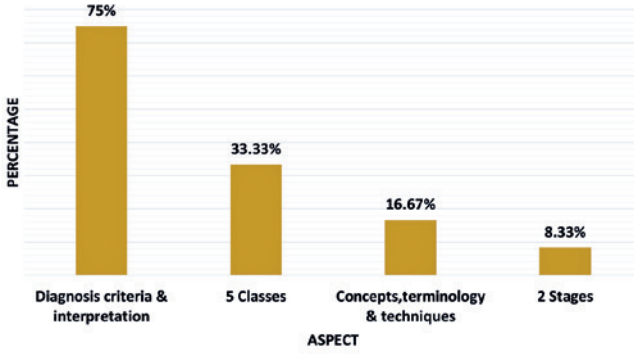

Figure 4. Reasons why some participants chose not to use the PCFD classification and aspects of the classification that were difficult to use.

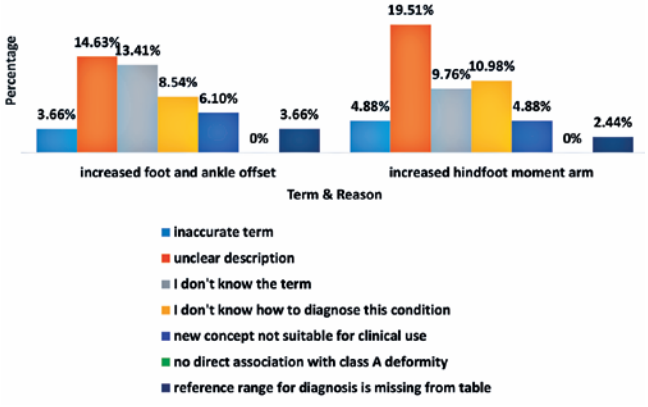

Figure 6. Reasons why class A is difficult to use.

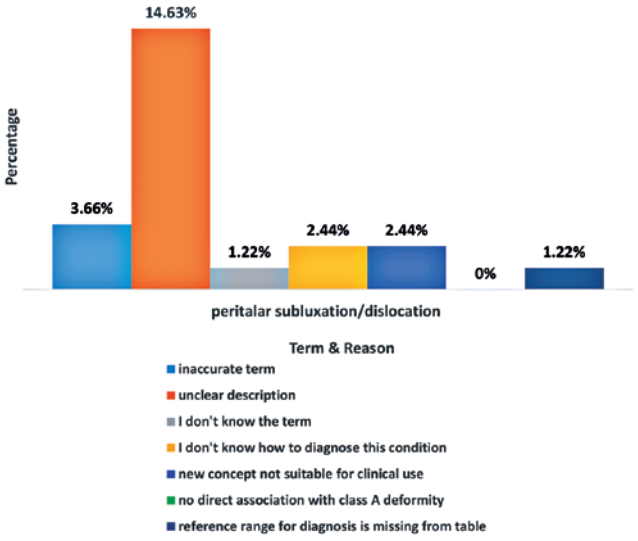

Figure 5. Reasons why class D is difficult to use.

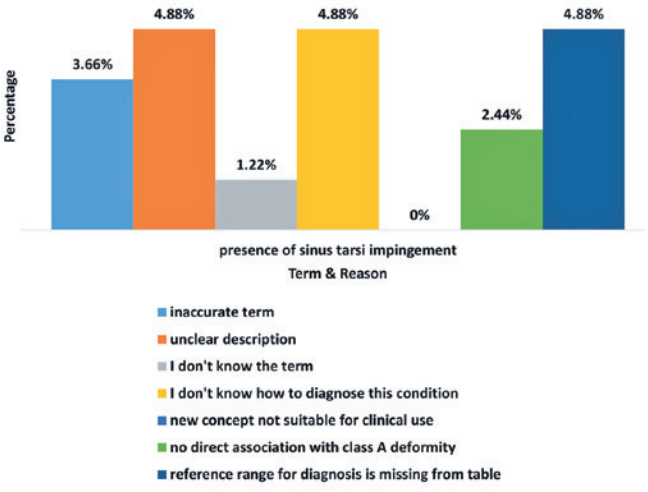

Figure 7. Reasons why class B is difficult to use.

interest with precision and accuracy[15,16]. Lee et al.[7] tested the reliability, Li et al.[8] evaluated the diagnostic accuracy, while our study investigated the content validity of the PCFD classification.

Most participants in this study agreed that a new classification system was needed for the flatfoot deformity, consistent with the statements of the consensus group for introducing the PCFD classification[6]. Regarding the "easy to use" aspect of this new classification, 14.7% reported "difficult to use," with 75% indicating difficulty, and the primary reason for these difficulties was the diagnostic criteria.

For the five classes, 100% had no difficulty with class A (hindfoot valgus), a very commonly applied term[2] supporting the previous finding that Class A had a high diagnostic rate (96.8%)[7]. However, regarding how to evaluate hindfoot valgus, the "hindfoot moment arm" and "foot and ankle offset" metrics had a high difficult-to-use rate of 35.4% and 42.7%, respectively. To date, there is no consensus on the best method for radiographic hindfoot measurement[17-20]. Saltzman and Khoury first described the hindfoot moment arm in 1995[21] using the lowest point of the calcaneus as the landmark to measure the hindfoot alignment. Arena et al.[22] reported that the hindfoot moment arm was a valid method with high intra- and inter-observer reliability with adequate delineation of the anatomical landmarks through a simple measurement, avoiding angular measurements, which are still imprecise. Neri et al.[23] compared multiple hindfoot radiographic alignment methods and reported that the hindfoot moment arm was subject to poor reproducibility among observers when trying to reach a consensus on the location of the lowest point of the calcaneus. The high susceptibility of hindfoot radiograph analysis to multiple errors led research to explore more accurate analysis on WBCT scans[19,20,24]. As a result, new measurements like "foot and ankle offset" and "calcaneal moment arm" were introduced[25]. "Foot and ankle offset" was developed as a 3D biometric WBCT measurement to represent an optimized biomechanical assessment of the relationship between the tripod of the foot and the center of the ankle joint[25,26]. It is a measurement exclusively used on WBCT scans[26-28].

Regarding the concepts of "sinus tarsi impingement" in class B and "subtalar joint subluxation/subfibular impingement" in class D, 13.4% and 8.5% considered the description unclear. Johnson and Strom, in their early descriptions of tibialis posterior tendon rupture, showed that pain could develop in the lateral tarsal region, worsening the flatfoot deformity and causing bony contact between the inferior aspect of the talus and the dorsal aspect of the calcaneus[2]. Malicky et al.[29] studied both concepts and reported the coexistence of calcaneofibular and sinus tarsi impingement in 100% of cases. However, Jeng et al.[30] stated that calcaneofibular and sinus tarsi impingement could occur separately in a reasonable percentage of cases. Moreover, Lalevee et al.[31] studied the correlation of peritalar subluxation with calcaneofibular and sinus tarsi impingements and reported the correlation between the peritalar subluxation and sinus tarsi impingement was statistically significant. Recently, Kim et al.[32] showed a strong "predictive value" correlating sinus tarsi impingement with talonavicular coverage and calcaneofibular impingement with hindfoot valgus in weight-bearing radiographs compared with WBCT[33,34]. There are no cut-off points to diagnose sinus tarsi and subfibular/calcaneofibular impingement clinically, radiographically, or on WBCT[31,32,35]. Li et al.[8] reported that users had difficulties with identifying and diagnosing subtalar subluxation and those impingements, explaining why there was a low misdiagnosis rate in class B (17.48%) and class D (26%)[8].

To incorporate the new WBCT technology in the diagnostic criteria of the PCFD classification, 46.3% of participants strongly agreed. WBCT has proved its significance in clinical practice by offering unique advantages, including improved spatial resolution, multiplanar 3-D assessments, minimizing rotational and positional bias, and bony superimposition under physiologic loading[36-39]. However, 22% of participants had doubts about the use of WBCT. In the PCFD classification, class D must mainly be diagnosed on WBCT scans; 19% of the participants in our study had problems with class D itself. Li et al.[8] reported a 26% misdiagnosis rate in class D, most of which were underdiagnosed[8]. It might be possible that participants were avoiding the diagnosis of this class because they may not have been familiar with it or were uncertain about how to apply it. Lee et al.[7] demonstrated that class D was the least agreed upon among observers when relying solely on weight-bearing radiographs. They emphasized the necessity of using WBCT to diagnose this class accurately[7]. In Lavelee's comparison with the refined classification, class D also received a lower interobserver reliability consensus as it was difficult to diagnose clinically and radiographically[40]. These results corroborate the findings of our study. In addition, foot and ankle offset[27,28], sinus tarsi impingement[29-31], and subfibular impingement[26,29-31,41] are concepts diagnosed mainly on WBCT. About one-third of the participants (29.3%) suggested that in the PCFD classification, those diagnosis criteria using WBCT should be separated from others depending on clinical examinations and weight-bearing radiographs.

Class C represents both forefoot varus and medial column instability and participants in our study had no difficulty with this class. Lalevee et al.[40] reported lower interobserver reliability in class C than other classes, which might be explained as forefoot varus and medial column instability being two separate entities described in the refined classification by Bluman et al.[5]. As a result, class C had a 9.52% underdiagnosis rate compared to a 1.6% overdiagnosis rate, that is, among 100 PCFD surgeon users in this study, 9.52% surgeons might miss a class C deformity. Moreover, the diagnostic cut-off point for medial column instability is obscure, making it susceptible to interobserver disagreement on clinical and radiological diagnostic reliability[42-46].

Class E refers to "ankle instability" and, in our study, had a high percentage of acceptance (Figure 8), and others had a high interobserver agreement[7,40]. Evidence, however,

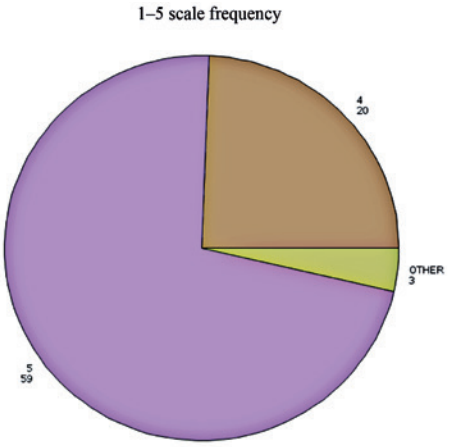

Figure 8. Preference evaluation of using class E in making diagnosis presented by 1–5 scale frequency.

supports the author's opinion that "ankle instability" is not an accurate term for a valgus ankle associated with a flatfoot since the ankle is not necessarily unstable. The authors suggest to use "ankle valgus deformity" for class E[5,47-49].

There are limitations in this study. Firstly, it did not cover extensive numbers of foot and ankle fellowship training programs worldwide. Secondly, a language barrier could limit some non-native English speaker's understanding of the PCFD classification and the survey used in this study. Thirdly, there was an inevitable overlap in this study population with that used in previous studies. The authors believe that repeating similar survey investigations in the same study group is not ideal since screening the target population multiple times could increase bias and decrease the participation rate.

Conclusion

This international survey-based study provides readers with insights into the content of the PCFD classification. The findings indicate that some terminologies used in the PCFD classification are not universally understood. The authors recommend that modifications may be beneficial to enhance the accuracy and user-friendliness of the PCFD classification.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MZ *(https://orcid.org/0000-0002-9685-4048) Conceived and planned the activities that led to the study, data collection, statistical analysis, interpreted the results of the study, bibliographic review, participated in the review process, formatting of the article, approved the final version. MAM *(https://orcid.org/0000-0001-7031-5137) Interpreted the results of the study, bibliographic review, participated in the review process, formatting of the article; WG *(https://orcid.org/0000-0002-7342-7000) Statistical analysis, interpreted the results of the study, participated in the review process; KJH *(https://orcid.org/0000-0002-8369-8744) Participated in the review process, formatting of the article, approved the final version; MSM *(https://orcid.org/0000-0001-5124-2403), and SL *(https://orcid.org/0000-0003-1238-8455) Conceived and planned the activities that led to the study, clinical examination, participated in the review process, approved the final version. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID).

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Original Article

Biomechanical evaluation of surgical techniques for Achilles tendon repair: a laboratory study in bovine tendons

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Abstract

Objective: To compare the biomechanical performance of three tendon suture techniques in bovine specimens. The parameters used were elongation after loading, the stiffness of the construct, the maximum force, and the type of suture failure.

Method: A complete transection distant 5 cm from the distal bone insertion was made in thirty-six bovine Achilles tendons which were subsequently repaired using Vicryl®#2 sutures in three different ways: Group 1, simple shoelace suture (SS); group 2, triple shoelace suture (TP) and group 3, Carmont & Mafulli suture (CM). All the tendons were submitted to the same biomechanical tests.

Results: The tendon elongation was 5.9 mm in group 1 (SS), 3.0 mm in group 2 (TS), and 3.8 mm in group 3 (CM), with statistical significancy between group 2 and groups 1 ($p = 0.0037$) and 3 ($p = 0.0005$). Regarding the system stiffness, group 1 presented 23.2 N/mm, group 2, 30.3 N/mm, and group 3, 28.6 N/mm, with statistical significancy of groups 2 ($p < 0.0001$) and 3 ($p = 0.0075$) in relation to group 1. The maximum strength results were 158.2 N in group 1, 346.5 N in group 2, and 146.1 N in group 3, with statistical significancy between group 2 and groups 1 ($p < 0.0001$) and 3 ($p < 0.0001$). The type of rupture failure was statistically significant among all studied groups.

Conclusion: The increased number of sutures decreased the elongation and increased the construct stiffness, com statistical significancy of groups 2 and 3 over group 1. The higher resistance to failure in group 2 (346.5 N) was due to its symmetry and the higher number of sutures passed through both tendon stumps. The TS suture technique showed the lower elongation index (3.0 mm), the greater system stiffness (30.3 N/mm), the maximum force (356.6 N), and proportionality between the types of system failures (suture failure or tendon pullout).

Level of Evidence V; **Therapeutic Studies; Expert Opinion.**

Keywords: Achilles tendon; Biomechanics; Rupture, Tendon suture

Introduction

The frequency of Achilles tendon rupture has raised in the last decades due to the increase in physical activity and encouragement to practice sports in all ages and all around the world. Surgical treatment has become the preferred option for active patients[1] looking to regain their pre-injury activity level faster[2] and percutaneous surgical techniques have gained more popularity, due to the lower complication rates[3,4].

Percutaneous sutures with nonabsorbable threads for Achilles tendon repair present greater resistance to failure[5], but sural nerve entrapement can occur, representing a complication that often requires an extra surgical procedure to decompress the nerve. To reduce this complication, absorbable threads are indicated[6,7] due to a 75% resorption rate around five weeks[8]. Absorbable threads exhibit reduced tensile strength and mechanical durability over a shorter timeframe[8]. The

Study performed at the Laboratório de Biomecânica da Universidade Federal, Florianopolis, SC, Brazil.

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literature on the subject suggests that by using a greater number of suture threads crossing the tendon rupture site (6 to 8 threads) one can achieve greater resistance to failure at levels higher than the tensions necessary for normal walking with the knee completely extended[9-11].

Biomechanical studies are relevant to determine the suture resistance in the Achilles tendon and, consequently, the possible tensile load on the repair site, but generally, these tests are in the bovine tendon[10-13], they are usually healthy, promoting greater stiffness in the suture system and lower tendon pullout rate, contrasting with greater disorganization of tendon fibers in Achilles tendon ruptures in humans[14,16].

Percutaneous techniques with absorbable sutures are described in different contexts[6,7,11-13,17]. Intratendinous sutures are noted for their minimal disruption to peritendinous circulation and ability to establish a larger contact surface between the tendon and the suture used for repairing the rupture. This approach diminishes the risk of tendon pullout and elongation, thereby preserving the tensile strength post-tendon repair[18,19]. According to the literature, the increased number of threads and knots in the suture enhances the overall strength of the construct and the anchoring system, thereby reducing the risk of failure. This improvement is attributed to the increased suture stability within the tendon stumps and the more efficient distribution of tension absorption across the entire construct, including the anchorage points between the proximal and distal threads of the system[9,20].

The objective of this study was to compare the biomechanical performance of three different tendon suture techniques on bovine Achilles tendons, using data relative to the tendon elongation after loading, the stiffness of the whole system, the maximum force, and types of system failures.

Methods

Preparation of the samples

Thirty-six pieces of bovine Achilles tendons were included, aged between 14 and 20 months, submitted to a cooling period of 24 hours at a temperature of -5 degrees[14,18]. The pieces were prepared promptly to maintain the viscoelastic characteristics of the tendons[14,18,21].

The bovine Achilles tendon was measured with a digital caliper (accuracy of 0.01 cm). The length, width, and thickness of the tendons 5 cm proximal from their insertion were measured. A model of the Achilles tendon rupture was created, performing a transverse cut at this point. After, all pieces were prepared to receive the types of sutures and start the biomechanical test[22,23].

The samples were randomly divided into three groups: group 1 in which a simple shoelace suture (Bunnell) was done (SS)[7], group 2 in which a triple shoelace was used (TP), and group 3, in which a Carmontt and Mafulli (CM) tendon suture was performed[24].

Surgical techniques

The SS Bunnell's technique[7] is a modification of the Ma & Griffith's technique[6,7] (group 1), consisting of suturing with a Vicryl® #2 thread with multiple sutures in crisscross shape. The technique starts with a curved needle, intramural entry, and ipsilateral exit, followed by a straight needle and proximal oblique crisscrosses sutures on three levels. A transverse incision is performed at this moment, and oblique crisscross sutures are performed distal equally to the proximal sutures. Again, with a curved needle, a suture is made from the contralateral side to the intramural face of the rupture. The procedure is repeated in the distal stump, imitating a lace image in each tendon stump (Bunnel type) and finally tying the suture on both sides (Figure 1A).

The TS technique (group 2) consisted of suturing with two pairs of three Vicryl®#2 threads, marked as smooth, with one and two knots at both ends of the threads. The technique follows the SS passes, starting with the three threads passing the first and second sutures; at this point, the threads (two knots) are released. In the next suture, we leave the thread (a knot) on the ipsilateral side. Next, one more suture is performed with a smooth thread facing the distal equal to the SS. At this moment, the thread (one knot) is passed transversely and relocated in the needle and passed to distal with two threads and repeated with the thread (two knots), and again having three threads in the needle, following the SS technique, finishing three levels of suture and with six ends of intramural thread from the tendon rupture. We repeat the procedure with the same thread configurations and passes in the distal stump, performing a suture of a similar configuration in both stumps. The threads are identified at this moment, and suturing is performed in pairs according to the number of knots. The suture of the thread pairs proceeded from the most distal to the proximal to the site of the tendon rupture (Figure 1B).

In group 3, suturing was performed according to the Carmont & Mafulli's technique[24] using two pairs of four Vicryl®#22 threads for suturing the tendon, starting with

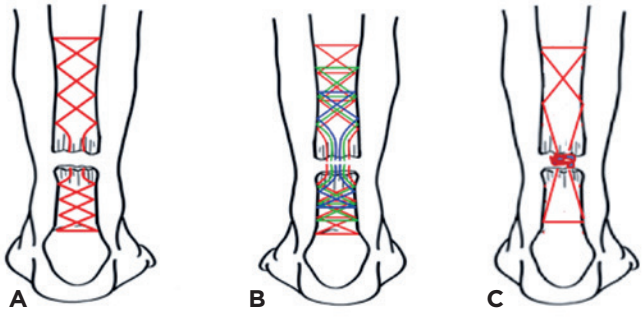

Figure 1. (A) Bunnell's suture technique (SS) (Edward T Mah), (B) triple shoelace technique (TS), (C) Carmont & Mafulli's technique (CM).

sutures in the proximal stump with threads transverse proximally to the rupture site and both ends of the suture threads are crossed in the distal direction, and a new suture is made diagonally in the direction of the rupture site distally (Bunnell suture type). In the distal stump, threads are passed in the transverse direction closest to the tendon insertion and followed by a diagonal suture in a proximal direction to the rupture site (Kessler's suture type) and sutured in two knots sets of the eight suture threads (Figure 1C).

Biomechanical testing

The tendons were fixed in a universal testing machine, Shimadzu AGS-X® 100kN (Shimadzu Corporation, São Paulo, Brazil), using Trapeziumx® software with a maximum load cell capacity of 1 kN. The tendons were subjected to axial force, initially at a constant load of 50 N for 300s (elongation measured). Afterward, the traction test was performed in displacement control, with a constant speed of 500 mm/min and passive force monitoring. The test is finalized after construct failure. With the data obtained, the Force Courve (force (N) vs. displacement in millimeters) were obtained to calculate the system stiffness parameters and maximum force supported by the construct. After the biomechanical tests, all pieces were evaluated for the type of system failure: (1) suture failure or (2) tendon pullout[12,18,26].

Statistical analysis

For statistical analysis**,** Microsoft Excel® (Microsoft Corporation, Redmond, Washington, USA) software was used. The Shapiro-Wilk normality test was used as a reference. We examined the distribution of data related to the thickness, width, and length of the tested Achilles tendons, considering various anatomical patterns as potential sources of bias. The f-test was used to hypothesize equality between the means of the measured parameters. The t-test was used to compare biomechanical variables among groups. Fisher's exact test was used to evaluate the failures observed after the rupture of the specimens. For all statistical tests, $p < 0.05$ was considered statistically significant.

Results

The anatomical characteristics of the tendons showed similarities in length, thickness, and width, as shown in Table 1.

The results of the tendon elongation at initial load had a mean of 5.9 mm in group 1, 3.0 mm in group 2, and 3.8 mm in group 3 (CM), the system stiffness had a mean of 23.2 N/mm in group 1, -30.3 N/mm in group 2, and -28.6 N/mm in group 3. The mean results of the maximum load force were 158.2 N in group 1, 346.5N in group 2, and 146.1N in group 3 (Figure 2A-C and Table 2).

The type of system failure was evaluated for suture rupture, with 11 in group 1 and seven in group 2. The tendon pullout was presented in one construct in group 1, five in group 2, and all constructs in group 3 (Table 3).

The statistical analysis focuses on the results categorized by data group, including tendon elongation, system stiffness, maximum load force (Table 4), and the type of system failure (Table 5).

Discussion

The type of suture in Achilles tendon repair is still widely discussed, and percutaneous techniques are increasingly adopted[4-7,13,24]. The resistance of sutures in percutaneous techniques has always been questioned regarding the reliability of the construct. Using sutures with non-absorbable thread, such as the Achillon or PARS techniques[14,17], shows increased resistance in the sutures, making them more reliable. However, they may have a longer reaction period and higher complication rates. Carmont et al.[6,24] suggested using absorbable suture thread to reduce complications and increase the number of threads to a better suture resistance[4,9,25,26].

The standard use of absorbable sutures (Vicryl®#2) in our study was due to its presentation of resorption of 75% in five weeks and its entirety in approximately 90 days [8]. This resorption process leads us to believe in lower complication rates, such as neurological injury and shorter periods of the local reaction process. Consequently, it presents lower suture resistance[15,18] compared to non-absorbable sutures[6,10,14]. The tendons tested in group 2 showed a high resistance index (346.5N), a value above that described by biomechanical studies (range 228.60 N–245 N[10-13,23,25,26] and clinical studies[11,27] considering the knee in extension and the ankle at 0 degrees with a value of 70.6 N and at 10 degrees of dorsiflexion of 183.2 N. Groups 1 (158.2 N) and 3 (146.1 N) were shown to be close to those described by Oroshimo et al.[11]. The results lead us to interpret that the three techniques are applicable in Achilles tendon repair. However, only the result found in group 2 allows us to consider that the resistance obtained in this suture allows us to use early loading on the repaired tendon.

Table 1. Anatomical values of tendons by group, where T is the thickness, W is the width, and L is the length. All measurements are in millimeters.

	Group 1			Group 2			Group 3		
	T*	W*	L*	T*	W*	L*	T*	W*	L*
Mean [mm]	9.90	13.01	137.85	9.89	14.23	129.93	7.25	11.86	117.63
Standard deviation [mm]	3.09	3.60	10.02	1.15	1.67	10.10	1.43	1.95	14.06

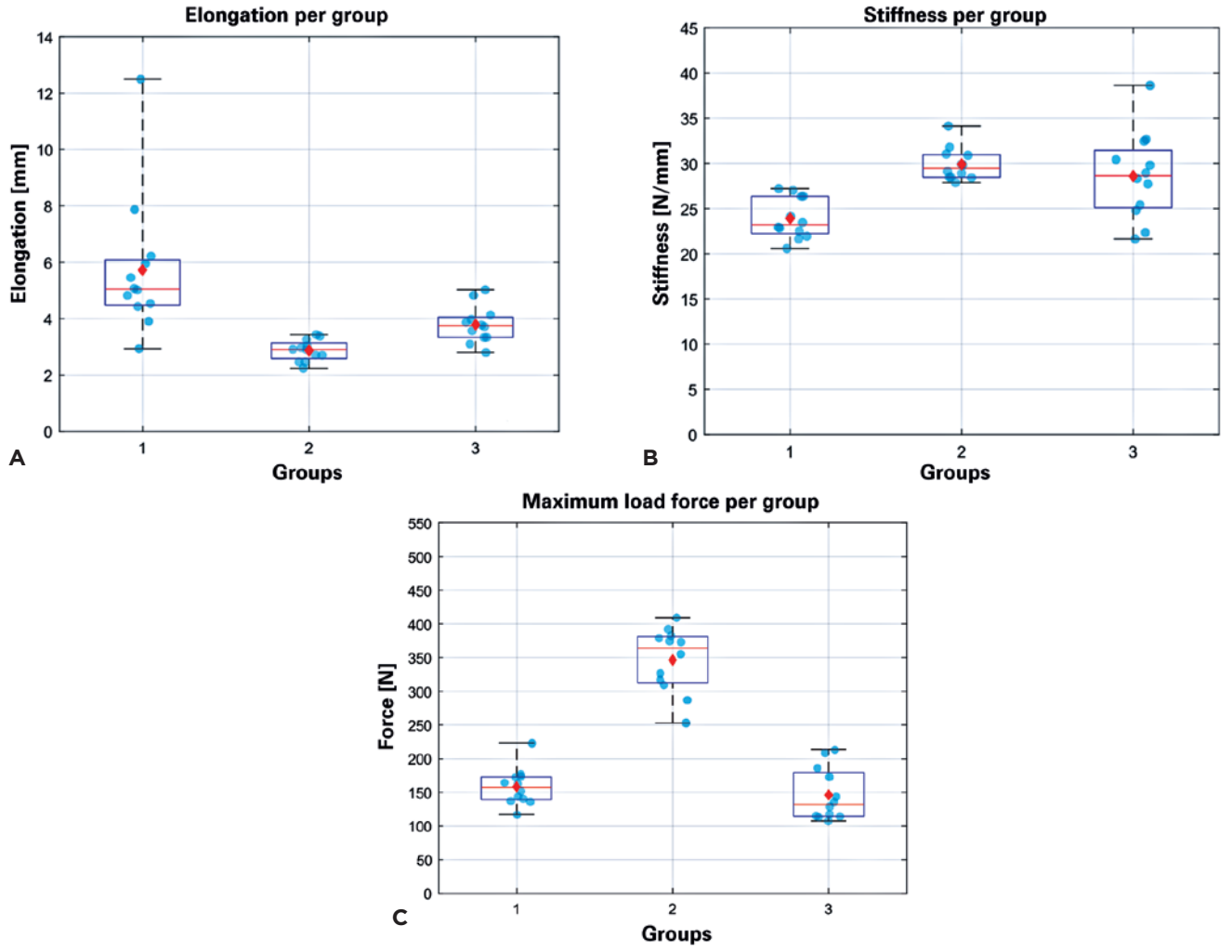

Figure 2. (A) Boxplot displaying the elongation between the tendon stumps during the constant load phase of 50 N for 300s. (B) Stiffness of the sutured tendons among the groups recorded in Nmm. (C) Maximum load force required for system failure. The red center horizontal line indicates the median and the box's lower and upper blue edges indicate 25% and 75%, respectively. The lines extend to the most extreme data points. The diamond-shaped point represents the mean value, and the spherical points represent each data point.

Table 2. Mean values and standard deviation (SD) of the biomechanical data for the Elongation, system stiffness, and maximum force of the test samples

Group (n = 12)	Elongation		Stiffness		Full Strength	
	Mean [mm]	SD [mm]	Mean [N/mm]	SD [N/mm]	Mean [N]	SD [N]
1	5.9	2.5	23,2	2.8	158.2	27.5
2	3.0	0.4	30.3	1.1	346.5	47.6
3	3.8	0.7	28.6	4.8	146.1	38.8

SD: Standard deviation.

Table 3. Type of failure in all groups

Failure mode	Group 1 (SS)	Group 2 (TS)	Group 3 (CM)
Suture rupture	11	7	0
Tendon pullout	1	5	12

Clinically, tendon elongating greater than 5 mm may decrease the performance of the technique, as described by Kangas et al. (19). Therefore, we consider elongation ≥ 5 mm as a system failure in our series. In our study, groups 2 and 3 showed elongations less than 5 mm (means of 3.0 mm and 3.8 mm, respectively). According to published studies [6,9,12,23], rising threads in the sutures increase the strength under low cyclic stresses. This fact corroborated with the result of the mean elongation of 5.9 mm in group 1, which can be considered

Table 4. The p-value in the statistical tests among the groups regarding the means for elongation, system stiffness, and maximum force load

Groups	Elongation		Stiffness		Maximum load	
	f-test	t-test	f-test	t-test	f-test	t-test
1-2	< 0.0050	0.0037	0.48	= 0	1494	= 0
1-3	0.0001	0.0210	0.0213	0.0075	0.2638	0.3915
2-3	0.0795	0.0005	0.0032	0.3849	0.5077	= 0

Table 5. The p-values in the statistical tests among the groups (Fischer's exact test)

Groups	Fisher's exact test
1-2	0.0730
1-3	= 0
2-3	0.0046

a system failure. Our study was statistically significant when comparing groups 1 vs. 2 (p = 0.0038) and 1 vs. 3 (p = 0.0210). Therefore, as described in the literature[9], using four and six sutures resulted in lower elongation of the repaired tendons. When we evaluated the results between groups 2 vs. 3 (p < 0.001), which also was statistically significant, we can consider that the increased number of threads in the suture is not the only factor determining the final elongation in the sutured tendon.

The mean system stiffness in our study was different among the groups: group 1 (23.2 N/mm), group 2 (30.3 N/mm), and group 3 (28.6 N/mm). Groups 2 and 3 presented greater rigidity with a relevant difference to group 1, statistically significant between groups 1 and 2 (p < 0.0005) and 1 vs. 3 (p = 0.0075). The result demonstrated that the number of sutures is directly related to the system's rigidity. The comparison of the system stiffness of groups 2-3 (p = 0.3845) showed no statistical difference. However, using three threads (group 2) showed a higher construct stiffness value than four threads (group 3). This leads us to believe that the symmetrical suture in both stumps promoted greater rigidity due to the similarity in the passes of the intratendinous suture and with greater suture attachment points within the stumps, promoting greater stability to the tendon and, consequently, the better distribution of system forces. Our results align with biomechanical studies demonstrating that systems with suture symmetry in both stumps behave more stably and with lower displacement[14,20,26]. Our results suggest that the TS technique (group 2) promotes a more stable construct, allowing early mobilization and loading[2].

In our study, the use of threads was standardized (Vicryl®#2) for all groups, and our objective was to compare the final mechanical strength performed in each construct[9,12,23]. The comparative analysis between the final resistance of group 1 (158.2 N) and group 2 (346.5 N) showed a statistically significant difference (p < 0.0050), confirming that the increased number of threads in the same type of suture system increases the resistance of the construct performed. When the results between group 1 (158.2 N) and group 3 (146.9 N) were compared, no statistically significant difference (p = 0.3915) was observed between the two groups, indicating that the number of threads was not the primary factor, evidenced by the type of suture used in group 1, where it presented the same resistance to the use of four threads in group 3. Therefore, the greater number of sutures in the tendon probably determined greater stability of the suture-tendon set, promoting increased resistance to the construct. The importance of the type of suture used in improving the resistance is evident when comparing the results between groups 2 (346.5 N) and 3 (146.1 N), which showed a statistically significant difference (p < 0.0050), demonstrating that the increase in the number of sutures in the tendon and in a symmetrical way of the construct in both stumps promotes greater stability of the threads-tendon construct, showing to be a more important factor than the number of threads used to increase the resistance of tendon repair, demonstrated by the use of a smaller number of threads in the TS technique than in Group 3.

The distribution of system failures, as outlined in the literature, exhibited varying frequencies within the groups. These frequencies were attributed to either suture rupture or tendon pullout, and they were influenced by factors such as the extent of elongation and system stiffness. In group 1, most cases (11 out of 12) were associated with suture rupture, likely due to the high elongation and low system stiffness. However, this difference was not statistically significant compared to group 2 (p = 0.0730). This observation is likely attributable to the relatively low final resistance of the system. In group 3, all tests (12 pieces) showed tendon pullout in the distal stump. Consequently, we infer that the low elongation in this group, resulting from increased stiffness at the tying point of the four grouped threads and the mean stiffness within the construct, is indicative of the elongation being primarily caused by the single-pass suture in the distal stump, leading to system failure due to its lower stiffness. This result is statistically significant compared to group 1 (p < 0.0050), despite increased threads and similar final resistance between groups 1 and 3. The pieces studied within group 2 showed a slight predominance of suture rupture (7 pieces) over tendon pullout (5 pieces). These cases demonstrated less elongation and greater rigidity within the system due to a better distribution of tension forces between the suture and the tendon, not statistically significant compared to group 1 (p = 0.0730) and statistically significant compared to group 3 (p = 0.0046). These results suggest that the simple suture method carries a higher risk of construct rupture, which, *in vivo*, could manifest as an increased likelihood of tendon re-rupture. In contrast, group 3 experienced progressive tendon pullout in the distal stump, causing elongation of the construct onto the tendon. This elongation appears to be directly proportional to the greater loss of muscle strength in the repaired tendon. The findings regarding system failure

in group 2 highlight that multiple levels and passes of the suture more effectively distribute forces through the tendon, thus safeguarding the integrity of the Achilles tendon repair against elongation.

Surgical Achilles tendon repair aims to accelerate the reorganization of tendon fibers and the recovery of tendon tension. Biomechanical studies collaborate clinically by evaluating the repair systems: the greater load resistance, the lower traction forces failure, the potential of the system stiffness in preventing tendon elongation, and the consequent loss of muscle force transmission. The TS technique (Group 2) showed a 3.0 mm elongation, below the limit for suture failure described in the literature (5 mm). The system stiffness was 30.3 N/mm, demonstrating a good suture and with a mean of 345 N failure resistance, close to non-absorbable sutures[25] and above the values described in biomechanical studies[10,12,14,15,23] and clinical studies[9,11,27]. We believe these results demonstrate the applicability of this technique for Achilles tendon repair with safety and the ability to support loading and early mobilization. This is reflected in the type of system failure observed in this group, where system rupture was the most common, although it typically occurred at loads exceeding those encountered during daily activities. However, due to tendon pullout failures, it is crucial to exercise caution and protect dorsiflexion until the repaired tendon fully regains its continuity. The biomechanical results found in our study lead us to consider that the triple shoelace technique is reproducible *in vivo* and safely using a rehabilitation protocol with equine load, early mobilization, and dorsiflexion protection until strength gain of the gastrocnemius soleus complex.

Conclusion

Our study demonstrated that an increased number of sutures decreased tendon elongation under load and increased construct stiffness in groups 2 and 3. The higher resistance of the suture until the system failure presented in group 2 (346.5 N) is above the other groups and in the literature for absorbable threads. The triple shoelace technique with multiple anchorages and symmetrically intratendinous sutures demonstrated a lower elongation index (3.0 mm), greater system stiffness (30.3 N/mm), and proportionality in the type of system failures. The high resistance until the system failure (346.5 N) is due to the more uniform distribution of tension between the suture and the knots in a paired way. The triple shoelace technique requires clinical studies to prove reproducibility *in vivo*.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MKA *(https://orcid.org/0000-0002-2555-9594), and APGS *(https://orcid.org/0000-0001-7122-1984) and MRD *(https://orcid.org/0009-0003-8185-7005) and CRMR *(https://orcid.org/0000-0002-9430-7059) Conceived and planned the activities that led to the study, wrote the article, participated in the review process, approved the final version; MGA *(https://orcid.org/0000-0001-5650-4564) Data collection, wrote the article, approved the final version. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor iD).

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Original Article

Percutaneous Intra-articular Chevron Osteotomy (PeICO): clinical and radiographic outcomes

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Abstract

Objective: Hallux valgus (HV) is a complex deformity with several surgical treatments described, and percutaneous methods are increasingly used. The objective of the study was to evaluate the clinical and radiographic outcomes of patients with mild or moderate HV submitted to surgical treatment using the Percutaneous Intra-articular Chevron Osteotomy (PeICO) technique.

Methods: A retrospective case series of 15 patients (18 feet) diagnosed with mild or moderate HV submitted to surgical treatment by the PeICO technique. Clinical variables analyzed were pain using the visual analog scale (VAS), function using the American Orthopaedic Foot and Ankle Society (AOFAS), personal satisfaction, and surgical complications. Radiographic parameters measured in the pre-and postoperative were hallux valgus angle (HAV), intermetatarsal angle (AIM), sesamoids position, and osteotomy consolidation.

Results: The mean follow-up time was 14 months. There was an improvement in clinical outcomes, with a mean increase in AOFAS of 31.1 and a reduction of 5.6 in VAS, with significant differences between the pre-and postoperative values ($p < 0.001$). There was also a significant radiographic correction in the HVA and AIM ($p < 0.001$). The most common complication observed was screw removal in three cases (16.6%).

Conclusion: The PeICO technique presented excellent radiographic correction, clinical improvement, high personal satisfaction, and low complication rate when used for the surgical treatment of mild or moderate hallux valgus.

Level of Evidence IV; Cases series; Retrospective Study.

Keywords: Hallux valgus; Minimally invasive surgical procedures; Reproducibility of results; Treatment outcome.

Introduction

Hallux valgus (HV) is a complex deformity in which a lateral deviation of the hallux is associated with a medial deviation and pronation of the first metatarsal[1]. Despite the various surgical techniques described in the literature to treat this pathology, there is still no consensus on the best approach. In the last decade, minimally invasive surgery (MIS) has been improved and has shown promising results in treating HV[2,3].

Distal open Chevron osteotomy is accepted as a well-established method for correcting mild to moderate HV[4]. Despite the several publications presenting good clinical and radiographic results of this classic approach, there are reports of complications related to soft tissue healing[5].

The MIS approach for treating HV proved to be a safe and effective method. In addition to providing adequate correction of forefoot deformities, MIS provides greater postoperative comfort, lower pain intensity, and lower risk of healing-related complications[6]. Due to these advantages, some osteotomies used for the open surgical treatment of HV have been adapted to the MIS[7]. Del Vecchio et al.[8] recently developed the classic Distal open Chevron technique for the

Study performed at the Rede Mater Dei de Saúde, Belo Horizonte, MG, Brazil.

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minimally invasive approach, the Percutaneous Intra-articular Chevron Osteotomy (PeICO). The PeICO is an intracapsular percutaneous "V" osteotomy of the first metatarsal (1MT) with an angle of 90º at its apex in the center of the head of the 1MT and fixed with screws. The only difference between the PeICO technique and the classic Chevron osteotomy is the access approach. In addition to maintaining the advantages of Chevron osteotomy, PeICO is performed minimally invasively, causing less aggression to the soft tissue. The anatomical bases of PeICO were performed through a cadaveric study, increasing the credibility of the procedure. In addition, the authors who described the technique published excellent clinical and radiographic results through a case series of patients with VH treated using the PeICO technique. Despite the promising results, the procedure is still recent, and more studies are needed to corroborate the findings and evaluate the effectiveness and reproducibility of the technique.

The objective of the study is to evaluate the clinical and radiographic outcomes of patients with mild or moderate HV submitted to surgical treatment using the PeICO technique. We hypothesize that the technique demonstrates good correction capacity in the studied population and improves pain and function.

Methods

The study was approved by the Institutional Research Board and followed the guidelines of good clinical practice and the Declaration of Helsinki. All included patients read and signed the informed consent form. We retrospectively evaluated 15 patients (18 feet) diagnosed with mild or moderate HV submitted to the PeICO technique between December 2019 and August 2020. The patients were operated on by the authors, who have training and experience in minimally invasive foot and ankle surgery.

Patients over 18 years of age who had symptomatic HV classified as mild or moderate and who had pain for at least six months without improvement with conservative treatment (adaptation of shoes and anti-inflammatory medication) were included. The degree of deformity was based on the hallux valgus angle (HVA), intermetatarsal angle (IMA), and the sesamoids position through anteroposterior (AP) radiographic analysis of the foot with support, according to the classification of Mann and Coughlin[1] (Table 1). Exclusion criteria were previous surgery in the hallux, symptomatic arthritis of the metatarsophalangeal (MTP) joint of the hallux, concomitant deformities of the hind and midfoot that required surgical treatment, and rheumatological and neurological diseases.

The preoperative clinical evaluation consisted of the hallux scale of the American Orthopedic Foot and Ankle Society (AOFAS)[9] and the visual analog scale (VAS)[10]. In the last evaluation, patients answered the AOFAS, VAS, and satisfaction with the procedure using the Coughlin scale (excellent, good, regular, bad, or very bad).

Radiographic evaluation was obtained at 6, 12, 24, and 48 weeks postoperatively. The variables evaluated were HVA, IMA, the sesamoids position, radiographic consolidation, migration of synthesis material, loss of reduction, and recurrence of the deformity.

Surgical technique and postoperative care

Under spinal anesthesia and sedation, patients were positioned in the supine position with their feet hanging, with the operated foot supported on the image intensifier without the use of a tourniquet. We use specific instruments for the percutaneous technique, such as the scalpel blade and cutters.

The portal (P1) was performed at the limit between the proximal 1/3 and distal 2/3 of the 1MT head, followed by the dorsomedial release of the joint capsule (Figure 1). Then, a 2.0mm Kirschner wire was inserted percutaneously in the medial region of the distal phalanx of the hallux up to the level of the MTP joint (Figure 2A), the wire served to maintain the temporary reduction of the osteotomy. Next, a 2.0 mm Shannon-type drill was inserted into the 1MT head in the medial-lateral direction, creating the apex of the osteotomy (Figure 2B). Then, the dorsal limb was created at a 10º to 20º angle, proximal to the axis of the 1MT.

Table 1. Hallux valgus classification, according to Mann and Coughlin, 1996

	Normal	Mild	Moderate	Severe
HVA	< 15	< 20	< 40	> 40
IMA	< 9	< 11	11–16	> 16
Sesamoid position		< 50%	50%–75%	> 75%

HVA: Hallux valgus angle; IMA: Intermetatarsal angle.

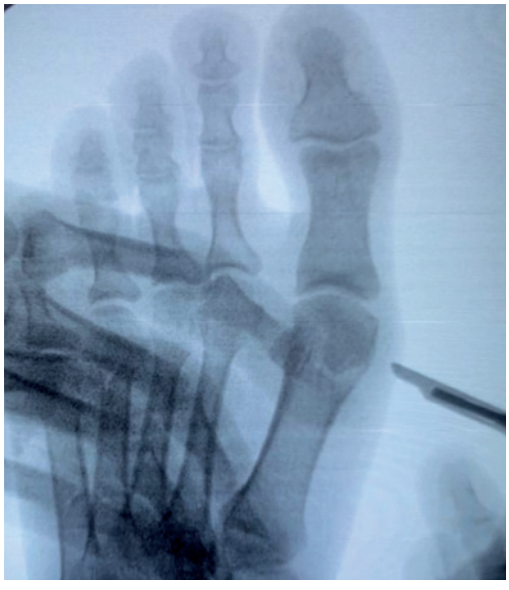

Figure 1. Portal P1.

The plantar limb was performed at a 90º angle to the dorsal limb and parallel to the ground, ending the osteotomy. The next step was to perform the lateral translation of the 1MT head (up to 50%), introducing an angular instrument through the portal P1 (Figure 3) in the midline of the metatarsal to avoid angular deviation in the sagittal plane (it is important at this moment to perform fluoroscopic control in the profile of the foot). Through a dorsomedial portal (P2 - approximately 15mm proximal and 3mm dorsal to P1), we inserted the screw guidewire in the dorsal-medial to plantar-lateral direction, forming a 45º angle in the AP view (Figure 4).

The fixation was performed using a 3.0mm conical screw (Figure 5). The remaining bunion resection was performed by the P2 portal using a 3.0mm wedge-type drill. Finally, through a dorsolateral portal in the MTP joint (P3), the tenotomy of the adductor of the hallux was performed, and lateral capsulotomy displacing the hallux medially promoting

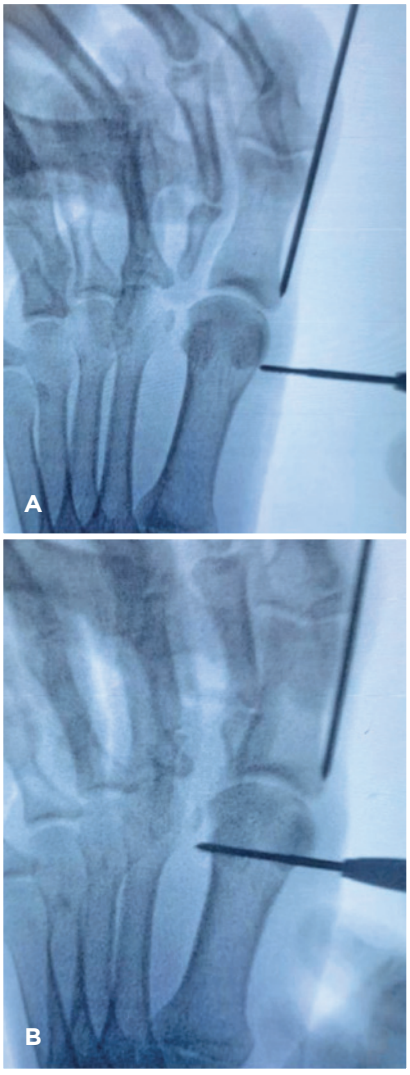

Figure 2. (A) Insertion of Kirschner wire. (B) Position of the osteotomy cutter.

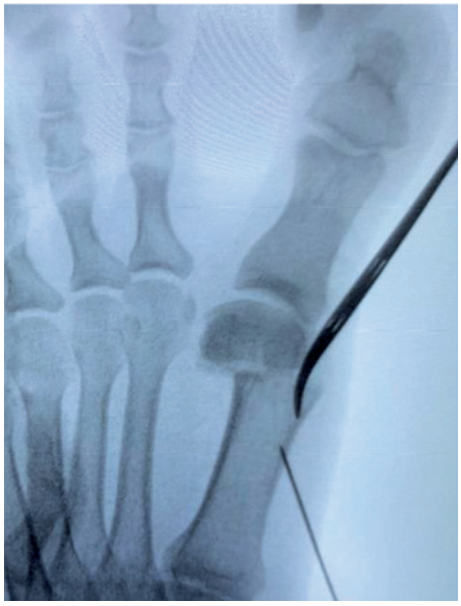

Figure 3. Lateral head translation.

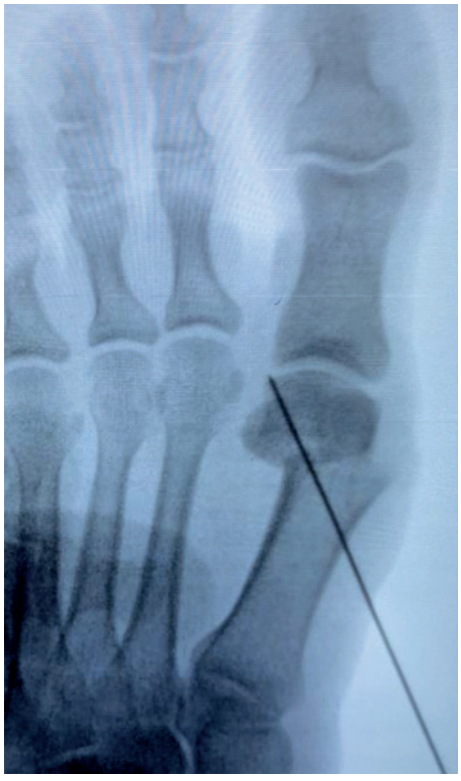

Figure 4. Temporary stabilization of osteotomy with a guidewire.

a varus and introducing the scalpel with the lateral cutting face and deeply. Ultimately, we performed copious irrigation through the portals to remove bone debris and suture the portals using nylon 4.0.

The dressing was changed weekly until the fourth week by the medical team, keeping the hallux positioned in varus for the first two weeks and neutral for the remaining. From then on, the patient should use a silicone toe spacer until the sixth week after surgery, when the first radiographic control was performed (Figures 6 and 7). Then, an immediate full load with rigid sandals was released for six weeks, and after this period, the patient was allowed to wear the shoes of their choice. There was no prescription for physiotherapy, and the patients were instructed to perform passive hallux flexion and extension from the second week postoperatively.

Statistical analysis

Statistical analysis was performed using the R software[11]. Continuous variables were measured through descriptive statistics by the mean, minimum, and maximum, and the Shapiro test was used for their distribution[12]. Categorical variables were described by their proportion.

The analysis of continuous variables between the pre-and postoperative was performed using the paired Wilcoxon signed rank test (non-parametric variables distribution) and the paired Student's t-test (parametric variables distribution). Pearson's Chi-square test was used to compare categorical variables[13]. A p-value ≤ 0.05 was adopted as the level of statistical significance.

Results

Fifteen patients were included, totaling 18 feet. Most patients were female (10), representing 66%. The mean age of the patients was 49 years (range 30–62), and the mean follow-up time was 14 months (range 12–18). The distribution regarding laterality was equal between the right and left feet. In thirteen feet (72.7%) the HV was classified as moderate.

The clinical and radiographic evaluation can be seen in Table 2. The clinical outcomes showed statistically significant differences between the pre-and postoperative values, with a mean increase in AOFAS of 31.1 and a reduction of 5.6 in VAS.

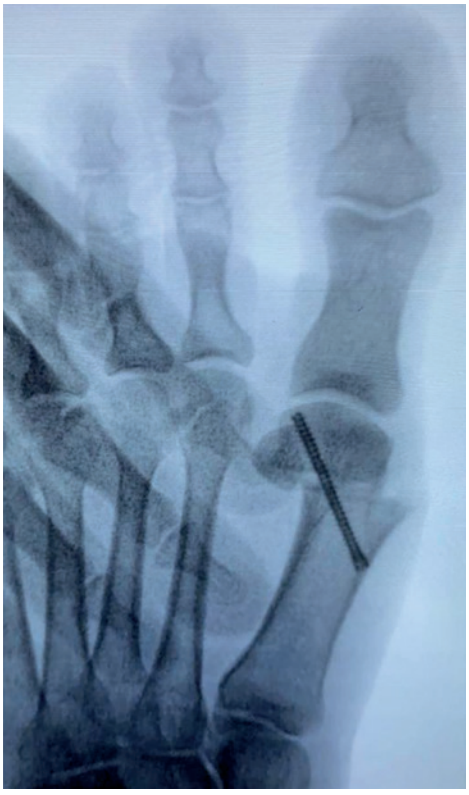

Figure 5. Fixing with a conical screw.

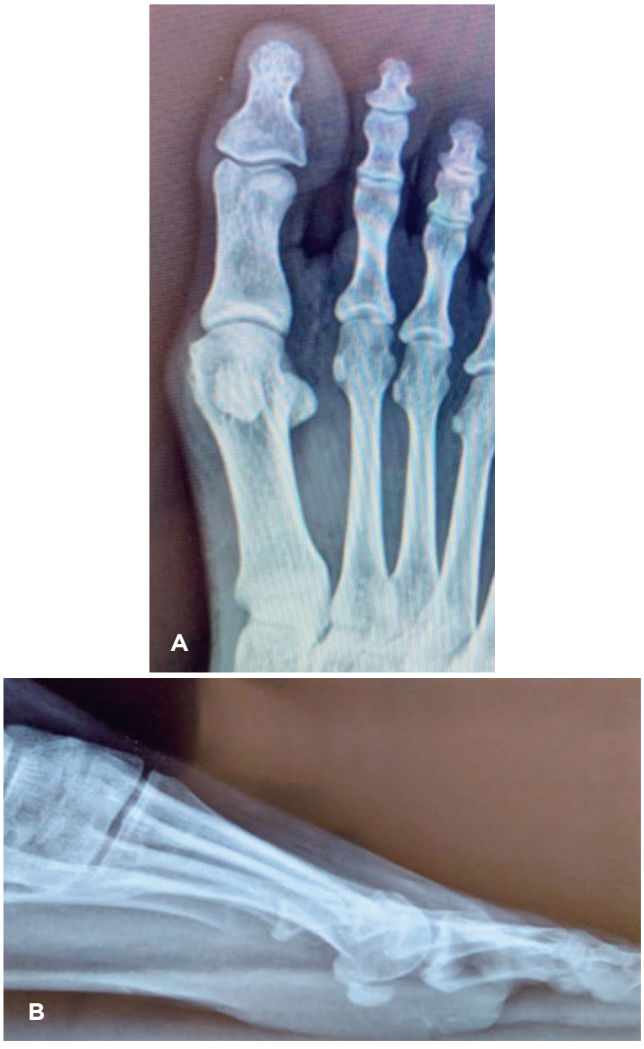

Figure 6. (A) Preoperative radiograph in AP. (B) Preoperative radiograph in profile.

Regarding personal satisfaction with the surgical result, according to the Coughlin score[14], 80% of patients considered the final result excellent and 20% good. No patient considered the final result regular or bad.

There was also a statistically significant difference in the pre-and postoperative radiographic analyses ($p < 0.001$), observing a mean reduction in HVA of 15.8º and IMA of 6.3º. The pre-and postoperative sesamoids position is described in Table 3. Osteotomy was consolidated in all cases.

No patient had a superficial or deep infection, skin complications, necrosis, or surgical wound dehiscence. There were no transfer metatarsalgia, hallux varus, necrosis, or vicious head consolidation in the sagittal plane. Because it is an intra-capsular osteotomy, a higher degree of stability and, therefore, a lower chance of undesirable deviations is inferred.

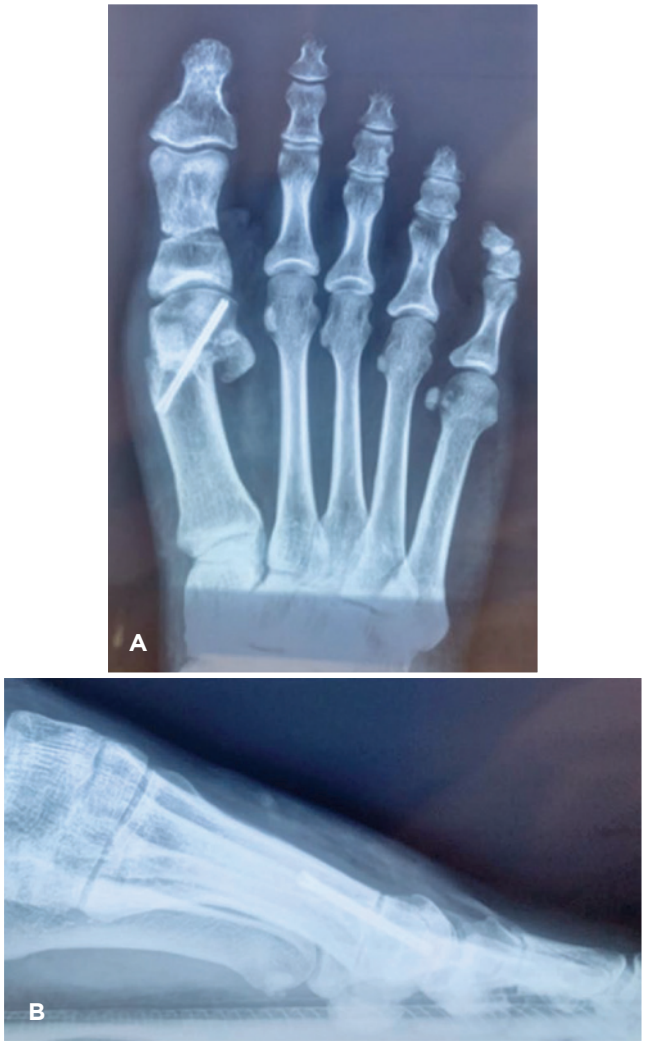

Figure 7. (A) Six weeks postoperative radiograph in AP. (B) Six weeks postoperative radiograph in profile.

Complications

The most common complication was screw removal in three cases (16.6%) due to local discomfort. The synthesis material was removed, when necessary, after a minimum of six months and with the osteotomy consolidated through radiographic analysis. There was complete remission of symptoms after the procedure. Two patients (10%) had medial dorsal cutaneous nerve neurapraxia, which improved spontaneously during follow-up. There were no major complications or need for surgical revision.

Discussion

Our study presented the clinical and radiographic results of a case series of patients with mild to moderate HV submitted to surgical treatment using the PeICO technique. There was a radiographic improvement with HVA and IMA reduction and the sesamoids position. In addition, clinical outcomes were favorable, with significant improvement in pain and increased quality of life, according to the VAS scale and AOFAS score. The most common complication was screw removal in three patients (16.6%).

The first published study of the PeICO technique[15] demonstrated only radiographic outcomes. The authors observed a mean reduction in HVA of 25.8º, ranging from 33.9º in the preoperative to 8.1º in the postoperative. The mean preoperative IMA angle was 12.4º to 8.1º (reduction of 4.3º) in the postoperative. Subsequently, Del Vecchio et al.[16] evaluated 114 feet using the PeICO technique, obtaining a mean reduction of 17.1º in HVA and 4.6º in IMA. Our study reproduced these radiographic results with a mean reduction of 15.º in HAV and 6.3º in IMA.

Table 2. Pre- and postoperative clinical and radiographic evaluation

Outcome	Pre (med, min, and max)	Post (med, min, and max)	Difference between pre and post	p-value
HVA	21.2 [15–32]	5.4 [1–9]	15.8	< 0.001
IMA	11.0 [8–14]	4.7 [1–9]	6.3	< 0.001
AOFAS	62 [52–78]	93.1 [80–100]	31.1	< 0.001
VAS	6.3 [5–8]	0.7 [0–2]	5.6	< 0.001

Pre: Preoperative; Post: Postoperative, Med: Median; Min: Minimum; Max: Maximum.

Table 3. Pre-and postoperative sesamoids position

Degree	Preoperative	Postoperative
0	0	15 (83.3%)
I	12 (66.7%)	2 (11.2%)
II	5 (27.8%)	1 (5.5%)
III	1 (5.5%)	0

Statistical analysis using the Chi-square test ($p < 0.001$).

Regarding the clinical outcomes of Del Vecchio et al.[16], they presented a mean increase of 39 points in AOFAS and a mean reduction of 5.3 points in VAS, confirming an improvement in pain and function. Our study also showed similar results, with a mean increase of 39 points in AOFAS and a mean reduction of 5.3 points in VAS. Personal satisfaction with the surgical outcome was also similar between studies, and most patients considered the result excellent.

Another important finding of our case series was evaluating the sesamoids position. The inadequate postoperative sesamoids position is considered a predictive factor for the recurrence of the deformity[17,18]. In our study, 83.3% of patients had a complete sesamoid position at the end of the procedure, which was maintained until the end of follow-up. Despite this, it is important to reiterate that this series evaluated mild and moderate deformities, and most patients had a slight change in the sesamoid position (classified as grade 1) preoperatively.

The main complication of this series was the screw removal, performed in three cases (16.6%) due to local discomfort. Screw removal is a frequent indication in percutaneous procedures for HV correction, ranging from 10%–24%[19,20]. After removal, there was a complete remission of symptoms. Despite the high implant removal rate, using a rigid internal fixation brought excellent radiographic results, and no cases of delayed consolidation or pseudoarthrosis were observed. Some studies of percutaneous osteotomies without fixation or fixed only with flexible wires have reported higher complication rates related to osteotomy consolidation[21].

The mean recurrence rate with chevron osteotomies is 19.1% (range 0%–75.6%)[22]. Recurrence is defined as the clinical development of HV after surgical correction[23]. All patients in our study submitted to the PeICO technique maintained joint consolidation, alignment, and sesamoid position until the end of follow-up, and no recurrences were identified.

Despite the good results obtained, the PeICO technique for mild and moderate HV correction is not free of complications, and the main are screw removal, praxis of the medial dorsal cutaneous nerve, and rigidity of the halux phalangeal metatarsal joint.

This study has several limitations. Firstly, it is a case series with a small sample. In addition, the follow-up period is relatively short, and the lack of a control group limits the comparison with other techniques and a reliable evaluation of the HV recurrence rate.

Conclusion

The PeICO technique presented excellent radiographic correction, clinical improvement, high personal satisfaction, and low complication rate when used for the surgical treatment of mild or moderate hallux valgus. Comparative studies with the open technique and larger sample are needed to consolidate the PeICO technique further.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JMBM *(https://orcid.org/0000-0002-4224-8149), and GFF *(https://orcid.org/0000-0001-8032-3077), and DS Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process; RCB *(https://orcid.org/0000-0003-4923-8370); BMB *(https://orcid.org/0000-0003-3712-1247), and RZ *(https://orcid.org/0000-0001-9692-5283) GAN *(https://orcid.org/0000-0003-4431-5576) Participated in the review process. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID).

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Original Article

Open calcaneal fractures with medial wound: mid-term results

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Abstract

Objective: Present the clinical and radiographic results of a series of patients with open calcaneal fractures with medial wound.

Methods: Retrospective study based on medical records of ten patients treated for open calcaneal fractures with medial wound from 2014 to 2020. All included patients had a minimum one-year follow-up. The variables analyzed were age, sex, laterality, associated diseases, mechanism of trauma, fracture according to Gustilo Anderson and Sanders classifications, associated fractures, surgeries performed, complications, and functional evaluation according to the AOFAS scale and radiographic evaluation.

Results: The mean age of the patients was 47.3 years, nine men and one woman. According to Gustilo Anderson's classification, eight cases were grade IIIA and two grade II; in Sanders' classification, four were type II and six were type III. No case evolved with chronic osteomyelitis or required amputation. After a mean 31.3 months follow-up, all fractures showed consolidation in the radiographic evaluation, with a mean Bohler angle of 4.1 degrees. According to the AOFAS scale, the mean value was 77.7 in the functional evaluation.
Conclusion: Open calcaneal fractures with medial wound are often treated in a non-standard manner. The functional and radiographic results followed the high variability of the treatments performed.

Level of Evidence IV; Cases series; Retrospective Study.

Keywords: Fractures, open; Calcaneus; Treatment.

Introduction

Open calcaneal fracture is uncommon but has the potential for serious complications such as chronic osteomyelitis and amputation. The most common open fracture site is the medial, found in about 90% of cases [1-4].

Due to its rarity, knowledge about treating open calcaneal fractures is based on small case series[1-14]. The first studies showed a bleak scenario with complication rates above 60%, including lower limb amputations in 29% and osteomyelitis in 19%–39% of cases[1-14].

With the standardization of emergency care and the creation of different flowcharts to guide the treatment of these fractures, the results presented in the most recent literature have improved considerably. Most authors agree that in the initial care, in addition to wound cleaning, debridement, and irrigation, only a temporary stabilization of the fracture should be performed[4-6,9,10]. After sufficient time for soft tissue recovery from the exposed area, the fracture is reduced and permanently fixed. The L-extended side is the most frequently used side access approach[12].

The objective of this study is to analyze the types of treatment employed and the clinical and radiographic results of a series of patients with open calcaneal fractures with medial wound treated in a public hospital from January 2014 to December 2020.

Study performed at the Department of orthopedics and traumatology of Dr. José de Carvalho Florence Hospital, São José dos Campos, SP, Brazil.

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Methods

This is a retrospective study based on the medical records and radiographic files of patients with open calcaneal fractures with medial wound treated in a public hospital from January 2014 to December 2020. All surgically treated calcaneal fractures are monitored by the Foot and Ankle Group, so the selection of cases was made based on the Group's case files. The study was approved by the Institutional Research Board under the number 4,960,116. All patients signed the informed consent form.

The cases had the initial open wound treatment performed urgently by the orthopedics team of the hospital's emergency room. All patients were submitted to wound cleaning, debridement, and irrigation with saline solution to prevent infection and wound closure with nylon suture threads. Conventional dressings with sterile bandages were used. The conduct regarding the urgent fracture fixation was made by the physician responsible in the emergency room. Patients were hospitalized and received intravenous antibiotic prophylaxis for infection with gentamicin 240mg and clindamycin 900mg for 48 hours, followed by oral cephalexin for seven days. The tetanus prophylaxis was performed following the health guidelines of the Ministry of Health[15]. The imaging analysis was performed through radiographs and computed tomography in all cases. After this first approach, the cases were transferred to the Hospital's Foot and Ankle Group.

The conduct regarding the definitive treatment of the fracture was decided after analysis of the following parameters: wound and limb condition, fracture type, fracture deviation after initial surgical treatment, and general condition of the patient. One group of patients had only surgery to treat the open wound without fracture fixation. In the second group, fixation was performed through the wound created. In these cases, the fracture reduction and fixation with Kirschner wires, screws, or plates were performed only medially, using the wound or enlarging it when necessary (Figure 1).

In the third group, a lateral tarsal sinus approach (Figure 2) was associated with a rectilinear incision initiated at the distal end of the lateral malleolus and directed to the axis of the fourth metatarsal. After skin and subcutaneous opening, fractures of the posterior facet of the calcaneus and sidewall were identified. The fibulocalcaneal ligament was sectioned to allow greater access to the deviated joint surface and facilitate its reduction.

The initial conduct was defined by the physician in the emergency room. The three groups initially received exhaustive wound cleaning, and after some familiarity with calcaneal fracture treatment, the fixation was performed. After the antibiotic therapy and wound care period, the foot group defined the definitive fixation. The approach choice was based on the fracture pattern. Fractures with large displacement or comminution of the support were approached medially, and those with central or medial sinking were approached laterally. The delay in soft tissue improvement defined the treatment of the group that received only cleaning.

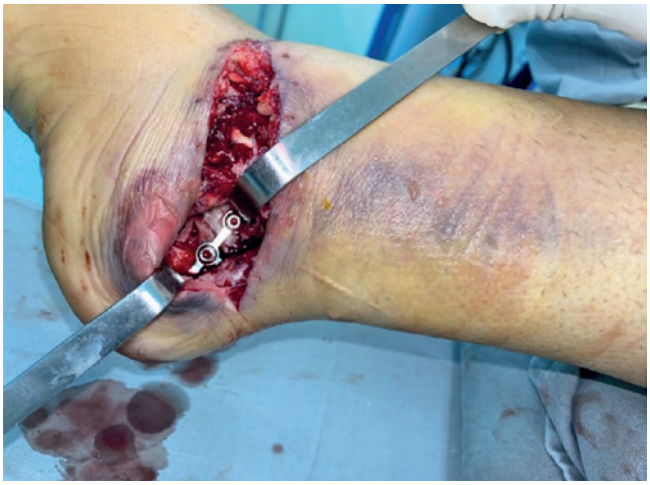

Figure 1. Direct reduction and osteosynthesis through the medial wound.

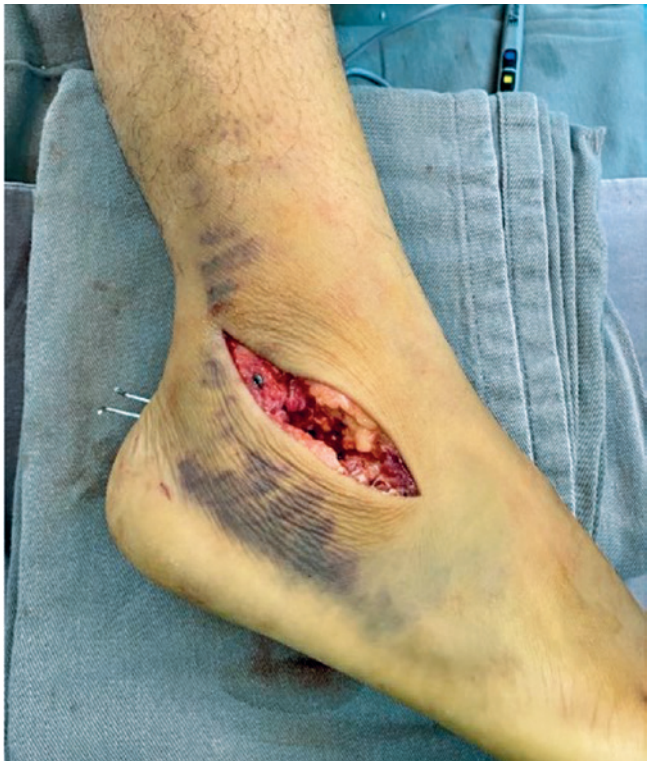

Figure 2. Lateral approach to the sinus tarsus for reduction and osteosynthesis.

The reduction control in all cases was by intraoperative radioscopy. All incisions were closed with subcutaneous and skin sutures, and a compressive dressing was applied.

Postoperatively, patients were placed in an immobilizer boot and bandaged in the outpatient clinic until the wound healed completely. Joint mobility exercises were stimulated from the start of treatment, and gait load was released only after signs of fracture consolidation. Outpatient visits were scheduled at 1, 2, 3, 6, 12, 26, and 52 weeks. The Kirschner wires were removed after six weeks. After one year, returns were scheduled every six months. All included patients had a minimum one-year follow-up and functional and radiographic evaluations were performed.

At the end of the follow-up period, the data collected for analysis were age, sex, laterality of the lesion, associated diseases such as hypertension or diabetes, mechanism of trauma, fracture classification according to Gustilo Anderson[16,17], fracture classification according to Sanders[18], associated fractures, urgent and definitive surgeries, secondary surgeries, complications, functional evaluation according to the American Orthopaedic Foot and Ankle Society (AOFAS) scale of the hindfoot[19] and radiographic evaluation with consolidation analysis and Bohler angle measurement, which reflects the loss of height of the posterior facet.

Results

Ten patients were treated, nine men and one woman, with a mean age of 47.3 years (minimum 15, maximum 57, and median 47.3). The right side was affected in seven patients and the left in three. There were no cases with bilateral involvement. The trauma mechanism was fall from height in nine cases and car accident in one case. According to Gustilo Anderson's classification, the distribution showed eight cases of grade IIIA and two cases of grade II. No patient had associated lesions on the same limb. According to Sanders' classification, the distribution showed four cases of type II and six cases of type III (Table 1).

Six patients were submitted to emergency surgery at admission for cleaning and debridement with saline solution. In four cases, the fracture was not fixed; one was fixed with Kirschner wire, and one a lateral approach to the tarsal sinus was associated. In this case, the fracture was fixed with a medial plate with lateral screws.

In addition to the emergency surgery, the other four patients were reoperated after a mean of nine days (minimum 2, maximum 19, median 9). In one case, the medial wound was reopened and the fracture was fixed medially. In the other three patients, a lateral approach to the tarsal sinus was associated with fracture reduction and fixation (Tables 2 and 3).

The median follow-up time was 31.3 months (minimum 12, maximum 61, median 31.3). Two patients required subtalar arthrodesis throughout the follow-up period, performed with 64 months and 68 months of fracture evolution. These patients received only surgical cleaning as initial treatment. All fractures evolved with radiographic consolidation and the

Table 1. Open wound degree and fracture classification

Patient	Sex	Age	Side	Trauma mechanism	Gustilo Anderson*	Sanders*
1	Men	41	Right	Car accident	IIIA	III
2	Woman	57	Right	Fall from height	IIIA	II
3	Men	15	Right	Fall from height	IIIA	II
4	Men	57	Right	Fall from height	II	III
5	Men	52	Left	Fall from height	IIIA	II
6	Men	49	Right	Fall from height	IIIA	III
7	Men	49	Left	Fall from height	II	II
8	Men	54	Right	Fall from height	IIIA	III
9	Men	56	Left	Fall from height	IIIA	III
10	Men	43	Right	Fall from height	IIIA	III

*Classifications.

Table 2. Group with secondary surgery

Patient	Urgent surgical treatment	Second-time definitive osteosynthesis: access approaches	Fixation type	Follow-up	Final Bohler angle	AOFAS	Complications
1	Cleaning only	Tarsal sinus	Medial plate and longitudinal screws	21	15	85	No
2	Cleaning only	Tarsal sinus and medial	Medial plate and screws	12	22	92	Superficial necrosis without infection
3	Cleaning only	Medial	Medial screws	13	34	100	No
4	Cleaning only	Tarsal sinus and medial	Medial screws	12	-30	89	Superficial necrosis

AOFAS: American Orthopaedic Foot and Ankle Society.

Table 3. Urgent surgery-only group

Patients	Urgent surgical treatment	Fixation type	Follow-up	Final Bohler angle	AOFAS	Complications	Secondary surgeries
5	Cleaning + plate and screw + tarsal sinus	Medial plate and screws	38	17	81	No	No
6	Cleaning and K-wire	K-Wire	30	21	58	No	No
7	Cleaning only	No	35	19	89	No	No
8	Cleaning only	No	44	1	59	No	No
9	Cleaning only	No	47	-34	62	No	Subtalar arthrodesis
10	Cleaning only	No	61	-24	62	No	Subtalar arthrodesis

AOFAS: American Orthopaedic Foot and Ankle Society.

Bohler angle measured in the last evaluation had a mean of 4.1 degrees (minimum -34 degrees, maximum 34, median 16 degrees). In the functional evaluation according to the AOFAS scale, the mean value was 77.7 (minimum 58, maximum 100, median 83), and the two cases submitted to subtalar arthrodesis were considered the values before surgery.

Two patients had medial wound healing problems with superficial necrosis without infection. No case evolved with chronic osteomyelitis or required amputation due to complications. One patient had a definitive injury to the tibial nerve and its branches in the tarsal tunnel caused by the accident.

Discussion

Regardless of the fracture mechanism, the axial compression forces of the talus on the calcaneus consistently produce two primary fracture patterns[20], sagittal and coronal planes, which divide the calcaneus into different fragments, among them the superomedial comprising the talus support with the medial wall of the calcaneal body. At the posteroinferior limit of this fragment, the fracture trace defines a tapered edge of the bone, visible on axial calcaneus radiographs (Figure 3). Lawrence[2] proposes three different mechanisms of calcaneal open wound on the medial aspect of the hindfoot. With the application of axial load on the foot, as the calcaneus rests on the ground at a point lateral to the mechanical axis of the tibia, the deformity generated at the time of trauma is in valgus and, in extreme conditions, can lead to rupture of the medial skin, exposing the fracture. Another possibility of rupturing the medial soft tissues would be the action of the fractured edge of the superomedial fragment described above, which would cause a laceration from the inside out. The third mechanism would be by direct action of a penetrating object such as a projectile or lawnmower blade. Analyzing the precise location of the medial wound, we noticed that in some cases, the second mechanism was responsible because the approach to the lesion gave direct access to the superomedial fragment, being easy to reduce by direct fracture visualization. In others, the wound did not have an alignment with the fracture focus, and the first mechanism would more correctly explain the open wound.

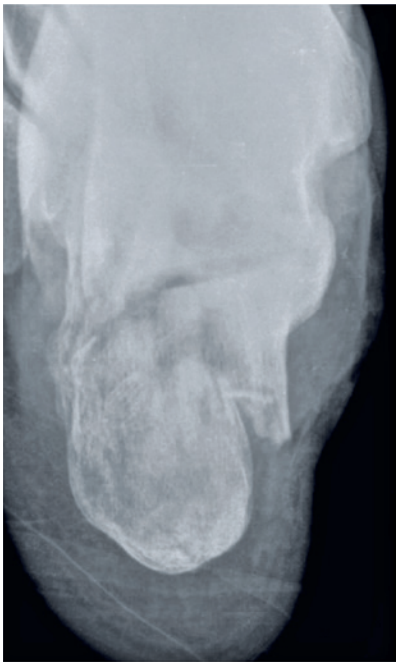

Figure 3. Axial calcaneus radiograph demonstrating the tapered edge of the superomedial fragment.

The conduct regarding the treatment in our cases varied due to the lack of a well-defined guideline on conducting fracture reduction and fixation at different times of patient care. Still, we understand that the surgical cleaning performed in the emergency room improved the prognosis of these injuries. Six patients were submitted only to one open wound surgery, and in four, no fixation was performed; in one case, fixation was performed with Kirschner wire, and in one case, a medial fixation with a plate associated with a lateral osteosynthesis at the same time. In the other four cases, osteosynthesis was performed a second time, and in three, a lateral approach of the tarsal sinus was associated. This same variability of approaches is described in the systematic review by Spierings et al.[6], which included 18 studies related

to different exposed calcaneal fractures with a total of 616 cases. In our study, the different treatment approaches had conservative treatment, temporary or permanent external fixator, percutaneous fixation, minimally invasive fixation, Kirschner wires, osteosynthesis through the open wound, a tarsal sinus approach, or an extensive lateral approach. It is clear that open calcaneal fractures are treated in different ways, and there is no consensus on the ideal method. This variability in treatment is greater in retrospective studies, such as our study, since a conduct protocol had not been previously established. There is a need to develop a flowchart with well-defined protocols based on the highest quality studies to guide the medical teams involved in the care of these patients. In the first surgery for wound debridement and irrigation, it seems that the tuberosity fragment should always be reduced in relation to the posteromedial segment (sustentacular) to decompress the medial soft tissues, thus favoring their recovery. The fixation can be temporary with Kirschner wires[5,10], or definitive with screws[21] or possibly small plates placed on the medial surface of the calcaneus using the wound as an access approach. After some time, with the regression of edema, we propose the definitive osteosynthesis by a lateral approach to the tarsal sinus. The preference for the tarsal sinus approach to the extensive lateral approach is because there are fewer complications with soft tissues when the former is used to treat closed calcaneal fractures[22,23].

The mean value of the AOFAS scale in our study was 77.7 points, which is compatible with studies that evaluated open calcaneal fractures, whose values ranged from 72.5 to 80.7 points[9,24 -26].

The mean 4.1 Bohler angle found in our cases was influenced by three cases that had highly negative values (-24, -30, and -34 degrees). In two of them, the fracture was not reduced, neither at the time of surgery to treat the open wound nor later, and these are the two cases that required subtalar arthrodesis.

There are some limitations to our study. The sample is small, and the study is retrospective, with high variability in the treatment performed. Surgeries were not performed by a single surgeon. The follow-up time was short for some cases, and there was no control group to compare the results. However, few publications address open calcaneal fractures with medial wound. Our observations suggest that standardization to care for these fractures, as proposed above, may lead to better results.

Conclusions

Open calcaneal fractures with medial wound are often treated in a non-standard manner. The functional and radiographic results followed the high variability of the treatments performed.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MHS *(https://orcid.org/0000-0001-7969-0515), and JMPB *(https://orcid.org/0000-0002-5280-1673) Conceived and planned the activities that led to the study, performed the surgeries, interpreted the results of the study, participated in the review process, bibliographic review, clinical examination, approved the final version; KMM *(https://orcid.org/0000-0003-0804-4078) Data collection, statistical analysis, formatting of the article; ACRL *(https://orcid.org/0000-0002-9677-4048), and GCCF *(https://orcid.org/0000-0001-8628-4072) Formatting of the article, data collection, clinical examination; GM *(https://orcid.org/0000-0003-0351-0009) Formatting of the article, data collection, clinical examination. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID).

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Original Article

A novel flexible fixation technique for Lisfranc injuries: clinical outcomes and radiographic follow-up

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Abstract

Objectives: The purpose of this investigation is to present the follow-up results and patient-reported outcome measures (PROMs) of a continuous series of surgically managed Lisfranc injuries whose constructs included a novel technique.

Methods: Our billing database was retrospectively queried by Current Procedural Terminology (CPT) codes to identify all Lisfranc injuries managed operatively between 2018 and 2021. Basic demographic data were collected. Clinical notes and radiographs were reviewed. Patients were contacted prospectively to complete the Foot and Ankle Ability Measurement – Activities of Daily Living (FAAM-ADL), Patient-Reported Outcomes Measurement Information System (PROMIS) Pain Intensity, PROMIS Pain Interference, and PROMIS Depression surveys. Descriptive statistics were calculated.

Results: Sixteen patients were included. While all patients underwent flexible fixation (FF), nine of them underwent concomitant open reduction internal fixation (ORIF) and seven, concomitant primary arthrodesis. Median radiographic and PROMs follow-up time was 7.3 months (IQR 4.4–11.6) and 25.8 (IQR 9.5–32.4), respectively. All fusion patients had evidence of joint fusion, and 8/9 of ORIF patients maintained articular congruity without evidence of arthritis at final follow-up. Median PROMs were 85 (64.75–93.5), 53.1 (49.7–57.75), 45.7 (37.7–51.3), and 46 (43.3–52.28) for the FAAM-ADL, PROMIS Pain Interference, PROMIS Pain Intensity, and PROMIS Depression scores, respectively.

Conclusion: The novel FF technique proposed for residual tarsometatarsal subluxation in Lisfranc injuries appears to be safe and effective, with good PROMs at two-year follow-up and low complication rates, obviating the need for hardware removal.

Level of Evidence IV; Therapeutics Studies; Cases Series.

Keywords: Fracture fixation, internal; Foot injuries; Tarsal joints.

Introduction

Trauma to the midfoot can result in a highly variable constellation of fractures, joint subluxations, and malalignments. Lisfranc injuries specifically result in tarsometatarsal (TMT) diastasis and instability[1]. The second TMT articulation, recessed proximally, acts as the keystone of the arch, and plays a critical role in coronal plane stability. Lisfranc ligament proper is an eponymous term that describes the plantar ligament running from the medial cuneiform to the base of the second metatarsal[2], with isolated injuries causing instability[3]. Given its importance, most of the literature on Lisfranc injuries has focused on this interval, and merits of fusion versus fixation are still debated.

Various implants have been utilized for the treatment of Lisfranc injuries, including plates, transarticular screws, k-wires, sutures, bioabsorbable screws, and staples. As our understanding of surgical fixation continues to evolve, increasing evidence is highlighting foot kinematics alterations caused by rigid constructs[4–6]. Furthermore, metal implants used during open reduction internal fixation (ORIF) are often

Study performed at the Beth Israel Deaconess Medical Center in Boston, MA, United States.

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considered for secondary removal procedures. Recently, a limited number of studies have introduced the idea of suture or suture-tape based fixation, also known as flexible fixation (FF), across the medial cuneiform–second TMT interval, with promising results[5,7]. To our knowledge, however, the application of such FF methods in other TMT joints has not been studied, nor have outcomes from robust clinical series been reported.

In 2019, we presented a novel technique for addressing instability using FF[8]. With second TMT joint stability restored either via ORIF or arthrodesis, adjacent TMT incongruity often remains subtly unstable. To address this issue, our joint-sparing technique consisted of wrapping a non-absorbable suture in a figure-of-eight fashion around two cortical screw posts, one placed in the metatarsal base and the other, in its respective tarsal bone. Potential benefits of our previously described technique include: (1) less rigidity than that of metal implant constructs, (2) joint preservation due to the lack of transarticular fixation, and (3) obviating the need for future hardware removal.

The primary aim of this investigation is to present patient-reported outcome measures (PROMs) at final follow-up of a cohort undergoing FF for Lisfranc injury. Secondary outcomes include complications, secondary surgeries, and radiographic outcomes at final follow-up.

Methods

This study was approved under the Institutional Review Board protocol no. 2021P000129. All data collected were secured in compliance with the Health Insurance Portability and Accountability Act, as per the Institutional Review Boards mandate.

Our billing database was retrospectively queried by Current Procedural Terminology (CPT) codes to identify all Lisfranc injuries managed operatively between 2018 and 2021. Injury radiographs, computed tomography (CT)/magnetic resonance imaging (MRI) scans, operative and clinical notes, and postoperative radiographs were reviewed to identify all patients who received adjunctive TMT FF. Patients were included if they had an operatively managed Lisfranc injury of at least one TMT joint treated with FF. Polytraumatized patients, patients with concomitant injuries to the ankle or hindfoot, and/or conservatively-treated patients were excluded. Sixteen patients met inclusion criteria and formed the study cohort, which represented a consecutive series of patients submitted to this technique.

Basic demographic data were collected, including age, gender, laterality, medical comorbidities, mechanism of injury, social history, and occupation. Operative reports and immediate postoperative radiographs were reviewed. Surgical constructs were categorized based on which joints (i.e., first, second TMT joint) received which construct type (i.e., dorsal plate, staple), as well as on the presence of any adjunctive intercuneiform fixation. Clinical notes and any additional operative records were evaluated to identify complications sustained or secondary procedures performed.

All surgeries were performed by one of two fellowship-trained foot and ankle orthopedic surgeons-senior author (JYK) performed 15/16 of the procedures. The FF technique was described in a previously published manuscript[8]. Briefly, after fixation (using a non-FF construct) or fusion of the second (and/or third) TMT joints(s) was performed, stability of the other TMT joints was assessed by performing a stress test under fluoroscopic guidance. If pathologic joint instability was demonstrated, FF was performed on the necessary joints (Figure 1). The TMT joint was anatomically reduced under direct visualization with fluoroscopic confirmation, being provisionally stabilized via extra-articular k-wire fixation. A 2.7 mm or 3.5 mm screw with washer was then placed in the base of the metatarsal and in the adjacent tarsal bone, respectively. A no. 2 Fiberwire (Arthrex, Naples, Florida) was then looped and tensioned in a figure-of-eight fashion around these screw posts (Figure 2). Suture was tightened and knotted and screws were tied to the bone to secure the construct.

Most recent radiographs were reviewed to evaluate for the presence of joint congruity, arthrosis, or other complication. Joint congruity was evaluated by assessing alignment on anterior-posterior, oblique, and lateral radiographs[1]. Specifically, for the fixation group, presence of TMT joint subluxation on any of these views would indicate malalignment. In patients who were indicated for primary arthrodesis, radiographic evidence of fusion, as evidenced by bridging bone, was evaluated. Radiographic follow-up was defined as time from surgery to the date of most recent radiographs, recorded in months.

Patients were then contacted in a prospective manner and requested to complete the Foot and Ankle Ability Measure – Activities of Daily Living (FAAM-ADL), Patient-Reported Outcomes Measurement Information System (PROMIS) Pain Intensity, PROMIS Pain Interference, and PROMIS Depression surveys. The FAAM-ADL survey is a validated tool to measure lower extremity function[9]. It is reported on a 0–100 scale - the higher score, the better function. Minimum clinically important difference for this tool has been previously established as 8 points. The PROMIS Adult Short Form v1.0 – Pain Interference 8a is a validated tool designed to measure the consequences of pain in "relevant aspects of a person's life" using a 7-day recall period[10]. The PROMIS Adult Short Form v1.0 – Pain Intensity 3a is a tool designed to measure pain using a 7-day recall period[11]. The PROMIS scores are reported in t-scores based upon a reference population, where a score of 50 represents the average, with a standard deviation of 10 points[11]. The PROMs follow-up was calculated as the time from surgery to the date of completion of the outcome survey, recorded in months.

Descriptive statistics were calculated and reported using means and standard deviations or medians and interquartile ranges (IQR) for normal and non-normal data, respectively.

Results

A total of 16 patients met inclusion criteria (Table 1). There were nine males and seven females. Mean age at time of

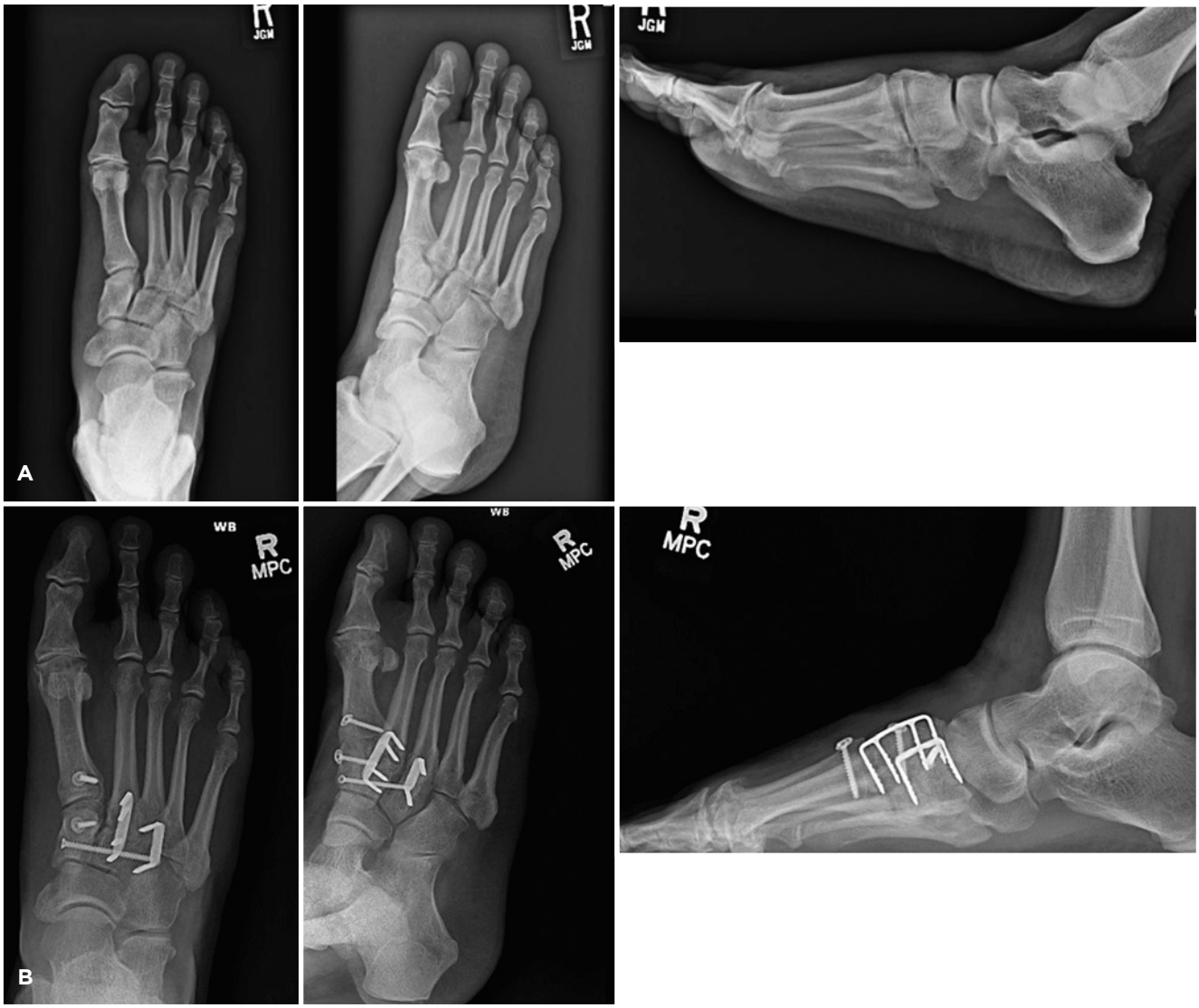

Figure 1. Flexible Fixation. (A) Anterior-posterior, lateral, and oblique injury radiographs of a patient who sustained Lisfranc injury after a mechanical fall. (B) Patient was indicated for primary fusion. After the second and third TMT joints were fused, residual instability was noted at the first TMT and a flexible fixation construct was placed.

surgery was 40 years of age (16–70). Nine patients had ORIF as their index surgery, while seven patients were indicated for acute primary arthrodesis of at least one TMT joint. Fifteen out of the 16 patients surveyed (93.3%) had FF inclusive of their first tarsometatarsal joint; one patient had isolated FF of their fourth TMT. One patient had FF of the second TMT and another patient, of the third TMT, in addition to the first TMT joint.

In the selective arthrodesis group, all patients had evidence of radiographic and clinical joint fusion and maintained midfoot alignment at time of final follow-up. As for the ORIF group, 8/9 of patients (88.8%) had maintained articular congruity, assessed as described above, without evidence of arthritis at final radiographic follow-up. Median radiographic follow-up time was 7.3 months (IQR 4.4–11.6).

Two patients who underwent initial ORIF required secondary arthrodesis. First patient was a police officer, body mass index (BMI) > 45, who was injured in a work-related motor vehicle accident. This patient was submitted to FF of the first and second TMT joints which was converted to fusion at 7.2 months after index surgery due to recurrent diastasis. Second patient was converted from ORIF to fusion at 10.8 months after index surgery due to persistent pain. Both patients underwent uncomplicated arthrodesis and successful fusion was noted at final radiographic follow-up.

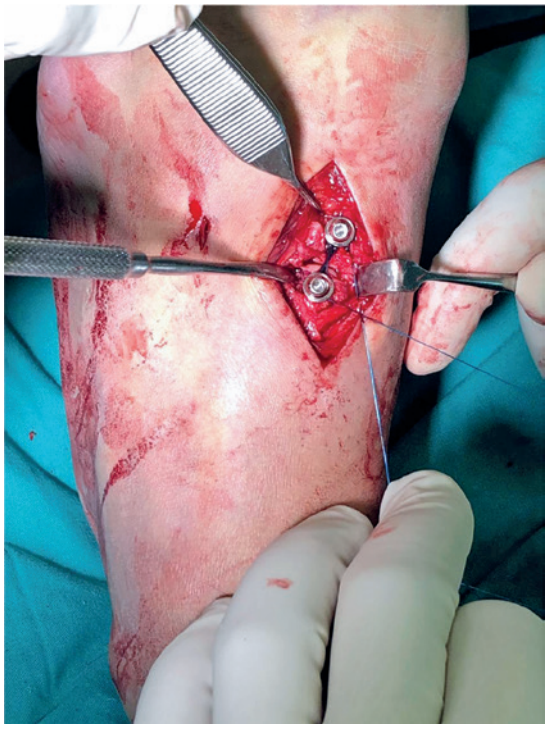

Figure 2. Flexible Fixation of the first TMT *in situ*. Two screws are placed in the metatarsal and in the respective cuneiform. A non-absorbable suture is wrapped in a figure-of-eight fashion and tied.

Elective, unplanned removal of hardware (ROH) was performed in 4/16 (25%) of the overall cohort, and only in 3/9 (33.3%) of patients who underwent ORIF. On average, ROH was performed 7.9 months after index procedure. Irritation from the FF hardware or suture knot, specifically, was not an indication for hardware removal in any case, with predominant complaint being "stiffness".

The PROMs were collected at a median follow-up time of 25.8 (9.5–32.4) months. Median IQR for FAAM-ADL, PROMIS Pain Interference, PROMIS Pain Intensity, and PROMIS Depression scores can be found in Table 2.

Discussion

The FF use to treat Lisfranc injuries has garnered increasing interest due to prior investigations demonstrating need for removal of hardware, altered gait mechanics, increased plantar foot pressures, and stiffness after surgical treatment of Lisfranc injuries using more rigid constructs[6,12]. While these previous investigations have mostly focused on the Lisfranc interval itself, the present investigation is the first to report outcomes of a novel FF method for Lisfranc injuries to treat residual TMT instability, mostly of the first TMT joint. Radiographic evidence at final follow-up consistently demonstrated maintenance of joint alignment. Median FAAM-ADL was 85%, with a median patient PROMIS score (Pain Interference, Intensity, and Depression) near or better than that of the reference population.

Prior investigations have reported on other FF strategies, including suture-button fixation, as well as the use of non-absorbable suture-tape fixation across the Lisfranc interval. In a recent study by Cho et al.[5], authors reported no difference in radiographic outcomes or American Orthopaedic Foot & Ankle Society (AOFAS) scores at one year follow-up between a group treated with traditional screw fixation and those treated with a suture-button placed across the Lisfranc interval. Interestingly, their study also confirmed the presence of altered plantar foot pressures in the screw fixation group prior to screw removal. Importantly, their study was limited to ligamentous injuries and to the placement of suture-button fixation across the Lisfranc interval only, while our study included more heterogenous Lisfranc phenotypes and applied FF beyond the Lisfranc interval. The use of FF for residual first, third, and lesser TMT joint instability may further optimize midfoot function by preventing unnecessarily rigid fixation.

Delman et al.[7] introduced the use of non-absorbable suture tape (InternalBrace, Arthrex, Naples, Fl) for the treatment of ligamentous Lisfranc injuries. Their technique paper described the application of InternalBrace to the medial cuneiform–second TMT interval as a joint-preserving technique. They suggested that, if used for other TMT joint instability, supplementation with dorsal plating should be considered (which can subsequently be removed while retaining the InternalBrace). Although comparison with the current investigation is difficult, given their lack of reported outcomes, the results of our study suggest that suture fixation can be used independent of dorsal plating, obviating the need for future removal of hardware.

Our interest in developing this technique resulted from frequently encountered subtle instability after a second TMT stabilization, particularly of the first TMT joint. We should emphasize that it is unclear whether FF is adequate for primary stabilization of the Lisfranc interval itself. Furthermore, it would seem intuitive that FF would be of inadequate rigidity if arthrodesis is to be performed. Rather, FF is meant to be a low-profile construct for joint-sparing stabilization specifically to address residual subluxation without committing to future hardware removal (i.e., if a dorsal plate is placed) and/or more rigid or expensive constructs (Figure 3). We feel that this technique addresses a specific need in fixation of Lisfranc injuries that have otherwise not been addressed.

Removal of hardware in our cohort was required in 3/9 of patients in the ORIF group and 1/7 of patients in the fusion group (we should stress that patient was submitted to previous ORIF and required ROH due to conversion to arthrodesis). Prior studies have evaluated ROH rates in Lisfranc injuries and have found planned ROH after ORIF to be as high as 70%–80%[13]. While unplanned ROH has been demonstrated to necessitate removal far less frequently, the

Table 1. Cohort details.

Patient	Sex	Age	Side	Mechanism of injury	Occupation	Major medical comorbidities	Fusion or ORIF?	Flexible fixation location	Remainder of construct	Radiographic follow-up (Months)	If fusion, radiographic evidence of fusion?	Secondary surgery (Time from index procedure)	PROMs Follow-up (Months)
1	F	39	Right	Acrobatics	Property management	None	Fusion	1st TMT	Lisfranc interval staple, 2nd TMT Fusion (with staple)	12.6	Yes		32.4
2	M	30	Right	Sports	Unemployed	None	ORIF	1st TMT	Lisfranc screw, intercuneiform screw, dorsal bridge plate of 2nd TMT	9.4	N/A		17.6
3	F	34	Right	Syncope fall	Nurse	None	ORIF	1st TMT	Bridge plating of 2nd and 3rd TMT, intercuneiform screw	13.6	Yes	Fusion (10.8 months)	27.6
4	F	29	Left	Dancing	Customer service	None	Fusion	1st TMT	Lisfranc screw, 2nd TMT, 3rd TMT staple, intercuneiform screw, lateral column plate dorsal spanning plate	4.0	Yes		4.7
5	F	16	Left	Sports	Student	None	ORIF	1st TMT	Lisfranc screw, intercuneiform screw, dorsal bridge plate of 2nd TMT	11.8	N/A	ROH (10 months)	23.9
6	M	70	Right	Trip and fall	Retired	None	Fusion	4th TMT	Fusion of 1st-3rd TMT with staples, bridge plate over 1st TMT, ORIF 2nd TMT shaft with plate bridging into the medial cuneiform, inter cuneiform screw	10.8	Yes		32.6
7	M	66	Right	Trip and fall	Boxing coach	None	Fusion	1st TMT	Fusion of 2nd and 3rd TMT with staples, intercuneiform screw	4.8	Yes		5.5
8	M	37	Left	Fall from 15 ft	Real estate broker	None	ORIF	1st TMT	Dorsal plates of 2nd, 3rd, 4th TMT, intercuneiform screw	3.8	N/A		18.1
9	F	27	Right	MVC	Software designer	None	ORIF	1st TMT	Lisfranc screw, intercuneiform screw, dorsal bridge plate of 2nd TMT	7.3	N/A	ROH (8.5 months)	34.9
10	M	19	Right	Sports	Student	None	ORIF	1st TMT	Lisfranc screw, intercuneiform screw	4.1	N/A	ROH (5.4 months)	30.8
11	F	40	Left	Fall from standing	Billing manager	None	ORIF	1st TMT	Lisfranc screw, intercuneiform screw, dorsal bridge plate of 2nd TMT	7.5	N/A		29.4
12	M	42	Right	MVC	Police officer	Smoking	ORIF	1st TMT	Lisfranc screw, intercuneiform screw, dorsal bridge plate of 2nd TMT	4.4	N/A		7.0
13	M	30	Right	MVC	Police officer	Obesity	Fusion	1st and 2nd TMT	Lisfranc staple, intercuneiform screw	24.7	Yes	Fusion (7.2 months); ROH (16.3 months)	32.8
14	F	50	Left	Trip and fall	Personal care assistant	None	ORIF	1st TMT	Lisfranc screw, dorsal bridge plate of 2nd TMT	5.7	N/A		10.4
15	M	49	Right	Trip and fall	Radiologist	None	Fusion	1st TMT	Lisfranc staple, 2nd TMT staple	2.3	Too early		3.0
16	M	56	Left	Trip and fall	Teacher	None	Fusion	1st and 3rd TMT	Lisfranc staple, 2nd TMT dorsal bridge plate	10.8	Yes		34.5

MVC: Motor vehicle collision; ORIF: Open reduction internal fixation; TMT: Tarsometatarsal; N/A: Not applicable; ROH: Removal of hardware; PROMs: Patient-reported outcome measures.

Table 2. Patient-reported outcomes collected prospectively approximately two years postoperatively.

Outcome scores	Median (IQR)
FAAM-ADL	85 (64.75–93.5)
PROMIS Interference	53.1* (49.7–57.75)
PROMIS Intensity	45.7* (37.7–51.3)
PROMIS Depression	46* (43.3–52.28)

IQR: Interquartile range; FAAM-ADL: Foot and Ankle Ability Measurement – Activities of Daily Living; PROMIS: Patient-Reported Outcomes Measurement Information System.
*T-score metric - 50 is the mean of a relevant reference population, and 10 is the standard deviation (SD) of that population.

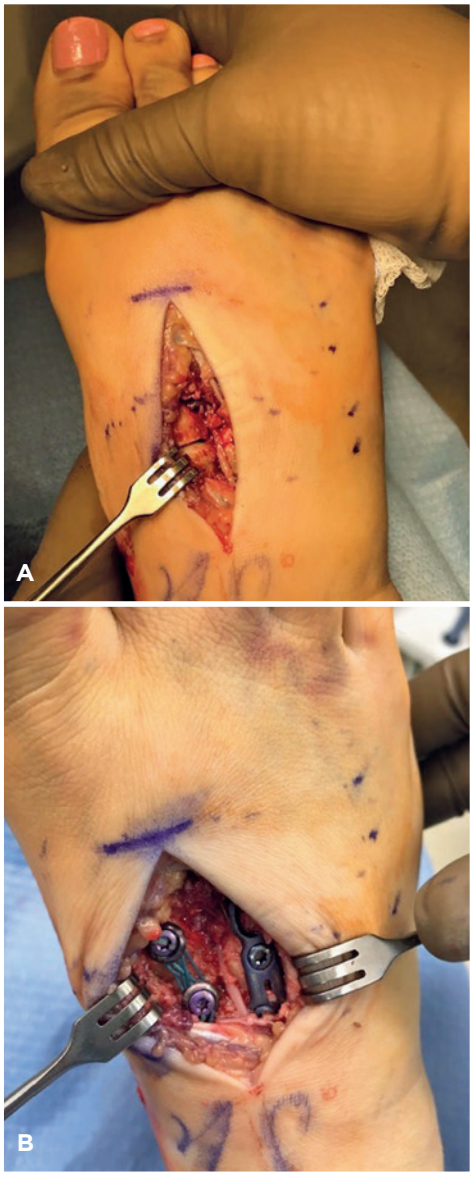

Figure 3. Stress testing after Lisfranc fixation/fusion. (A) After second TMT fusion (in this case), residual subtle instability was noted clinically. (B) Decision was made to stabilize the joint using the flexible fixation technique described.

previously accepted practice of removing hardware placed during ORIF may be changing, and the senior author does not routinely remove hardware after Lisfranc fixation. In any event, our series demonstrates low ROH rates and, importantly, no removals were specifically indicated due to irritation from the FF construct. Given concerns over wound-healing issues or nerve injuries after hardware removal[14], avoiding this secondary surgery is a possible benefit of this technique.

We also report PROMs that are consistent with prior literature. It is well-known that studying clinical outcomes after Lisfranc injuries is difficult because they are both uncommon and heterogenous. Despite this heterogeneity, multiple prior investigations[15–18] have used the FAAM-ADL survey with scores generally falling between 80% and 90%. Our findings, of 85% (IQR 64–93), corroborate these results. In terms of PROMIS scores, patients scored within half of one standard deviation of the t-scores of a reference population for the PROMIS Pain Interference, Pain Intensity, and Depression surveys. These outcomes, at a median of over two years of follow-up, are indeed promising, suggesting that this method of addressing residual TMT stability is both safe and effective.

Finally, two patients required secondary surgery (other than ROH) in our cohort. One was a patient who underwent primary ORIF and was later converted to arthrodesis at approximately 10 months after index surgery due to continued pain. Although there was no malalignment visualized on radiographs and only minimal evidence of arthrosis on CT, patient opted for arthrodesis rather than a trial of hardware removal due to confirmed joint pain based on diagnostic injections. Prior literature reports a variable rate of post-traumatic arthritis, approximately 25%, with a subset of patients requiring conversion to fusion[19,20]. For one patient (in a cohort of 16 patients) to undergo a secondary arthrodesis procedure at a median of two years of follow-up would not be unexpected and likely not attributable to the use of FF. Our second complication was a failure of the FF construct in a police officer patient with BMI > 45 who sustained a high energy Lisfranc injury after a motor vehicle accident. While initial injury was primarily ligamentous and ultimately converted to arthrodesis successfully, this was admittedly a failure in judgement. Given his body habitus and significant occupational demands, patient was likely best served with primary arthrodesis as index procedure. While our technique appears adequate for the majority of patients, judicious use should be considered in obese patients or in those with a high risk for postoperative non-compliance.

There are several limitations to our study. First, our study is limited by the heterogeneity of Lisfranc injuries and the resultant need for a similarly heterogenous choice of procedures and fixation strategies. In spite of this, our results demonstrate that this technique is promising at treating residual instability across a variety of injury presentations, including those of higher energy. Secondly, this study is limited by its case series nature and lack of a comparative

control group, which is often inherent to a single-surgeon series. However, as surgeons develop new techniques to address clinical problems, these early reports in literature are critical to demonstrate efficacy and safety and to promote the conduction of more rigorously designed studies.

Certain host and injury factors should be carefully considered prior to applying this technique. Patients with uncontrolled diabetes mellitus, neuropathy, and those with significantly elevated BMI may require a more rigid fixation than that afforded with this technique. Similarly, if there is a concern for non-compliance with weightbearing restrictions, this technique should be considered carefully, as the extra stiffness of a dorsal plate/screw construct may be advantageous if joints are being consistently loaded prior to ligamentous healing. Furthermore, specific injury characteristics should be evaluated prior to the application of this technique. In significant metatarsal base fractures, if comminution and/or dislocation is present, more rigid constructs may be preferred given the significant disruption of secondary osseo-ligamentous stabilizers of the TMT joints. Similarly, this method of stabilization may not be adequate for sole stabilization of the second TMT joint or the Lisfranc interval. We recommend this technique for stabilization of surrounding TMT joints (most notably, the first TMT joint) only after this key articulation has been stabilized using traditional techniques. In this vein, FF is not a ligament repair or reconstruction technique per se, but rather a form of internal stabilization secondarily addressing ligament disruption.

Conclusion

The novel FF technique proposed for residual TMT subluxation in Lisfranc injuries appears to be safe and effective, with good PROMs at two-year follow-up and low complication rates. This joint-sparing technique may be a reasonable alternative to adjunctive rigid fixation with dorsal plating, transarticular screws, or staples in selected patients, and may obviate the need for hardware removal.

Authors' contributions: Each author contributed individually and significantly to the development of this article: EMI (https://orcid.org/0000-0003-4842-5801), and FR *(https://orcid.org/0000-0002-2922-1929) Conceived and planned the activities that led to the study, approved the final version; JYK *(https://orcid.org/0000-0001-5700-238X) Interpreted the results of the study, participated in the review process and approved the final version. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID) .

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Case Report

A rare case of calcaneal bone osteomyelitis resulting from local paracoccidioidomycosis in an immunosuppressed patient: a case report

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Abstract

Isolated bone involvement of paracoccidioidomycosis without any pulmonary focus is rare. This report documents the first case of calcaneal osteomyelitis, where bone infection was the only manifestation of the disease. A young 22-year-old male, mixed race, from a rural area in Brazil, was treated in the orthopedics emergency room. He reported a callus in the region of the Achilles tendon and developed intermittent claudication and, at times, inability to walk. In addition to having a low fever and sweating. He was hypertensive and on immunosuppressive medication due to a previous kidney transplant. An intracalcaneal collection was observed on magnetic resonance imaging, requiring surgical treatment for debridement and filling of the bone defect. After surgical intervention and administration of antifungal medication, the patient's symptoms gradually improved. The epidemiological evaluation for differential diagnosis and the multidisciplinary clinical-orthopedic approach with effective diagnosis and treatment enabled the best clinical outcomes for the patient.

Level of Evidence IV; Therapeutic studies; Case Report.

Keywords: Bioactive glass s53p4; Calcaneo; Immunocompromised Host; Paracoccidioides; Osteomyelitis.

Introduction

Paracoccidioidomycosis (PCM) is an endemic systemic mycosis caused by thermodimorphic fungi, *Paracoccidioides brasiliensis,* and Brazil accounts for 80% of the infected worldwide population[1]. The biggest risk factors for infection are related to activities that involve managing contaminated soil and patients using immunosuppressive medication[1,2].

Fungal infections of the musculoskeletal system are uncommon and can occur in dead space in infected bone. Several procedures are available to manage bone defects resulting from bone involvement, such as autologous bone grafts, synthetic grafts, and antibiotic-loaded cement-based grafts[3].

This is the first report of osteomyelitis caused by *Paracoccidioides brasiliensis* in the calcaneal bone, and the restoration of the bone defect performed with a bioactive glass (BAG) S53P4 graft (Bonalive®) allowed the total rehabilitation of the patient.

Case description

A 22-year-old male patient residing in a rural area in Brazil was admitted to the orthopedics emergency room complaining of pain in his right ankle. He reported an injury five weeks prior due to a callus in the posterior region of the ankle (Figure 1A) with good wound healing but presented progressive pain in the calcaneus region and intermittent claudication a

Study performed at the Oswaldo Cruz German Hospital Departament of Foot and Ankle Surgery, São Paulo, SP, Brazil.

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few weeks later, mainly at night, coursing with edema, heat, and local redness, in addition to night sweats with low fever (37.5º–37.8º Celsius), without respiratory symptoms. He was hypertensive and submitted to a kidney transplant three years before in continuous use of immunosuppressant medication (Tacrolimus®) and prednisone. Ultrasonography (USG) of soft tissues showed thickening of the Achilles tendon. Laboratory markers of inflammatory/infection status were as follows: leukocyte count = 10,120/mm^3; C-reactive protein = 5.06 mg/dL, and erythrocyte sedimentation rate = 109 mm/hour. Due to alteration on the USG, magnetic resonance imaging (MRI) of the ankle was performed, showing intense bone edema and an intraosseous collection of 22.5 cm^3 in the calcaneus (Figure 1B) with a transcortical fistulous path into the Achilles tendon (Figure 1C).

After collecting blood cultures, he started antimicrobial therapy with meropenem and daptomycin at adjusted doses and was hospitalized for surgical treatment. In the intraoperative, drainage of purulent secretion was observed in the Achilles tendon adjacent to the intracalcaneal collection (Figure 2), with signs suggestive of osteomyelitis and a large cortical defect of the posterior calcaneal process. Three surgical procedures were performed to remove all infected and necrotic tissue until healthy bone was exposed (Figures 2E and 2F). Negative pressure therapy dressing was used with instillation and changed weekly until the culture and pathology results were awaited. The cultures were partially negative, but the anatomopathological examination of the bone fragment showed fungal infection in the conventional anatomopathological examination (Figure 3A). After special Grocott staining, the fungus was distinguished in *Paracoccidioides brasiliensis* (Figure 3B). A daily dose of 200 mg of itraconazole was started. The bone defect was filled with a BAG S53P4 graft (Figure 2), and the patient remained immobilized with load restriction. Pulmonary infection was suspected due to the presence of a granulomatous inflammatory process and the presence of "ground-glass" opacities on tomography, which was not confirmed by complementary exams.

The patient was discharged using itraconazole and reevaluated after one week with no complaints and good wound healing (Figure 2). He returned to his usual activities five months after the surgical procedure and ended the use of antibiotics after eight months. One year after the surgery, the radiographs showed one formation and active remodeling of the biomaterial with good consolidation (Figure 2).

Discussion

Paracoccidioidomycosis infection, in general, is acquired by inhaling dimorphic fungal propagules with two types of clinical presentations: the acute-subacute (juvenile) and chronic (adult) forms[4]. Isolated osteoarticular involvement of *Paracoccidioides brasiliensis* is responsible for approximately 0.01%–0.04% of osteomyelitis, and in the disseminated forms (involving multiple organs), the bone involvement can occur in up to 20% of patients. As described in our report, bone involvement by contiguity from skin lesions is considered rare[5]. Osteomyelitis is most common in bone around the thorax because of lymphohematogenous dissemination from the pulmonary system[5,6].

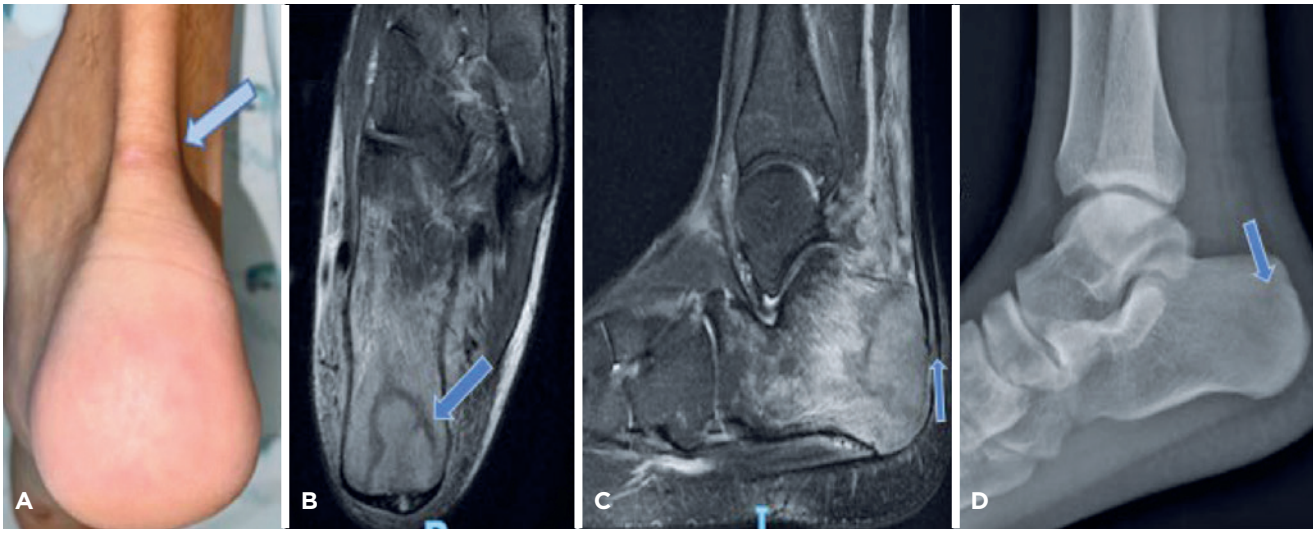

Figure 1. (A) Image with an arrow indicating blunt injury site before symptoms. (B) Magnetic resonance imaging – axial T2 FAT SAT. (C) Magnetic resonance imaging – sagittal T2 FAT SAT. Both magnetic resonance imaging show bone edema, an intraosseous collection with a transcortical fistulous path into the Achilles tendon. (D) Lateral radiograph on admission to the orthopedic emergency room, with slight radiographic alteration and little sclerosis around the lesion.

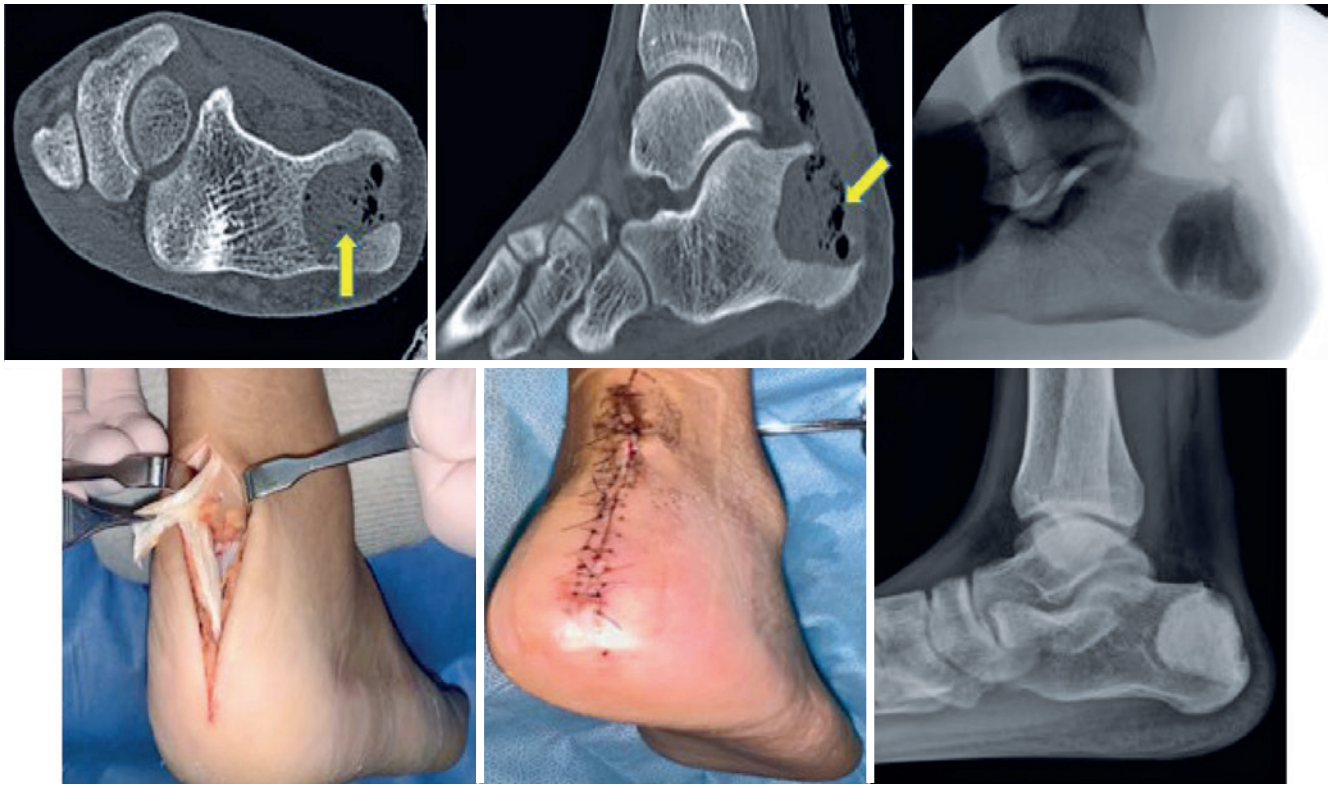

Figure 2. Computed tomography - Axial view after surgical debridement. Computed tomography – Sagittal view after surgical debridement. Intraoperative radioscopy after filling with bioactive glass S53P4. Intraoperative image showing drainage of purulent secretion from the calcaneal bone adjacent to the calcaneal tendon sheath. Image before the surgical wound in the outpatient follow-up**.** Weight-bearing ankle control radiograph after one year of surgical treatment.

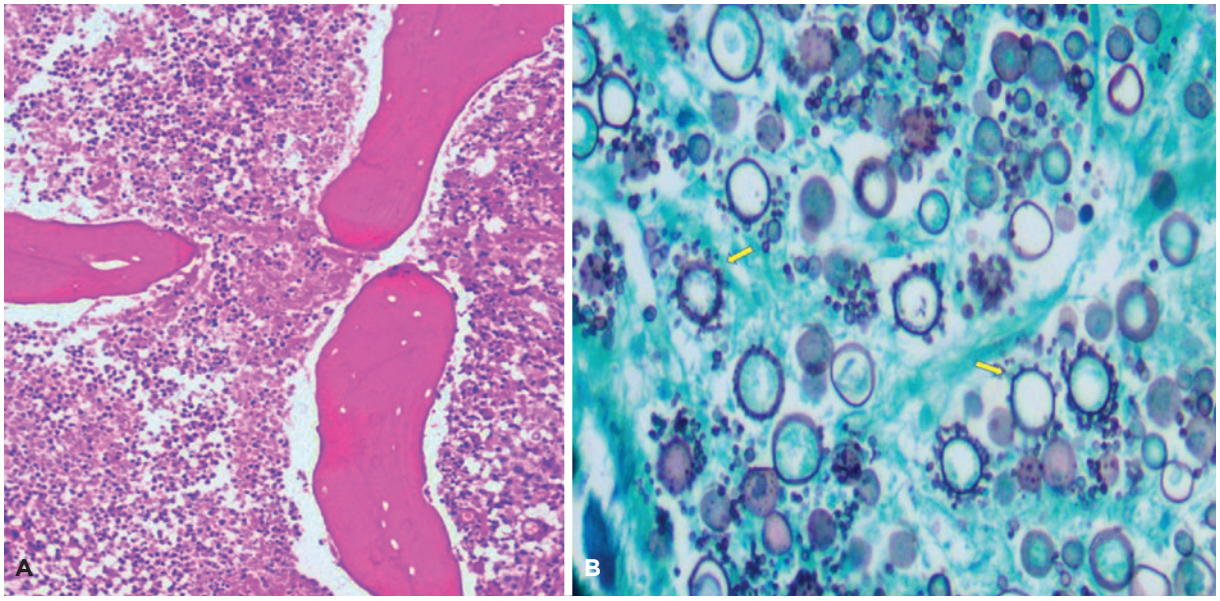

Figure 3. (A) Histopathological analysis hematoxylin-eosin 100x – bone tissue with neutrophilic inflammatory infiltrate showing extensive necrosis. (B) The histiocytic reaction with epithelioid granulomas predominates. Grocott staining reveals the presence of yeast-like structures with size variation and helm-wheel budding.

In osteoarticular infections, radiographs show lytic lesions without marginal sclerosis, with little or no periosteal reaction, and without pathognomonic signs[7], similar to the radiographic findings of our patient (Figure 1D).

In their series of 19 cases, Monsignore et al.[6] demonstrated that performing MRI as a complementary exam was important for the differential diagnosis of bone tumors, bacterial osteomyelitis, histiocytosis, tuberculosis, and other diseases involving the bones. It also demonstrated that most of the findings were in meta-epiphyseal regions of long bones, differing from the bone location in our case. However, it had similar MRI findings, such as exuberant bone edema, well-defined margins, and little sclerotic reaction (Figures 1C and 1D).

As previously mentioned, our patient lived in a rural area and was on immunosuppressive medication due to a previous kidney transplant. The incidence of fungal infections affects only 5% of all infections in transplant patients, and in these patients, PCM infection is a rare condition associated with postrenal transplant immunosuppression[7].

Histopathological evaluation of *Paracoccidioides brasiliensis* by Groccot staining shows rounded elements, with thick birefringent walls, distinguished in single or multiple buds connected to the parental cell by a narrow cytoplasmic bridge, with pathognomonic finding rudder of a ship[8], confirming the findings of this case's analysis of the collected material (Figure 3).

Surgical management can leave a major bone gap that must be repaired, infection recurrence, and bone fragility fractures. Autologous bone grafts are the gold standard for bone reconstruction and have osteogenic, osteoinductive, and osteoconductive properties[8,9]. In our case, the BAG S53P4 graft was used; it has bactericidal, osteoinductive, and osteogenic functions, producing an ideal environment for treating bone defects in osteomyelitis. Bioactive glass is a silica composed of SiO_2, Na_2O, CaO, and P_2O_5, facilitating tissue growth chemically linked to the bone matrix and promoting bone formation. Ion exchange occurs with increased pH and osmotic pressure, ensuring a hostile environment for bacteria without local antibiotics[9]. We did not find a specific validation of using BAG S53P4 graft for infection by *Paracoccidioides brasiliensis* in the literature, but the description of the bactericidal function that limits the growth of microorganisms is quite consolidated. Another characteristic of BAG S53P4 in microorganisms is its bacteriostatic effect. An isothermal microcalorimetry study demonstrated a reduction in the microbial activity of microorganisms that cause osteomyelitis[9].

The medications used to control the infection caused by *Paracoccidioides brasiliensis* include amphotericin B, sulfamethoxazole-trimethoprim, and azole derivatives. Unfortunately, amphotericin B is associated with substantial toxicity, while trimethoprim-sulfamethoxazole is associated with relapses. In these situations, azole derivatives are the best option[10].

Due to the risk of toxicity and failure to diagnose disseminated infection, 200 mg/day for eight months was chosen. According to the Brazilian guidelines, the treatment time can vary from nine to 18 months in mild and moderate cases. Continuous investigation of clinical, radiological, and immunological criteria in the patient is necessary[10].

The osteoarticular infection of *Paracoccidioides brasiliensis* is rare in the appendicular skeleton and occurs mostly in renal transplant patients. In this case, the establishment of an interdisciplinary relationship, with an effective surgical approach with identification of the pathogen, filling of the bone defect with a bioactive glass S53P4 graft, and, synergistically, the choice of antifungal therapy appropriate to the patient's comorbidities enabled the patient to return to their usual activities and work effectively.

Authors' contributions: Each author contributed individually and significantly to the development of this article: ECSS *(https://orcid.org/0000-0001-5018-3923) conceived and conceived and planned the activities that led to the study, wrote the article, participated in the review process, approved the final version; interpreted study results, participated in the review process; and participated in the review process, approving the final version; CDF *(https://orcid.org/0000-0002-6649-2066), and PBR *(https://orcid.org/0000-0002-7215-8187) Conceived and conceived and planned the activities that led to the study, wrote the article, participated in the review process, approved the final version; and interpreted study results, participated in the review process approved the final version; DAS *(https://orcid.org/0009-0008-8395-8797), and MLSK *(https://orcid.org/0009-0009-9003-0863), and EAP *(https://orcid.org/0000-0001-6008-8671) Interpreted study results, participated in the review process; and participated in the review process, approving the final version. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID).

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Technical Tips

Anterior tibial tendon transfer: a novel surgical proposal

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Abstract

Congenital equinovarus clubfoot is one of the most common congenital musculoskeletal deformities, and the treatment described by Ponseti is considered the gold standard; however, the recurrence rate can be significant. In cases of failed conservative treatment and persistent dynamic forefoot adduction and supination deformities, transfer of the anterior tibial tendon to the dorsolateral region of the foot may be indicated. In this paper, we present a novel surgical technique involving a double passage of the tendon through osseous tunnels and final fixation of the transferred tendon onto itself, ensuring optimal fixation and cost-effectiveness while mitigating complications associated with the conventional method. We advocate for adopting this novel technique as a treatment method for dynamic deformities resistant to non-surgical interventions for congenital clubfoot.

Level of Evidence V; Therapeutic Studies; Expert Opinion.

Keywords: Ankle joint; Clubfoot; Tendon transfer.

Introduction

Congenital equinovarus clubfoot is one of the most common congenital musculoskeletal deformities, and the treatment approach utilizing repeated manipulations and serial casting, as described by Ponseti, is considered the optimal strategy for addressing this condition. However, the recurrence rate can range from one-third to 52% of cases[1,2]. In such instances, a recurrent attempt at correction is typically pursued using the same serial casting technique; in some cases, surgical interventions involving soft tissue releases, tendon transfers, or osteotomies are employed to achieve pain-free and plantigrade feet. Despite successfully correcting the peri-talar complex in certain scenarios, dynamic deformity involving forefoot adduction and supination may persist. In such cases, transfer of the anterior tibial tendon to the dorsolateral region of the foot may be indicated.

Originally described by Garceau[3] in 1940, the anterior tibial tendon transfer technique has evolved over the years as clinical practice and patient follow-up have allowed the assessment of outcomes and complications associated with this procedure. Among the techniques described and employed thus far, some involve the use of implant materials such as anchors or screws for fixation of the transplanted tendon. In contrast, others present complications when anchoring to the plantar skin using buttons.

Given this context, the authors in this study have conceived a new surgical technique detailed herein for anterior tibial tendon transfer. This method involves passing the tendon through osseous tunnels and securing the transferred tendon onto itself, ensuring optimal efficacy and cost-effectiveness.

Surgical technique

With a pneumatic tourniquet inflated on the thigh, the detachment of the anterior tibial tendon from the medial aspect of the foot is performed through an anteromedial skin incision. It is crucial to preserve maximum tendon length by mobilizing its entire insertion. A thorough dissection of the tendon is important, as there might be expansions at its insertion site (Figure 1A).

Study performed at the Hospital Israelita Albert Einstein, São Paulo, SP, Brazil.

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The tendon is secured with a Krakow-type suture using absorbable Vycril thread, either size 0 or 1, ensuring at least 20 cm of suture thread remains beyond the tendon's end. Proximal dissection of the tendon extends to the ankle retinaculum, with the release of any vincula if present (Figure 1B).

A second 2 cm longitudinal incision is made on the dorsum of the midfoot, aligned with the third metatarsal, to expose the midfoot capsules. Care is taken to mobilize the short extensor muscle of the toes and its tendons.

The anterior tibial tendon is transferred from the medial to the dorsal incision through a subcutaneous passage between the two incisions. The tendon should easily slide laterally to its new position. The ankle retinaculum offers ample space for tendon gliding, allowing it to remain straight up to the point of the new insertion. Any residual bands of scar tissue or vincula should be released (Figure 1C).

A capsule and perichondrium or periosteum flap are fashioned to expose the midfoot joints, enabling inspection of the midfoot joints, which must be avoided when creating the incisions to pass the transplanted tendon (Figure 2).

A large incision, typically around 4 mm in diameter, is vertically drilled into the lateral cuneiform, and a second incision of the same diameter is created in the cuboid or intermediate cuneiform, depending on the surgeon's preference for the most suitable location to accommodate the transplanted tendon. These incisions should ideally be the same diameter as the tendon (Figure 3).

A perforated guide wire, with the ends of the suture thread attached, is passed through the osseous tunnel from the dorsal to the plantar, directed medially to prevent neurovascular structure injury. A small incision of approximately 5 mm is made on the plantar region to exteriorize this guide wire (Figure 4).

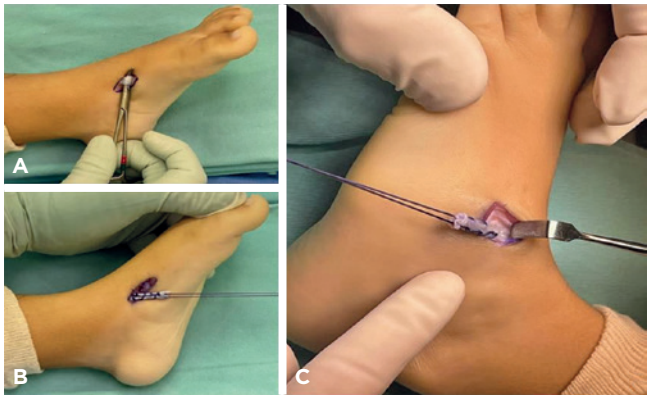


Figure 1. A) Dissection and detachment of the anterior tibial tendon from the medial aspect of the foot; B) The tendon is secured with a Krakow-type suture; C) Anterior tibial tendon is transferred from the medial incision to the dorsal incision.

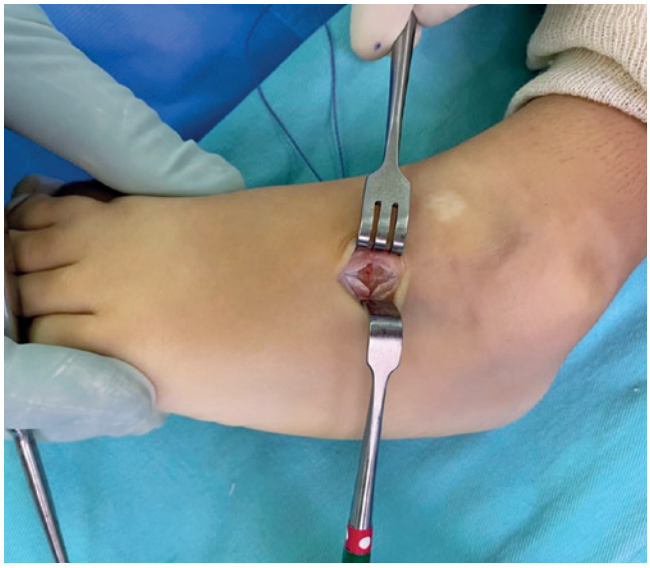


Figure 2. A capsule and perichondrium or periosteum flap are fashioned.

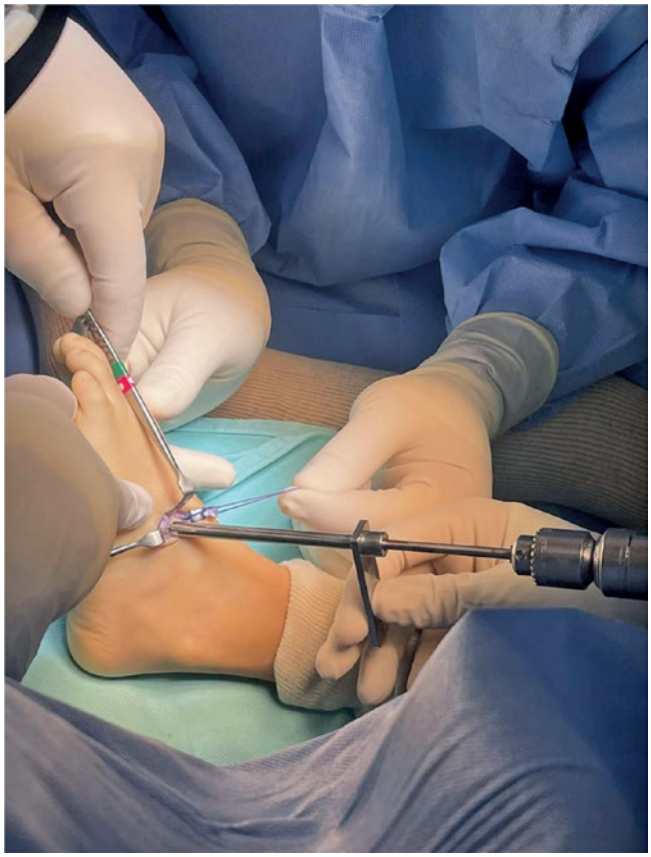


Figure 3. A incision is vertically drilled into the lateral cuneiform.

Through this incision, soft tissues of the plantar region are dissected to the plantar bony surface of the lateral cuneiform. Using the same incision, a cannula with approximately 5 mm is introduced through the guide wire to the plantar bony surface. The passage of the guide wire through the cannula is completed, guiding the suture thread to be exteriorized through the skin while ensuring the cannula maintains its snug osseous position (Figures 5 and 6).

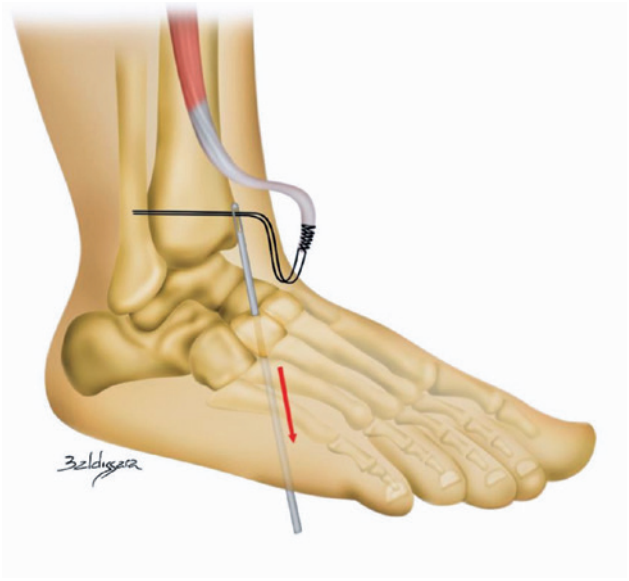


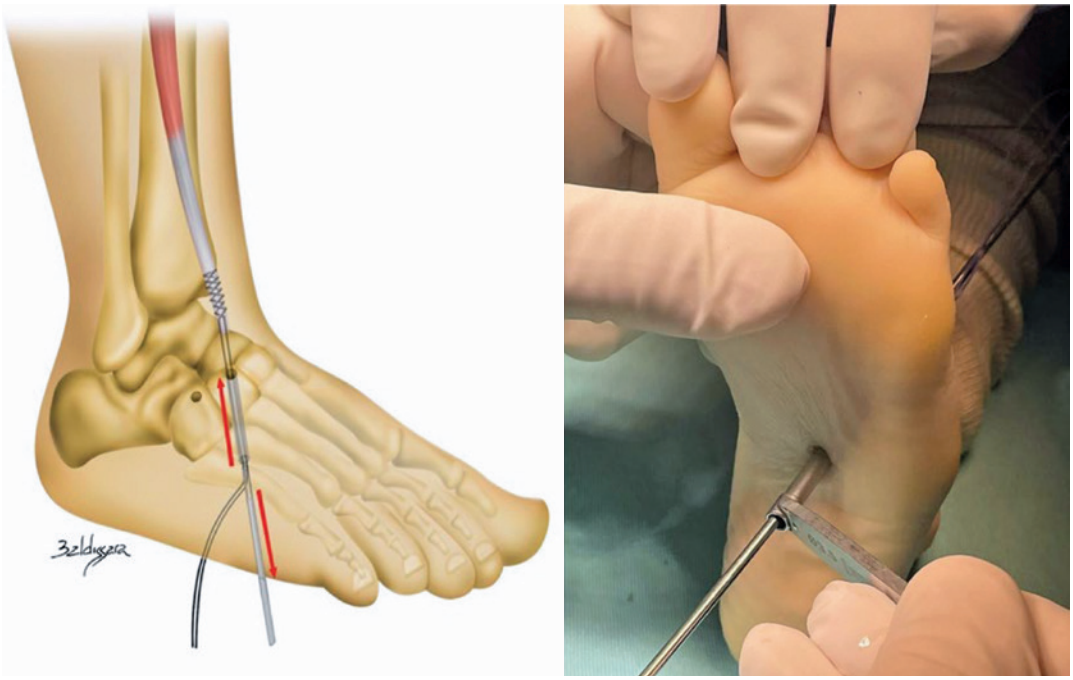
Figure 4. A guide wire, with the ends of the suture thread attached, is passed through the osseous tunnel from the dorsal to the plantar.

The guide wire, which was retracted, is then inserted through the second bone incision, from the dorsal to the plantar, but now with the incisions facing the plantar surface. The cannula is slid laterally, maintaining bony contact until it meets the inserted guide wire in the second incision, allowing the guide wire to be fully passed through the cannula (Figure 7).

The ends of the suture thread are then attached to the guide wire, and at this point, traction is applied by tensioning the tendon in the first incision. With the tendon maintained in position, noting that the child's foot should be in dorsiflexion and slight eversion, the guide wire is pulled from the plantar to the dorsal, thus exteriorizing the suture thread ends dorsally (Figures 8 and 9), forming a loop around the two perforated incisions (Figure 10).

With traction on the suture threads and the tendon introduced through the first incision, the desired tension is calibrated, and dorsal suturing of the threads onto the tendon itself is performed. The flap of the capsule and periosteum is also sutured over the tendon (Figures 11 and 12).

Postoperative management follows standard protocols, including suropodalic cast immobilization in 10-degree dorsiflexion and slight foot eversion, to be maintained for six weeks. Weight-bearing is allowed after four weeks post-surgery.



Figures 5 and 6. Plantar soft tissue dissection and passage of the guide wire through a cannula to exteriorize the suture thread through the plantar skin.

Discussion

The anterior tibial tendon transfer to the dorsolateral region of the foot aligned with the axis of the third metatarsal[4], indicated for persistent dynamic deformities refractory to conservative treatment, is employed in 15%–40% of cases of congenital clubfoot[5], effectively addressing dynamic forefoot supination[6,7].

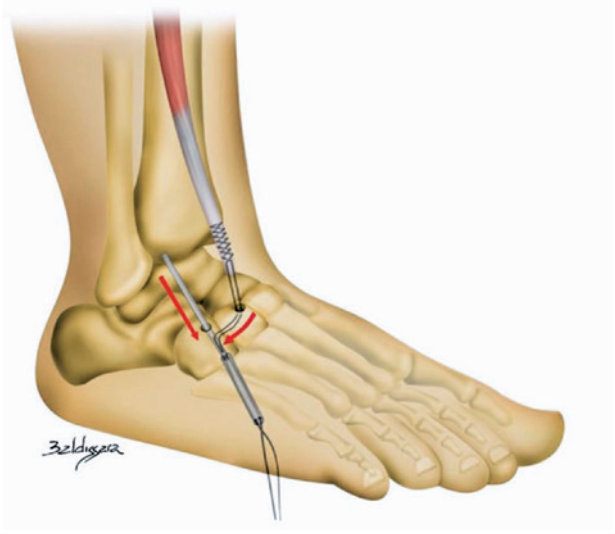


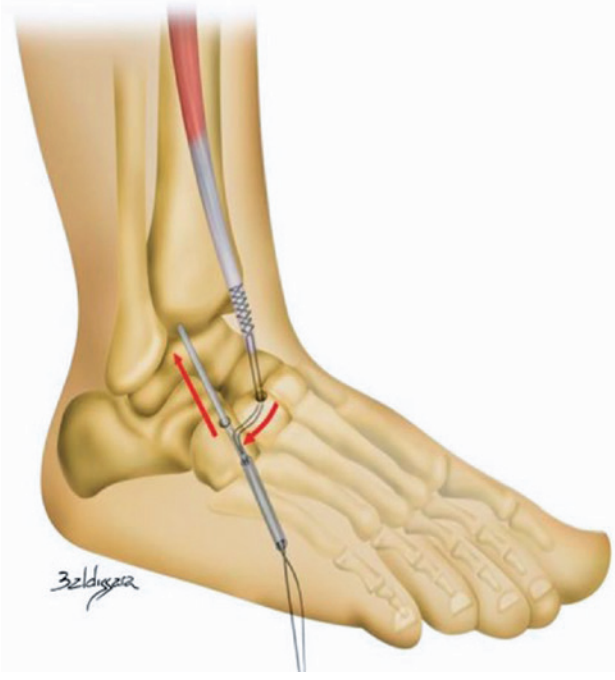
Figure 7. The guide wire is inserted through the second bone incision, from the dorsal to the plantar, with the incisions facing the plantar surface until it is passed through the cannula to protect the soft tissues.

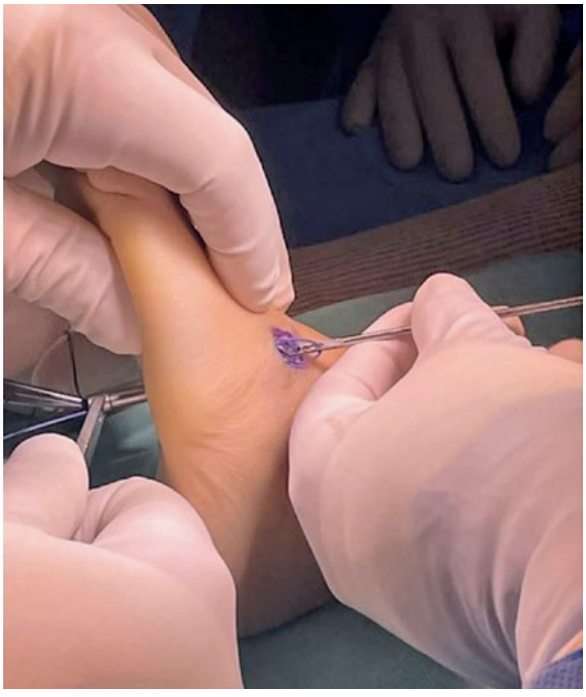
The most commonly used technique to execute this procedure involves passing the tendon through an osseous tunnel in the lateral cuneiform and threading and anchoring the suture threads through the plantar surface of the foot[8]. This method may entail potential complications such as skin necrosis, vascular injury, and tension loss in the transplanted tendon. Other technical possibilities have also been described, including biotenodesis screws, suture buttons, and anchor fixation[2,9].

Radiographic and histological outcomes obtained using different methods of fixation for the transferred anterior tibial tendon in immature porcine skeletons were compared by Korth et al.[10], demonstrating superior results for fixation performed through osseous tunnels and bone sutures and poorer results for cases fixed with suture anchors.

The technique presented involves the double passage of the transferred tendon through osseous tunnels, combined with the final suturing of the tendon onto itself, ensuring excellent fixation. Furthermore, it does not need specific materials, making it financially economical. By avoiding plantar "pull out," this technique circumvents potential complications occasionally observed with the traditional method, particularly tendon tension loss and skin necrosis.

In our institution, this technique has been utilized for treating cases of congenital clubfoot with dynamic defor-





Figures 8 and 9. The guide wire is pulled from the plantar to the dorsal, thus exteriorizing the suture thread ends dorsally.

mities involving forefoot supination and adduction, yielding satisfactory outcomes.

The surgical technique detailed here for anterior tibial tendon transfer, utilizing a double passage of the tendon through osseous tunnels and final fixation of the transferred tendon onto itself, ensures excellent fixation and cost-effectiveness while mitigating complications associated with the conventional method. We advocate for adopting this novel technique as a treatment method for dynamic deformities resistant to conservative interventions for congenital clubfoot.

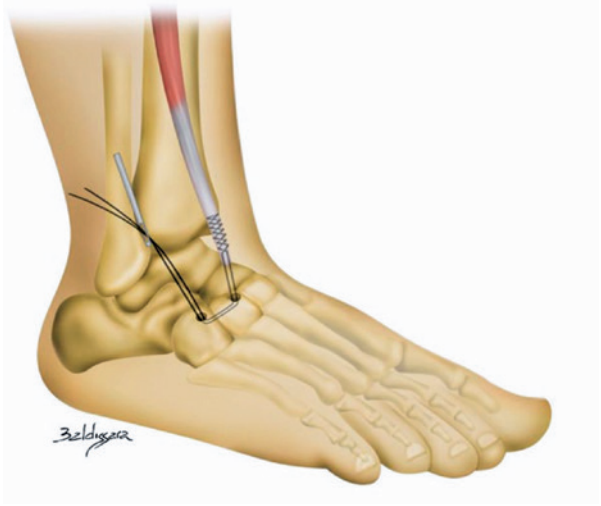
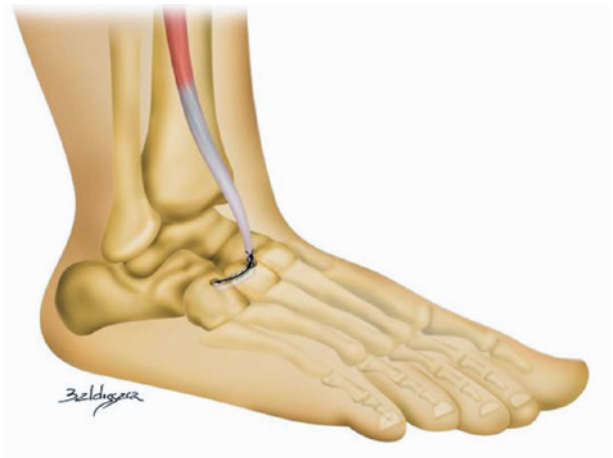
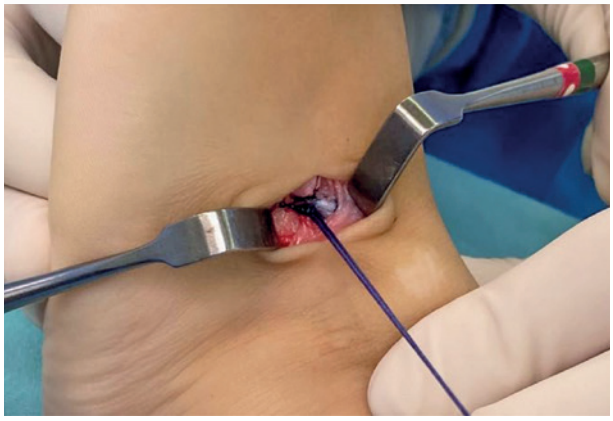


Figure 10. A loop is formed with the suture thread around the two perforated bones.





Figures 11 and 12. Suturing of the threads onto the transferred tendon.

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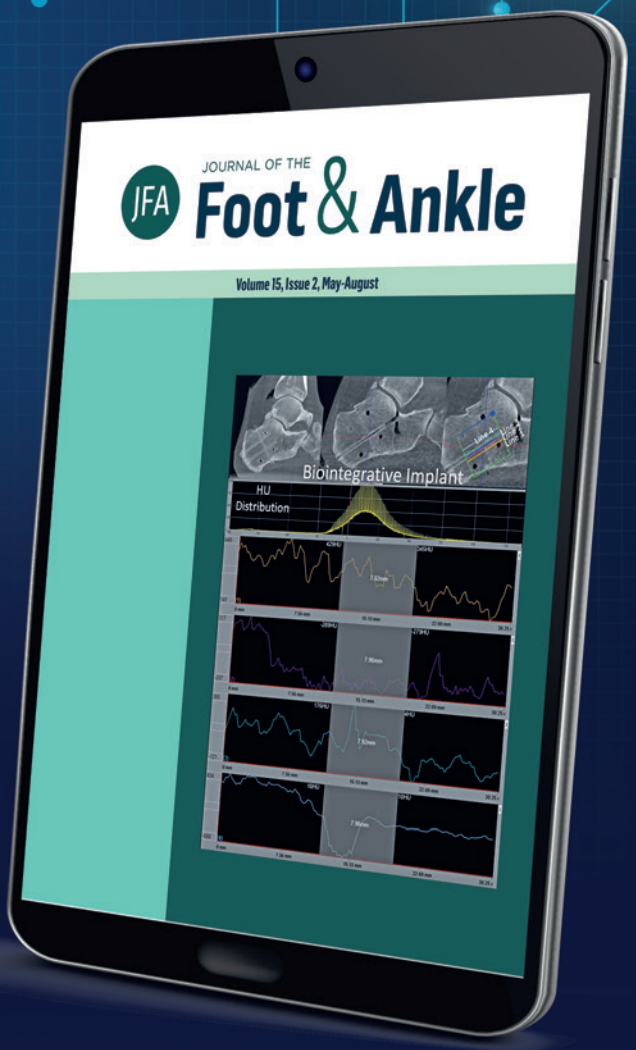

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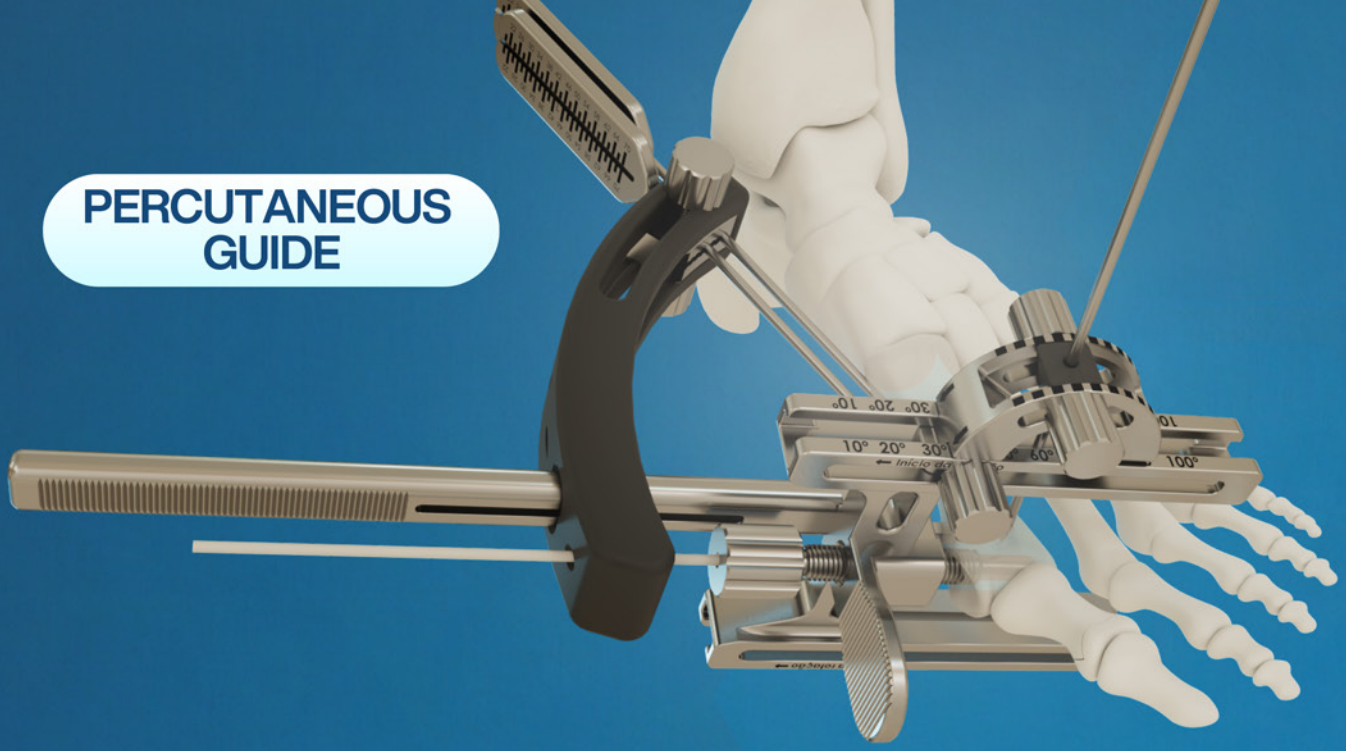
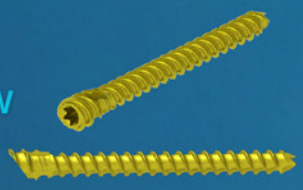
PERCUTANEOUS GUIDE



PERCUTANEOUS BEVEL SCREWS

BEVELED SCREW
AD 3.0mm



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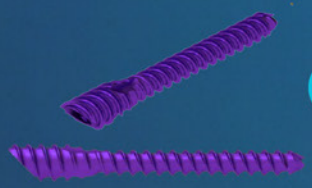

BEVELED SCREW
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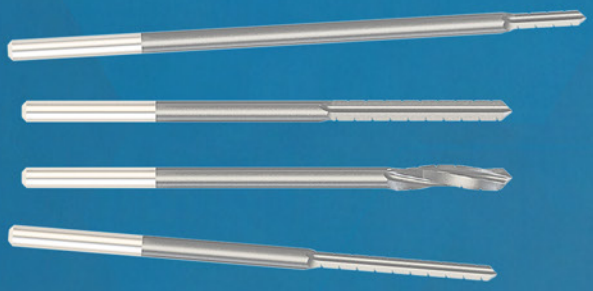
BURS FOR OSTEOTOMY

zirconia coating



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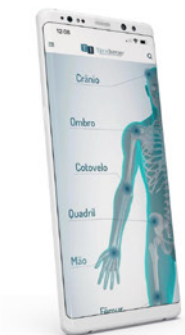

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