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Original Article

Outcome parity in low and high-energy Lisfranc injuries: Evaluation of minimally invasive percutaneous plate osteosynthesis

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Abstract

Objective: This study aims to present the clinical and radiographic results of a prospective cohort followed for three years, treated with indirect reduction and percutaneous fixation in Lisfranc injuries.

Methods: A prospective study of 27 consecutive patients with Lisfranc injury was conducted. Patients underwent percutaneous plate and extraarticular screw fixation. Quality of reduction was classified as anatomical, almost anatomical, and non-anatomical. The AOFAS score was used for clinical evaluation. A statistical analysis was performed.

Results: Twenty-seven patients with a mean follow-up of 35.5 months were analyzed. Seventeen sustained high-energy injuries, while ten presented low-energy injuries. The postoperative AOFAS at the final follow-up was 81 points. Patients with a greater number of affected columns, evident instability, or staged procedures had lower AOFAS scores. Global quality of reduction positively correlates with the AOFAS score, although no significant association between the number of affected columns and the quality of reduction was observed.

Conclusion: Patients with high-energy injuries achieved good results, with a high percentage of anatomical reductions, without differences compared with low-energy injuries.

Level of Evidence; IV Case series

Keywords: Lisfranc injuries; Tarsometatarsal injuries; Percutaneous plate; Minimally invasive plating.

Introduction

Although Lisfranc injuries comprise only 0.2% of all human body fractures, they still represent an ongoing challenge, especially in terms of treatment decisions. These injuries are often caused by both direct and indirect forces, ranging from high-energy trauma to severe midfoot disorganization to subtle subluxations from simple sprains[1].

Consensus on the optimal treatment method is still being determined; nonetheless, both anatomic reduction and proper alignment, and adequate stabilization of the tarsometatarsal columns are essential for achieving good results[2].

However, even when achieving anatomic reduction and joint complex alignment restoration, the percentage of secondary osteoarthritis remains high, ranging from 30% to 36% in some series[3]. This fact could be related to two specific aspects: first, the chondral damage from initial trauma[4] and then the perforation of the different articular facets, necessary for stabilization with position screws[5].

Study performed at the Instituto de Ortopedia y Trauma Dr. Jaime Slullitel. Rosario, Argentina and Hospital Escuela Eva Peron, Granadero Baigorria, Santa Fe, Argentina.

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Another controversial point is the infection and dehiscence rates associated with the surgical wound required for reduction, which reached up to 12.5% in a systematic review published in 2019[6,7].

With the emergence of minimally invasive surgery in the trauma setting and bearing in mind that the percentages of complications and sequelae despite the good results in reduction quality are still important, we began to use minimally invasive surgery for reduction and fixation in the treatment of Lisfranc complex injuries.

We previously published an initial cohort of patients with low- and high-energy Lisfranc injuries treated with percutaneous plating[8], followed up for a short period. This study aims to present the clinical and radiographic results of a prospective patient cohort followed for three years.

Methods

A prospective, cross-sectional, observational study was conducted. Twenty-seven consecutive patients who attended our foot and ankle clinic with a Lisfranc injury were enrolled. Informed consent was obtained from all of the subjects. Adult patients with clinical suspicion of acute Lisfranc trauma are defined as pain in the midfoot associated with plantar hematoma together with the positive piano key sign (referred pain in the tarsometatarsal joint during corresponding metatarsal head palpation), were included[9]. Exclusion criteria extended to open injuries or patients who expressed their will against participating in this study.

As previously published[8], upon referral, patients underwent systematic radiographic evaluation. All radiographs underwent standardized imaging procedures, employing a radiograph beam directed at a 15-degree caudocranial angle towards the feet in the anteroposterior (AP) position, precisely centered on the second ray during weight-bearing to mitigate potential procedural artifacts. Additionally, non-weight-bearing AP, lateral, and oblique radiographs were obtained for comprehensive evaluation. A positive Lisfranc injury diagnosis was established through meticulous assessment, including the evaluation of specific radiographic signs: 1) Loss of alignment between the medial border of the second metatarsal and the medial edge of the second cuneiform in the AP view (Figure 1), and 2) Loss of parallelism between the lateral border of the third metatarsal and the lateral edge of the lateral cuneiform in the oblique view. In cases where these criteria yielded negative results but clinical suspicion persisted, dynamic studies were conducted, comprising comparative weight-bearing AP and lateral radiographs. A diastasis exceeding 2 mm between the bases of the first and second metatarsals was indicative of a positive case[10].

Preoperative assessment included computed tomography scans, employing Toshiba Activion 16-track multislice technology, to evaluate the articular congruency of the medial and lateral edges of the three cuneiforms and their respective metatarsal bases in both sagittal and coronal planes. Joint incongruity, if detected, was quantified in mm. Image classification followed Myerson's system for high-energy injuries, while unstable Lisfranc sprain injuries were classified according to Schepers' criteria, informed by Arrondo and Peratta's research[11]. In the postoperative phase, reduction quality was categorized as "anatomical" in the absence of diastasis between the first and second metatarsal bases, "almost anatomical" when incongruence measured less than 2 mm, and "non-anatomical" when incongruence exceeded 2 mm[12,13].

At the final follow-up, patients were clinically evaluated using the American Orthopaedic Foot and Ankle Society Midfoot (AOFAS) score system.

For statistical analysis, the Kolmogorov-Smirnov test was used to determine whether the collected variables followed a normal distribution. Pearson's correlation was used for continuous variables, and group comparisons for categorical variables were performed using Chi-square tests. Regression analysis was employed to compare AOFAS results stratified by initial injury classification, as well as for age, mechanism, quality of the reduction, and the presence of surgical site infection. A one-way ANOVA (Analysis of Variance) was used to compare means across independent groups and determine whether there is a statistically significant difference among them.

Statistical analyses were performed using SPSS Statistics Software version 23.0 (IBM, Armonk, NY), and significance was set at $p < 0.05$.

A post hoc power analysis was performed for the comparison between high-energy and low-energy injuries ($n = 17$ vs $n = 10$). Based on the reported pooled standard deviation of 10.81 and the corresponding test statistic ($p = 0.069$, two-sided), the observed effect size was estimated as Cohen's $d \approx 0.76$ (mean difference ≈ 8.2 AOFAS points). The statistical power

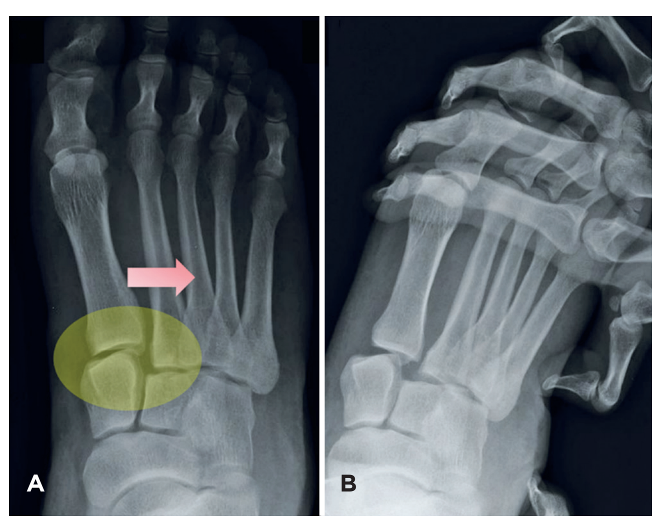

Figure 1. Case 1: Myerson A Lisfranc injury. A): Yellow circle: Joint incongruity of 1st cuneiform–1st metatarsal and 2nd cuneiform–base of 2nd metatarsal. Red arrow: Lateral displacement. B) Intraoperative testing: marked instability of the medial and central columns.

achieved to detect this effect at $\alpha = 0.05$ was approximately 45%. With the current sample size and allocation, an effect size of $d \approx 1.16$ would be required to achieve 80% power, while detecting a moderate effect ($d = 0.5$) with 80% power would necessitate approximately 64 patients per group.

Surgical technique

In accordance with our prior publication[8], in the presence of divergent or convergent displacements, initial closed reduction and transient stabilization with 1.5 mm pins or external fixation were performed, with close attention to restoring anatomical congruity, especially between the first cuneiform and the second metatarsal base. In every case, the definitive procedure was executed during the first week after the initial injury, provided there were no blisters or excessive swelling. The patient was placed in a supine position with a bump under the ipsilateral hip to neutralize the limb. Initially, a 15 mm proximal portal centered on the dorsomedial region of the first wedge and a distal 15 mm portal centered on the proximal and medial region of the first metatarsal were established, with special care of the dorsal insertion of the anterior tibial tendon (Figure 2). A subperiosteal curettage from proximal to distal was performed with a small fine curette. The correct position of the medial tarsometatarsal column in the AP and sagittal planes was visualized under fluoroscopy. Stabilization was achieved with a pre-molded varus 2.7 bridge anatomical plate (Variax Foot Locking Plate System, Stryker, Kalamazoo, Michigan, EEUU) to reproduce the normal adduction of the medial column (Figure 3).

In the second stage, depending on the type of injury, an indirect reduction of the incongruities of the middle columns was achieved (second cuneiform - second metatarsal base, third cuneiform - third metatarsal base) and lateral (fourth and fifth metatarsal bases-cuboid) by manual manipulation and percutaneous periosteal elevator assistance. Subsequently, a clamp was placed at the base of the second metatarsal and the first cuneiform to close the intermetatarsal space (Figure 4A, B). Under fluoroscopy control in the AP and sagittal planes, and after checking a correct alignment (C1 to C2 and M1 to M2), a 1.5 mm pin was inserted through the proximal portal made in the first metatarsal and then progressed in a distal and dorsal direction from the first cuneiform to the second metatarsal base without crossing the joint surfaces. After fluoroscopic control, the transient pin was exchanged for a 4 mm cannulated fully threaded position screw (Cannulated Screw System, Trauson, Changzhou, Jiangsu Province) (Figure 4C, D). In cases where any instability or simple fracture in the central columns was present, proximal

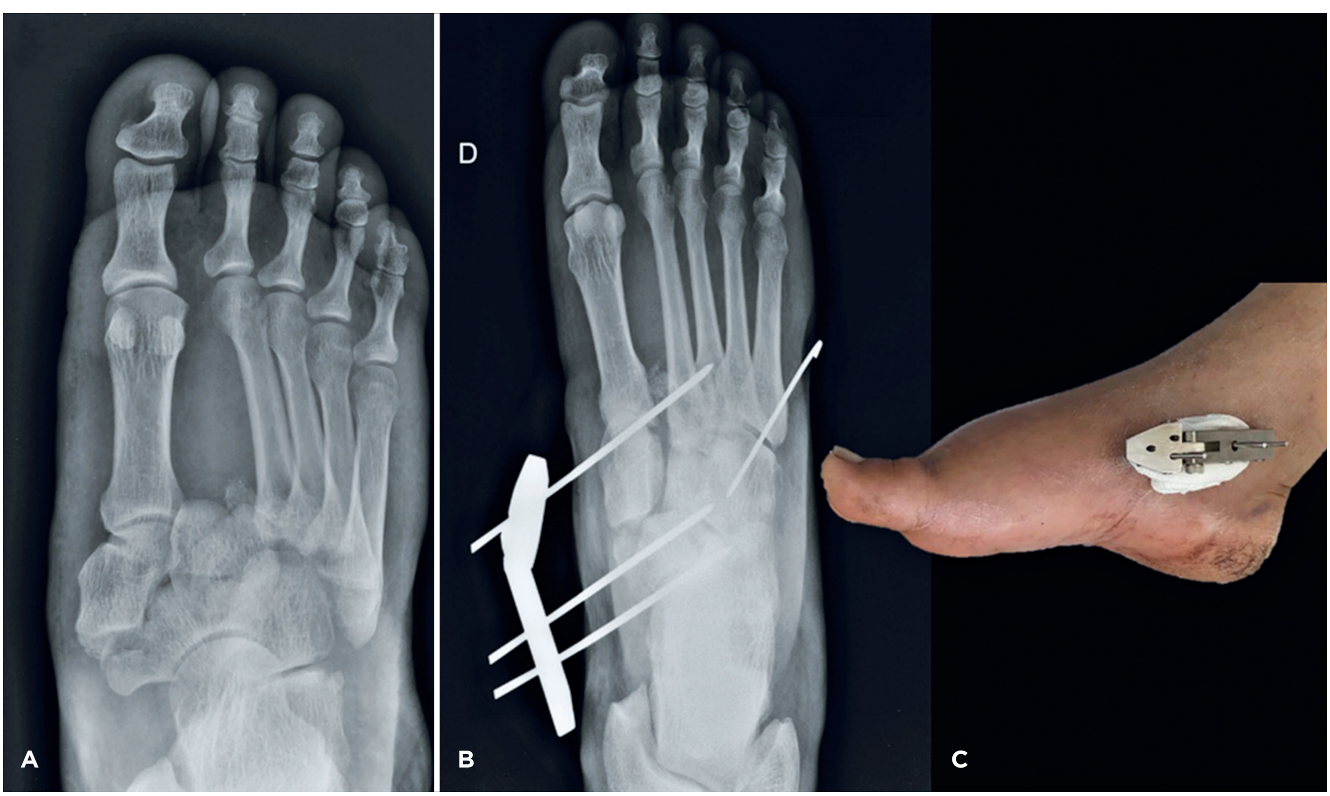

Figure 2. Case 2: Myerson B2 Lisfranc injury. A) Radiograph with incongruency of the central and lateral column with intercuneiform and naviculocuneiform dislocation. B) Initial reduction and external fixation. C) Clinical image.

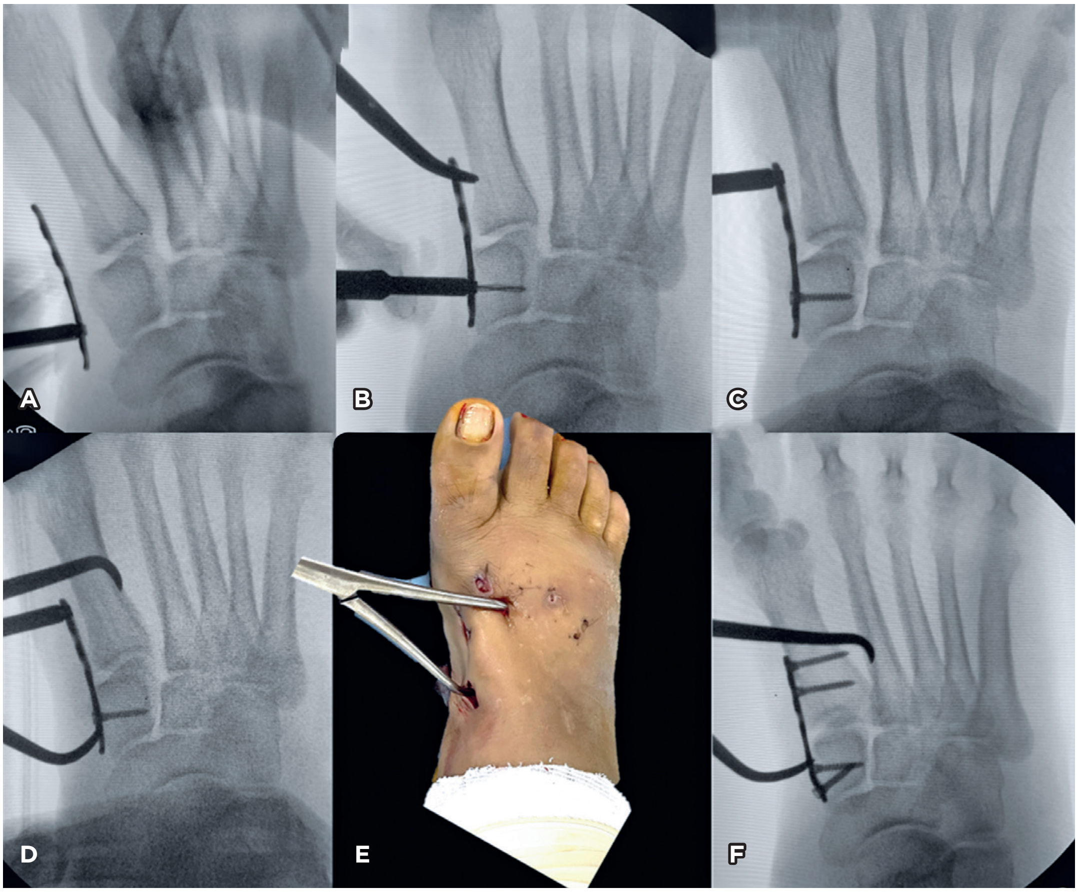

Figure 3. Case 1: Reduction and stabilization of medial column. A) Intraoperative fluoroscopy depicting the of sliding maneuver of the bridge plating on the medial tarsometatarsal column. B-C) Partial Fixation. D-E) Reduction assisted with long branch clamp. E) Correct alignment and final fixation control.

and distal dorsal portals were also established at every metatarsocuneiform joint, and these were indirectly reduced through the bridging of a straight 2.7 mm anatomical locking plate (Variax Foot Locking Plate System, Stryker, Kalamazoo, Michigan) (Figures 5 and 6). In patients with a lateral column injury, 1.5 mm percutaneous pins were used for stabilization.

The patients were immobilized in a non-weight-bearing cast for the first 15 days. Then transferred to a walking boot concomitant with the initiation of a physio-kinesiotherapy protocol that included assisted passive mobility. Progressive weight-bearing, according to tolerance, was authorized after four weeks. Full loading was authorized at six weeks (Figure 7). The return to activities and low-impact sports, such as bicycling, progressive walking in the gym, and swimming, was authorized at eight weeks.

Immediate postoperative non-weight-bearing radiographs were obtained, and four-week follow-up radiographs were taken in all cases; the osteosynthesis was removed at four months postoperatively, although this was not performed in eight patients (Figure 8).

Results

We explored the impact of this technique on the AOFAS scores among 27 patients. Our analysis focused on identifying factors that could influence AOFAS scores, including age, need for stage procedures, number of affected columns, classification (EPTP and Myerson), presence of surgical site infection, presence of osteoarthritis at the final follow-up, and the need for implant removal. Our analyzed population consisted of 27 patients (2 females and 25 males) with a mean age of 31.1 years (range 18 to 50 years). The mean follow-up was 35.5 months (range 12 to 71 months). According to the EPTP classification, ten patients (37%) had a 1B injury, 13 patients (48.15%) had a 2A injury, and four patients (14.8%) had a 2B injury. Myerson classification was stratified as follows: six injuries (22.2%) were type A, 13 injuries (48.15%) were type B1, and eight injuries (29.6%) were type B2. Of the 27 patients, 17 sustained high-energy injuries, while ten sustained low-energy injuries. The postoperative AOFAS score at final follow-up was 81 points (SD 10.81, range 58 to 94) (Table 1).

Figure 4. Case 2: A-B) Intraoperative fluoroscopy control of sliding bridge plating on the medial tarsometatarsal column. C-D-E) Clamp-assisted reduction of the medial column and intercuneiform instability through one medial large plate with a 3.5 canulate screw. F) Stabilization of the central column and positional Lisfranc Screw and Clinical image of the minimally invasive approach.

We observed a weak-to-moderate negative correlation between the number of affected columns and AOFAS scores, with a correlation coefficient of -0.397. A box plot analysis (Figure 9) further illustrated the trend where AOFAS scores decreased as the number of affected columns increased. This trend was substantiated by a one-way ANOVA test, although the differences in AOFAS scores across column groups were not statistically significant ($p = 0.073$).

When exploring the relationship between preoperative classification and AOFAS scores, we found, with a regression analysis, a moderate negative correlation (-5.7632, $p = 0.044$), although statistically significant, suggesting that patients with evident unstable Lisfranc injuries (EPTP 2A and 2B) or Myerson A tend to have lower AOFAS scores.

AOFAS score did not display statistically relevant differences related to the injury mechanism (low- or high-energy) ($p = 0.069$).

Both age and staged procedures showed moderate negative correlations with AOFAS scores, with correlation coefficients of -0.523 and -0.482, respectively. This suggests that older patients and those who needed a two-stage procedure in high-energy injuries tended to have lower AOFAS scores.

The quality of reduction shows a positive correlation with the AOFAS score (6.9430), suggesting that higher reduction quality is associated with higher AOFAS scores, which was statistically significant ($p = 0.031$) (Figure 10). It is worthy of note that the Chi-square statistic of approximately 2.93 with a $p = 0.5688$ suggests that there is no statistically significant association between the number of columns affected and the quality of reduction achieved by this technique.

The presence of osteoarthritis (OA) at the final follow-up and the need for implant removal were also examined. OA; was present in four patients; one of them was a type A injury, which experienced loss of reduction in the medial column at the radiographic control four months after the removal of the osteosynthesis, and needed an arthrodesis at less than a year follow-up; showed a weak negative correlation with AOFAS scores (Pearson 0.372, $p = 0.056$), just above the used significance level, suggesting that this correlation is not statistically significant at the 5% level, while implant removal

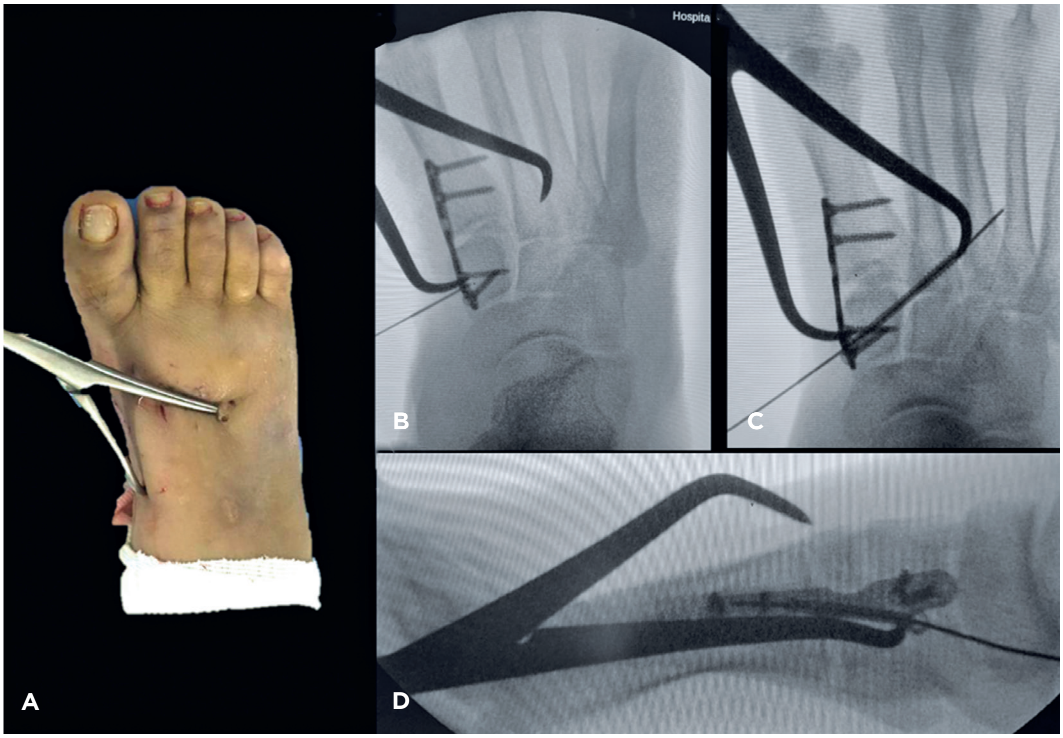

Figure 5. Case 1: Reduction and stabilization of the central column. A) Clamp-assisted reduction and stabilization of the central columns B) C1-M2 Transitory K-wire fixation (Lisfranc). C-D) Final fixation with a 3.5mm cannulated screw.

Figure 6. Case 1: A) Fluoroscopic dorsal plate length measurement for the central column and intercuneiform stabilization. G) Final intraoperative fluoroscopy control and clinical images of the minimally invasive approach.

showed a weak positive correlation (Pearson 0.274, p = 0.167). However, neither correlation was statistically significant.

No patient presented major wound-related complications, and we observed two minor complications: soft-tissue infection, which showed a negative correlation with the AOFAS score (-0.378), indicating that patients with soft-tissue infection tended to have lower AOFAS scores.

Discussion

Several clinical series have investigated the influence of reduction techniques on long-term outcomes and patient satisfaction[14,15]. As early as 1982, Hardcastle et al.[16] reported findings from a series of 69 patients with both low- and high-energy Lisfranc injuries. They highlighted that the pivotal factor foreseeing a successful outcome was the preservation

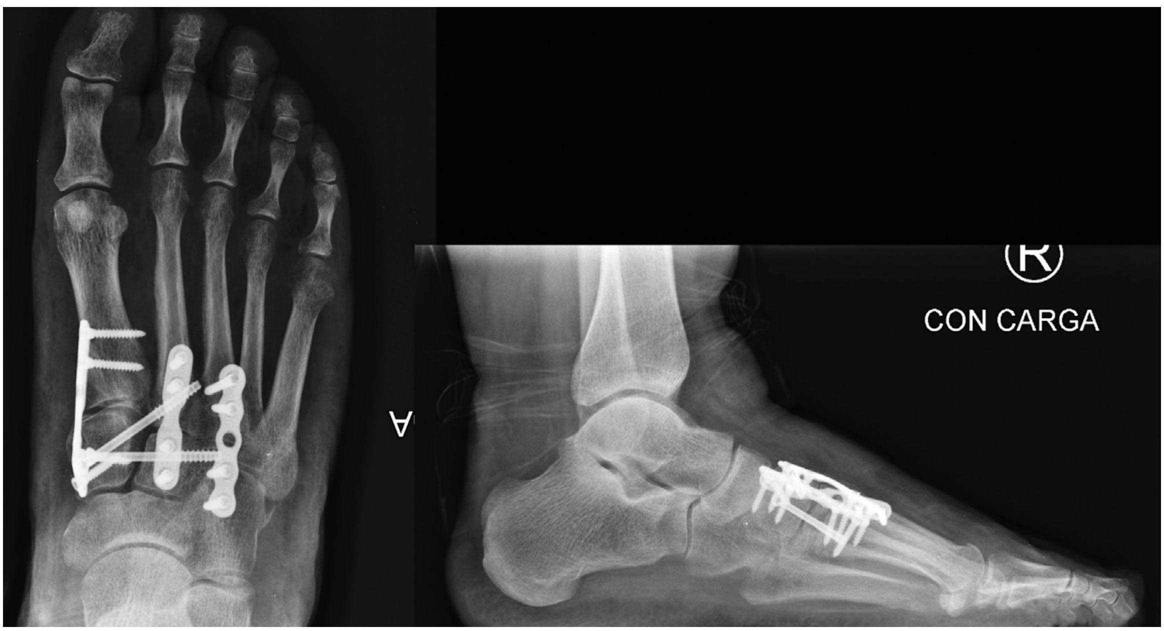

Figure 7. Case 1: Postoperative weight-bearing radiograph at six weeks.

Figure 8. Case 2: Clinical and weight-bearing radiograph at six weeks postoperative control.

Table 1. Data from the analyzed series

Case	Side	Age	Myerson	EPTP*	Energy	Columns (n)	SSSI**	DSSI***	OA****	AOFAS
1	Right	45	A	2A	H	2	No	No	Yes	75
2	Right	36	B	2B	H	3	No	No	No	65
3	Left	27	A	2B	H	3	Yes	No	No	80
4	Right	41	B1	2B	H	2	No	No	No	75
5	Right	37	B1	2A	H	3	No	No	Yes	75
6	Right	25	B1	2A	H	3	No	No	No	70
7	Right	18	B2	2A	H	2	No	No	No	92
8	Left	18	B2	2A	H	2	No	No	No	92
9	Left	36	A	2A	H	3	No	No	Yes	58
10	Right	21	B1	1 B	L	2	No	No	No	94
11	Left	25	B1	1 B	L	2	No	No	No	90
12	Right	21	B1	1 B	L	1	No	No	No	89
13	Right	49	B2	2A	H	2	No	No	Yes	80
14	Left	35	B1	1 B	L	2	No	No	No	94
15	Right	32	B2	2A	L	2	No	No	No	92
16	Right	26	B2	1 B	H	2	No	No	No	89
17	Right	21	B1	1 B	H	1	No	No	No	90
18	Left	27	B2	2A	L	2	No	No	No	94
19	Right	26	B2	2 A	L	3	No	No	No	90
20	Right	32	B1	1 B	L	2	No	No	No	80
21	Right	34	B1	1 B	H	1	No	No	No	75
22	Right	42	A	1 B	H	2	No	No	No	70
23	Right	23	A	2 A	H	3	No	No	No	80
24	Right	40	A	2 B	H	3	No	No	No	75
25	Right	27	B1	2 A	H	2	No	No	No	65
26	Right	50	A	2 A	H	2	Yes	No	No	75
27	Right	34	A	2 A	H	2	No	No	No	80

*Classification of the EPTP; **Superficial surgical site infection; ***Deep surgical site infection;
****Tarsometatarsal osteoartritis.

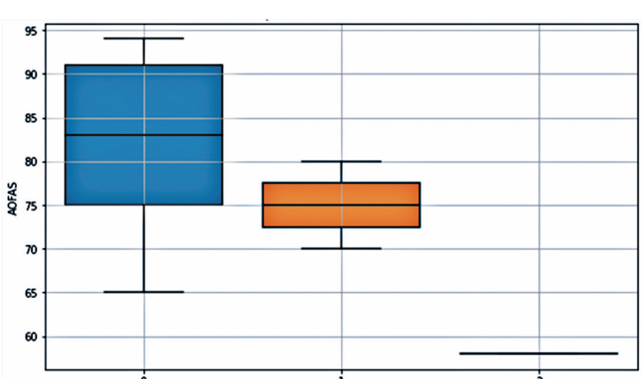

Figure 9. Box plot depicting the negative relationship between AOFAS scores and the number of affected columns. 1C: one central column. 2MC: 2 columns medial and central. 3C: three columns.

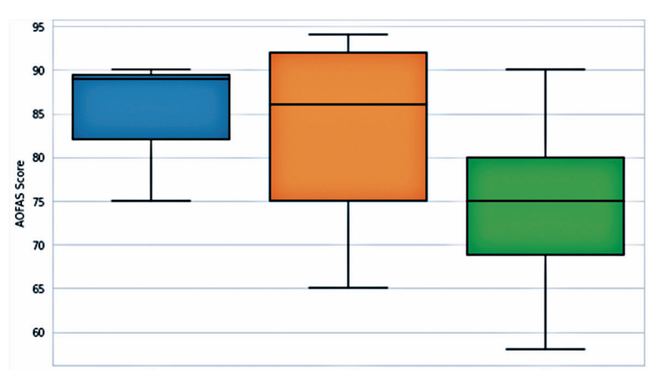

Figure 10. Box plot depicting the relationship between the quality of the reduction and the AOFAS score. 0: anatomical 1: almost anatomical 2: non-anatomical.

of anatomic reduction, regardless of the initiating injury or treatment method. Myerson's team, in a subsequent examination of 52 patients with 55 Lisfranc injuries, reiterated these insights. Their study showed that 49% of patients achieved good-to-excellent results, underscoring the importance of attaining and sustaining an anatomic reduction at the Lisfranc joint for positive outcomes. The decision to endorse open reduction and internal fixation stemmed from concerns about potential midfoot reduction loss, with 83% of surgically treated patients exhibiting acceptable outcomes[17].

Despite the consistent literature underscoring the vital role of anatomic restoration and the superior outcomes linked with operative techniques ensuring a stable reduction, these interventions are not without drawbacks. Complications, including soft-tissue or wound issues, postoperative infections, and complex regional pain syndrome (CRPS), may ensue[18]. This circumstance has ushered in the era of less invasive approaches, aiming to optimize outcomes while curtailing complications.

The use of temporary bridge plating in foot surgery was initially documented by Schildhauer et al.[19] as an alternative to external fixation, particularly for managing comminuted fractures of the medial column of the foot. More recently, Del Vecchio et al.[20] reported outcomes after closed reduction and minimally invasive medial plating for low-energy Lisfranc injuries in a small patient cohort with a 19-month follow-up. We believe that our study is the first to report stabilization with bridge plating in low- and high-energy injuries using a minimally invasive approach and to analyze midterm outcomes.

As the literature regarding percutaneous bridge plating is scarce, it is our perspective that a comparison between open reduction and internal fixation with plates and percutaneous screws fixation may shed some light on each method's performance differences when discussing both the stabilization method and the approach.

Van Koperen et al.[21] retrospectively analyzed and compared a series of patients treated with open reduction and internal fixation, divided into two groups: one with transarticular screws and the other with dorsal bridge plating. They obtained mean AOFAS scores of 66 and 77 points, respectively. Additionally, the authors highlight a higher rate of surgical-site infections in the transarticular screw group (13% vs. 5%). They assume this may be related to better soft-tissue management in the plate group, in which greater attention was paid to the presence of the wrinkle sign before surgery. We believe that the lesser manipulation of soft tissues required by the minimally invasive method in our series is one of the reasons for the low surgical site infection rate (7%) we report.

Wagner et al. [22] shared insights from a study of 22 patients with low-energy injuries treated percutaneously. While the primary focus was assessing early weight-bearing outcomes following percutaneous fixation, patient-reported results indicated high satisfaction, with a mean AOFAS score of 94 (range, 90-100). Anatomic or near-anatomic reduction was maintained in all patients, and no soft-tissue complications were documented. A retrospective series of 38 patients with low-energy Lisfranc injuries followed for six years was published by Vosbikian et al. in 2017[23]. These authors report a mean FAAM-ADL of 94.2, with 91.4% of patients who returned to their preinjury functional level. Our series also evaluated patients with high-energy injuries, depicting good functional results with a high percentage of anatomic reductions over time, with no statistical differences from the low-energy injuries, although this could probably be related to the fact that high-energy injuries need an intermediate step of acute correction and temporary fixation to allow for this method to be applied.

A point worth discussing is that the previously published series used screws for percutaneous fixation. We perform our fixation with plates via proximal and distal portals. We believe that, to be less invasive and possibly less aggressive to the joint, screws could be avoided, except for the one necessary to restore the position of the second metatarsal base and the first cuneiform.

Even when concern may arise about the learning curve needed for this technique to properly reduce and stabilize the columns affected, we found that there is no statistically significant association between the number of columns involved and the quality of reduction achieved, meaning that anatomy restoration of those even more complex injuries could be obtained using percutaneous plates. With our numbers, this also remains true for both low- and high-energy injuries.

Our study's main strength is its prospective design, which enabled a thorough evaluation throughout follow-up. Although we can draw some conclusions, caution is warranted, as our sample size is still below the 64 patients needed in an a priori power analysis. Additionally, we are conducting a comparative non-inferiority study using a historical cohort of patients treated with open reduction and internal fixation, which will provide deeper insights.

It is important to note that the present series was underpowered to detect small-to-moderate differences. Although the observed effect size between groups was relatively large ($d \approx 0.76$), the post hoc power was only about 45%. This limitation highlights that our findings should be interpreted with caution and not extrapolated beyond this cohort. Larger, adequately powered studies—requiring approximately 60-70 patients per group—would be necessary to confirm the intervention's potential effect with greater statistical confidence.

Conclusion

In this series, patients with high-energy injuries achieved good functional outcomes and a high percentage of anatomic reductions, with outcomes not different from those with low-energy injuries. The authors' perspective is that, in the hands of experienced surgeons, minimally invasive fixation with bridge plating could be a viable option for carefully selected patients.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JPR *(https://orcid.org/0000-0003-3709-8163) Conceived and planned the activities that led to the study, performed the surgeries; LG *(https://orcid.org/0000-0002-1621-3081); interpreted the results of the study, participated in the review process; EG *(https://orcid.org/0000-0002-6109-1431); interpreted the results of the study, participated in the review process; GA *(https://orcid.org/0000-0001-5826-690X) data collection and survey of the medical records; GS *(https://orcid.org/0000-0002-4842-7447) format the article and performed the bibliographic review; VL *(https://orcid.org/0000-0001-6345-5991) interpreted the results, wrote the introduction, material and methods and discussion sections. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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