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Surgical controversies and current concepts in Lisfranc injuries

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Abstract

Introduction: Lisfranc injuries, not as rare as previously reported, range from ligamentous to complex fracture-dislocations. Anatomical studies have identified a complex of discrete structures, and defined the anatomical characteristics of the Lisfranc joint.

Sources of data: A narrative evidence-based review encompassed and analyzed published systematic reviews. Outcomes included clinical and surgical decision-making, including clinical-presentation, diagnosis, pathological-assessment, surgical-management techniques and indications, post-surgical care and comparative outcomes.

Areas of agreement: Better understanding of the Lisfranc complex anatomy aids surgical treatment and tactics. Prognosis is related to injury severity, estimated by the number of foot columns affected. Surgical outcome is determined by anatomical reduction for most fixation and fusion techniques. Appropriate treatment allows return to sport, improving outcome scores.

Areas of controversy: Identification of Lisfranc injuries may be improved by imaging modalities such as weight-bearing computer tomography. Recent evidence supports dorsal plate fixation as a result of better quality of reduction. In complex injuries, the use of combined techniques such as trans-articular screw and plate fixation has been associated with poorer outcomes, and fusion may instead offer greater benefits.

Growing points: Open reduction is mandatory if closed reduction fails, highlighting the importance of understanding surgical anatomy. If anatomical reduction is achieved, acute arthrodesis is a safe alternative to open reduction internal fixation in selected patients, as demonstrated by comparable outcomes in subgroup analysis.

Areas for developing research: The current controversies in surgical treatment remain around techniques and outcomes, as randomized controlled trials are infrequent.

Key words: Lisfranc injury, midfoot injury, midfoot fracture, midfoot sprain

Introduction

Lisfranc injuries are rare, accounting for 0.2% of fractures annually,[1] although rates have increased to 14/100 000 person/years.[2] They are devastating if inadequately treated, leading to chronic pain and dysfunction. The function of the foot is affected by instability within the injured Lisfranc joint complex, and, left untreated, fibrosis, stiffness, cartilage loss and degenerative joint disease are likely to result. Several different surgical techniques are advocated to treat Lisfranc injuries. Clinical decision-making and optimal management therefore remain controversial. Several questions remain unanswered around anatomical understanding, including whether current novel surgical techniques have really improved outcomes.

Methods

A narrative evidence-based review was performed encompassing an analysis of systematic reviews published. Utilizing an independent literature search of Medline, EMBASE and CINAHL, thesaurus terms (Lisfranc injury Midfoot injury Midfoot fracture Midfoot sprain and key words (Lisfranc* or midfoot*or metatarsal fracture or metatarsal dislocation or tarsometatarsal joint fracture and/or dislocation) were combined with the following key words: fracture OR 'ligamentous' OR Open reduction and internal fixation OR ORIF OR fusion OR arthrodesis OR 'screw OR plate OR Motion Preserving OR Per-cutaneous'.

Article inclusion was restricted to work published in English to April, 2022. In addition to our electronic search, a manual reference list check was conducted of all included studies to ensure that all relevant investigations were included. All authors had to agree on all included and rejected studies, and disagreements were resolved by discussion between the authors.

Outcomes were defined by key clinical and pathological areas that may affect clinical and surgical decision-making, including clinical-presentation, diagnosis, pathological-assessment, surgical-management techniques and indications, post-surgical care and comparative outcomes. No new data were generated or analyzed in support of this review.

Results

Clinical-presentation—common and subtle but specific signs

High-energy Lisfranc injuries are typically produced by direct trauma, from axial load or excessive supination/pronation to the plantar flexed foot,[3] e.g. as seen in high impact sports. Low-energy ligamentous injuries are also less likely to occur with concomitant foot fractures (4 vs. 78%).[4] The association with other concurrent hindfoot/forefoot

(4%) or non-foot (6%) injuries is low. Low-energy injuries require a higher level of suspicion.[1,5]

A clinically swollen foot with bruising over the plantar aspect of the midfoot is commonly described.[6] Vascular injuries are uncommon; compartment syndromes are rare, as is injury to the deep peroneal nerve leading to altered sensation on the dorsal aspect of the first inter-metatarsal (IMT) space from post-traumatic neuropathy.[7,8] Other historically described signs include a positive 'piano key test' and the 'gap sign' thought to describe inter-cuneiform instability.[9]

Pathological anatomy—advancing understanding of the Lisfranc complex

The Lisfranc articulation is formed by the three cuneiforms and cuboid proximally, and the five metatarsal bases distally, linked together by the associated capsulo-ligamentous structures. The additional ligamentous structures stabilize the Lisfranc joint and the osseous anatomy. The midfoot is usually described as being composed of three osseous columns.[10] The medial column is formed by the navicular, medial cuneiform and the first metatarsal. The middle column between the second and third metatarsals, and the middle and lateral cuneiforms are the most rigid articulation. The lateral column consists of the cuboid and the base of the fourth and fifth metatarsals and is more compliant, to accommodate weight-weight-bearing gait. Injuries range from stable dorsal ligament tears, complete ligamentous rupture and instability, to fracture-dislocations.[11]

The principal structure of the Lisfranc ligament runs from the plantar lateral aspect of the medial cuneiform, inserting on the medial aspect of the second metatarsal base. This Lisfranc ligament is the strongest and the largest of the Lisfranc joint ligaments (8–10-mm long and 5–6-mm thick). The primary ligament is associated with a complex of ligaments, which need to be understood to appreciate injuries, reduction and reconstruction:

(i) Dorsal and Plantar Lisfranc and tarso-metatarsal (TMT) ligaments—run in between all the across the dorsal surface of the TMT joints. These ligaments are weaker than the plantar ligaments, providing a third of the strength of the Lisfranc ligament. Their rupture leads to dorsal subluxation of the second ray.[12,13] In anatomical studies, the Lisfranc ligament and plantar ligament between the first and second metatarsals need to be sectioned before transverse instability or widening between the first and second metatarsal is seen.[14]

(ii) Inter-metatarsal (IMT) ligaments—originate from the second, third, fourth and fifth metatarsals, with no IMT ligament between the first and the second metatarsals. They form four distinct bands and combine with the multiple plantar tarsometatarsal bands ($n = 9$) up to the dorsal tarsometatarsal ligaments, which occur as 7–9 multiple distinct bands.

(iii) Lateral Lisfranc ligament (LLL)—is a plantar transverse suspensory metatarsal ligament spanning the bases of the second to the fifth metatarsals. This recently described ligament is a consistent structure identified in cadaveric studies with an average length of 33.7 mm and width of 4.6 mm.[15] It functionally stabilizes the transverse arch of the foot and the lateral rays. This could explain why reduction of the middle column in partial incongruity patterns often leads to stabilization of the lateral column (fourth and fifth metatarsals).[16]

Secondary restraints include osseous structures, and recent reports highlight anatomical variations as potential prognostic markers including:

(i) The height of the second tarsometatarsal joint is usually lower in unstable injuries ($P = 0.036$), though the actual difference was only 1 mm.[2]

(ii) A shallow medial mortise depth is a risk factor for Lisfranc injuries.[17]

The combination of a shallow medial mortise and a shorter height of the second metatarsal base is more common in women, but no direct association has been reported, with women being more prone to these injuries.[18] A deeper medial mortise and a higher second tarsometatarsal joint might have a broader and stronger Lisfranc ligament, and thereby decrease the risk of an unstable Lisfranc injury.[2]

Imaging—improving current diagnostics

Radiographic evaluation is difficult. Subtle diastasis can be missed in 50% of cases on non-weight-bearing radiographs. Computed tomography (CT) permits detection of 50% more fractures, and more accurately evaluates osseous malalignment. These injuries may be identified more readily with weight-bearing radiographs.[19] Penev *et al*.[20] assessed the impact of sequential injuries to the Lisfranc complex on weight-bearing CT. Instability from transection of the Lisfranc ligament together with both plantar ligaments between the medial cuneiform and the second and third metatarsals was detectable on weight-bearing CT. Further finite analysis of weight-bearing CT has larger diastasis in the tarsometatarsal joint, and has a higher interobserver reliability compared with non-weight-bearing (NWB) imaging.[21] This is also the case with magnetic resonance imaging (MRI) scanning, which can define the Lisfranc ligament and the plantar Lisfranc ligament as distinct structures.[22,23] Castro *et al*.[10] described the pathological MRI findings as a striated or homogeneous and low to intermediate signal within the ligament, which correlated to subsequent intra-operative findings.[24]

Injury classification

Historically, the first anatomical classification was introduced by Quenu and Kuss in 1909,[25] with a three column concept and fracture-dislocations being described as homolateral, isolated and divergent. Hardcastle *et al*.[26] modified it into type A (all metatarsals are displaced in one direction with total incongruence); type B (partial incongruence with one or more displaced metatarsals) and type C (divergent pattern of incongruence) as shown in Table 1. Partial incongruity patterns include disruptions of a single column that is displaced away from the midline of the foot. Total incongruity or homolateral injuries include complete separation of all columns through the tarsometatarsal articulations with displacement in the same direction, typically lateral or dorsoplantar, reflecting the intrinsic strength of the ligamentous complex (see Table 1).

Nunley and Vertullo introduced a classification for midfoot sprains in athletes using weight-bearing radiographs, clinical examination and bone scintigram.[5] The classification includes stage I: sprain to the Lisfranc ligament with no diastasis or arch height loss seen on radiographs but increased uptake on bone scintigrams. Stage II: first to second intermetatarsal diastasis of 2–5 mm, but no arch height loss. Stage III: first to second intermetatarsal diastasis and loss of arch height (seen on lateral radiograph). Sivakumar *et al*.[27] modified Hardcastle's classification introducing to the so-called subtle injury of the Lisfranc joint lesion i.e. type D. These were divided into D1 (distance from the first cuneiform bone to the second metatarsal $\leqslant 2$ mm and does not require surgical fixation); and D2 (distance between the first cuneiform bone to the second metatarsal > 2 mm). These classifications are not thought to be reliable, prognostic or able to guide treatment.[28]

Surgical fixation techniques

Management ranges from conservative treatment for injuries that are often described as a midfoot sprain with no displacement on weight-bearing radiographs to surgical reduction and internal fixation for Lisfranc joint dislocation and fracture-dislocation. The management of Lisfranc joint dislocation by closed or open means is still a matter of debate. The main techniques are Motion Preservation, Percutaneous Screws, Dorsal Plating and Combination techniques. We describe the current scientific and clinical evidence for each method, their use and overview of outcomes.

Motion preserving fixation techniques

These techniques have a goal of stable fixation that allows natural physiological movement of the

Table 1 Classification of Lisfranc injuries

Nunley–Vertullo (ligamentous)	Modified Hardcastle (osseous)
Stage 1: midfoot sprain, no diastasis on the WB X rays, positive bone scintigraphy	*Type A: complete* *A* Dislocation of M1–M5 in the same direction (either lateral or dorsoplantar)
Stage 2: 1–5-mm diastasis between the first and second metatarsal, no arch collapse on the WB X rays *Stage 3:* >5-mm diastasis, arch collapse	*Type B: incomplete* *B1* Medial dislocation involving only the M1 joint *B2* Lateral dislocation involving any of the M2–M4 *Type C: incomplete/complete* *C1* Divergent, incomplete dislocation involving M1 and some of the lateral metatarsals *C2* Divergent, complete dislocation involving M1 and all of the lateral metatarsal *Type D: subtle injury of Lisfranc joint* *D1* Distance from the first cuneiform bone to the second metatarsal ⩽ 2 mm *D2* Distance between the first cuneiform bone to the second metatarsal > 2 mm

Lisfranc joint.[29] The Mini Tight Rope® (Arthrex Inc., Naples, FL) is a suture-button device, and is used for fixation in adults with certain Lisfranc injuries. Cadaveric studies indicate that these techniques can provide similar results to screw fixation alone. However, increased diastasis with the suture-button compared with a 4.0-mm cannulated screw[30] raises concerns about the long-term mechanical adequacy of fixation. A recent small case series evaluated the effect of Tightrope system in purely ligamentous injuries at a mean of 20.5 months, showing little change in diastasis width following reduction.[31] The advantage of avoiding an additional operation to remove hardware[32] makes this technique warrant further investigation. A recent report suggests that suture-button supplemented by dorsal bridge plate construct can further reduce second TMT instability.[33]

Another motion preserving fixation technique uses the Internal-Brace™ (Arthrex Inc., Naples, FL), which allows collagen ingrowth into the FiberTape®.[34] These implants are used to stabilize the medial column if instability is present. Crates *et al*.[35] modified this technique to address rotational stability by adding a second adjustable suture-button to connect the medial cuneiform to the middle cuneiform. Miyamoto *et al.*[36] used a hamstring tendon graft for athletes with chronic subtle injury and all returned to sport. To date, small case series have described the use of these techniques with satisfactory results, providing low quality evidence.

Percutaneous internal fixation and trans-articular screw fixation

A good to excellent functional outcome can be expected with percutaneous reduction and internal fixation (PRIF; Fig. 1), as long as anatomic reduction of the Lisfranc joint has been achieved. In 2019, four studies of 106 patients were selected for a systematic review of percutaneous screw fixation.[37] Injuries with partial incongruency or fracture-dislocations showed improved outcomes, though this was not statistically significant. Perugia *et al.* recorded an average AOFAS (American Orthopaedic Foot and Ankle Society) score of 81 ± 13.5 SD with PRIF.[38] There was no significant difference across all types of injury with anatomical or near anatomical reduction. However, subgroup analysis showed a significant difference in outcome scores between purely ligamentous injuries and combined ligamentous and osseous injuries, the latter having better outcomes with this technique. Other studies[39,40] support these observations: anatomical reduction and injury type influence outcome rather than fixation method.

Fig. 1 Per cutaneous fracture fixation. Per cutaneous fixation undertaken after weightbearing radiographs confirming subluxation and stable reduction in the follow up radiographs.

Fig. 2 Use of dorsal bridge plating with a 4 corner plate allowing for rigid anatomical fixation. Weight-bearing radiographs at 3 months where the diastasis was closed.

The screw combinations reported include 3–4.5-mm cannulated screws, cortical or cancellous screws.[41–46] Closed reduction with percutaneous Kirschner wire fixation alone is associated with an increased incidence of subluxation or suboptimal reduction and secondary post-traumatic degenerative changes.[46] Complications reported included a patient developing transient paraesthesiae of the intermediate superficial peroneal nerve (SPN)[45] and one patient with persistent widening of the Lisfranc distance.[42] No specific studies to date compare open vs. percutaneous screw placement.

Dorsal bridge plating

The principles of management are to realign and stabilize the midfoot. This has traditionally been achieved through the use of trans-articular screw fixation. However, this method of fixation may cause further injury to joints when they are crossed with larger screws. A recent cadaveric study demonstrated that the expected articular surface disruption for a 3.5-mm screw drill hole would be 6.0% for the second cuneiform and 5.9% for the second metatarsal.[47] However, with multiple passes and corresponding thermal necrosis, the impact may be greater, and these figures are likely to underestimate the amount of additional cartilage damage.

The concern for joint damage is eliminated by dorsal plate fixation, as by definition it decreases iatrogenic cartilage damage. Dorsal plate fixation is an alternative to trans-articular screws and is as robust biomechanically,[47–49] even when stabilizing comminuted or fragmented fractures (see Fig. 2).[50,51] It offers better reduction, with a reduced rate of loss of reduction (24 vs. 11%).[49,52,53] Better outcomes and a lower re-operation rate were obtained with bridge plating compared with standard screw ORIF.[54] A recent retrospective study of 34 patients[55] showed better AOFAS scores (77 vs. 66) and higher patient satisfaction (90 vs. 80%) for bridge plate fixation vs. screw fixation, without statistical significance. Dalal *et al*.[56] described a combination technique with plantar plating with satisfactory outcomes, but one should be aware of the complexities of the plantar approach to the first ray.

Currently, there is no consensus about best practice. Most studies have compared imaging and functional outcome of dorsal bridge plating and trans-articular screw fixation. Kirzner *et al*.[57] reviewed 108 patients treated with trans-articular screws, dorsal plating or a combination of techniques. Dorsal plating achieved better outcomes with the mean AOFAS score of 82.5 (59–100), compared with 71.1 (5–95) in the screw group, and 63.3 (18–100) in the combination group ($P < 0.001$). The mean MOXFQ scores were better at 34 months in the bridge plate group (25.6 (16–49) compared with the screw group (38.1 (17–77) and combination group (45.5 (16–77) ($P < 0.001$)).

At 2 years, plating showed a better AOFAS score compared with screw fixation (83.1 vs 78.5 ($P < 0.01$). The longevity of dorsal plate fixation outcomes may represent a higher percentage of good reduction being retained on radiographs in patients with plate fixation vs. screw fixation (24 vs. 11%) in this series, or possible loss of reduction with screw fixation over time. This may result from the increased reduction stability, or by the neutralization of rotational forces, whereas the shape or design of the dorsal plate may improve reduction and confer a greater likelihood for anatomical reduction at the time of surgery.[58] This is especially true in the presence of significant bone loss, when bridge plating can be an effective technique to stabilize the joint and allow limited fusion.[59]

The combination of plates and trans-articular screws results in poorer imaging outcomes and leads to poorer functional outcomes.[60] This may be reasoned by understanding that these fractures are more complex, and a greater number of columns needs to be secured. Combined with more extensive soft tissue dissection, this could result in greater scarring and inherently require greater stabilization. Recent studies suggest poorer functional outcomes for patients requiring increasing column stabilization at definitive fixation, a surrogate marker for the severity of injury. The mean AOFAS score reduces as we move from uni- to bi- and tri-column stabilization (64 (5–100) vs. 77 (36–100) vs. 84 (52–100)). The same pattern is seen within the MOXFQ scores ($P < 0.001$).[57]

Acute partial primary arthrodesis

Partial arthrodesis involves the first, second and third tarsometatarsal joints the middle column, and is superior to combined medial and lateral column tarsometatarsal arthrodesis.[59] The indications in the acute setting include purely ligamentous arch injuries followed by delayed treatment and chronic deformity. An arthrodesis is contraindicated if insufficient soft tissue coverage or active infection is present at definitive operative management. A systematic review reported a mean AOFAS score of ORIF patients of 72.5, whereas in arthrodesis it was 88.0 at 1 year.[60]

Recent studies have specifically reported on this technique in a variety of injury patterns.[61–63] Reinhardt *et al.*[63] assessed 25 patients undergoing primary partial arthrodesis for a ligamentous or combined osseous and ligamentous injury. At an average of 42 months, the AOFAS score was 81 points (scale 0–100); no statistical difference between ligamentous or combined osseous injuries was observed in the physical or mental component scores on the SF-36. Cochran *et al.*[64] retrospectively compared ORIF and primary arthrodesis in military personnel who sustained low-energy Lisfranc or ligamentous injuries. The arthrodesis group returned to full military duty 2 months faster than the ORIF group ($P = 0.0066$); at 1 year postoperatively, the arthrodesis group scored closer to their pre-injury run times (1.5 or 3 mile run; $P = 0.032$).

Kirzner *et al.*[65] reported a cohort of 39 patients treated for a complete Lisfranc fracture dislocation. Primary arthrodesis was offered to those over 50, with a high body mass index (BMI) or significant comminution, making ORIF not possible. The mean MOXFQ score was 30.1 points, compared with 45.1 for the ORIF group ($P = 0.017$). Similarly, the mean AOFAS score was 71.8 points in the fusion group vs. 62.5 in the ORIF group ($P = 0.14$). However, functional outcome was dependent on reduction ($P < 0.001$). Primary arthrodesis achieved good initial reduction in 83% of patients compared to 62% with ORIF ($P = 0.138$), and over time there was a 47% loss of reduction quality of the ORIF group.

Patients need to understand the long-term implications of an arthrodesis, and surgeons the need to stabilize the midfoot and preserve column lengths. MacMahon *et al.*[62] reported that 1/3 of patients experienced postoperative limitations in exercise. This included increased difficulty in physical activities, with participation levels impaired in 25% of physical activities, though overall 97% of respondents were satisfied with their operative outcome. Qiao *et al.*[66] suggest lower rates of common complications but reported limitation of motion of the foot and pain during walking, with an eversion deformity of the forefoot. Complications are infrequent with arthrodesis, but non-union, infection, nerve irritation and symptomatic implants have been reported.[67]

Alcelik *et al.*[68] confirmed a higher risk of metalwork removal with ORIF, but the overall complication rates were equivalent in both groups with no differences in functional outcome. However, the overall power of the studies is low. A meta-analysis[69] reported on return to sport after fusion, and Smith *et al.*[70] reported on hardware removal, revision surgery, AOFAS and Baltimore Painful Foot Score and anatomic reduction outcomes with equivalence in all parameters. Further inferences could not be drawn given the high level of heterogeneity in the type of injuries and measured outcomes included in each study. Albright *et al.*[71] observed that ORIF failed to show functional or financial benefits over fusion and to gain one additional QALY. Primary arthrodesis costed \$1429/QALY, whereas ORIF costed \$3958/QALY.

The role of anatomical reconstruction in surgical outcomes

Traditionally, Lisfranc injuries have produced poor outcomes, with the walking speed of patients treated for a Lisfranc lesion slower than in healthy patients.[72] Epidemiologically, there is little or no evidence of correlation between surgical outcomes, age, gender, open or closed status.[73,74] The fixation debate continues, but the consensus is that anatomical and stable reduction is a prerequisite for a good outcome. Analysis of anatomical reduction is based on imaging classification of each injury as either good, fair or poor.[75] One of the few comparative studies demonstrated in 26 patients that open reduction and internal fixation with screws or plating resulted in better reduction and better maintenance of reduction in both low and high-energy injuries than percutaneous Kirschner wire fixation.[76]

The literature has so far focused on stabilization of the medial and middle column. Lateral column instability or displacement has been traditionally stabilized with Kirschner wires or trans-articular screws: neither technique appears superior, but little high-quality evidence other than case reports or series exists to support either.[77] Screw fixation has the additional issue of requiring surgical hardware removal, but may be more useful in complex situations.[74]

Lau *et al.*[78] conducted a multivariate analysis, finding a 18.2% (95% confidence interval 15.9–21.8) risk reduction of severe osteoarthritis with good reduction compared with fair or poor reduction utilizing trans-articular screw fixation, dorsal plating, a combination of plate and screw fixation and nonoperative management. Importantly, the presence of osteoarthritis was independent of the type of fixation used ($P < 0.0001$). Secondary displacement and loss of reduction[46] were more likely to occur in the Kirschner wire fixation group (37.5%) vs. those having undergone rigid fixation group (plate or screw; $P = 0.024$).[76] Kirschner wires are satisfactory temporizing measures prior to definitive stabilisation,[76] and should be used only in lateral column stabilization and in case of severe comminution.[10]

Smith *et al.*[70] evidenced poorer outcomes in terms of function if anatomical reduction was not achieved in arthrodesis. Kizner *et al.*[65] found functional outcome for fusion to be dependent on the quality of reduction ($P < 0.001$). In complex injuries undergoing arthrodesis, higher rates of good reduction were obtained (83% cases vs. 62% ($P = 0.138$)) and were more likely to be maintained at follow-up. Anatomical reduction is associated with statistically improved functional outcomes; specifically, in the areas of pain and functionality in the MOXFQ score.[57] Critically, athletes with greater than 2-mm residual displacement had worse outcomes across all assessed variables compared to athletes with residual displacement of < 2 mm.[79] Concluding, there could be a long-lasting negative effect on the athlete's career.

Therefore, reduction is the key: if anatomical reduction is not achieved by closed means, open reduction should be mandated. Richter *et al.*[74] suggested that this is especially true if the injuries were combined with a fracture dislocation affecting

Fig. 3 Rare complex dislocation of the mid foot and Lisfranc joint and medial malleolus fracture in an adolescent. Reconstruction using dorsal bridge plating, of the 3 columns; surgery was undertaken in 2 stages due to swelling.

the Chopart joint. Initial failure of surgical reconstruction and subsequent salvage arthrodesis leads to poorer outcomes in highly active individuals.[80] Therefore, long-term stable anatomical reduction is important regardless of whether ORIF or fusion is undertaken. Subgroup analysis by anatomical reduction showed superior scores with excellent reduction (AOFAS 90) as compared with good (AOFAS 75–89), average (AOFAS 50–74) or poor reduction (AOFAS 49) at a mean of 4.81 years.

Even so, these differences may result from the severity of the injury and the ability to achieve a good reduction. High-velocity mechanisms, e.g. motor vehicle accidents and falls from standing heights, produce significantly worse results when compared with low-velocity injuries, regardless of the fixation technique used.[73,74,81] In understanding outcomes, one needs to consider confounding factors including the pattern, number of columns affected by the injury, energy transfer and anatomical reduction. Injuries involving multiple columns are associated with greater energy transfer and poorer outcome (Fig. 3). In a retrospective study,[82] 68 of 80 patients with Lisfranc injuries and a mean follow-up of 24 months showed statistically improved functional outcomes between type B (homolateral incomplete medially or laterally) compared with more significant multiple column injuries e.g. type A (homolateral complete) and/or C (divergent partially or completely). In incomplete injuries, an intact LLL may not require multi-column stabilization, therefore reducing surgical dissection and producing better outcome.

Postoperative rehabilitation

Postoperative protocols remain highly variable. Some authors suggest to immobilize the operated limb in a NWB casts for 6 weeks, followed by a controlled ankle movement boot and progressively increasing weight-bearing for another 6 weeks.[47,51] Others recommend 3 weeks in a NWB cast or splint followed by partial weight-bearing (PWB) in a controlled ankle motion (CAM) boot for another 3 weeks[35,48] Wagner *et al.*[45] reported that, after good anatomical reduction with percutaneous screw fixation, weight-bearing could be permitted as early 3 weeks, a time when surgical healing has progressed.

Several studies report return to training at 7 weeks (range: 6–9 weeks), recreational activities at 7.2 weeks (range: 6–9 weeks), resumption of training for low-impact sports at 7.6 weeks (7–8 weeks) and sport activities without restriction at 12.4 weeks (range: 11–13 weeks).[8,57,69,83] Robertson *et al.*[69] reported quicker return to sports after percutaneous Lisfranc fixation as compared with open methods in low-energy injuries. It is reasonable to infer that the more unstable injuries require an extended period of NWB.

Deol *et al.*[83] showed that 16 of 17 players returned to elite sport within 25.3 weeks following either an osseous or ligamentous Lisfranc injury. Ninety per cent of NFL athletes who sustained Lisfranc injuries returned to play in a median of 11.1 months.[84] Players had no statistically significant difference in career length compared with controls, but the authors did not report on the quality of the career. However, one in three recreational athletes experienced continued pain at the injury site after ORIF.[85] Overall rates of return to sport were above 94%, and only a slightly lower percentage returner to their pre-injury levels.[85]

Healing, recovery, and hardware removal and complications

Questions still remain on how or whether the Lisfranc ligament actually heals, as no studies report the reconstitution of the ligament following injury. Traditionally, physiological loading is used to confirm healing, but little is known on whether and how this corresponds to anatomical reconstitution, as postoperative CT or MRI are not routinely undertaken.

Many authors advocate removal of metalwork, and this may be required in up to 16% of patients.[39,61,86] Typical reasons for removal are ongoing pain, irritation, fear of impending or future screw fracture, or metalwork failure with loss of position.[87] Removal of fixation and subsequent loss of reduction has been reported after removal of implants in ORIF.[70] One study showed no loss of alignment or reduction with removal as early as 8 weeks.[88] From the authors personal experience, many patients do not exercise their right for metal work removal and report no significant long-term limitation.

By its nature, arthrodesis less frequently requires metal work removal, but, excluding hardware removal, patients treated with ORIF do not have a higher rate of re-operation (29.5%) compared with those who are treated with a primary partial arthrodesis (29.6%).[89] The rates of compartment syndrome, skin problems, infection, deep vein thrombosis (DVT) and reflex sympathetic dystrophy (RSD) are all <3%.[8] Even so, implant issues, e.g. screw problems of 16%, and Lisfranc post-traumatic osteoarthritis are estimated at 49%, and ultimately the delayed arthrodesis rate was 7.8%.

Little is known regarding open Lisfranc injuries. Anatomical reduction was not possible in almost half of 13 patients given the severity of injury, and, at a mean 56 months follow-up, fusion had occurred in 10 patients; good to excellent outcomes were noted in 9 of 13 patients, and 10 returned to their pre-injury occupation.[90] Similarly, unstable chronic Lisfranc injuries (longer than 6 weeks from the inciting traumatic episode) without osteoarthritis pose a challenge in clinical decision-making. A recent systematic review showed improved patient outcome and few post-surgical complications,[91] with the mean preoperative AOFAS scores of 55.7 significantly improving to 88.1 (Table 2). The techniques used included ORIF with various types of hardware, Lisfranc ligament reconstruction (utilizing the gracilis tendon or half of the extensor hallucis longus tendon) and arthrodesis using screws. The quality of these studies was satisfactory, though a larger patient cohort and prospective analysis could further strengthen arguments for or against certain surgeries.[92]

Summary

Lisfranc injuries constitute a spectrum, ranging from ligamentous to complex fracture-dislocations. Anatomical and stable reduction of a Lisfranc injury is a prerequisite for good outcomes. Ligamentous injuries may be better managed with early fusion guaranteeing long-term stable anatomical reduction, especially for low demand patients (see Fig. 4). High demand athletes need a stable reconstruction, to allow them to pivot and load the foot, and need to be aware of long-term irritative symptoms that should not stop them returning to sport.

The outcomes of homolateral dislocations are independent of fixation technique for the lateral column, as an intact LLL may offer inherent stability on reduction. The literature supports percutaneous reduction, and/or trans-articular screw or plate fixation. However, several studies report improved functional outcomes with plate fixation.[54,57] This may reflect improved maintenance of anatomical reduction. Further damage to the articular surface with trans-articular screws results in less arthrosis thereby improving the functional outcome. Also, plate fixation can be easily extended to provide robust fixation to span associated cuboid and metatarsal fractures.[57] Combining techniques such as trans-articular screw and plate fixation may result in poorer outcomes from selection bias towards more severe injuries, as defined by the number of columns affected.[57]

The lack of high-quality studies is reflected in a small number of systematic and recent meta-analyses (Table 2).[37,68–70,77,91] Studies are generally case series or single-center retrospective studies, which assess a particular fixation method and are thus open to the possibility of collection, selection and small population bias. Single surgeon series lack long-term follow-up, which may underestimate the possibility that results deteriorate over time. Long-term clinical follow-up will help elucidate any superiority

Table 2 Summary of systematic reviews and meta-analyses

Author/year	Review type	Study question	Number of studies included/patients	Results	Conclusion
Alcelik *et al*. (2018)[68]	SR + MA	ORIF vs. primary arthrodesis (PA)—outcomes	8 (2 RCT, 6 non-RCT) $N = 547$	**ORIF vs. PA** *Complications:* Risk difference 0.03 (Cl 95%, −0.15 to 0.21, $P = 0.76$) *Unplanned return to theatre:* OR 1.40 (CI 95%, 0.45–4.31, $P = 0.56$) *Removal of metalwork:* OR 13.13 (Cl 95%, 7.65–22.54, $P < 0.00001$) *AOFAS:* OR 11.40 (CI 95%, −3.55 to 26.36, $P = 0.14$) *Return to work or activity:* OR 0.80 (CI 95%, 0.32–2.02, $P = 0.64$)) *Satisfaction rates:* OR 0.15 (CI 95%, 0.01–4.00, $P = 0.25$)	No statistical difference in outcomes or complication rates. Significantly more metal work removal in ORIF group.
Smith *et al*. (2016)[70]	SR + MA	ORIF vs. primary arthrodesis (PA)—patient outcomes	3 (2 RCT, 1 RC) $N = 101$	**ORIF vs. PA** *Hardware removal:* RR 0,23 (Cl 95%, 0.11–0.45, $P < 0.001$) *Revision surgery:* RR 0.36 (Cl 95%, 0.08–1.59, $P = 0.18$ *Patient reported outcomes:* Standard mean difference 0.5 (Cl 95%, −2.13–3.12, $P = 0.71$) *Non-anatomic reduction:* RR 1.48 (Cl 95%, 0.34–6.38, $P = 0.60$)	Increased risk of hardware removal along with its associated morbidity and discuss this with the patient preoperatively when considering ORIF No significant difference in revision surgery, patient reported outcomes, anatomic reduction.
Robertson *et al*. (2019)[69]	SR + MA	Return to sport	17 (1 RCT, 13 RC, 3 CS) $N = 366$	*Undisplaced (Stage 1), nonoperatively ($n = 35$):* Return to sport 100% Return time 4.0 (0–15) wks. *Stable minimally-displaced (Stage 2), nonoperatively ($n = 16$):* Return to sport 100% Return time 9.1 (4–14) wks. *Operative:* PRIF ($n = 42$) vs. ORIF ($n = 139$) Return to sport—98% vs. 78%, $P < 0.019$; Return time—11.6 wks. vs. 19.6 wks., $P < 0.001$) PRIF ($n = 42$) vs. PPA ($n = 85$) (Return to sport—98% vs. 85%, $P < 0.047$: return time—11.6 wks. vs. 22.0 wks., $P < 0.002$)	Stage 1 and stable Stage 2 Lisfranc injuries—good results with nonoperative management. PRIF offers the best return to sport and return time from the operative methods, though this may not be possible with high-energy injuries.

(*Continued*)

Table 2 Continued

Author/year	Review type	Study question	Number of studies includ-ed/patients	Results	Conclusion
Sripanich *et al.* (2020)[91]	SR	Chronic Lisfranc injuries without secondary degenerative arthritis—surgical outcomes	10 (10 CS—9 retrospective, 1 prospective *N* = 70	Overall generally low complication rates and good functional outcomes. Mean preoperative AOFAS scores of 55.7 significantly improved to 88.1 at final follow-up Many different operative techniques, retrospective, all but 1 single-center Low numbers	No consensus on operative management. Despite the delay in diagnosis, patients who undergo surgical repair have improved patient outcome and few post-surgical complications. A larger patient cohort and prospective analysis could further strengthen arguments for or against certain surgeries.
Stavlas *et al.* (2010)[73]	SR	Role of reduction + internal fixation	11 (2 RCT, 2 CC, 7 CS—retrospective) *N* = 257	*first—third metatarsal rays:* CRIF with screws—16.3% ORIF with screws—66.5% ORIF with k-wires—17.1% fourth—fifth metatarsal rays: Preferred method—k-wires Screw related complications 16.1% Mean AOFAS midfoot: 78.1 Post traumatic radiographic arthritis: 49.6%; 7.8%—arthrodesis	First 3 metatarsal rays: screws reliable method Complement with k-wires for fourth and fifth metatarsal rays as needed
Stavrakakis *et al.* (2019)[37]	SR	Closed reduction + percutaneous screw fixation—outcomes	7 (7 CS—retrospective) *N* = 106	*Average AOFAS score:* Type A: 86,2 Type B: 87,54 Type C: 85 Pure dislocation group: 86,43 Fracture-dislocation group: 87,36. Good to excellent outcome all types post percutaneous fixation. Patients with type B injury or a fracture-dislocation injury might have better outcome, but not statistically significant.	Percutaneous fixation relatively simple and safe, leading to a good functional outcome, especially for Myerson type B as well as for fracture dislocation type of injuries, provided anatomical reduction has been achieved.

(*Continued*)

Table 2 Continued

Author/year	Review type	Study question	Number of studies included/patients	Results	Conclusion
Ter Lak Bolk *et al.* (2020)[85]	SR	Adequate return to sport and sporting activities	15 (5 RCT, 10 RC) $N = 440$	Overall, 94% of patients retuned to sport, and 86% reached pre injury levels. Differences between treatment modalities were not significant. Mean time to return to sport ranged from 7–33 wks	Found equally good outcomes with different treatment strategies independent of severity of injury. Authors suggest that the pure effectiveness of treating a Lisfranc injury is very high.
Engelmann *et al.* (2022)[93]	SR + MA	Dorsal bridge plating compared with trans-articular screws	4 (4 retrospective observational studies)	111 patients in the BP group and 87 patients in the TAS group. AOFAS score was higher in DBP group (mean difference 7.08, 95% CI 1.50–12.66, $P = 0.01$). Osteoarthritis less common in the BP group (odds ratio 0.45, 95% CI 0.22–0.94, $P = 0.03$)	No significant difference was found between the groups in terms of postoperative infection, hardware removal, chronic pain and secondary arthrodesis. Dorsal bridge plating of fractures in the Lisfranc joint may lead to better functional outcome and a lower incidence of post-traumatic arthritis when compared to trans-articular screws.

Abbreviations: SR = systematic review, MA = meta-analysis;
RCT = randomized control trial, RC = retrospective cohort, CC = comparative cohort, CS = case series;
ORIF = open reduction internal fixation, PA = primary arthrodesis, PPA = primary partial arthrodesis PRIF = percutaneous reduction internal fixation, CRIP = closed reduction internal fixation, DBP = dorsal bridge plate.

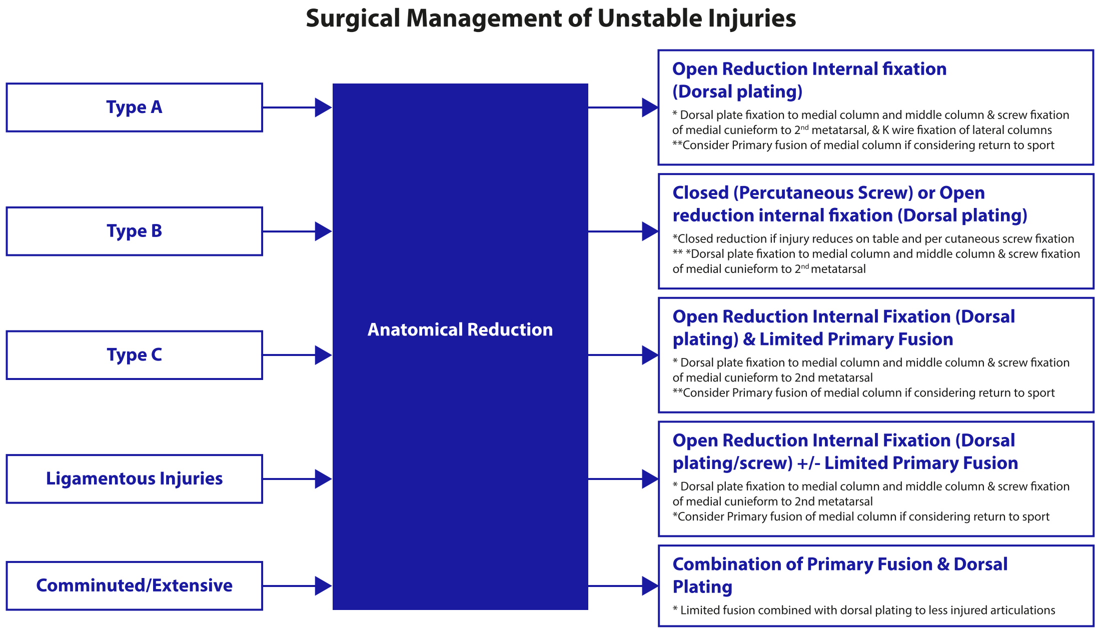

Fig. 4 Evidence based considerations to management of Lisfranc injuries based on the modified Hardcastle and Nunley-Vertullo classification. Anatomical re-alignment is a pre-requsite for all operative fixation/fusion techniques are assigned to the different types.

between the techniques when addressing fixation of these injuries.[54] Currently, strong evidence supports multicenter studies and randomized controlled trials on these injuries to define treatment strategies or consider registries.[92]

Conclusion

Both anatomical and biomechanical studies have provided more detailed evidence-based recommendations for the management of Lisfranc injury. Current treatment options offer good early functional outcomes, especially for partial incongruent injuries, provided that anatomical reduction is achieved. Anatomical reduction is the key to successful outcomes. Consequently, open reduction should be undertaken if closed reduction is not satisfactory.

There is strong evidence in favor of dorsal plating, being biomechanically stable, with improved reduction offering good clinical outcome without transarticular screws and consequent joint injury. New implants such as compression staples and anatomical plates, e.g. four corner plates, may provide rigid durable anatomical fixation.

There is a clear place for arthrodesis in pure ligamentous injuries, severe patterns or as a salvage tool, but comparative studies are required. Further evaluation is required to assess and define hardware removal needs and advise patients of what is actually being achieved.

There is a clear place for arthrodesis in pure ligamentous injuries, severe patterns or as a salvage tool, but comparative studies are required. Further evaluation is required to assess and define hardware removal needs and advise patients of what is actually being achieved. The following key points have been highlighted in this review:

- Lisfranc injuries represent a spectrum of injuries from ligamentous to complex fracture-dislocation and are not as rare as previously reported.
- Evaluation of weight-bearing CT could be the modality of choice in diagnosis and surgical planning.

- The prognosis of Lisfranc lesions is related to injury severity and energy and can be estimated by the number of columns in the foot affected.
- Surgical outcome is determined by anatomical reduction for most ORIF and fusion techniques.
- If anatomical reduction is achieved, acute arthrodesis is a safe alternative to ORIF in selected patients, as demonstrated by comparable outcomes in ligamentous only and complex injuries.

Conflict of interest statement

The authors have no potential conflicts of interest.

References

1. Mantas JP, Burks RT. Lisfranc injuries in the athlete. *Clin Sports Med* 1994;13:719–30.
2. Stødle AH, Hvaal KH, Enger M et al. Lisfranc injuries: incidence, mechanisms of injury and predictors of instability. *Foot Ankle Surg*Published online 2019;26:535–40. https://doi.org/10.1016/j.fas.2019.06.002.
3. Kent RW, Brent Lievers W, Riley PO et al. Etiology and biomechanics of tarsometatarsal injuries in professional football players: a video analysis. *Orthop J Sports Med* 2014;2:232596711452534. https://doi.org/10.1177/2325967114525347.
4. Renninger CH, Cochran G, Tompane T et al. Injury characteristics of low-energy Lisfranc injuries compared with high-energy injuries. *Foot Ankle Int* 2017;38:964–9. https://doi.org/10.1177/1071100717709575.
5. Nunley JA, Vertullo CJ. Classification, investigation, and management of midfoot sprains: Lisfranc injuries in the athlete. *Am J Sports Med* 2002;30:871–8. https://doi.org/10.1177/03635465020300061901.
6. Ross G, Cronin R, Hauzenblas J, Juliano P. Plantar ecchymosis sign: a clinical aid to diagnosis of occult lisfranc tarsometatarsal injuries. *J Orthop Trauma* 1996;10:119–22. https://doi.org/10.1097/00005131-199602000-00008.
7. Rosenbaum A, Dellenbaugh S, DiPreta J, Uhl R. Subtle injuries to the lisfranc joint. *Orthopedics* 2011;34:882–7. https://doi.org/10.3928/01477447-20110922-23.
8. Moracia-Ochagavía I, Rodríguez-Merchán EC. Lisfranc fracture-dislocations: current management. *EFORT Open Rev* 2019;4:430–44. https://doi.org/10.1302/2058-5241.4.180076 PMID: 31423327; PMCID: PMC6667981.
9. Davies MS, Saxby TS. Intercuneiform instability and the “gap” sign. *Foot Ankle Int* 1999;20:606–9. https://doi.org/10.1177/107110079902000912.
10. Chiodo CP, Myerson MS. Developments and advances in the diagnosis and treatment of injuries to the tarsometatarsal joint. *Orthop Clin North Am* 2001;32:11–20. https://doi.org/10.1016/S0030-5898(05)70190-5.
11. Weatherford BM, Anderson JG, Bohay DR. Management of tarsometatarsal joint injuries. *J Am Acad Orthop Surg* 2017;25:469–79. https://doi.org/10.5435/JAAOS-D-15-00556.
12. Milankov M, Miljkovic N, Popovic N. Concomitant plantar tarsometatarsal (Lisfranc) and metatarsophalangeal joint dislocations. *Arch Orthop Trauma Surg* 2003;123:95–7. https://doi.org/10.1007/s00402-003-0477-0.
13. De Palma L, Santucci A, Sabetta SP et al. Anatomy of the Lisfranc joint complex. *Foot Ankle Int* 1997;18:356–64. https://doi.org/10.1177/107110079701800609.
14. Pearce CJ, Calder JD. Surgical anatomy of the midfoot. *Knee Surgery, Sport Traumatol Arthrosc* 2010;18:581–6. https://doi.org/10.1007/s00167-010-1101-9.
15. Mason L, Jayatilaka MLT, Fisher A et al. Anatomy of the lateral plantar ligaments of the transverse metatarsal arch. *Foot Ankle Int* 2020;41:109–14. https://doi.org/10.1177/1071100719873971.
16. Peicha G, Labovitz J, Seibert FJ et al. The anatomy of the joint as a risk factor for Lisfranc dislocation and fracture-dislocation. *J Bone Jt Surg - Ser B* 2002;84-B:981–5. https://doi.org/10.1302/0301-620X.84B7.12587.
17. Yu-Kai Y, Shiu-Bii L. Anatomic parameters of the Lisfranc joint complex in a radiographic and cadaveric comparison. *J Foot Ankle Surg* 2015;54:883–7. https://doi.org/10.1053/j.jfas.2015.02.021.
18. Solan MC, Moorman CT, Miyamoto RG et al. Ligamentous restraints of the second tarsometatarsal joint: a biomechanical evaluation. *Foot Ankle Int* 2001;22:637–41. https://doi.org/10.1177/107110070102200804.
19. Hatem SF. Imaging of Lisfranc injury and midfoot sprain. *Radiol Clin North Am* 2008;46:1045–60. https://doi.org/10.1016/j.rcl.2008.09.003.
20. Penev P, Qawasmi F, Mosheiff R et al. Ligamentous Lisfranc injuries: analysis of CT findings under

weightbearing. *Eur J Trauma Emerg Surg Published online* 2020;47:1243–8. https://doi.org/10.1007/s00068-020-01302-7.

21. De Bruijn J, Hagemeijer NC, Rikken QGH et al. Lisfranc injury: refined diagnostic methodology using weightbearing and non-weightbearing radiographs. *Injury* 2022;53:2318–25.
22. Kaar S, Femino J, Morag Y. Lisfranc joint displacement following sequential ligament sectioning. *J Bone Jt Surg - Ser A* 2007;89:2225–32. https://doi.org/10.2106/JBJS.F.00958.
23. Castro M, Melão L, Canella C et al. Lisfranc joint ligamentous complex: MRI with anatomic correlation in cadavers. *Am J Roentgenol* 2010;195:W447–55. https://doi.org/10.2214/AJR.10.4674.
24. Raikin SM, Elias I, Dheer S et al. Prediction of midfoot instability in the subtle Lisfranc injury: comparison of magnetic resonance imaging with intraoperative findings. *J Bone Jt Surg - Ser A* 2009;91:892–9. https://doi.org/10.2106/JBJS.H.01075.
25. Quenu E, Kuss G. Étude sur les luxations du métatarse. *Rev Chir Orthop Reparatrice Appar Mot* 1909;39:281–336.
26. Hardcastle PH, Reschauer R, Kutscha-Lissberg E, Schoffmann W. Injuries to the tarsometatarsal joint. Incidence, classification and treatment. *J Bone Jt Surg - Ser B* 1982;64-B:349–56. https://doi.org/10.1302/0301-620x.64b3.7096403.
27. Sivakumar BS, An VVG, Oitment C, Myerson M. Subtle Lisfranc injuries: a topical review and modification of the classification system. *Orthopedics* 2018;41:e168–75.
28. Shariff S, Clark C, Dega R. Lisfranc injury classifications. *Internet J Orthop* 2008;11:1.
29. Granberry WM, Lipscomb PR. Dislocation of the tarsometatarsal joints. *Surg Gynecol Obstet* 1962; 114:467–9.
30. Ahmed S, Bolt B, McBryde A. Comparison of standard screw fixation versus suture button fixation in Lisfranc ligament injuries. *Foot Ankle Int* 2010;31:892–6. https://doi.org/10.3113/FAI.2010.0892.
31. Yongfei F, Chaoyu L, Wenqiang X et al. Clinical outcomes of tightrope system in the treatment of purely ligamentous Lisfranc injuries. *BMC Surg* 2021;21:395.
32. Panchbhavi VK, Vallurupalli S, Yang J, Andersen CR. Screw fixation compared with suture-button fixation of isolated lisfranc ligament injuries. *J Bone Jt Surg - Ser A* 2009;91:1143–8. https://doi.org/10.2106/JBJS.H.00162.
33. Baravarian B, Geffen D. Lisfranc tightrope. *Foot Ankle Spec* 2009;2:249–50. https://doi.org/10.1177/1938640009347169.
34. Hopkins J, Nguyen K, Heyrani N et al. Internal brace has biomechanical properties comparable to suture button but less rigid than screw in ligamentous lisfranc model. *J Orthop* 2020;17:7–12. https://doi.org/10.1016/j.jor.2019.06.020.
35. Crates JM, Barber FA. Dual tight rope fixation for subtle Lisfranc injuries. *Tech Foot Ankle Surg* 2012;11:163–7. https://doi.org/10.1097/BTF.0b013e3182732eeb.
36. Miyamoto W, Takao M, Innami K et al. Ligament reconstruction with single bone tunnel technique for chronic symptomatic subtle injury of the Lisfranc joint in athletes. *Arch Orthop Trauma Surg* 2015;135:1063–70. https://doi.org/10.1007/s00402-015-2250-6.
37. Stavrakakis IM, Magarakis GE, Christoforakis Z. Percutaneous fixation of Lisfranc joint injuries: a systematic review of the literature. *Acta Orthop Traumatol Turc* 2019;53:457–62. https://doi.org/10.1016/j.aott.2019.08.005.
38. Prugia D, Basile A, Battaglia A et al. Fracture dislocations of Lisfranc's joint treated with closed reduction and percutaneous fixation. *Int Orthop* 2003;27:30–5. https://doi.org/10.1007/s00264-002-0396-7.
39. Kuo RS, Tejwani NC, Digiovanni CW et al. Outcome after open reduction and internal fixation of Lisfranc joint injuries. *J Bone Jt Surg - Ser A* 2000;82:1609–18. https://doi.org/10.2106/00004623-200011000-00015.
40. Richter M, Wippermann B, Krettek C et al. Fractures and fracture dislocations of the midfoot: occurrence, causes and long-term results. *Foot Ankle Int* 2001;22:392–8. https://doi.org/10.1177/107110070102200506.
41. Bleazey ST, Brigido SA, Protzman NM. Technique tip: percutaneous fixation of partial incongruous Lisfranc injuries in athletes. *Foot Ankle Spec* 2013;6:217–21. https://doi.org/10.1177/1938640013486515.
42. Lien SB, Shen HC, Lin LC et al. Combined innovative portal arthroscopy and fluoroscopy-assisted reduction and fixation in subtle injury of the Lisfranc joint complex: analysis of 10 cases. *J Foot Ankle Surg* 2017;56:142–7. https://doi.org/10.1053/j.jfas.2016.05.003.
43. Mohamed Abdelgaid S, Salah M et al. The effect of Kinesiotaping on functional performance in chronic ankle instability - preliminary study. *Clin Res Foot Ankle Abdelgaid al* 2013;01:109. https://doi.org/10.4172/2329-910X.1000109.

44. Vertullo CJ, Easley ME, Nunley JA. The transverse dorsal approach to the Lisfranc joint. *Foot Ankle Int* 2002;23:420–6. https://doi.org/10.1177/107110070202300509.
45. Wagner E, Ortiz C, Villalón IE et al. Early weight-bearing after percutaneous reduction and screw fixation for low-energy lisfranc injury. *Foot Ankle Int* 2013;34:978–83. https://doi.org/10.1177/1071100713477403.
46. Schepers T, Oprel PP, Van Lieshout EMM. Influence of approach and implant on reduction accuracy and stability in Lisfranc fracture-dislocation at the tarsometatarsal joint. *Foot Ankle Int* 2013;34:705–10. https://doi.org/10.1177/1071100712468581.
47. Alberta FG, Aronow MS, Barrero M et al. Ligamentous Lisfranc joint injuries: a biomechanical comparison of dorsal plate and trans-articular screw fixation. *Foot Ankle Int* 2005;26:462–73. https://doi.org/10.1177/107110070502600607.
48. Cosculluela PE, Ebert AM, Varner KE. Dorsomedial bridge plating of lisfranc injuries. *Tech Foot Ankle Surg* 2009;8:215–20. https://doi.org/10.1097/BTF.0b013e3181c266cd.
49. Watson TS, Shurnas PS, Denker J. Treatment of lisfranc joint injury: current concepts. *J Am Acad Orthop Surg* 2010;18:718–28. https://doi.org/10.5435/00124635-201012000-00002.
50. Frigg R. Locking compression plate (LCP). An osteosynthesis plate based on the dynamic compression plate and the point contact fixator (PC-fix). *Injury* 2001;32:63–6. https://doi.org/10.1016/S0020-1383(01)00127-9.
51. Cosculluela DA, Parks BG, Schon LC. Screw fixation compared to H-locking plate fixation for first metatarsocuneiform arthrodesis: a biomechanical study. *Foot Ankle Int* 2005;26:984–9. https://doi.org/10.1177/107110070502601114.
52. Purushothaman B, Robinson E, Lakshmanan P, Siddique M. Extra-articular fixation for treatment of Lisfranc injury. *Surg Technol Int* 2010;19:199–202.
53. Wilson MG, Gomez-Tristan A. Medial plate fixation of Lisfranc injuries. journals.lww.com. Medial plate fixation of Lisfranc injuries. *Tech Foot Ankle Surg* 2010;9:107–10.
54. Hu SJ, Chang SM, Li XH, Yu GR. Outcome comparison of Lisfranc injuries treated through dorsal plate fixation versus screw fixation. *Acta Ortop Bras* 2014;22:315–20. https://doi.org/10.1590/1413-78522014220600576.
55. van Koperen PJ, de Jong VM, Luitse JSK, Schepers T. Functional outcomes after temporary bridging with locking plates in Lisfranc injuries. *J Foot Ankle Surg* 2016;55:922–6. https://doi.org/10.1053/j.jfas.2016.04.005.
56. Dalal D, Curry C, Carter R et al. Surgical treatment of Lisfranc injury with plantar plate approach. *J Foot Ankle Surg* 2018;57:794–800. https://doi.org/10.1053/j.jfas.2017.11.006.
57. Kirzner N, Zotov P, Goldbloom D et al. Dorsal bridge plating or trans-articular screws for Lisfranc fracture dislocations: a retrospective study comparing functional and radiological outcomes. *Bone Jt J* 2018;100-B:468–74. https://doi.org/10.1302/0301-620X.100B4.BJJ-2017-0899.R2.
58. Kommalapti V, Wek C, Coffey D et al. A comparison of trans-articular screw versus dorsal bridge plate versus compression locking plate fixation in B2 Lis franc injuries: a 5-year experience in a Level 1 Trauma Centre, in the United Kingdom. *J Foot Ankle Surg* 2021;S1067-2516:00457–9.
59. Mulier T, Reynders P, Dereymaeker G, Broos P. Severe Lisfrancs injuries: primary arthrodesis or ORIF? *Foot Ankle Int* 2002;23:902–5. https://doi.org/10.1177/107110070202301003.
60. Sheibani-Rad S, Coetzee JC, Giveans MR, DiGiovanni C. Arthrodesis versus ORIF for Lisfranc fractures. *Orthopedics* 2012;35:e868–73. https://doi.org/10.3928/01477447-20120525-26.
61. Ly TV, Coetzee JC. Treatment of primarily ligamentous Lisfranc joint injuries: primary arthrodesis compared with open reduction and internal fixation a prospective, randomized study. *J Bone Jt Surg - Ser A* 2006;88:514–20. https://doi.org/10.2106/JBJS.E.00228.
62. Macmahon A, Kim P, Levine DS et al. Return to sports and physical activities after primary partial arthrodesis for Lisfranc injuries in young patients. *Foot Ankle Int* 2016;37:355–62. https://doi.org/10.1177/1071100715617743.
63. Reinhardt KR, Oh LS, Schottel P et al. Treatment of lisfranc fracture-dislocations with primary partial arthrodesis. *Foot Ankle Int* 2012;33:50–6. https://doi.org/10.3113/FAI.2012.0050.
64. Cochran G, Renninger C, Tompane T et al. Primary arthrodesis versus open reduction and internal fixation for low-energy Lisfranc injuries in a young athletic population. *Foot Ankle Int* 2017;38:957–63. https://doi.org/10.1177/1071100717711483.

65. Kirzner N, Teoh W, Toemoe S et al. Primary arthrodesis versus open reduction internal fixation for complete Lisfranc fracture dislocations: a retrospective study comparing functional and radiological outcomes. *ANZ J Surg* 2020;90:585–90. https://doi.org/10.1111/ans.15627.
66. Sen QY, Li JK, Shen H et al. Comparison of arthrodesis and non-fusion to treat Lisfranc injuries. *Orthop Surg* 2017;9:62–8. https://doi.org/10.1111/os.12316.
67. Kuhn K, Renninger C, Cochran G, Bellamy J. Acute arthrodesis of lisfranc injuries. *Tech Foot Ankle Surg* 2019;18:8–15. https://doi.org/10.1097/BTF.0000000000000200.
68. Alcelik I, Fenton C, Hannant G et al. A systematic review and meta-analysis of the treatment of acute lisfranc injuries: open reduction and internal fixation versus primary arthrodesis. *Foot Ankle Surg* 2019;26:299–307. https://doi.org/10.1016/j.fas.2019.04.003.
69. Robertson GAJ, Ang KK, Maffulli N et al. Return to sport following Lisfranc injuries: a systematic review and meta-analysis. *Foot Ankle Surg* 2019;25:654–64. https://doi.org/10.1016/j.fas.2018.07.008.
70. Smith N, Stone C, Furey A. Does open reduction and internal fixation versus primary arthrodesis improve patient outcomes for Lisfranc trauma? A systematic review and meta-analysis. *Clin Orthop Relat Res* 2016;474:1445–52. https://doi.org/10.1007/s11999-015-4366-y.
71. Albright RH, Haller S, Klein E et al. Cost-effectiveness analysis of primary arthrodesis versus open reduction internal fixation for primarily ligamentous Lisfranc injuries. *J Foot Ankle Surg* 2018;57:325–31. https://doi.org/10.1053/j.jfas.2017.10.016.
72. van Hoeve S, Stollenwerck G, Willems P et al. Gait analysis and functional outcome in patients after Lisfranc injury treatment. *Foot Ankle Surg* 2018;24:535–41. https://doi.org/10.1016/j.fas.2017.07.003.
73. Lau S, Guest C, Hall M, Tacey M, Joseph S, Oppy A. Functional outcomes post lisfranc injury – transarticular screws, dorsal bridge plating or combination treatment? *J Orthop Trauma* 2017;31. Lippincott Williams and Wilkins:447–52. https://doi.org/10.1097/BOT.0000000000000848.
74. Richter M, Thermann H, Huefner T et al. Chopart joint fracture-dislocation: initial open reduction provides better outcome than closed reduction. *Foot Ankle Int* 2004;25:340–8. https://doi.org/10.1177/107110070402500512.
75. Wilppula E. Tarsometatarsal fracture-dislocation: late results in 26 patients. *Acta Orthop* 1973;44:335–45. https://doi.org/10.3109/17453677308988700.
76. Herscovici D Jr, Scaduto JM. Acute management of high-energy lisfranc injuries: a simple approach. *Injury* 2018;49:420–4. https://doi.org/10.1016/j.injury.2017.11.012 Epub 2017 Nov 16. PMID: 29157841.
77. Stavlas P, Roberts CS, Xypnitos FN, Giannoudis PV. The role of reduction and internal fixation of Lisfranc fracture-dislocations: a systematic review of the literature. *Int Orthop* 2010;34:1083–91. https://doi.org/10.1007/s00264-010-1101-x.
78. Lau S, Howells N, Millar M et al. Plates, screws, or combination? Radiologic outcomes after Lisfranc fracture dislocation. *J Foot Ankle Surg* 2016;55:799–802. https://doi.org/10.1053/j.jfas.2016.03.002.
79. McHale KJ, Vopat BG, Beaulieu-Jones BR et al. Epidemiology and outcomes of lisfranc injuries identified at the national football league scouting combine. *Am J Sports Med* 2017;45:1901–8. https://doi.org/10.1177/0363546517697297.
80. Hawkinson MP, Tennent DJ, Belisle J, Osborn P. Outcomes of Lisfranc injuries in an active duty military population. *Foot Ankle Int* 2017;38:1115–9. https://doi.org/10.1177/1071100717719532.
81. Thompson MC, Mormino MA. Injury to the tarsometatarsal joint complex. *J Am Acad Orthop Surg* 2003;11:260–7. https://doi.org/10.5435/00124635-200307000-00005.
82. Yu X, Pang QJ, Yang CC. Functional outcome of tarsometatarsal joint fracture dislocation managed according to Myerson classification. *Pakistan J Med Sci* 2014;30:773–7. https://doi.org/10.12669/pjms.304.4259.
83. Deol RS, Roche A, Calder JDF. Return to training and playing after acute Lisfranc injuries in elite professional soccer and Rugby players. *Am J Sports Med* 2016;44:166–70. https://doi.org/10.1177/0363546515616814.
84. Mora AD, Kao M, Alfred T et al. Return to sports and physical activities after open reduction and internal fixation of Lisfranc injuries in recreational athletes. *Foot Ankle Int* 2018;39:801–7. https://doi.org/10.1177/1071100718765176.
85. ter Laak Bolk CS, Dahmen J, Lambers KTA et al. Adequate return to sports and sports activities after treatment of Lisfranc injury: a meta-analysis. *ISAKOS* 2021;6:212–9 Epub 2020 Dec 10. PMID: 34272297.
86. Sands AK, Grose A. Lisfranc injuries. *Injury* 2004;35:71–6. https://doi.org/10.1016/j.injury.2004.07.014.
87. Busam ML, Esther RJ, Obremskey WT. Hardware removal: indications and expectations. *J Am Acad*

Orthop Surg 2006;14:113–20. https://doi.org/10.5435/00124635-200602000-00006.

88. Rammelt S, Schneiders W, Schikore H et al. Primary open reduction and fixation compared with delayed corrective arthrodesis in the treatment of tarsometatarsal (Lisfranc) fracture dislocation. *J Bone Jt Surg - Ser B* 2008;90-B:1499–506. https://doi.org/10.1302/0301-620X.90B11.20695.
89. Buda M, Kink S, Stavenuiter R et al. Reoperation rate differences between open reduction internal fixation and primary arthrodesis of Lisfranc injuries. *Foot Ankle Int* 2018;39:1089–96. https://doi.org/10.1177/1071100718774005.
90. Nithyananth M, Boopalan PRJVC, Titus VTK et al. Long-term outcome of high-energy open lisfranc injuries: a retrospective study. *J Trauma - Inj Infect Crit Care* 2011;70:710–6. https://doi.org/10.1097/TA.0b013e3181f02ab9.
91. Sripanich Y, Weinberg MW, Krähenbühl N et al. Surgical outcome of chronic Lisfranc injury without secondary degenerative arthritis: a systematic literature review★. *Injury* 2020;51: 1258–65. https://doi.org/10.1016/j.injury.2020.04.005.
92. Ponkilainen VT, Mattila VM, Laine HJ et al. Nonoperative, open reduction and internal fixation or primary arthrodesis in the treatment of Lisfranc injuries: a prospective, randomized, multicenter trial - study protocol. *BMC Musculoskelet Disord* 2018;19:301. https://doi.org/10.1186/s12891-018-2222-4.
93. Engelmann EWM, Roelofs A, Posthuma J, Schepers T. Evaluation of functional outcome and complications in bridge plating compared to trans-articular screws for Lisfranc injuries: a systematic review and meta-analysis. *J Foot Ankle Surg* 2022;S1067-2516:00085–0. https://doi.org/10.1053/j.jfas.2022.03.002 Epub ahead of print. PMID: 35459613.