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Systematic Review

Ligamentous ankle injuries in relation to the morphology of the incisura fibularis: A systematic review☆

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ABSTRACT

Importance: Ligamentous ankle lesions are among the most frequent sports injuries. One of the key intrinsic stabilizers of the ankle joint is the incisura fibularis (IF), as it interlocks the distal tibia and fibula. Despite an abundant amount of studies related to ligamentous ankle injuries, scant attention has been given to the specific role of the IF morphology.

Objective: We systematically reviewed all literature focused on the relation between ligamentous ankle lesions and IF morphology.

Evidence review: A systematic literature search was conducted on PubMed, Embase, and Web of Science according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines and registered on the International Prospective Register of Systematic Reviews (PROSPERO) database (CRD42021282862). In general, search terms were related to ankle and syndesmosis trauma/instability in combination with morphology parameters of the IF. Studies categorizable as original research (randomized controlled trial or observational) were included. Studies concerning degenerative ankle disease and cadavers were excluded.

Findings: Thirteen studies were confirmed eligible and consisted of a prospective cohort ($n = 1$), retrospective comparative ($n = 10$), and observational ($n = 2$) study design. Several studies have found an increased number of ankle ligament injuries and a higher incidence of chronic ankle instability in association with a shallow IF depth. In addition, statistically significant differences in incisura height and angle were also noted: a shorter incisura and more obtuse angle were more present in patients with ankle ligament injuries.

Conclusion and relevance: Most studies found distinct characteristics of the IF morphology associated with ligamentous ankle lesions, potentially due to lower osseous resistance against tibiofibular displacement. However, not all studies could identify this association and presented a heterogeneous methodological quality. Therefore, further prospective studies are warranted to clarify the relationship between the IF morphology and ligamentous ankle injuries.

Lever of evidence: Level III, systematic review.

☆ The work is not under consideration by any other journal and has not been previously published. The manuscript underwent several revisions with substantial contributions provided by each of the co-authors. The integrity of the work has been guaranteed by each of the co-authors.

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What is already known?

- The incisura fibularis is a key anatomical structure in providing intrinsic stability to the ankle joint.

What are the new findings?

- This review suggests that distinct morphological aspects of the incisura fibularis are associated with ligamentous ankle lesions.
- A more shallow incisura fibularis is the main morphological parameter that could be more frequently identified in lateral ligament injuries and isolated as well as fracture-associated syndesmotic ligament injuries.

INTRODUCTION

Ligamentous ankle lesions comprise injury to one or more of the ligaments that surround and stabilize the ankle mortise [1–3]. They are one of the most frequent sports injuries [4–7] and account for more than 1,000,000 emergency department visits annually in the United States [8]. Because of their complexity in the amount of associated lesions, ankle injuries can impose an important return to play challenge [9]. Ankle sprains can be categorized as a low/lateral or a high/syndesmotic ankle sprain [10]. The most common ankle sprain is a lateral ankle sprain (LAS), as they encompass 80% of all ankle sprains [11]. A LAS is defined as an injury to the lateral ligamentous complex: anterior talofibular (ATFL), calcaneofibular, and posterior talofibular ligament [12]. A forceful inversion and plantar flexion of the ankle is the most common mechanism of injury in LAS [13–16]. A high ankle sprain, also called a syndesmotic ankle sprain, is a type of sprain that involves ligaments stabilizing the distal tibiofibular joint (DTFJ) [17–19]. Syndesmotic ankle sprains can contribute approximately up to 18% of all ankle sprains [20]. They involve injury to one of the following distal tibiofibular ligaments: anterior-inferior tibiofibular, interosseous, posterior-inferior tibiofibular, and transverse tibiofibular ligament [21–23]. The most common mechanism of injury is dorsiflexion, external rotation, and pronation [21,24–27]. Injuries to the syndesmotic ligaments can also be associated with ankle fractures [28,29]. These can occur in up to 25% of ankle fractures and often need addition surgical fixation [30–32].

Within the ligamentous ankle complex, the incisura fibularis (IF), also called the fibular incisura or fibular notch, constitutes an important component of the DTFJ [33]. It is well known that the ankle joint requires adequate stability to resist high loads when maintaining mortise congruency during functional activities [34]. The concave osseous morphology of the IF provides intrinsic stability by interlocking the distal tibia and fibula [11]. The morphology of the IF can be classified into C-shape, 1-shape, and Γ-shape (Fig. 1). Several recent reports have suggested that the type and extent of ligamentous ankle injuries might depend, among other factors, on the morphology of the IF [11,35]. With the broad availability of modern imaging technologies, such as computed tomography (CT) scan or magnetic resonance imaging (MRI), it is possible to conduct a more detailed evaluation of the IF morphology. Despite these recent advances, myriad research has been conducted on the role of the ligaments in providing extrinsic ankle stability. On contrary, scant attention has been given to the osseous morphology of the IF, as intrinsic stabilizer (Fig. 2). Moreover, recent systematic reviews on intrinsic factors in the setting of ligamentous ankle injuries did not focus specifically on the morphology of the IF [36–38].

Therefore, the aim of this study is to perform a systematic review of all studies that investigated the role of the IF morphology in lateral ankle ligament injuries as well as isolated and fracture-associated syndesmotic ligament injuries. We hypothesized that certain IF morphologies, i.e., a shallow IF, could contribute to a higher incidence or severity of injury to the ankle ligaments.

METHODS

Search methodology

A systematic literature review was performed in accordance with the "Preferred Reporting Items for Systematic reviews and Meta-Analysis" (PRISMA) guidelines. The Database of Abstracts of Reviews of Effects, the Cochrane Database of Systematic Reviews, and International Prospective Register of Systematic Reviews (PROSPERO) could not identify previously performed reviews investigating the role of the IF in ligamentous ankle lesions. This review was registered in the PROSPERO database (CRD42021282862). A literature search was carried out on three major databases: PubMed, Embase, and Web of Science. The following keywords were used: "ankle syndesmosis," "syndesmotic stability," "ankle trauma," "ankle injury," "ankle sprain," "ankle fracture," "tibiofibular," "fibular notch," "fibular incisura," "incisura fibularis," "morphometric analysis," and "ligamentous ankle lesions." The keywords were internally

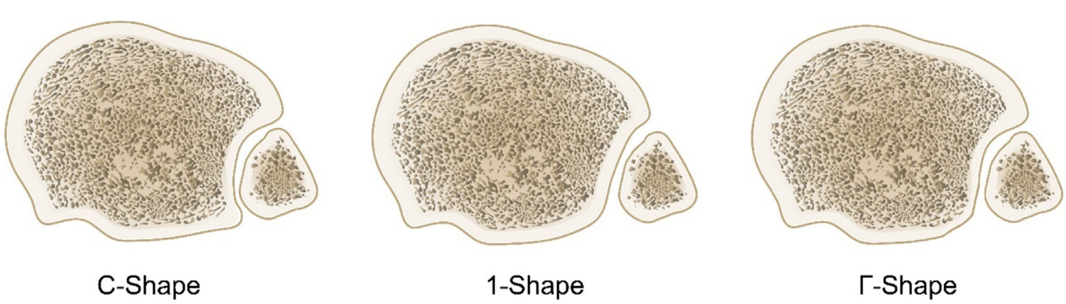

Fig. 1. Classification the incisura fibularis morphology: C-shape (left), 1-shape (middle) and Γ-shape (right).

validated by four of the co-authors (R.V., L.S., W.H., and A.B.). Inclusion criteria consisted of studies (1) published between January 1, 2000, and March 31, 2024, (2) available as full text in English, (3) categorizable as randomized controlled trials or observational studies (cohort, case–control, and case series), and (4) concerning adults with ankle injury (sprain, fracture, instability) and contain sufficiently relevant imaging. Articles concerning children and adolescent (<18 years), degenerative ankle disease (i.e. arthritis), and cadaveric studies were excluded. Database screening was closed on March 31, 2024. The rationale for including studies starting from 2,000 until closure of database screening was based on the quality of the MRI scans. Before 2,000, MRI of the foot and ankle was mainly suited to assess larger structures, such as the tibialis posterior tendon, and more challenging for smaller structures, such as the ankle ligaments. Only articles in the English language were included to avoid misinterpretations. Titles and abstracts were reviewed to verify inclusion criteria and relevance. If all inclusion criteria were present and the article seemed relevant or if this remained unclear, the articles were fully read. All studies were screened for eligibility by two independent reviewers (L.W. and R.V.) who reviewed titles, abstracts, and full text. Any disagreements were resolved by discussion, and a third reviewer was consulted (A.B.). Additional literature was obtained through searching references in the manuscripts (snowball method). The citation manager Endnote 21 (Clarivate, London, UK) was used during the entire literature study.

Quality appraisal

The quality evaluation instrument developed by Hawker et al. [30] was used for the assessment of methodological quality. This instrument evaluates nine items: abstract and title, introduction and aims, methods and data, sampling method, data analysis, ethics and bias, results, generalizability, and implications for practice (Table 1). Quality assessment was performed by a single reviewer (L.W.) to avoid mean scores within these nine items. Each item is scored ranging from one (very poor) to four (good), resulting in an aggregate maximum score of 36 and minimum score of 9. Scores for high-quality studies range between 30 and 36, scores between 24 and 29 indicate average quality, and scores lower than 24 indicate poor quality.

RESULTS

Study selection and analysis

The results of the search process are summarized in a PRISMA flow diagram (Fig. 3) [40]. After screening, the search in PubMed yielded 1, 276, in Embase yielded 515, and in Web of Science yielded 587 articles. After removing duplicates ($n = 2{,}123$), 249 articles were screened on title and abstract. A total of 205 articles were excluded for not being relevant to the topic. The remaining 43 articles were assessed based on full text. Through the snowballing method of screening the reference lists of relevant articles, 17 additional articles complying with the inclusion criteria could be identified and were added. These articles were then assessed based on the full text. After full-text screening, 13 articles were subjected to a risk bias analysis and quality assessment. Because of the heterogeneity in terms of study design and comparator data, it was not possible to conduct a meta-analysis of the included source studies. Therefore, a systematic narrative review, with information presented in text and tables, summarized the characteristics and findings of the

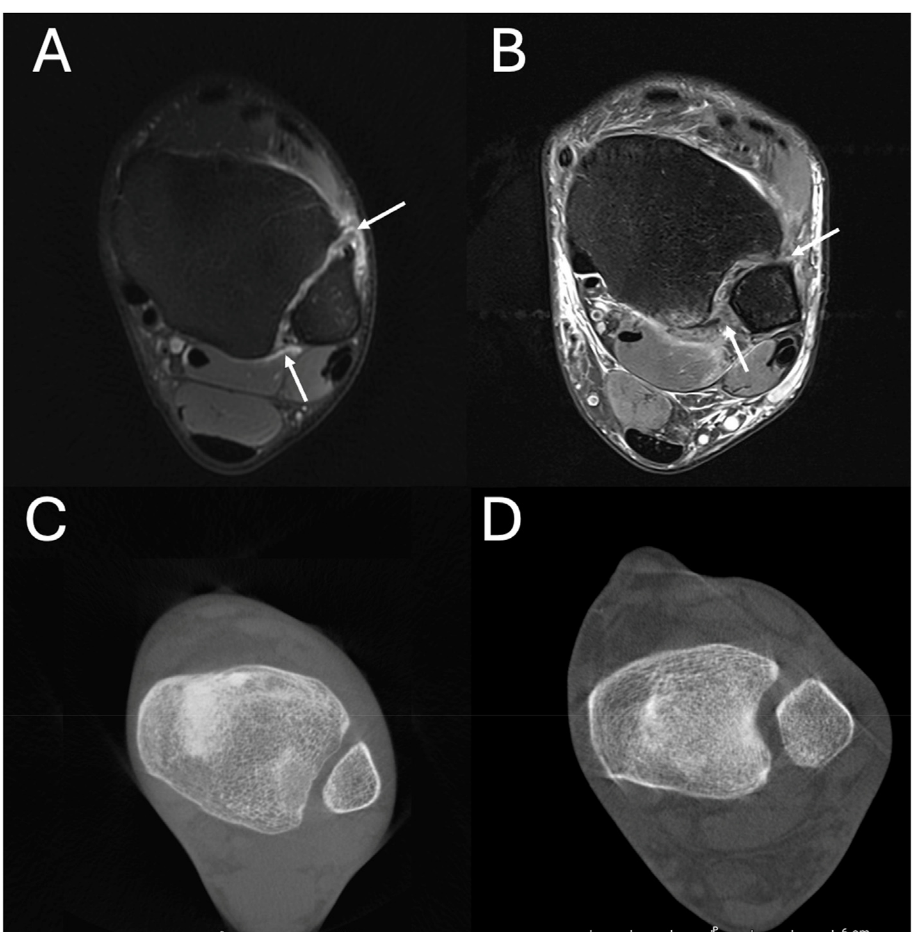

Fig. 2. Origin of the study rationale: two patients presented with both an anterior and posterior tibiofibular ligament injury (arrows; A, B). The first patient presented with a shallow '1' shape of the incisura fibularis (C) and the second patient demonstrated a deep 'C' shape of the incisura fibularis (D). Despite similar type of syndesmotic ankle ligament injuries (A, B), the patient with a shallow '1' shape (C) required a longer rehabilitation compared to the patient with a deep 'C' shape of the incisura fibularis (D).

Table 1
Quality evaluation tool developed by Hawker et al. [39].

	Items	Questions
1	Abstract and title	Was there a clear description of the research?
2	Introduction and objective	Was there a good background and a clear description of the purpose of the study?
3	Method and data	Is the method suitable and clearly explained?
4	Sampling method	Was the sampling method suitable to meet the purpose of study?
5	Data analysis	Was the description of the data analysis sufficiently detailed?
6	Ethics and bias	Were the ethical issues raised and were they approved provided that they were relevant? Is the relationship between researchers and participants described adequately?
7	Results	Is there a clear description of the results?
8	Generalization	Can the findings of this study generalize to a larger population?
9	Implications for practice	How important are these findings to the policy and the practice?

This table is used to evaluate the nine items and the associated questions. With each item/each question are four criteria with a corresponding score (1–4). This score is used to judge the methodological quality of the articles. The criteria and scores are not shown in this table.

selected source studies. The narrative synthesis explored the findings both within and between the studies, in line with the guidance from the Centre for Reviews and Dissemination [41].

Role of the IF in lateral ankle ligament injuries

A The study of Liu et al. [42] performed CT imaging of the ankle joint and prospectively looked at the incidence of LAS and recurrence of LAS (Table 2). Three groups of IF shapes were defined ("C"-shape, "1"-shape, and "Γ"-shape) based on the obtained measurements of the CT, which were compared to each other (Table 3). Of the 300 participants, 56% ($n = 168$) had a "C"-shape, 25% ($n = 76$) had a "1"-shape, and 19% ($n = 56$) had a "Γ"-shape. In the study, 27 participants suffered a recurrent LAS, of which seven had a "C"-shape, 13 had "1"-shape, and 3 had "Γ"-shape. The "1" shape of the IF was overrepresented and showed the highest risk of the three shapes in the incidence of LAS ($p < 0.05$). In addition, there were four participants with an ATFL injury with avulsed bone fragments in the "1"-shape group, and none were observed in the "C" or "Γ"-shapes [42]. Liu et al. [42] also looked at the range of movement (ROM) based on the IF shape. The "1"-shape had a statistically significant increase in lateral displacement along with ankle inversion or eversion of more than 20° ($p < 0.01$). The "1"-shape also had a statistically significant increase in lateral displacement along with ankle dorsiflexion of more than 20° ($p < 0.01$) [42].

Ataoglu et al. [11] compared the measurements of the IF between patients with and without instability. It was found that instability was

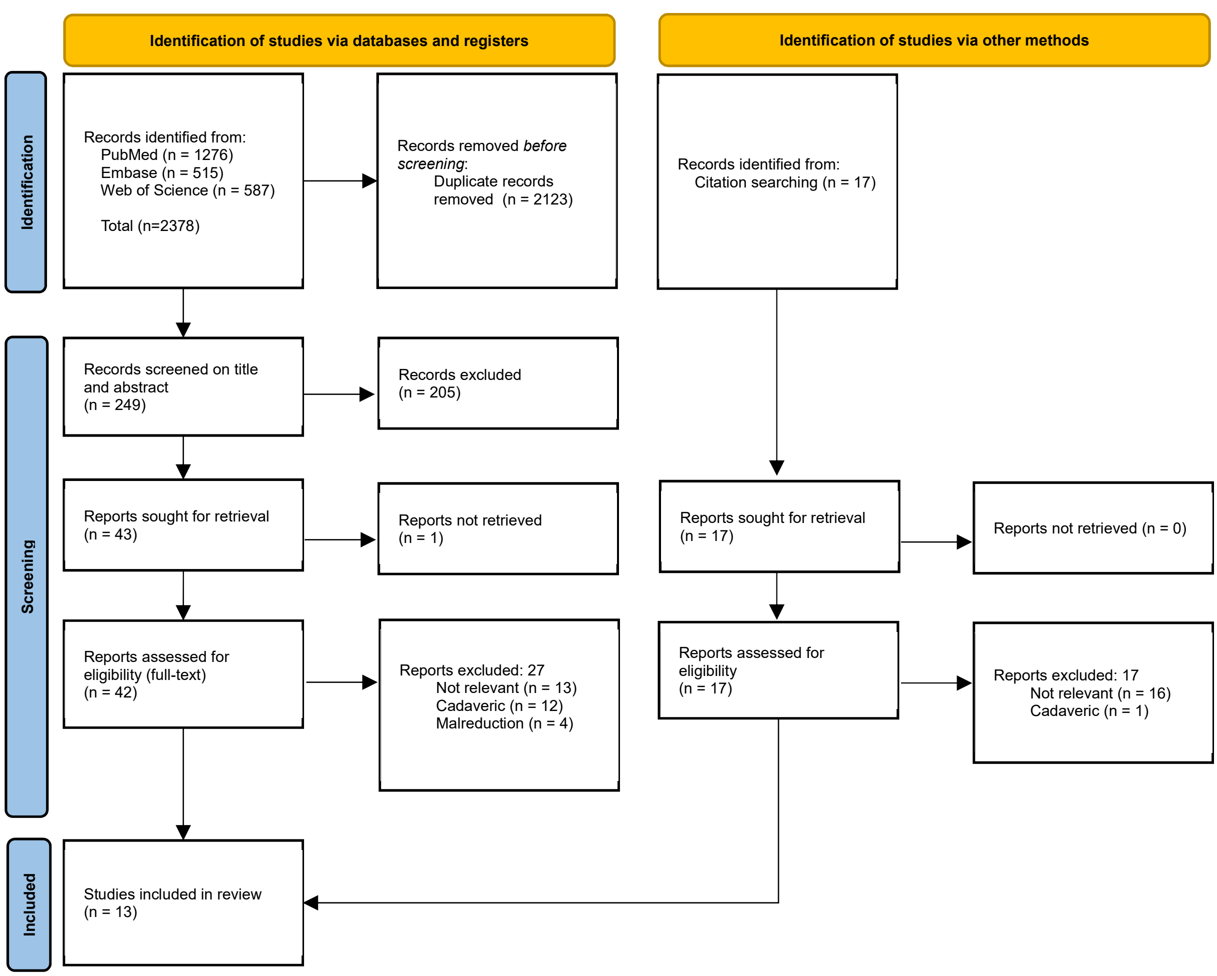

Fig. 3. Review stages based on PRISMA flow diagram. From Page et al. [40].

Table 2
Overview of the study characteristics included in the systematic review.

Number	Author	Year	Country	Sample size	Study population	Design	Method
1	Ataoglu et al.	2020	Turkey	100	Fifty patients with arthroscopically proven ankle instability + 50 without instability	Retrospective comparative	MRI section 1 cm proximal to the tibiotalar joint; distal tibiofibular joint anterior facet length (a), posterior facet length (b), angle between the anterior and posterior facets (c), fibular notch depth (d), tibia thickness (e), and fibula thickness (f) was measured.
2	Boszczyk et al.	2019	Poland	150	Seventy-five patients who sustained a high fibular fracture with syndesmosis disruption + 75 patients with unrelated foot problems	Retrospective comparative	The CT examinations of 75 patients with a high fibular fracture and a control group of 75 patients with unrelated foot problems were compared. The depth, fibular engagement, and rotational orientation of the tibial incisura were analyzed.
3	Chen et al.	2023	China	360	One hundred and eighty patients with high ankle sprains (HAS) were included in this study as the experimental group. Another 180 normal individuals were set as the control group	Retrospective comparative	The 180 patients with HAS were divided into four groups according to gender and incisura fibularis (IF) depth, with deep concave IF $\geq$4 mm and shallow/flat IF depth $<$4 mm. The IF morphological indicators, tibiofibular distance (TFD), and ankle mortise indices were measured and compared between the control group and the HAS group.
4	Ebraheim et al.	2003	USA	7	Seven patients with a type B Weber fibular fracture associated with deltoid ligament disruption and diastasis of the inferior tibiofibular joint	Observational	All the measurements were taken 1 cm above the tibial plafond. The first three measurements were taken on the mortise view and the other three were taken on the AP view.
5	Hagemeijer et al.	2019	USA	36	Twelve patients with unilateral syndesmotic instability + 24 without unilateral syndesmotic instability	Retrospective comparative	The patients and controls underwent preoperative bilateral ankle weightbearing CT. For each weightbearing CT, a series of seven axial plane tibiofibular joint measurements, including one angular measurement, were used to evaluate parameters of the syndesmotic anatomy at a level 1 cm above the tibial plafond.
6	Huysse et al.	2021	Belgium	40	Fifteen patients with an unstable high ankle sprain and 25 control subjects	Retrospective comparative	The obtained CT images were converted to 3D models, and the following radiographic parameters of the incisura fibularis were determined using 3D measurements: incisura width, incisura depth, incisura height, incisura angle, incisura width-depth ratio, and incisura-tibia ratio.
7	Kobayashi et al.	2014	Japan	17	Seventeen males with unilateral chronic ankle instability	Observational	Geometric bone models of the tibia and fibula were created from non–weight-bearing CT images, and anatomical coordinate systems were embedded in the tibia model. Bilateral tibiae were superimposed using a best-fit algorithm that moved the tibia to the position of best congruity, and the amount of side-to-side difference in position of the fibulae was measured.
8	Lee et al.	2015	South Korea	674	Two hundred seventy-four patients with lateral malleolar fracture and 400 patients with lateral ankle sprain	Retrospective comparative	Ankle radiographs were examined for seven measures: distal tibial articular surface angle, bimalleolar tilt, medial malleolar relative length, lateral malleolar relative length, medial malleolar slip angle, anterior inclination of tibia, and fibular position. Measurements were compared between the two groups.
9	Liu et al.	2017	China	300	Three hundred young physical training soldiers	Prospective cohort	All 300 young physical training soldiers, with normal ankles, underwent CT scans by a single medical imaging technician for measuring the shapes of the DTFS. Right/left ankle was selected at random. All participants were asked to attend the clinic to check immediately after ankle injury during a 3-year study period.
10	Mavi et al.	2002	Turkey	18	Eighteen patients with a control group of 75 volunteers without history of trauma of the ankle syndesmosis	Retrospective comparative	Eighteen limbs (nine right, nine left) were examined for the fibular incisura of the tibia by MRI. These

(*continued on next page*)

Table 2 (*continued*)

Number	Author	Year	Country	Sample size	Study population	Design	Method
							measurements were compared to a control group (n = 75)
11	Yaka et al.	2023	Turkey	142	Seventy-one patients with isolated ATFL rupture on MRI. Seventy-one patients without ankle instability, who underwent ankle MRI for other reasons and were evaluated as normal.	Retrospective comparative	Seventy-one patients with isolated ATFL rupture on MRI that presented due to lateral ankle instability were compared to 71 patients without ankle instability, who underwent ankle MRI for other reasons and were evaluated as normal. Measurements of the DTFJ were made 1 cm proximal to the tibiotalar joint
12	Yeung et al.	2015	Hong Kong	123	One hundred twenty-three patients who underwent CT preoperatively to open reduction and internal fixation for ankle fracture	Retrospective comparative	The morphology of incisura fibularis was categorized as deep or shallow. The TFD between the medial border of the fibula and the nearest point of the lateral border of tibia were measured at anterior (aTFD), middle (mTFD), posterior (pTFD), and maximal (maxTFD) portions across the syndesmosis on axial CT images at 10 mm proximal to the tibial plafond.
13	Yüce et al.	2024	Turkey	59	Fifty-nine patients with isolated lateral malleolar fracture, Mason-Malloy type 1 posterior malleolar fracture, syndesmosis injury in those without posterior malleolar fracture, supination external rotation type 3 injuries according to Lauge-Hansen classification, and preoperative bilateral ankle CT images	Retrospective comparative	Fifty-nine patients were divided into two groups: group 1 included individuals with Mason-Malloy type 1 posterior malleolar fractures ($n = 41$), and group 2 included those with only syndesmosis injury ($n = 18$). The fibula morphologies and syndesmosis measurements were assessed based on reoperative CT images.

AP = anterior-posterior; ATFL = anterior talofibular ligament; CT = computed tomography; DTFJ = distal tibiofibular joint; DTFS = distal tibiofibular syndesmosis; MRI = magnetic resonance imaging.

more frequent in: shorter anterior facet ($p < 0.001$) and thinner tibia width ($p < 0.001$), smaller anterior/posterior facet length ratio ($p < 0.016$), and tibia/fibula width ratio ($p < 0.020$; Fig. 4). Instability was not notably more frequent based on the posterior facet length ($p = 0.466$), IF depth (IFD; $p = 0.840$), fibula width ($p = 0.887$), or facetal angle ($p = 0.146$). Yaka et al. found that the anterior-posterior facet angle was lower in patients with an ATFL rupture compared with patients with an intact ATFL (respectively, 123.9° ± 10° [range 100.3° 0.138°], 95% CI: 121.58–126.22 vs 129.7° ± 7.8° [range 112°–141.4°], 95% CI: 127.89–131.51; $p = 0.014$). Yaka et al. [43] also found a higher fibular notch version in patients with ATFL rupture, indicating an more retroverted IF (respectively, 16.6° ± 4.85°, 95% CI: 14.79–18.42 vs 12.4° ± 5.04°, 95% CI: 10.88–14.40; $p = 0.002$). Kobayashi et al. [44] found that the fibula was statistically significantly more laterally positioned in an ankle with chronic ankle instability (CAI) compared with the contralateral healthy ankle. There was also a slight difference in external fibular rotation of 0.07° ± 2.61°. No statistically significant difference was observed in anteroposterior fibular position (FP) [44]. Lee et al. [45] observed statistically significant differences between the ankle with LAS and the contralateral healthy ankle. The distal tibial articular surface was more anterosuperiorly tilted ($p = 0.023$), and the fibula showed a more posterior location ($p < 0.001$) [45]. Mavi et al. [46] found, in women with recurrent ankle sprains, a deeper IF (4.0 mm ± 1.1 vs 2.9 mm ± 0.8; $p < 0.05$). This deeper IF was also noted in men, but no statistically significant difference was seen (4.2 mm ± 0.6 vs 3.6 mm ± 1.0) [46].

Role of the IF in syndesmotic ankle ligament injuries

Isolated syndesmotic ligament injuries

Ebraheim et al. [47] found a shallow IF, mean 2.7 mm (range 2.0–4.0 mm), in patients with a syndesmotic ankle sprain. Hagemeijer et al. [48] found that in patients with unilateral syndesmotic injuries, there was no difference between the injured ankle and the contralateral ankle in IFD (3.5 mm ± 1.0 vs 3.3 mm ± 1.3; $p = 0.63$), θ_{fib} (fibular rotation) (10.3° ± 5.5 vs 8.4° ± 7.0; $p = 0.12$), and fibular sagittal plane position (1.7 mm ± 1.1 vs 1.9 mm ± 1.1; $p = 0.36$). Huysse et al. [35] found statistically significant differences in IFD, IF height, and IF angle between patients with a syndesmotic sprain and a control group. The IF was more shallow in patients with a syndesmotic sprain (3.83 mm ± 1.07 vs 4.76 mm ± 1.09; $p = 0.015$). The IF height was shorter in patients with a syndesmotic sprain (31.99 mm ± 3.20 vs 36.10 ± 5.27; $p = 0.02$). The IF angle is more obtuse in patients with a syndesmotic sprain (143.15° ± 8.34 vs 137.21° ± 7.91; $p = 0.047$). No statistically significant differences were found for the IF width, IF width/depth ratio, and incisura width/tibia width ratio ($p > 0.05$) [35]. Chen et al. [49] looked at the severity and functional outcome of a syndesmotic ankle sprain. They found that in male patients with a syndesmotic sprain, IFD was negatively correlated with posterior tibiofibular distance (pTFD; −0.634, $p < 0.05$), middle tibiofibular distance (mTFD; −0.434, $p < 0.05$), and anterior tibiofibular distance (aTFD; −0.414, $p < 0.05$). This was also noted in women (aTFD −0.535, mTFD −0.481, and pTFD −0.724, all <0.05), indicating less severe syndesmotic sprains based on the CT measurements. They also found that patients with a shallow IF had statistically significantly lower American Orthopedic Foot and Ankle Society Score scores compared to patients with a deep concave type IF (respectively, in men: 91.21 ± 4.02 vs 93.30 ± 3.52; $p = 0.002$; in women: 90.44 ± 3.89 vs 92.70 ± 3.54; $p < 0.001$).

Fracture-associated syndesmotic ligament injuries

Boszczyk et al. [33] used CT imaging to compare the bony anatomy of the syndesmosis in patients with a high fibular fracture with syndesmosis disruption and a healthy control group. A statistically significant difference was found between the groups in IFD, fibular engagement, and the orientation angle of the incisura. The mean IFD was statistically significantly more shallow in the injury group compared with the control (3.3 mm ± 1.3 vs 4.0 mm ± 1.2; $p = 0.02$). The fibular engagement was statistically significantly lower in the injury compared with the control

Table 3
Overview of the study outcomes and key findings.

Number	Author	Year	Purpose	Key findings
1	Ataoglu et al.	2020	Radiologically investigate the relationship between bony variations of the distal tibiofibular joint and arthroscopically proven ankle instability.	• Instability was more frequent in: shorter a (anterior facet; $p < 0.001$) and thinner e (tibia thickness; $p < 0.001$), smaller a/b (anterior/posterior facet length; $p < 0.016$), and e/f ratio (tibia/fibula thickness; $p < 0.020$). • Negative correlation between the values of a, e, and instability ($r = -0.348$, $p < 0.001$, and $r = -0.328$, $p = 0.001$; respectively). • This study demonstrated that the presence of narrow anterior facet and thinner tibia were strongly correlated with lateral ankle instability. • There was no statistically significant difference in posterior facet length (b), angle between anterior and posterior facets (c), fibular notch depth (d) and fibula thickness (f).
2	Boszczyk et al.	2019	Compare the bony anatomy of the syndesmosis in patients who sustained a high fibular fracture with syndesmosis disruption and that of the noninjured population.	• Using the median values of the control group as cutoff, there were 71% shallow, 71% disengaged, and 77% retroverted syndesmoses in the injury group. • The incisura depth ranged 1.2–6.9 mm (mean 4.0, median 4.0 mm, SD 1.2 mm) for the control group (group A) and 0–6.3 mm (mean 3.3, median 3.3 mm, SD 1.3 mm) for the injured population (group B). Using the mean of group A (4.0 mm), there were 22 (29%) deep and 53 (71%) shallow syndesmoses in group B. A comparison between the groups showed statistically significant differences ($p = 0.002$). • The fibular engagement ranged from −2.0 to 3.8 mm (mean 0.7, median 0.7 mm, SD 1.2 mm) for group A and −3.9 to 2.7 mm (mean −0.6, median −0.8, standard deviation 1.7 mm) for group B. Using the mean of group A (0.7 mm), there were 22 (29%) engaged and 53 (71%) disengaged syndesmoses in group B. A comparison between the groups showed statistically significant differences ($p < 0.0001$). • The orientation angle of the incisura ranged from −1 to 25° (mean 8.2°, median 8.0°, standard deviation 4.1°) for group A and −2 to 27° (mean 11.3°, median 12.0°, standard deviation 4.6°) for group B. Using the mean of group A (8.2°), there were 58 (77%) retroverted and 17 (23%) anteverted incisurae in group B. A comparison between the groups showed statistically significant differences ($p < 0.0001$). • Patients with a shallow, disengaged, and retroverted bony configuration of the syndesmosis are overrepresented among patients with syndesmosis disruption.
3	Chen et al.	2023	Explore the impact of different types of fibular notch on the severity of HAS and to estimate the prognosis of patients with HAS while excluding anatomical differences caused by gender.	• The tibiofibular distance of HAS patients was statistically significantly larger than that of normal people • The IF depth was negatively correlated with tibiofibular distance, and the American Orthopaedic Foot and Ankle Score score of patients with shallow flat type was statistically significantly lower than that of patients with deep concave type after treatment ($p < 0.05$). • The results suggested that shallow IF may be related to more severe distal tibiofibular ligament injury and widening of ankle mortise, leading to poor prognosis. • In males with shallow flat type, the measurements of anterior tibiofibular distance (aTFD), middle tibiofibular distance (mTFD), posterior tibiofibular distance (pTFD), front ankle mortise width (fAMW), middle ankle mortise width (mAMW), posterior ankle mortise width (pAMW), and depth of ankle mortise (DOAM) in HAS group were statistically significantly larger than those in normal group ($p < 0.05$). • In female patients with shallow flat type, the measurements of aTFD, mTFD, pTFD, fAMW, mAMW, pAMW, and DOAM were found to be statistically significantly larger than those in normal group ($p < 0.05$)
4	Ebraheim et al.	2003	Report on patients with low fibular fractures associated with deltoid ligament injury and syndesmotic disruption.	• In all patients, the axial CT section showed that the syndesmosis was disrupted, and the incisura fibularis was shallow. • The average depth of the incisura fibularis in this study was 2.7 mm (range 2–4 mm). • Difficult to detect the syndesmosis disruption on the initial assessment of the AP and mortise radiographs obtained preoperatively. However, the syndesmotic disruption was easily recognizable on the axial CT scan. • A tear of the interosseous membrane might have contributed to the instability of the syndesmosis.
5	Hagemeijer et al.	2019	Evaluate both distal tibiofibular articulations using weightbearing CT scan in patients with known syndesmotic instability, thereafter, comparing findings between the injured and uninjured sides. Additionally define the range of normal measurement variation among patients without syndesmotic injury.	• Among those with unilateral syndesmotic instability, values differed between the injured and uninjured sides of the patients in four of the seven measurements performed including the syndesmotic area (mean ± SD; uninjured 118.7 ± 37.7 vs injured 164.8 ± 46.8; $p < 0.001$), direct anterior (mean ± SD; uninjured 6.0 ± 2.1 vs injured 8.4 ± 2.4; $p < 0.001$), middle (mean ± SD; uninjured 4.6 ± 1.4 vs injured 6.0 ± 1.4; $p < 0.001$), and posterior differences (mean ± SD; uninjured 9.14 ± 2.1 vs injured 11.6 ± 3.0; $p < 0.001$). • Fibular rotation (mean ± SD; uninjured 10.3 ± 5.5 vs injured 8.4 ± 7.0; $p = 0.12$), fibular sagittal plane position (mean ± SD; uninjured 1.7 ± 1.1 vs injured 1.9 ± 1.1; $p = 0.36$) and incisura depth (mean ± SD; uninjured 3.5 ± 1.0 vs injured 3.3 ± 1.3; $p = 0.63$) were not statistically significantly different between the two ankles.

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Table 3 (*continued*)

Number	Author	Year	Purpose	Key findings
				• In the control population without ankle injury, no differences were identified between any of the bilateral measurements (*p* value range, 0.172–0.961).
6	Huysse et al.	2021	Compare the morphometry of the incisura fibularis between patients with HAS and a control group using three-dimensional radiographic techniques.	• The mean incisura depth (M = 4.76 mm, SD = 1.09 mm), incisura height (M = 36.10 mm, SD = 5.27 mm), and incisura angle of the control group (M = 137.21°, SD = 7.91°) differed statistically significantly from patients with a HAS (resp., M = 3.83 mm, SD = 1.07 mm, $p = 0.015$; M = 31.99 mm, SD = 3.20 mm, $p = 0.02$; M = 143.15°, SD = 8.34°, $p = 0.047$). • The incisura width (mean ± SD; 25.1 ± 2.7 mm), incisura width-depth ratio (5.5 ± 1), and incisura-tibia ratio (0.6 ± 0.1) of the control group demonstrated no statistically significant difference compared to the incisura width (23.7 ± 2.1 mm; $p = 0.11$), incisura width-depth ratio (6.7 ± 2.1; $p = 0.07$), and incisura-tibia ratio (0.6 ± 0.2; $p = 0.27$) of the patients with HAS. • A shallower and shorter fibular incisura was detected in patients with HAS. This distinct morphology could have repercussion on the intrinsic or osseous stability of the DTFJ.
7	Kobayashi et al.	2014	Determine whether abnormal fibular alignment is present in individuals with chronic ankle instability (CAI) using 3D analysis of CT-based bone models.	• The fibula of the ankles with CAI was statistically significantly more laterally positioned than that of the healthy ankles at all three reference points: the mean (95% CI) at the most prominent point of the lateral malleolus, 5 cm proximal to the lateral malleolus, and 10 cm proximal to the lateral malleolus was 0.60 mm (0.04, 1.16), 0.57 mm (0.15, 0.98), and 0.68 mm (0.09, 1.27), respectively. • There was no statistically significant difference in anteroposterior position between the healthy ankles and those with CAI.
8	Lee et al.	2015	Compare the radiographic indices representing anatomical structures of the ankle between a lateral malleolar fracture and a lateral ankle sprain in terms of bony constraints.	• Bimalleolar tilt showed more varus orientation (104.7° ± 3.3 vs 103.8° ± 2.9; $p = 0.001$) and medial malleolar slip angle (112.8° ± 7.4 vs 110.6° ± 7.2; $p < 0.001$) showed a greater obtuse angle of the medial malleolar articular surface in the fracture group compared to the sprain group. • AI showed more anterosuperiorly tilted distal tibial articular surface (82.0° ± 3.1 vs 81.0° ± 3.1; $p = 0.023$), and fibular position showed more a posteriorly located fibula in the sprain group compared with the fracture group (0.64 ± 0.088 vs 0.58 ± 0.098; $p < 0.001$). • Fibular position showed the highest discriminant validity between the fracture and sprain groups. • Distal tibial articular surface angle, medial malleolar relative length, and lateral malleolar relative length showed no statistically significant difference
9	Liu et al.	2017	Investigate associations between shape of the distal tibiofibular syndesmosis and risk of recurrent lateral ankle sprains.	• The shapes of the distal tibiofibular syndesmosis were organized into three distinct types based on the morphology of incisura fibularis: "C" shape (56%), "1" shape (25%), and "Γ" shape (19%). • Thirty-nine participants suffered ankle sprain, and 23 cases experienced recurrent lateral ankle sprains. Of the 23 recurrent lateral ankle sprains, seven participants of the incisura fibularis were the "C" shape, 13 participants were the "1" shape, and three participants were the "Γ" shape. • The "1" shape of the incisura fibularis showed highest risk in the three shapes in incident recurrent lateral ankle sprains ($p < 0.05$). • When the ROM of ankle plantar flexion was regularly increased, the displacement of each shape type in the x and y axes was gradually increased, but the displacement in the z axis showed no statistically significant change. The "1" shape showed the widest range of displacement but was not statistically significantly different from the "C" and "Γ" shapes ($0.05 < p < 0.1$). • When the ROM of ankle dorsiflexion was regularly increased, the displacement of each shape type in the x and y axes was gradually increased, but the displacement in the z axis showed no statistically significant change. The "1" shape exhibited statistically significantly increased displacement in the y axis, during ankle dorsiflexion was 20°, compared with the "C" and "Γ" shapes ($p < 0.01$). • When the ROM of ankle inversion was regularly increased, the displacement of each shape type in the x, y and z axes was gradually increased. Comparing with the "C" and "Γ" shapes, the "1" shape had a statistically significantly increased displacement in the y axis, along with the range of motion (ROM) of ankle inversion on the position more than 20° ($p < 0.01$). • When the ROM of the ankle eversion was regularly increased, the displacement of each shape type in the y and z axes was gradually increased, but the displacement in the x axis was gradually decreased. Comparing with the "C" and "Γ" shapes, the "1" shape had a statistically significantly increased displacement in the y axis, when the ankle eversion was 20° ($p < 0.01$). • There were four participants with ATFL injury with avulsed bone fragments in the '1' shape group, none in the 'C' or 'Γ' group. A widening of the ankle mortise with ankle motion was seen in the '1' shape group, and people with this shape may have more risk of recurrent lateral ankle sprains and ATFL injury with avulsed bone fragments.

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Table 3 (*continued*)

Number	Author	Year	Purpose	Key findings
10	Mavi et al.	2002	Investigate the relationship of the distal tibia and fibula in the area of the syndesmosis of adult patients who had recurrent ankle sprains (type I and II) on magnetic resonance image.	• The measurements of the length of the anterior and posterior facets, depth of the fibular incisura of the tibia, and the distance between anterior margin of the tibia and anterior margin of the fibula in the patient group were visibly different from the measurements of the control group. • The following was observed in the group of recurrent ankle sprains compared to the control group: longer anterior (11.4 mm ± 1.3 vs 10.4 mm ± 1.4; $p < 0.05$) and posterior tubercles (11.5 mm ± 1.3 vs 10.4 mm ± 1.4; $p < 0.05$) and a more anteriorly positioned fibula (11.8 mm ± 1.4 vs 14.3 mm ± 3.5; $p < 0.05$) in men and a deeper fibular incisura (4.0 mm ± 1.1 vs 2.9 mm ± 0.8; $p < 0.05$) in women compared with the control group. • In recurrent sprained ankles, the depth of incisura fibularis was deeper than the control group. • In the patients group, 90% of men and 50% of women showed a deep (>4 mm) fibular incisura. In the control group, 54.6% of men and 29.6% of women showed a deep fibular incisura.
11	Yaka et al.	2023	Describe the fibular notch version (FNV) and evaluate the relationship between ATFL rupture and FNV, anterior facet length (AFL), posterior facet length (PFL), anterior-posterior facet angle, and notch depth (ND).	• When both groups of patients were compared, the anterior-posterior facet angle (APFA) value of patients with ATFL rupture was statistically significantly lower than those with intact ($p = 0.014$). The mean APFA value of patients with ruptured ATFL was 123.9° ± 10° (range 100.3°–0.138°) (95% CI: 121.58–126.22), while the mean APFA value of patients with intact ATFL was 129.7° ± 7.8° (range 112°–141.4°) (95% CI: 127.89–131.51). • The FNV value of patients with ruptured ATFL was statistically significantly higher than those who were healthy ($p = 0.002$, power: 0.99, effect size: 0.79). The mean FNV value of patients with ruptured ATFL was 16.6° ± 4.85° (10.7°–25.5°; 95% CI: 14.79–18.42), while the mean FNV value of patients with intact ATFL was 12.4° ± 5.04° (0.7°–19.0°; 95% CI: 10.88–14.40). • There was no statistically significant difference between the two groups in terms of AFL ($p = 0.31$, for ruptured ATFL 95% CI:8.9–9.7, for intact ATFL 95% CI: 8.88–9.92), PFL ($p = 0.289$, for ruptured ATFL 95% CI:13.08–14.12, for intact ATFL 95% CI: 13.67–14.93), and ND ($p = 0.105$, for ruptured ATFL 95% CI: 4.37–4.87, for intact ATFL 95% CI: 3.99–4.55).
12	Yeung et al.	2015	Explore the diagnostic accuracy of CT measurements in predicting syndesmosis instability of injured ankle, with correlation to operative findings.	• Of the 123 patients, 39 (31.7%) were operatively diagnosed with syndesmosis instability. • The axial CT measurements were statistically significantly higher in ankles diagnosed with syndesmosis instability than the group without (maxTFD mean 7.2 ± 2.96 mm vs. 4.6 ± 1.4 mm, aTFD mean 4.9 ± 3.7 mm vs. 1.8 ± 1.4 mm, mTFD mean 5.3 ± 2.4 mm vs. 3.2 ± 1.6 mm, pTFD mean 5.3 ± 1.8 mm vs. 4.1 ± 1.3 mm, $p < 0.05$). • Their respective cutoff values with best sensitivity and specificity were calculated; the aTFD (AUC 0.798) and maxTFD (AUC 0.794) achieved the highest diagnostic accuracy. The optimal cutoff levels were aTFD = 4 mm (sensitivity, 56.4%; specificity, 91.7%) and maxTFD = 5.65 mm (sensitivity, 74.4%; specificity, 79.8%).
13	Yüce et al.	2024	Examine the relationship between incisura morphology and posterior malleolar avulsion injury.	• There was a statistically significant difference between the groups in terms of PFL (group 1 12.30 ± 1.60 vs group 2 13.63 ± 1.70, $p = 0.005$) and incisura width (group 1 23.96 ± 2.81 vs group 2 22.40 ± 2.51, $p = 0.051$). • There were no statistically significant differences in the distribution of gender, fracture side, incisura type, fibula type, and incisura version between the groups. • The groups did not statistically significantly differ in terms of incisura depth, AFL, interfacet angle and age values.

AP = anterior-posterior; ATFL = anterior talofibular ligament; CI = confidence interval; CT = computed tomography; DTFJ = distal tibiofibular joint; DTFS = distal tibiofibular syndesmosis; HAS = high ankle sprains; IF = incisura fibularis; MRI = magnetic resonance imaging; SD = standard deviation.

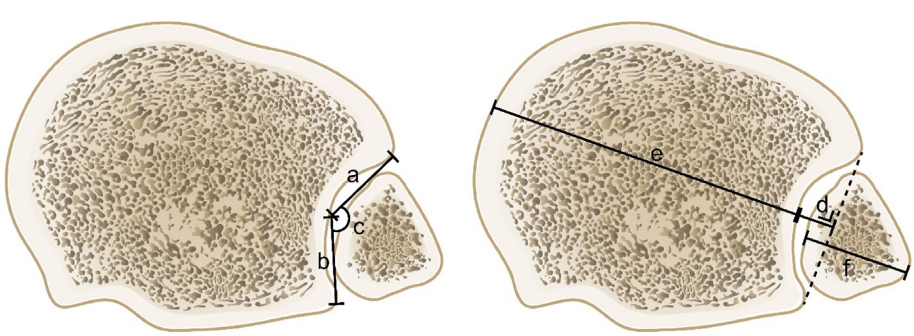

Fig. 4. Measurements of the incisura fibularis (schematic): (A) length of anterior facet; (B) length of posterior facet; (C) angle between the anterior and posterior facet; (D) incisura fibularis depth; (E) tibia width; (F) fibula width.

(-0.6 mm $\pm$ 1.7 vs 0.7 mm $\pm$ 1.2; $p < 0.001$). The orientation angle of the incisura was statistically significantly more obtuse than the control ($11.3° \pm 4.6$ vs $8.2° \pm 4.1$; $p < 0.001$). An overrepresentation of shallow, retroverted, and disengaged IF types was found in patients with a fracture-associated syndesmotic sprain [33].

Yüce et al. [50] found a statistically significant difference between a group of patients with an associated posterior malleolar avulsion fracture (group 1) and a group of patients with an isolated syndesmotic ankle sprain (group 2). In terms of posterior facet length, a shorter posterior facet was noted in the fracture-associated group (group 1 12.30 $\pm$ 1.60 vs group 2 13.63 $\pm$ 1.70, $p = 0.005$). In terms of incisura width, a broader IF was seen in the fracture-associated group (group 1 23.96 $\pm$ 2.81 vs group 2 22.40 $\pm$ 2.51, $p = 0.051$).

Lee et al. [45] showed statistically significant differences in the radiographic indices of bimalleolar tilt (BT; $p = 0.001$), medial malleolar slip angle (MMSA; $p < 0.001$), anterior inclination of tibia (AI; $p = 0.023$), and FP ($p < 0.001$) between the lateral malleolar fracture and LAS groups. FP showed the highest discriminant validity between the fracture and sprain groups. Multiple regression analysis showed that BT, medial malleolar relative length, MMSA, and FP were statistically significantly affected by the group difference after adjusting for the effects of age and sex. On the contrary, the effect of group difference on AI was not statistically significant after adjusting for the age and sex effects [45].

Quality appraisal

The mean Hawker score of the included studies was 28.8 out of 36 (range = 24–31; Table 4).

DISCUSSION

The principal finding of this systematic review demonstrated an association between ligamentous ankle injuries and variation of the IF morphology in the majority of the identified reports. This might suggest that the bony anatomy of the IF could contribute to the stability of the ankle in conjunction with ligaments, tendons, and muscles. However, the identified studies presented a heterogeneous methodological quality and not all studies were unanimous on the association between IF morphology and ligament injuries in the ankle joints.

Role of the IF in lateral ankle ligament injuries

Regarding lateral ankle ligament lesions, Liu et al. [42] found that a shallow IF, with a “1”-shape morphology, showed the highest risk of LAS compared with a more deep “C”-shape or “Γ”-shape (Fig. 5). Liu et al. [42] also found avulsion fractures in the shallow “1”-shape in patients with a LAS, while these were absent in the other IF morphologies. These avulsion fractures are clinically important as they increase the risk of CAI [51]. The increase in LAS in a “1”- shape was explained by Liu et al. [42] using ROM measurements categorized by IF morphology. A shallow IF causes a widening of the ankle mortise and more lateral displacement of the fibula with ankle inversion, eversion, or dorsiflexion, resulting in higher forces on the ligaments, most notably the ATFL [42]. This widening of the ankle mortise is further supported by Kobayashi et al. [44] who found that the fibula was more laterally positioned and externally rotated in a shallow IF.

Lee et al. [45] also observed a more posteriorly positioned fibula in LAS. They hypothesized that a more posteriorly positioned fibula allows for a wider anterolateral space of the ankle joint, which provides space for the talus to subluxate anterolaterally during an ankle sprain [45]. Inversely, a more anteriorly positioned fibula narrows this space, resulting in a transfer of force from the subluxed talus to the distal part of the fibula, possibly causing an associated fracture [45]. The study of Ataoglu et al. [11] observed that a shorter anterior facet length, a smaller anterior/posterior facet ratio and a thinner tibia correlated with more instability in patients with LASs (Fig. 5). A possible explanation for this increase in instability is that the anterior facet plays an important role in the bony congruence counteracting anterior displacement of the fibula [11]. The decrease of bony stabilization and the thinner fibula result in a higher possibility of anterior displacement of the fibula and a tendency of the ankle to remain inverted [11]. This could cause a higher load and forces being put on the ligaments and increasing the risk of injury to the ATFL [11]. This hypothesis is supported by the fact that Mavi et al. [46] found a more anteriorly positioned fibula in patients with recurrent ankle sprains. A notable finding in the study by Ataoglu et al. [11] is that, although patients with LAS instability had a thinner tibia, there was no evidence of a reduced IFD or an increase in the angle between the anterior and posterior facet, which would typically indicate a more shallow IF. The studies of Ataoglu et al. [11] and Mavi et al. [46] could not find convincing evidence regarding the involvement of IFD in LAS. However, as aforementioned, they did find several other morphological differences in the IF for patients with LAS.

Role of the IF in syndesmotic ankle ligament injuries

Regarding isolated syndesmotic ligament injuries, in syndesmotic sprains without associated fracture, Huysse et al. [35] and Ebraheim et al. [47] found a more shallow IF. When looking at a potential explanation for the increase in syndesmotic ankle sprains in patients with a shallow IF, Taşer et al. [52] proposed that as the IF becomes more shallow, the angle between the anterior and posterior facet becomes more obtuse. This results in a decrease of the vertical tibiofibular overlap and consequently less stability [52]. Furthermore, Huysse et al. [35] measured morphology factors of the IF itself, which might accentuate the above theory of Taşer et al. [52]. A shorter IF height and more obtuse angle between the facets were seen in patients with syndesmotic ankle sprains compared to a control group, further decreasing the vertical tibiofibular overlap [35]. Conversely, Hagemeijer et al. [48] compared the injured ankle to the uninjured contralateral ankle and did not find any difference in IFD. However, a trend could be observed that the

Table 4
Quality assessment of the selected articles.

Criteria	Ataoglu et al.	Boszczyk et al.	Chen et al.	Ebraheim et al.	Hagemeijer et al.	Huysse et al.	Lee et al.	Liu et al.	Mavi et al.	Yaka et al.	Yeung et al.	Yüce et al.	Kobayashi et al.
Abstract and title	4	4	4	2	3	3	3	3	3	4	4	4	3
Introduction and purpose	3	3	3	3	3	4	3	3	3	3	3	3	3
Method and data	4	3	3	2	3	3	4	3	3	3	3	3	3
Sampling method	3	3	3	3	3	3	4	3	3	3	3	3	3
Data analysis	4	4	4	2	3	4	3	3	3	3	3	3	3
Ethics and bias	2	3	3	3	3	4	4	4	3	3	3	3	3
Results	3	3	3	3	3	4	3	4	3	4	4	4	3
Generalization	3	4	4	3	3	3	3	3	3	3	3	3	3
Implications for practice	3	3	3	3	3	3	3	4	3	4	4	4	3
Total	**29**	**30**	**30**	**24**	**27**	**31**	**30**	**30**	**27**	**30**	**30**	**30**	**27**
Quality level	**Medium**	**High**	**High**	**Medium**	**Medium**	**High**	**High**	**High**	**Medium**	**High**	**High**	**High**	**Medium**

Quality level: high: 30–36, medium: 24–29, low: <24.

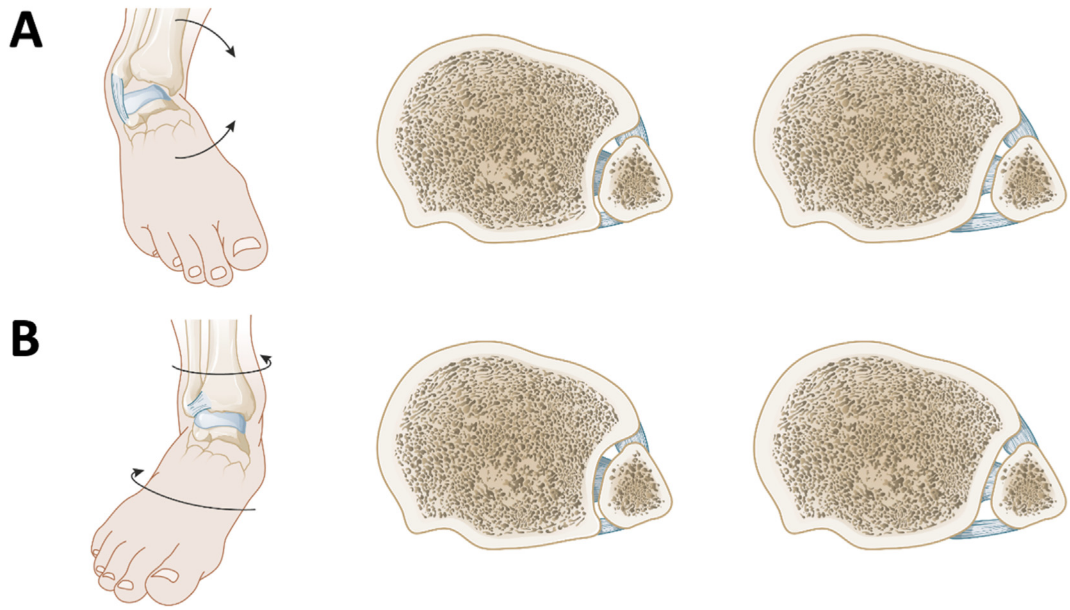

Fig. 5. Difference between a deep (middle) and shallow (right) morphology of the incisura fibularis in the ankle syndesmosis. (A) Patient with a lateral ankle sprain; (B) patient with a syndesmotic ankle sprain.

obtained IFD of both ankles in patients with a syndesmotic sprain were shallow when compared to different studies, indicating a possible association between IFD and syndesmotic ankle sprains [48].

Regarding fracture-associated syndesmotic ankle lesions, Boszczyk et al. [33] and Ebraheim et al. [47] found a more shallow IF and in patients with fracture-associated syndesmotic ankle lesions. Boszczyk et al. [33] additionally found that the IF itself was more retroverted. The exact role of this retroversion of the IF in syndesmotic ankle sprains is still unknown as this was the only study measuring this parameter. It could be hypothesized that the retroversion of the IF itself impacts the position of the fibula, causing it to be more posteriorly located, resulting in more stress on the ligaments stabilizing the ankle joint [33]. On the contrary, Yeung et al. [53] did not find distinct IF morphology in patient with stable versus unstable fracture-associated syndesmotic lesions. However, the majority of patients with unstable fracture-associated syndesmotic lesions presented a more shallow IF.

Limitations

This study encountered several limitations. First, in common with other systematic reviews, some papers may not have been identified with the search criteria which we used. This could be attributed to the initial search terms or exclusion of papers not written in English. However, additional screening of the references was performed to improve this process. Second, only a relatively small number and heterogenous group of studies was found to be eligible for this systematic review. There were considerable variations in the reported radiographic and morphological outcomes, which were reported. This did not allow us to perform a meta-analysis or overall effect size analysis. Finally, a control group is paramount to obtain optimal statistical evidence with further analysis of the data and counteract the influence of confounding factors. Ideally, the control group is matched as best as possible, consists of a sufficient size, and excludes any pathology, in particular of the ankle or foot [54–57]. In practice, the control group is often limited and consists of patients receiving a CT scan for other ankle or foot pathology, which is presumed to have minimal effect on the researched pathology [53,58–62].

Clinical implication

A potential clinical implication could concern a sport patient population in which IF morphology could be determined to identify those athletes that potentially have less bony resistance against lateral or syndesmotic ankle sprains. These athletes might benefit from additional preventive proprioception exercises of the ankle joint. It could also be of interest to determine whether a more shallow IF predisposes these population to recurrence of ankle sprains.

Research implication

Prospective long-term comparative studies are indicated to further investigate the involvement of the IF in ankle ligament injuries as well as differentiation between unstable or stable injuries, e.g., in case of ankle syndesmotic injury, to determine whether or not a shallow IF increases the need for surgical stabilization. These studies should also contain a fixed set of standardized measurements that determine the IF morphology and include a matched control group.

CONCLUSION

The majority of the identified studies found a distinct morphology of the IF in association with ligamentous ankle injuries. This review suggests that a more shallow IF was the main morphological parameter that could be more frequently identified in patients with lateral ligament injuries and isolated and fracture-associated syndesmotic ankle ligament injuries compared with control populations. This might be attributed to a diminished bony congruence and disengagement of the fibula, resulting in an increased strain on the ligaments stabilizing the ankle joint. However, it should be taken into account that a substantial number of studies presented a heterogeneous methodological quality, and not all studies were unanimous on the association between IF morphology and ligament injuries in the ankle joints. Therefore, further research is still required to strengthen these findings and assess the potential implementation in the assessment of patients with complex ligamentous ankle injuries.

CRediT authorship contribution statement

Louise Wittouck: Formal analysis. **Ruben Vermeir:** Formal analysis. **Matthias Peiffer:** Conceptualization. **Wouter Huysse:** Conceptualization. **Lauren Pringels:** Conceptualization. **Nicolò Martinelli:** Conceptualization. **Emmanuel Audenaert:** Conceptualization. **Arne Burssens:** Formal analysis, Conceptualization.

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Declaration of competing interest

The authors declare that they have no conflict of interest related to this study.

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