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SCIENTIFIC ARTICLE

Imaging in syndesmotic injury: a systematic literature review

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Abstract
Objectives To give a systematic overview of current diagnostic imaging options for assessment of the distal tibio-fibular syndesmosis.
Materials and methods A systematic literature search across the following sources was performed: PubMed, ScienceDirect, Google Scholar, and SpringerLink. Forty-two articles were included and subdivided into three groups: group one consists of studies using conventional radiographs (22 articles), group two includes studies using computed tomography (CT) scans (15 articles), and group three comprises studies using magnet resonance imaging (MRI, 9 articles).The following data were extracted: imaging modality, measurement method, number of participants and ankles included, average age of participants, sensitivity, specificity, and accuracy of the measurement technique. The Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) tool was used to assess the methodological quality.
Results The three most common techniques used for assessment of the syndesmosis in conventional radiographs are the tibio-fibular clear space (TFCS), the tibio-fibular overlap (TFO), and the medial clear space (MCS). Regarding CT scans, the tibio-fibular width (axial images) was most commonly used. Most of the MRI studies used direct assessment of syndesmotic integrity. Overall, the included studies show low probability of bias and are applicable in daily practice.
Conclusions Conventional radiographs cannot predict syndesmotic injuries reliably. CT scans outperform plain radiographs in detecting syndesmotic mal-reduction. Additionally, the syndesmotic interval can be assessed in greater detail by CT. MRI measurements achieve a sensitivity and specificity of nearly 100%; however, correlating MRI findings with patients' complaints is difficult, and utility with subtle syndesmotic instability needs further investigation. Overall, the methodological quality of these studies was satisfactory.

Keywords Syndesmotic injury · Imaging · Conventional radiographs · CT · MRI

Introduction

Syndesmotic injuries of the ankle are common and often present with nonspecific clinical and radiographic findings [1–4].

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Approximately up to 18% of all ankle sprains and up to 23% of all ankle fractures show an additional injury of the distal tibio-fibular syndesmosis [3, 5–7]. Undiagnosed injuries of the syndesmosis may lead to chronic instability of the ankle joint and degenerative changes over time [4, 5, 8–14]. Injury can occur to any of the four ligaments that comprise the syndesmosis: the anterior inferior tibio-fibular ligament (AITFL), the interosseous membrane (IOM), the posterior inferior tibio-fibular ligament (PITFL), and the transverse tibio-fibular ligament (TTFL) [5, 15–21]. Additionally, the deltoid ligament stabilizes the distal syndesmosis [8]. The deltoid ligament, which consists of four superficial and two deep components, anchors the tibia medially and restrains a lateral shift of the talus in the ankle joint [22–26]. Deltoid injuries are commonly seen in patients with acute syndesmotic injury [9, 27–30].

Conventional (weight-bearing) radiographs (antero-posterior and mortise view), computed tomography

Table 1 Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool

Domain	Patient selection	Index test	Reference standard	Flow and timing
Bias (yes, no, unclear)	Was a consecutive or random sample of patients enrolled? Was a case-control design avoided? Did the study avoid inappropriate exclusions?	Were the index test results interpreted without knowledge of the results of the reference standard? If a threshold was used, was it prespecified?	Is the reference standard likely to correctly classify the target condition? Were the reference standard results interpreted without knowledge of the results of the index test?	Was there an appropriate interval between index test and reference standard? Did all patients receive a reference standard? Did all patients receive the same reference standard? Were all patients included in the analyses?
Applicability (yes, no, unclear)	Are there concerns that the included patients do not match the review questions?	Are there concerns that the index test, its conducts, or its interpretation differ from the review question?	Are there concerns that the target condition as defined by the reference standard does not match the review question?	–

(CT) scans and/or magnetic resonance imaging (MRI) are widely used for assessment of the distal tibio-fibular syndesmosis [9]. Due to the insufficient accuracy of conventional radiographs for detecting syndesmotic injuries, CT scans and MRI have gained popularity over the last few years [31]. However, there is heterogeneous evidence regarding the accuracy of the various measurement techniques, especially in chronic syndesmotic injuries. The objective of this article is to give a systematic overview of the current imaging options for assessment of the distal tibio-fibular syndesmosis.

Materials and methods

Search strategy

Four major medical databases were searched from inception through July 10, 2017: PubMed, ScienceDirect, Google Scholar, and SpringerLink. The bibliographies of articles of interest were additionally reviewed. There were no limitations on type of journal or publication date of the article. Articles in English, German, French and Russian were included. Following keywords were used: syndesmosis/-otic AND

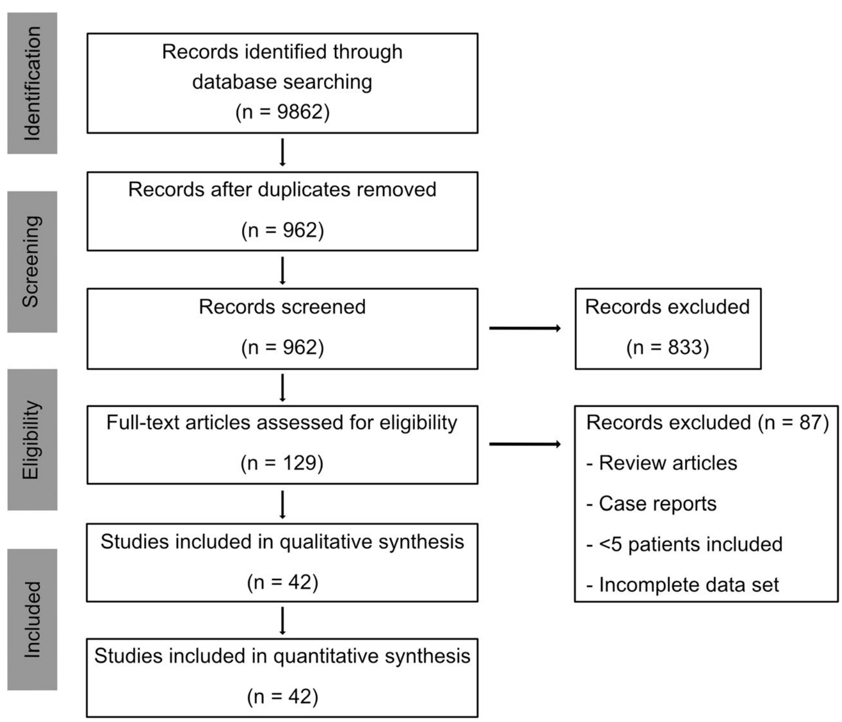

Fig. 1 Flow chart depicting the strategy used to select relevant studies. The literature search was done according to the guidelines of preferred reporting items for systematic reviews and meta-analysis (PRISMA)

instability, syndesmosis/-otic AND injury, syndesmosis/-otic AND imaging, syndesmosis/-otic AND augmentation. The systematic literature search was performed by three reviewers (N.K., M.W.W., and A.B.).

Data extraction

The following data were extracted from each study: Imaging modality, measurement method, number of participants and ankles included, average age of participants, sensitivity (if mentioned), specificity (if mentioned), and accuracy of the technique (if mentioned). If a study used multiple radiographic modalities (i.e. MRI and CT scans), data for each cohort were extracted separately. For studies with multiple readers for each imaging examination, the data were averaged. Data extraction was performed by three reviewers (N.K., M.W.W., and A.B.).

Study selection

Studies were included if they were original research studies (incl. cadaver studies) that assessed the distal tibio-fibular syndesmosis using conventional radiographs/ fluoroscopy, CT scans, or MRI. Exclusion criteria consisted of studies that used incomplete data (i.e. intraoperative assessment without preoperative evaluation), studies that were published as either case reports or review articles, finite-element modeling studies, studies including less than five participants and studies written in another language than English, German, French, or Russian. Furthermore, studies that did not have their full text available on the aforementioned sources were excluded. The study selection process was conducted independently by three reviewers (N.K., M.W.W., and A.B.). The decision to include or exclude the study was made based on a group consensus agreement. Disagreements were discussed and a group consensus was reached.

Study quality assessment

The Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) tool was used to assess the methodological quality (Table 1) [32]. Studies which solely characterize the distal tibio-fibular syndesmosis in healthy ankles were excluded from assessment. In total, 16 studies underwent quality assessment: seven studies using X-rays or fluoroscopy, three

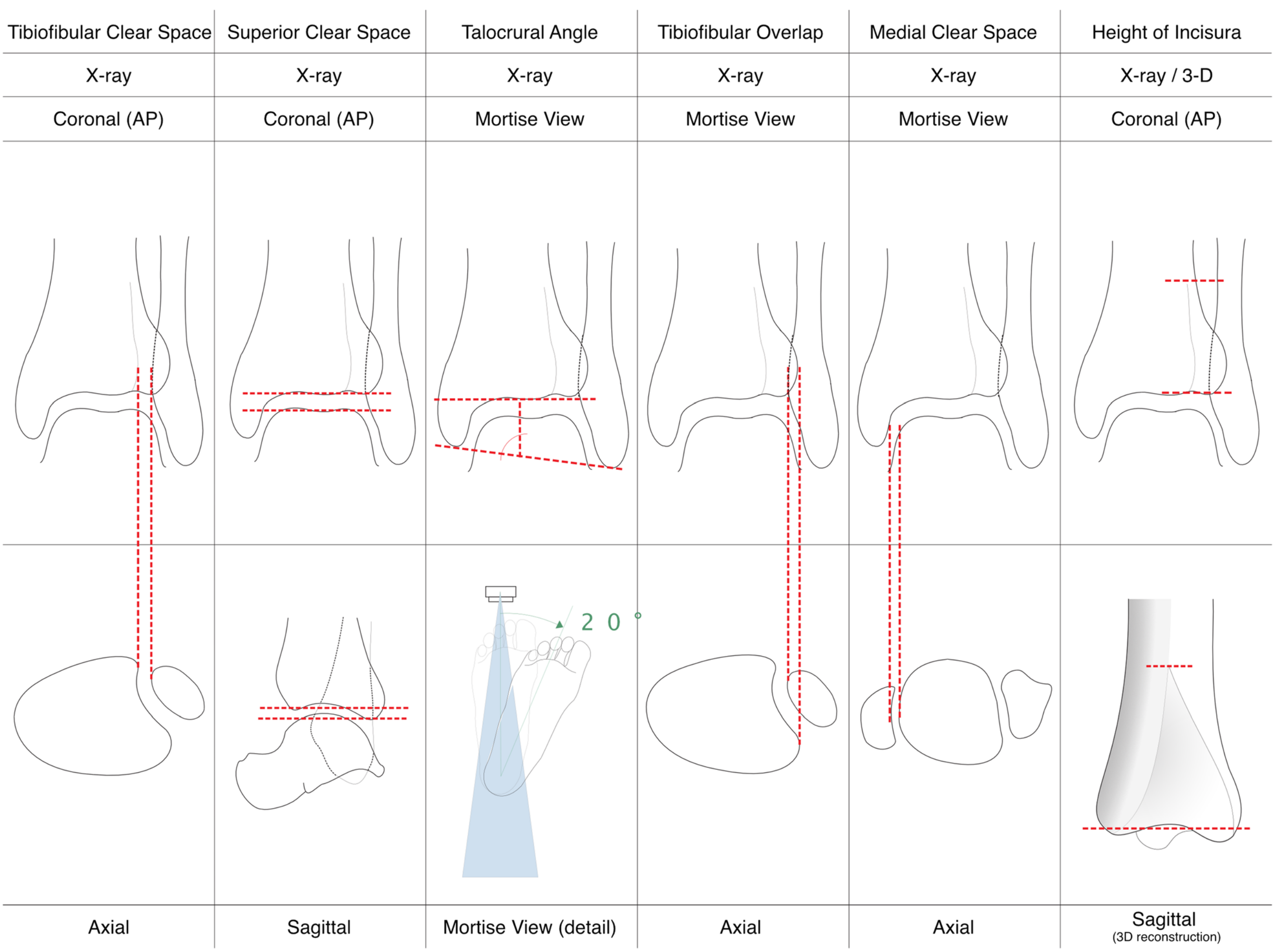

Fig. 2 Frequently used measurement methods to assess the distal tibio-fibular syndesmosis using plain radiographs

studies using CT scans, and six studies using MRI. Two studies investigated both the diagnostic accuracy of X-ray and MRI. Each of the studies were evaluated for risk of bias regarding patient selection, index test, reference standard, and flow and timing (e.g. time between index test and reference standard) [32]. Additionally, each study was evaluated for concerns of applicability regarding patient selection, index test, and reference standard.

Statistics

Sensitivity and specificity were calculated if they were not mentioned in the study using a fourfold table. The quality of the studies included in our analysis was assessed by using both internal and external validity measures within the framework provided by the QUADAS-2 tool [32].

Results

Included studies

The initial screening showed 9,862 studies which potentially could be included (Fig. 1). After removing all duplicates and reviewing the title and abstract of each study, 8900 studies were excluded. Another 920 studies were excluded if they

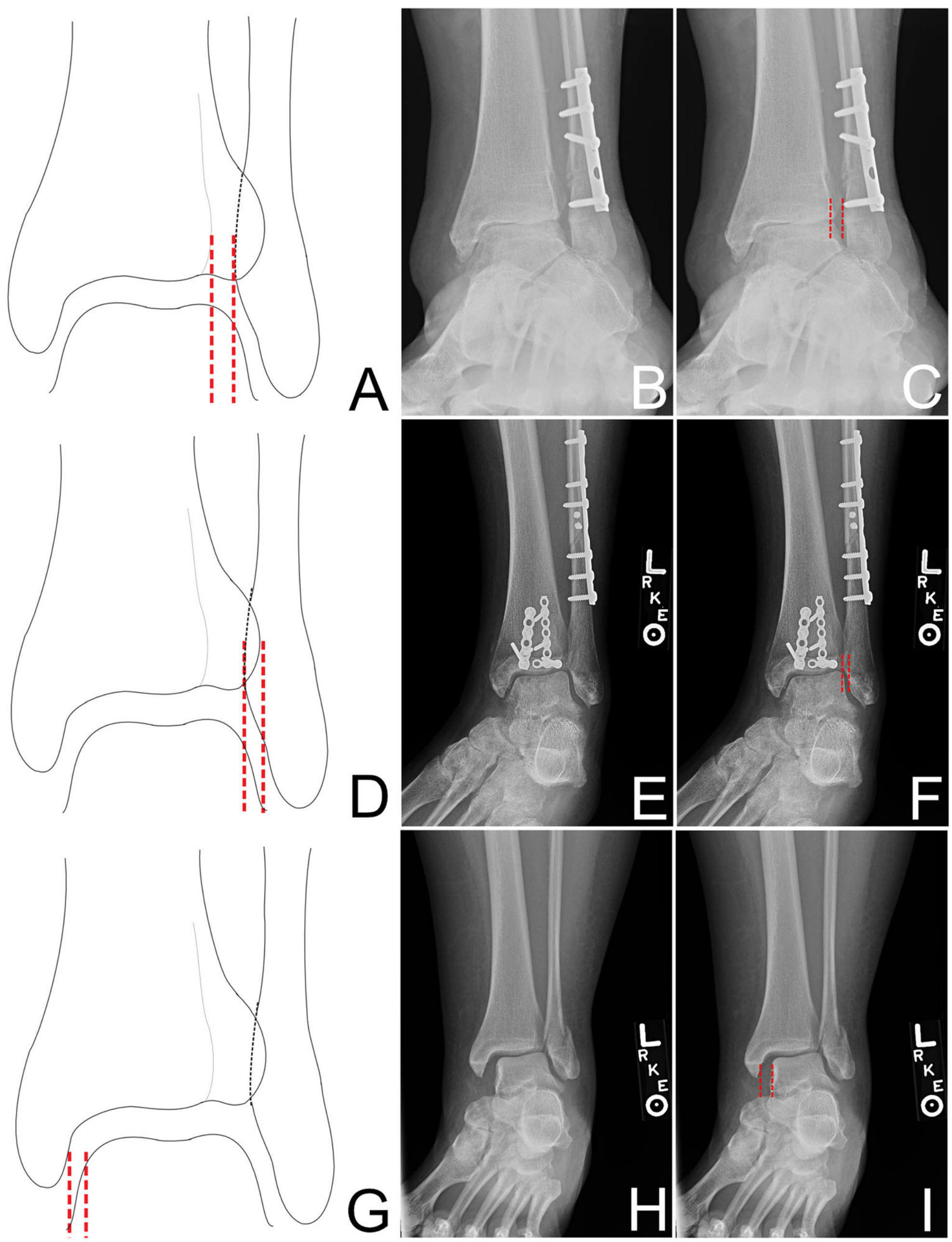

Fig. 3 The three most frequently used measurement methods to assess the distal tibio-fibular syndesmosis using plain radiographs. **a** Measurement of the tibio-fibular clear space (TFCS). **b** 65-year old patient with a chronic syndesmotic instability following a malleolar fracture. **c** Measurement of the TFCS. **d** Measurement of the tibio-fibular overlap (TFO). **e** 29-year old patient with an acute syndesmotic injury following a high fibular and posterior malleolar fracture. The syndesmotic injury was not addressed on the primary surgery. **f** Measurement of the TFO. **g** Measurement of the medial clear space (MCS). **h** 55-year old patient with an acute syndesmotic injury and injury of the deltoid ligament following a malleolar fracture. **i** Measurement of the MCS

Table 2 Assessment of the syndesmosis using conventional radiographs or fluoroscopy

Author	Cohort		Measurements	Healthy ankle	Isolated syndesmotic injury	Ankle fracture with syndesmotic injury	Sens.	Spec.
	Patients	Ankles						
Leeds and Ehrlich, 1984 [37]	34	34	Tibio-fibular clear space	3.8 mm (2.5–5.0)	NR	NR	NR	NR
Harper and Keller, 1989 [38]	12 (C)	12 (C)	Tibio-fibular clear space Tibio-fibular overlap	APV: 3.6 mm (±0.8) MV: 3.6 mm (±0.8) APV: 9.4 mm (±1.8) MV: 4.2 mm (±1.7)	NR	NR	NR	NR
Xenos et al., 1995 [39]	25	25	Tibio-fibular clear space	1.9 mm (±0.1)	NR	NR	NR	NR
Brage et al., 1997 [40]	25	25	Tibio-fibular clear space Tibio-fibular overlap Medial clear space Bimalleolar angle Talocrural angle	APV: 4.0 mm (3.0–6.5) APV: 8.0 mm (4.0–15.0) MV: 2.2 mm (−1.5–11.0) MV: 3.0 mm (0.0–5.5) MV: 79° (70.0–83.0) MV: 78° (72.0–83.0)	NR	NR	NR	NR
Takao et al., 2001 [28]	38	38	Tibio-fibular clear space Tibio-fibular overlap Medial clear space Talocrural angle Talar tilt	NR	NR	APV: 4.6 mm APV: 8.9 mm MV: 4.9 mm MV: 86.1° MV: 1.8 mm	APV: 48.5% MV: 63.6%	APV: 100% MV: 100%
Grass et al., 2003 [41]	16	16	Tibio-fibular clear space Tibio-fibular overlap	4.4 mm (3.0–5.0) 7.9 mm (5.0–9.0)	NR	7.0 mm (6.0–9.0) 3.6 mm (2.0–5.0)	NR	NR
Oae et al., 2003 [35]	58	58	Tibio-fibular clear space Tibio-fibular overlap	NR	Mixed cohort		APV: 43.0%	APV: 100%
Takao et al., 2003 [36]	52	52	Tibio fibular overlap	NR	Mixed cohort		APV: 44.1% MV: 58.3%	APV: 100% MV: 100%
Beumer et al., 2004 [27]	20	20	Medial fibula-posterior tibial tubercle Medial fibula anterior tibial tubercle Medial fibula- incisura fibularis Incisura fibularis- anterior tibial tubercle Incisura fibularis- anterior tibial tubercle Medial fibula- lateral fibula Superior (tibiotalar) clear space Medial (tibiotalar) clear space	0.3 mm (−4.0–7.0) 4.2 mm (−3.0–9.0) 2.2 mm (0.0–4.0) 2.5 mm (0.0–13.0) 6.4 mm (0.0–12.5) 14.1 mm (12.0–17.0) 3.9 mm (2.0–5.0) 2.7 mm (1.0–4.0)	NR	NR	NR	NR
Nielson et al., 2005 [29]	70	70	Tibio-fibular clear space Tibio-fibular overlap Medial clear space	NR	NR	Sens. and spec of different injury patterns available in the original publication		

Table 2 (continued)

Author	Cohort		Measurements	Healthy ankle	Isolated syndesmotic injury	Ankle fracture with syndesmotic injury	Sens.	Spec.
	Patients	Ankles						
DeAngelis et al., 2007[42]	94	94	Medial clear space Superior clear space	2.7 mm (±0.5) 3.6 mm (±0.6)	NR	NR	NR	NR
Schuberth et al., 2008 [11]	6	6	Tibio-fibular clear space Tibio-fibular clear space Medial clear space	NR	NR	APV: 9.6 mm (8.0–10.9) APV: 2.9 mm (0.4–4.8) APV: 6.5 mm (5.8–8.2)	NR	NR
Marmor et al., 2011 [43]	10 (C)	10 (C)	Tibio-fibular clear space Tibio-fibular overlap	APV: 3.1 mm (± 0.9) MV: 3.7 mm (± 0.7) APV: 9.0 mm (± 1.9) MV: 4.4 mm (± 1.8)	NR	NR	NR	NR
Hermans et al., 2012V [33]	51	51	Tibio-fibular clear space Tibio-fibular overlap Medial clear space Superior clear space	NR	NR	APV: 4.7 mm APV: 4.7 mm APV: 3.2 mm APV: 3.5 mm	APV: 47.0% (incl. Weber/ OTA) APV: 92.0% (incl. Lauge-Hansen)	APV: 100% (incl. Weber/ OTA) APV: 92.0% (incl. Lauge-Hansen)
Shah et al., 2012 [44]	392	392	Tibio-fibular clear space Tibio-fibular overlap	APV: 4.6 mm (± 1.1) MV: 4.3 mm (± 1.0) APV: 8.3 mm (± 2.5) MV: 3.5 mm (± 2.1)	NR	NR	NR	NR
Grenier et al., 2013 [45]	30	60	Tibio-fibular ratio	0.94 (± 0.13)	NR	NR	NR	NR
Choi et al., 2014 [46]	38	38	Medial clear space	NR	NR	MV: 5.8 mm (± 3.4)	NR	NR
Schoennagel et al., 2014 [34]	84	84	Tibio-fibular clear space Tibio-fibular overlap Medial clear space	MV: 4.5 mm (±1.1) MV: 4.7 mm (±2.3) MV: 2.6 mm (±0.7)	MV: 5.8 mm (±1.1) MV: 4.4 mm (±2.1) MV: 3.0 mm (±0.7)	NR	MV: 82.0% MV: 36.0% MV: 73.0%	MV: 75.0% MV: 78.0% MV: 59.0%
Chen et al., 2015 [47]	484	484	Tibio-fibular clear space Tibio-fibular overlap Height of incisura	Male (APV): 5.5 mm (3.1–8.2) Female (APV): 3.7 mm (2.4–5.1) Male (APV): 4.1 mm (2.1–5.8) Female (APV): 3.8 mm (2.3–6.1) Male (APV): 28.3 mm (18.4–37.2) Female (APV): 25.6 mm (20.1–31.5)	NR	NR	NR	NR
Peterson et al., 2015 [48]	56	56	Tibio-fibular clear space Tibio-fibular overlap Medial clear space	NR	NR	APV: 5.2 mm (±1.8) APV: 6.9 mm (±2.9) APV: 3.8 mm (±1.4)	NR	NR
Kim et al., 2016 [12]	44	44	Tibio-fibular clear space Tibio-fibular overlap Medial clear space	NR	APV: 6.8 mm (2.8–15.9) APV: 4.9 mm (0.0–9.4) APV: 7.6 mm (4.0–19.5)	NR	NR	NR

Table 2 (continued)

Author	Cohort		Measurements	Healthy ankle	Isolated syndesmotic injury	Ankle fracture with syndesmotic injury	Sens.	Spec.
	Patients	Ankles						
Feller et al., 2017 [49]	10 (C)	10 (C)	Tibio-fibular clear space	ERSR (group 1 + 2): 5.1 mm	Details available in the original publication	NR	NR	NR
			Tibio-fibular overlap	ERSR (group 1 + 2): 4.8 mm				
			Medial clear space	ERSR (group 1 + 2): 4.4 mm				

Studies using cadavers are marked with a *(C)*

Values are given as mean and standard deviation or range

NR not reported, *Sens.* sensitivity, *Spec.* specificity, *incl.* inclusive, *OTA* Orthopaedic Trauma Association, *APV* antero-posterior view, *MV* mortise view, *ERSR* external rotation stress radiograph

met any of the following exclusion criteria: review article, case report, <5 patients included, incomplete data set or not available as a full-text article. Data screening was done according to the guidelines of “Preferred Reporting Items for Systematic Review and Meta-Analyses” (PRISMA). The remaining 42 articles were subdivided into three groups: group one consists of studies using conventional radiographs (22 articles), group two includes studies using CT scans (15 articles), and group three comprises studies using MRI (9 articles). If one study included more than one imaging modality (e.g. conventional radiographs and CT scans), it was included in more than one group (four articles).

Study characteristics

With the exception of four studies using conventional radiographs, one study using CT scans, and one study using MRI, every included study reported the average patient age. Overall, the average patient age was 42.4 years in group one, 42.7 in group two, and 32.9 in group three. A total of 3,246 patients (3,441 ankles) were assessed. Conventional radiography or fluoroscopy was the most popular diagnostic tool (1,587 ankles), followed by CT scans (1,250 ankles), and lastly by MRI (604 ankles). Assessment of the syndesmosis using conventional radiographs was most frequently done on weight-bearing antero-posterior (AP) radiographs in combination with mortise view, while axial images were preferred for assessments done using CT scans. Assessments using MRI often included coronal, sagittal, and axial images and allowed direct visualization of the syndesmosis.

Using conventional radiographs or fluoroscopy, data were available for healthy ankles, patients suffering from isolated syndesmotic injuries (e.g. high ankle sprains), and patients with an ankle fracture in combination with a syndesmotic injury. Two studies investigated chronic syndesmotic injuries in patients with history of an ankle fracture, nine studies investigated acute syndesmotic injuries (isolated and in combination with an ankle fracture), eight studies assessed the syndesmosis in healthy ankles, and three studies included cadavers. Studies using CT scans included data from healthy ankles (nine studies), ankle fractures in combination with a syndesmotic injury (three studies investigated acute and one study investigated chronic syndesmotic injuries in patients with history of an ankle fracture) but not from isolated syndesmotic injuries. Two additional studies used cadavers for assessment of the syndesmosis. Studies using MRI included results from healthy ankles (two studies), isolated syndesmotic injuries (two studies, whereas both included a mixed cohort of patients suffering from isolated syndesmotic injuries and patients suffering from syndesmotic injuries in combination with an ankle fracture), and ankle fractures (one study and two studies including the above mentioned mixed cohort).

Table 3 Assessment of the syndesmosis using computed tomography (CT) scans

Study	Cohort		Measurements	Healthy ankle	Isolated syndesmotic injury	Ankle fracture with syndesmotic injury	Sens.	Spec.
	Patients	Ankles						
Tang et al., 2003 [51]	30	60	Rotational ratio	PER (above fracture): 0.984 PER (below fracture): 0.980 SER (above fracture): 0.938 SER (below fracture): 0.932	NR	PER (above fracture): 0.994 PER (below fracture): 1.050 SER (above fracture): 0.942 SER (below fracture): 0.980	NR	NR
			Tibio-fibular ratio	NR		PER (above fracture): 0.0114 PER (below fracture): 0.0701 SER (above fracture): 0.00548 SER (below fracture): 0.0377		
Elgafy et al., 2010 [52]	100	100	Deep incisura Shallow incisura	67% 33%	NR	NR	NR	NR
			Tibio-fibular width (anterior)	Men: 2.0 mm (1.0–3.0) Women: 2.0 mm (1.0–3.0)				
			Tibio-fibular width (posterior)	Men: 5.0 mm (3.0–6.0) Women: 4.0 mm (3.0–6.0)				
Marmor et al., 2011 [43]	10 (C)	10 (C)	Tibio-fibular angle	25.6 mm (±5.6)	NR	NR	NR	NR
Mukhopadhyay et al., 2011 [53]	19	19	Tibio-fibular width (anterior) Tibio-fibular width (posterior)	2.6 mm (0.9–4.7) 5.2 mm (2.5–8.7)	NR	NR	NR	NR
Dikos et al., 2012 [54]	30	60	Tibio-fibular clear space Tibio-fibular overlap	2.7 mm (± 1.4) 3.2 mm (± 1.2)	NR	NR	NR	NR
			Tibio-fibular distance	14.6 mm (±1.8)				
			Fibular rotation	12.7° (±6.5)				
			Length incisura	23.0 mm (±2.4)				
			Depth incisura	3.9 mm (±1.2)				
			Fibular width	17.1 mm (±2.1)				
Knops et al., 2013 [55]	9 (C)	9 (C)	Tibio-fibular opening angle Anterior tibial surface angle	−10.0° (±10) −1.0° (±6)	NR	NR	NR	NR
			Tibio-fibular ratio	0.94 (±0.1)				
			Tibio-fibular angle	18.0° (±15)				
Nault et al., 2013 [56]	93	100	Tibio-fibular width (anterior) Tibio-fibular width (middle)	4.4 mm 8.0 mm	NR	NR	NR	NR
			Tibio-fibular width (posterior)	2.8 mm				
			Anterior fibular distance	10.4 mm				
			Posterior fibular distance	7.1 mm				
			Anterior tibio-fibular distance	2.3 mm				
			Anterior tibio-fibular angle	8.7° (internal)				
			Talar angle	6.9° (external)				
Choi et al., 2014 [46]	38	38	Medial clear space	NR	NR	3.4 mm (±1.6; if stable)	NR	NR

Table 3 (continued)

Study	Cohort: Patients	Cohort: Ankles	Measurements	Healthy ankle	Isolated syndesmotic injury	Ankle fracture with syndesmotic injury	Sens.	Spec.
						5.6 mm (±3.5; if unstable)		
Lepojarvi et al., 2014 [57]	64	107	Length incisura Depth incisura	22.2 mm (±0.2) 4.1 mm (±0.1)	NR	NR	NR	NR
			Sagittal translation	4.1 mm (±0.1)				
			Tibio-fibular width (anterior)	2.8 mm (±0.1)				
			Tibio-fibular width (posterior)	5.1 mm (±0.2)				
			Narrowest part incisura	1.8 mm (±0.1)				
Malhotra et al., 2014 [58]	14	14	Lateral tibio-fibular angle Tibio-fibular area	68.4° (±6.1) 1.2 cm^2 (±0.3)	NR	63.4° (±6.6) 1.71 cm^2 (±0.4)	NR	NR
Mendelsohn et al., 2014 [59]	21	38	Tibio-fibular width (anterior) Tibio-fibular width (middle)	1.7 mm (±0.9) 1.7 mm (±0.6)	NR	NR	NR	NR
			Tibio-fibular width (posterior)	2.3 mm (±1.1)				
Chen et al., 2015 [47]	484	484	Measuring plane (tibia)	Male (3D): 12.1 mm (8.4–15.2) Female (3D): 7.8 mm (6.4–9.2)	NR	NR	NR	NR
			Tibio-fibular clear space (anterior)	Male (3D): 2.8 mm (2.2–3.5) Female (3D): 1.8 mm (2.3–6.1) Male (2D): 2.8 mm (2.3–3.7) Female (2D): 1.8 mm (1.4–2.9)				
			Tibio-fibular clear space (posterior)	Male (3D): 35.1 mm (28.6–39.8) Female (3D): 33.7 mm (30.2–37.5)				
			Length incisura	Male (3D): 35.1 mm (28.6–39.8) Female (3D): 33.7 mm (30.2–37.5)				
			Depth incisura	Male (3D): 5.1 mm (4.0–6.3) Female (3D): 4.2 mm (3.2–5.2) Male (2D): 5.0 mm (3.6–6.5) Female (2D): 4.3 mm (3.0–5.6)				
Kotwal et al., 2016 [60]	36	36	Tibio-fibular width (anterior) Tibio-fibular width (posterior)	3.0 mm (± 1.2) 5.3 mm (± 1.5)				
Yeung et al., 2015 [50]	123	123	Tibio-fibular width (anterior)	NR	NR	Stable: 1.8 mm (±1.4) Unstable: 4.9 mm (±3.7)	56.4%	91.7%
			Tibio-fibular width (middle)			Stable: 3.2 mm (±1.6) Unstable: 5.3 mm (±2.4)	74.4%	75.0%
			Tibio-fibular width posterior			Stable: 4.1 mm (±1.3) Unstable: 5.3 mm (±1.8)	NR	NR
			Tibio-fibular width max			Stable: 4.6 mm (±1.4) Unstable: 7.2 mm (±3.0)	74.4%	79.8%

Table 3 (continued)

Study	Cohort		Measurements	Healthy ankle	Isolated syndesmotic injury	Ankle fracture with syndesmotic injury	Sens.	Spec.
	Patients	Ankles						
Kocadal et al., 2016 [61]	52	52	Antero-posterior translation	1.8 mm (−2.0–5.0)	NR	NR	NR	NR
			Fibular rotation	13.3 mm (0.5–28.8)				
			Upper syndesmotic area	83.1 mm^2 (37.8–168.3)				
			Middle syndesmotic area	79.5 mm^2 (40.7–129.0)				
			Lower syndesmotic area	67.5 mm^2 (34.4–137.3)				
			Syndesmotic volume	1534.0 mm^3 (900.4–2,367.1)				

Studies using cadavers are marked with a *(C)*

Values are given as mean and standard deviation or range

NR not reported, *Sens.* sensitivity, *Spec.* specificity, *PER* pronation external rotation, *SER* supination external rotation

Measurement methods

Conventional radiographs or fluoroscopy (AP, mortise, and lateral view) used 13 different measurement techniques, while CT scans and MRI used 29 and 10, respectively (direct visualization of the ligaments excluded). Summaries of commonly used measurement techniques using conventional radiographs are shown in Figs. 2 and 3. The three most common techniques used for assessment of the syndesmosis in conventional radiographs or fluoroscopy are the tibio-fibular clear space (TFCS), tibio-fibular overlap (TFO), and medial clear space (MCS). Two cadaver studies used stress views (one study using plain radiographs, one study using fluoroscopy), while none of the studies using healthy volunteers or patients performed stress radiographs. In case of an ankle fracture, sensitivity and specificity (when additionally using the Weber and Orthopedic Trauma Association classification for decision-making) were 47.0 and 100%, respectively [33]. Using the Lauge-Hansen Classification instead of the Weber or Orthopedic Trauma Association (OTA) classification, sensitivity and specificity were each 92.0% [33]. In acute isolated syndesmotic injuries, sensitivity/ specificity was 82.0%/ 75.0% for TFCS, 36.0%/ 78.0% for TFO, and 73.0%/ 59.0% for MCL [34]. MRI was used as a reference standard in both studies. Using arthroscopy as a reference standard, sensitivity/ specificity was found to be 48.8%/ 100% for TFCS and TFO (AP view) and 63.6%/ 100% for MCS, talocrural angle and talar tilt (mortise view, study included patients with ankle fractures) [28]. Two more studies assessed the sensitivity and specificity but had mixed cohorts (ankle fracture in combination with a syndesmotic injury and isolated syndesmotic injury) [35, 36]. Included studies are summarized in Table 2.

Investigators assessing the use of CT scans most common assessed the tibio-fibular width on axial images (anterior, middle, and posterior); however, only one study investigated sensitivity and specificity for syndesmotic injury using this technique in patients with ankle fractures [50]. Sensitivity/ specificity of 56.5%/ 91.7% was evident for the anterior (cut-off 4.0 mm), 74.4%/ 75.0% (cut-off 4.0 mm) for the middle, and 74.4%/ 78.8% for the maximum (cut-off 5.7 mm) tibio-fibular width [50]. The posterior tibio-fibular width was not a reliable predictor (Table 3 and Fig. 4) [50].

Most of the MRI studies used direct assessment of syndesmotic integrity. Only three studies (from the same author) used indirect assessment techniques [62–64]. Of the studies that assessed the syndesmosis directly, two studies included a mixed cohort (ankle fracture in combination with a syndesmotic injury and isolated syndesmotic injury), while three studies included patients with isolated syndesmotic injuries [35, 36, 65–67]. One study included patients with an ankle fracture in combination with a syndesmotic injury [68]. Ankle arthroscopy was used as a reference standard in all studies. Two studies used contrast media for MRI. Better sensitivity and specificity were reported when using a 3-Tesla (T) rather than a 1.5 T MRI (Table 4) [65, 67].

Methodological quality

Low probability of bias regarding patient selection, index test, reference standard, and flow and timing was found in 37.5% of the included studies [28, 33, 34, 55, 65]. Lack of clarity regarding flow and timing was found in 50.0% [29, 35, 36, 66–68]. Most of these studies used MRI for assessment of the syndesmosis. In 12.5% of the studies, lack of clarity regarding the index test was present (e.g. not specified if the investigator had knowledge of the reference standard while assessing the index test) [43, 58]. No relevant bias was found regarding the reference standard or patient selection. Ankle arthroscopy or MRI (the latter in group 1 and 2) was most commonly used as the reference standard. Studies were overall applicable to daily practice. One study did not clearly provide information about patient characteristics; therefore, the selection was unclear [55]. Another study did not provide sufficient information about the MRI used for assessment of the index test [68]. The methodological quality is summarized in Fig. 5.

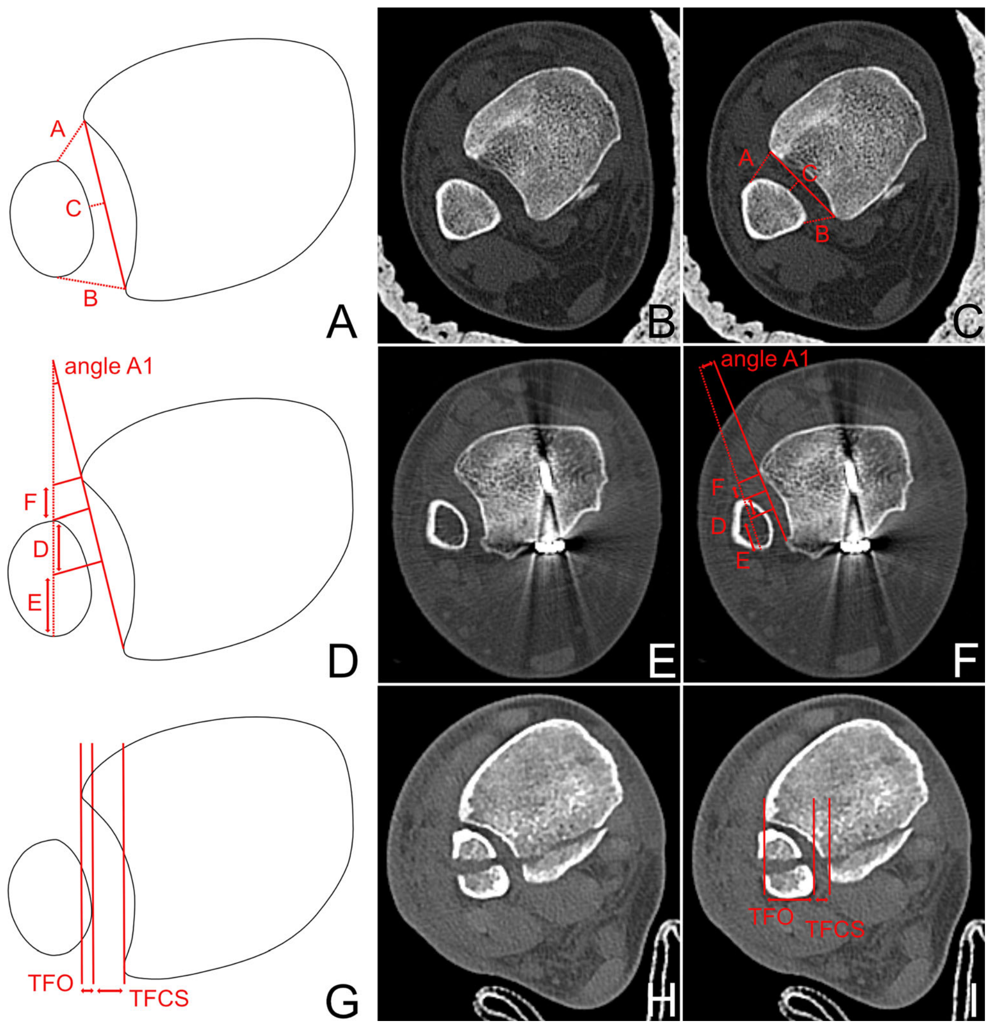

Fig. 4 Frequently used measurement methods to assess the distal tibiofibular syndesmosis using computed tomography (CT) scans. Measurements were performed 1 cm above the distal tibial plafond. **a** Measurement of the tibio-fibular width anterior (A), middle (C) and posterior (B). **b** 35-year old patient with an acute syndesmotic instability following a high fibular and posterior malleolar fracture. The syndesmotic injury was not addressed on the primary surgery. **c** Measurement of the tibio-fibular width. **d** Measurement of the antero-posterior translation (D, E, F) and the rotation (angle A1) of the distal fibula. **e** 47-year old patient with an acute syndesmotic injury following a high fibular fracture and small posterior malleolar avulsion. **f** Measurement of the antero-posterior translation and rotation of the distal fibula. **g** Measurement of the tibio-fibular clear space (TFCS) and tibio-fibular overlap (TFO). **h** 37-year old patient with an acute syndesmotic injury following a high fibular fracture. **i** Measurement of the TFCS and TFO. Radiologists and orthopedic surgeons should be aware that a distal fracture of the fibula and/or an additional tibia fracture influence the measurements. It is important to mention that the rotation of the ankle also influences the measurements

Table 4 Assessment of the syndesmosis using magnet resonance imaging (MRI)

Study	Cohort		Measurements	Healthy cohort	Isolated syndesmotic injury	Ankle fracture with syndesmotic injury	Sens.	Spec.
	Patients	Ankles						
Oae et al., 2003 [35]	58	58	Criterion 1: Lig. discontinuity	NR	Mixed cohort		AITFL: 100% PITFL: 100%	AITFL: 70.0% PITFL: 94.0%
			Criterion 2: Criterion 1 + Lig. wavy or curved				AITFL: 100% PITFL: 93.0%	AITFL: 93.0% PITFL: 100%
Takao et al., 2003 [36]	52	52	Lig. tear or discontinuity, decrease of tension, abnormal course	NR	Mixed cohort		AITFL: 100% PITFL: 100%	AITFL: 93.1% PITFL: 100%
Han et al., 2007 [66]	78	78	Criterion 1: no visualization of syndesmosis. Criterion 2: abnormal course, wave or thickening. Criterion 3: increased signal in T1 and T2. Criterion 4: contrast enhancement in the syndemosis	NR	Isolated syndesmotic injuries	NR	90.0%	94.8%
Kim et al., 2007 [67]	45	45	Score 1: AITFL not injured. Score 2: AITFL probably not injured. Score 3: AITFL possibly injured. Score 4: AITFL probably injured. Score 5: AITFL definitive injured	NR	Isolated syndesmotic injuries	NR	Routine MRI: 52.1% Contrast-enhanced MRI: 94.4%	Routine MRI: 58.8% Contrast-enhanced MRI: 84.4%
Chun et al., 2015 [65]	50	50	Ligaments investigated for integrity: 1: Lateral = ATFL, CFL, PTFL. 2: Deltoid = superficial and deep. 3: Syndesmosis = AITFL, IOM, PITFL, TL	NR	Isolated syndesmotic injuries	NR	Syndesmosis: 91.0% Deltoid: 84.0%	Syndesmosis: 100% Deltoid: 93.5%
Warner et al., 2015 [68]	122	122	Assessment of PITFL injury	NR	NR	Ankle fractures with syndesmotic injury	70.0%	84.0%
Nault et al., 2016 [63]	51	51	Tibio-fibular width (anterior) Tibio-Fibular width (middle)	3.5 mm (±0.9) 2.6 mm (±0.7)	NR	NR	NR	NR
			Tibio-fibular width (posterior)	7.0 mm (±1.5)				
			Anterior fibular distance	9.7 mm (±1.6)				
			Posterior fibular distance	7.1 mm (±1.1)				
			Anterior tibio-fibular distance	0.5 mm (±0.9)				
			Anterior tibio-fibular angle	−10.5° (±3.7)				
			Talar angle	5.8° (±3.9)				
			Fibular rotation	0.5 (±0.14)				
			Antero-posterior translation	1.4 (±0.3)				
Nault et al., 2017a [62]	34	34	Tibio-fibular width (anterior) Tibio-fibular width (middle)	3.5 mm (±1.0) 2.4 mm (±0.9)	NR	NR	NR	NR
			Tibio-fibular width (posterior)	6.7 mm (±1.2)				
			Anterior fibular distance	10.2 mm (±1.1)				
			Posterior fibular distance	8.0 mm ±(1.6)				

Table 4 (continued)

Study	Cohort		Measurements	Healthy cohort	Isolated syndesmotic injury	Ankle fracture with syndesmotic injury	Sens.	Spec.
	Patients	Ankles						
			Anterior tibio-fibular distance	0.6 mm (±0.9)				
			Anterior tibio-fibular angle	−8.0° (±3.7)				
			Talar angle	6.3° (± 3.7)				
			Fibular rotation	0.5 (± 0.2)				
			Antero-posterior Translation	1.3 (± 0.3)				
Nault et al., 2017b [64]	114	114	Tibio-fibular width (anterior)	3.5 mm (±0.9)	4.5 mm (±1.7)	NR	NR	NR
			Tibio-fibular width (middle)	7.0 mm (±1.5)	3.5 mm (±1.4)			
			Tibio-fibular width (posterior)	2.6 mm (±0.6)	7.3 mm (±2.2)			
			Anterior fibular distance	9.7 mm (±1.7)	10.0 mm (±1.7)			
			Posterior fibular distance	7.1 mm (±1.1)	7.5 mm (±1.7)			
			Anterior tibio-fibular distance	0.5 mm (±1.0)	1.0 mm (±1.4)			
			Anterior tibio-fibular angle	−10.6° (±3.7)	9.2° (±5.5)			
			Talar angle	5.7° (±3.8)	7.7° (±4.7)			
			Fibular rotation	0.5 (±0.1)	0.6 (±0.3)			
			Antero-posterior translation	1.4 (±0.3)	1.4 (±0.4)			

Values are given as mean and standard deviation or range

NR not reported, *Sens.*, sensitivity, *Spec.*, specificity, *Lig.*, ligament, *AITFL*, anterior inferior tibio-fibular ligament, *PITFL*, posterior inferior tibio-fibular ligament, *IOM* interosseous membrane, *TL* transverse ligament, *ATFL* anterior tibio-fibular ligament, *CFL* calcaneo-fibular ligament, *PTFL* posterior tibio-fibular ligament

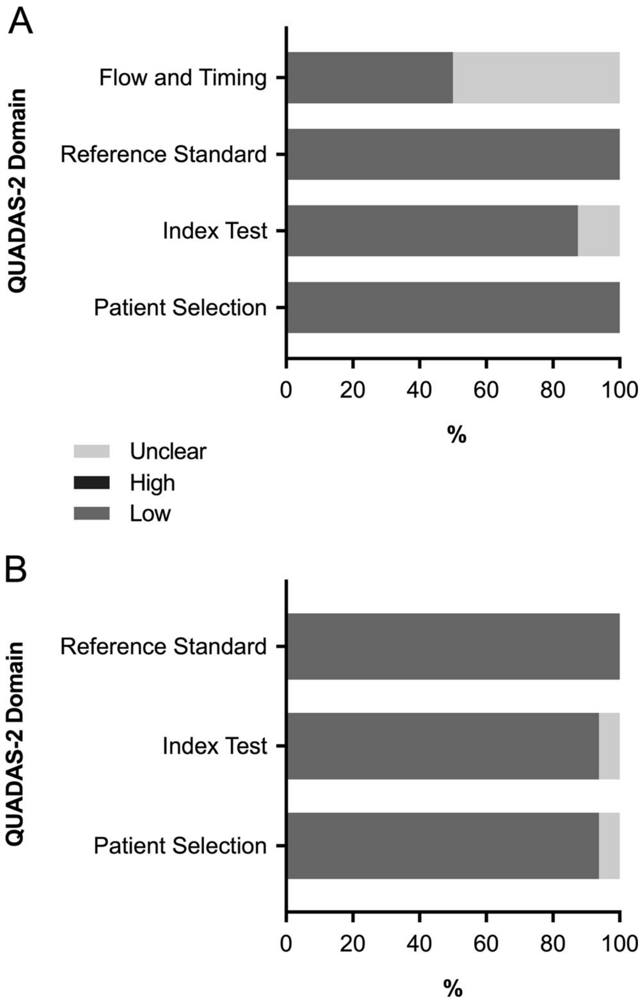

Fig. 5 Evaluation of the Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) tool to assess studies using conventional radiographs, computed tomography (CT) scans and magnet resonance imaging (MRI) for assessment of syndesmotic instability. **a** Proportion of studies with low, high or unclear risk of bias. **b** Proportion of studies with low, high, or unclear concerns regarding applicability

Discussion

Several different measurement techniques are described in the literature assessing the distal tibiofibular syndesmosis [37, 38, 40, 41, 42, 45, 48, 69]. Chaput first described the TFCS ("*la ligne clair*") in 1908 [70]. Pettrone et al. introduced a measurement algorithm for assessment of the distal tibiofibular interval in 1983 [69]. In 1989, Harper et al. defined radiographic criteria for physiologic syndesmotic dimensioning on AP and mortise radiographs [38]. TFCS should be less than 6 mm in both the AP and mortise view [38]. Overlap of the fibula and anterior tibial tubercle should be greater than 42% of the width of the fibula on the AP view [38].

Evaluation starts with conventional radiographs, including weight-bearing lateral, AP, and mortise views of the ankle joint. Several studies have shown that radiographic measurements of the distal tibio-fibular alignment have limited use and are not always predictive of injury severity [27–29, 49]. In these cases, intraoperative stress radiography may help assess the distal tibiofibular syndesmosis [39, 71, 72]. Widening of the TFCL and the MCL by more than 2 mm during external rotation stress indicates injury of the syndesmosis [39]; however, the evidence for stress views as the principal assessment for syndesmotic injuries is weak, especially in the case of chronic injuries.

The diagnostic accuracy of conventional radiographs differs considerably between authors [28, 33–36]; however, accuracy also differs between isolated syndesmotic injuries (e.g. high ankle sprains) and additional ankle fractures [33, 34]. Considering the Weber and/or Orthopedic Trauma Association (OTA) classification in combination with assessment of the TFCS, TFO medial clear space (MCS), and superior clear space (SCS) achieved a sensitivity of 47% and a specificity of 100% [33]. The sensitivity can be increased to 92.0% if the Lauge-Hansen classification is used instead of the Weber or OTA classification [33]. Of note, Nielson et al. found better sensitivity for TFO (assessment using AP radiographs) than TFCS or MCS when predicting syndesmotic injury in presence of an ankle fracture, but specificity was low [29]. Interestingly, X-ray findings did not correlate with anterior or posterior tibiofibular injury detected by MRI. The authors concluded that traditional radiographic measurements should not solely be relied on for determining if the syndesmosis is intact (Fig. 6). Acute isolated syndesmotic injuries have a sensitivity of 82.0% and a specificity of 75.0% when using the TFCS for assessment (AP view) [34]. A higher sensitivity was found for TFCS than either TFO or MCL [34]. The cut-off value in this study has been shown to be 5.3 mm for TFCS, 2.8 mm for TFO, and 2.8 mm for MCS [34]. AP views were used in this study for assessment of TFCS, while TFO and MCS were evaluated on the mortise view. It is important to mention that there is a wide variance regarding the normal tibio-fibular interval in the literature. In addition, most measurement methods are highly dependent on how severely the ankle joint was mal-rotated when the X-ray was taken [27, 73]. Significant differences were also found between male and female patients; therefore, published cut-off values must be interpreted with care [44].

CT scans have been investigated extensively in the recent years. Axial images 1 cm above the tibial plafond are frequently used to assess rotation of the distal fibula and tibiofibular width [43, 47, 50, 52–61]. The tibio-fibular width measured at the level of maximal distance has a sensitivity of 74.4% and a specificity of 79.8% to detect acute syndesmotic injuries (study including patients with ankle fracture) [50]. The cut-off value was found to be 5.7 mm [50]. Recently, Nault et al. introduced a novel algorithm for syndesmotic assessment which considers mal-rotation, lateral displacement, and antero-posterior displacement of the distal fibula [56].

This algorithm was additionally used for assessment of the distal syndesmosis on MRIs [62–64].

CT scans possess several advantages over conventional X-rays—first, no osseous overlaps are present, making the assessment more precise [46]; second, the tibiofibular joint can be visualized directly, which positively influences the accuracy [31]; third, the shape of the incisura fibularis and mal-rotation of the distal fibula can be assessed [51, 54, 74, 75]. As with conventional radiographs, the average measurements between male and female are significantly different [54]; however, bilateral CT scans of healthy ankles did not vary by more than 2.3 mm in tibiofibular interval and 6.5° in fibular rotation [54]. Recently, weight-bearing CT scans have gained in popularity with patients who have foot and ankle disorders; however, to our knowledge, no study has been published assessing this imaging technique to investigate syndesmotic instability.

High diagnostic accuracy is best achieved by utilizing MRI over conventional radiographs or CT scans, especially in chronic syndesmotic instability [35, 36, 66–68]; furthermore, contrast media and/or a 3 T MRI improve diagnostic accuracy of MRI [65, 67]. While direct assessment of the tibiofibular syndesmosis is possible by MRI, assessment of syndesmotic injury by X-ray or CT scans must rely on recognition of secondary signs. Sensitivity of up to 91.0% and specificity of 100% have been reported for syndesmotic injuries. Sensitivity of 84.0% and specificity of 93.5% have been reported for additional deltoid ligament tears using MRI [65]. Despite its high sensitivity and specificity, MRI has some notable disadvantages when compared to conventional X-rays or CT scans—first, MRI is both costly and not always readily available; second, interpretation errors may lead to over- or underestimation of the syndesmotic injury; third, MRI cannot be performed under weight-bearing condition.

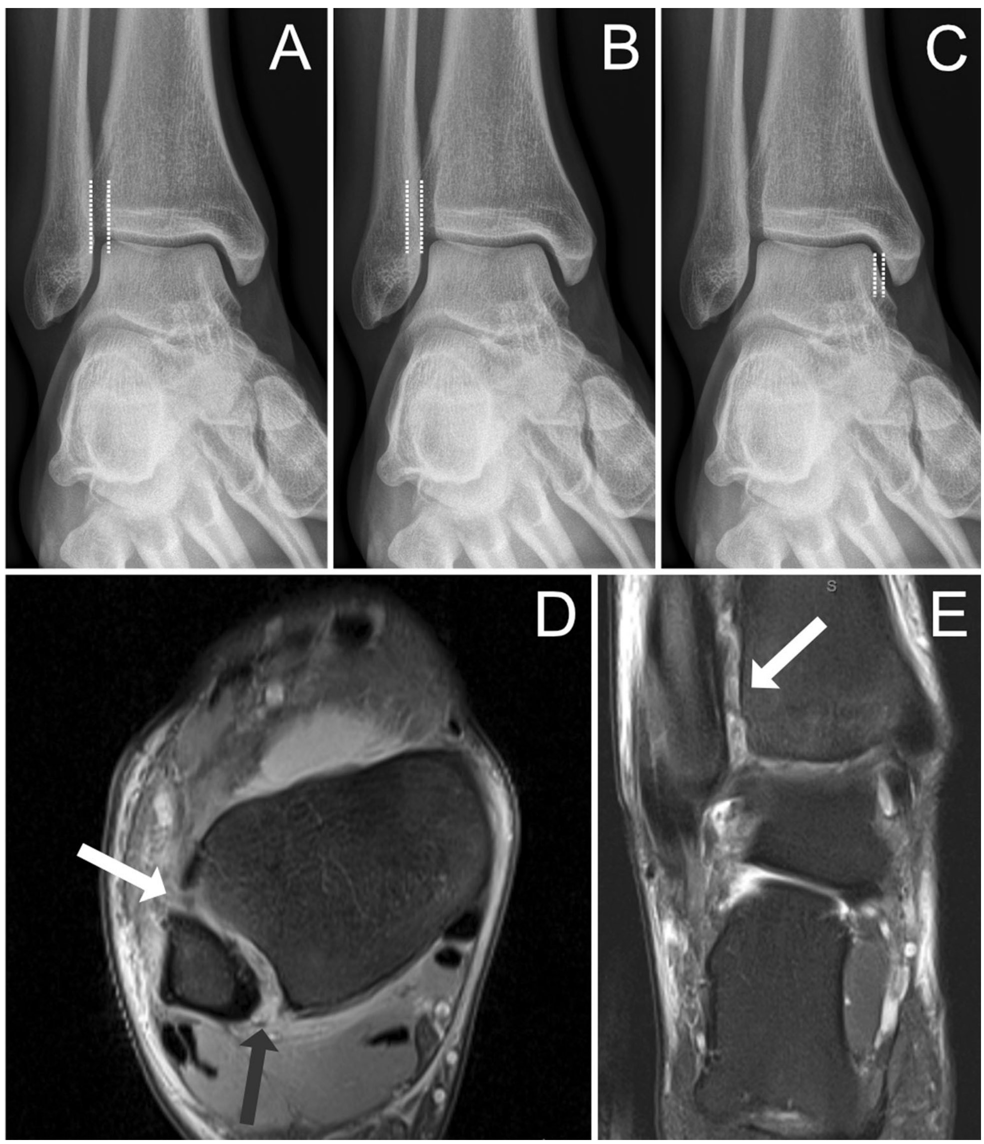

Fig. 6 Example of a 37-year-old man with an acute isolated syndesmotic injury. The conventional radiographs (mortise view) cannot predict reliably the syndesmotic injury. **a** Normal tibio-fibular clear space (TFCS). **b** Normal tibio-fibular overlap (TFO). **c** Normal medial clear space (MCS). **d** Axial magnet resonance imaging (MRI) proton density with fat saturation demonstrates full thickness tear of both the anterior (white arrow) and posterior (gray arrow) tibiofibular ligaments. **e** Coronal T2 fat saturated MRI image shows heterogeneity and increased signal of the syndesmotic ligaments (arrow), consistent with syndesmotic injury

A reliable diagnostic protocol under weight-bearing condition would be desirable, especially for assessment of subtle chronic syndesmotic injuries. It is important to mention that ankle arthroscopy is likely the best definitive tool for assessing the degree of syndesmotic instability and mortise widening with up to 100% accuracy [36, 76].

Overall, the methodological quality of the included studies was satisfactory. Many studies using MRI failed to note how long had passed between when the MRI was obtained and when the surgery was performed. Too much time between the index test and the reference standard could cause bias. The included studies were generally applicable to daily practice.

In conclusion, conventional radiographs cannot predict syndesmotic injuries reliably. CT outperforms conventional X-rays in detecting syndesmotic mal-reduction. Additionally, the syndesmotic interval can be assessed in greater detail by CT. Using MRI, sensitivity and specificity of nearly 100% can be achieved. However, correlating MRI findings with patients' complaints can be difficult, and utility with subtle syndesmotic instability needs further investigation. The methodological quality of the included studies is satisfactory.

Compliance with ethical standards

Conflict of interests Nicola Krahenbuhl is supported by a grant from the Swiss National Science Foundation (SNF; grant number P2BSP3_174979).

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