

Clinical assessment of antero-medial rotational knee laxity: a systematic review

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Abstract

Purpose To inventory the examination methods available to assess antero-medial rotational laxity (AMRL) of the knee following medial collateral ligament injury.

Methods Searches were conducted in accordance with the PRISMA guidelines and using four online databases: WEB OF SCIENCE, MEDLINE, EMBASE, and AMED. The Critical Appraisal Skills Programme guidelines for *Diagnostic Test Studies* were used for the quality assessment of the articles.

Results A total of 2241 articles were identified from the database searches. From this, four articles were included in the final review. All were case–control studies, considered a combined ACL/MCL injury and had small study populations. Specialised equipment was required in all studies, and one needed additional imaging support before measurements could be taken. Two employed commercially available measuring equipment as part of the assessment process.

Conclusion Clinical assessment of AMRL in relation to a MCL injury remains challenging. Although methods

have been developed to support clinical examination, they are limited by a number of factors, including the need for additional time in the clinical environment when setting up equipment, the need for specific equipment to produce and measure rotational movement and imaging support. In addition, there are patient safety concerns from the repeated imaging. A reliable and valid clinical examination remains to be found to truly assess antero-medial rotational laxity of the knee.

Level of evidence IV.

Keywords Clinical examination · Knee injury · Knee stability · Medial collateral ligament · Deep medial collateral ligament · Rotational laxity

Abbreviations

AMRL	Antero-medial rotational laxity
CT	Computerised tomography
ACL	Anterior cruciate ligament
MCL	Medial collateral ligament
sMCL	Superficial medial collateral ligament
dMCL	Deep medial collateral ligament
MM	Medial meniscus
VKLD	Vermont knee laxity device

Introduction

Knee stability, key for successful locomotion, is achieved through static and dynamic structures working synergistically to maintain knee integrity against destabilising forces [34]. Static structures include the menisci, cruciate and collateral ligaments, and joint capsule. Dynamic structures include the quadriceps, hamstring, and calf muscles traversing the joint [18, 44]. Often, there is a fine balance

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between the different elements, particularly those on the medial and lateral aspects of the knee [35].

Knee injuries commonly cause morbidity, and the medial collateral ligament (MCL) is most frequently traumatised [15, 32, 46]. The MCL is the primary restraint to knee valgus movement throughout flexion, but also limits external rotation, functioning as a secondary restraint anterior displacement with the Anterior cruciate ligament (ACL) [6, 41, 51, 54, 56].

O'Donoghue [40] identified two components to the MCL, the superficial (sMCL) and deep (dMCL). The larger sMCL runs from the medial femoral condyle, inserts on the tibia anteriorly, and resists valgus stress [45]; studies have suggested it sustains forces of up to 557.1 ± 55.4 N [57]. The dMCL is reported as the primary restraint for antero-medial rotational laxity (AMRL) at all ranges of knee flexion [9, 10, 23] and tolerates forces up to 100.5 ± 10.3 N [8, 54]. Due to its close association with the joint and fibrous attachments to the medial meniscus (MM), concurrent dMCL/MM pathologies often occur [5, 47, 50]. Moreover, there is also load sharing between the dMCL/sMCL and dMCL/ACL complexes; injury to one component confers additional stabilising responsibilities to the other [7, 19, 45, 58].

With its relative vulnerability from rotational forces, dMCL disruption should be frequently anticipated. Injuries to the dMCL have been reported to prevent patients returning to sporting activities due to persistent symptoms, and therefore, focused interventions are necessary to restore function [25, 43].

Three degrees of MCL injury are recognised, based on gapping and perceived end-point feel [33]. This is assessed with valgus forces in straight leg (sMCL) and in 30° degrees flexion (dMCL). Valgus–varus assessment does not fully assess rotatory knee stability, due to the lack of rotational stressors, and hence dMCL disruption might be missed [31]. In general, grade I/II injuries improve with conservative measures and traditionally grade III was thought to require surgical correction. However, the availability of bracing and rehabilitation techniques has made surgical intervention less common [8, 14, 17].

Slocum and Larson [49] described AMRL along the long axis of the knee, speculating that this may be a limiting factor for athletes participating in sports requiring sudden changes in direction or rotational movements. While routine examinations assess valgus and varus knee stability [27], Slocum and Larson's [49] work prompted anatomical investigations of the MCL and methods to clinically evaluate AMRL [13]. While methods to assess rotational movement of the knee in vitro have been considered in the past [32], this review aims to inventory the available methods, including diagnostic tests, which can be applied in the clinical setting to assess rotational laxity in the context of

a dMCL injury. This will support practicing clinicians by providing them with up to date information to enable an informed choice when choosing a method to assess this pathology.

Materials and methods

Search strategy

The PRISMA statement was used as a guideline to conduct the review [37]. A systematic computerised search was conducted using WEB OF SCIENCE, MEDLINE, PubMed, and EMBASE from inception until August 2016, including the following keywords:

- Knee.
- (Medial AND collateral AND ligament) OR MCL OR (Deep and medial AND collateral AND ligament) OR dMCL.
- Antero-medial OR External.
- Rotatory OR Rotational OR Laxity.
- Physical OR Clinical OR Examination OR Assessment.

Eligibility criteria

The following inclusion criteria were applied to select relevant papers:

- The study included human subjects over 18 years old.
- The investigation focused on assessing knee AMRL with MCL injury either in isolation or with another concurrent pathology.
- The study was published in English.

Articles were excluded if they were:

- Not peer-reviewed.
- Reviews.
- Cadaveric or anatomical studies.
- Did not include an MCL injury.

Review process

Articles were imported into Endnote X7.5 (Thomson Reuters, CA, USA). Duplicates were removed before two authors (DS; EP) independently screened the titles and abstracts of articles retrieved from the databases searches. The full texts of the remaining articles were then reviewed to check for eligibility. Disagreements were resolved by consensus discussion. References of relevant papers were checked for additional studies that the database searches may have overlooked.

Study analysis

An adapted Critical Appraisal Skills Programme for *Diagnostic Test Studies* was used to extract information including population, methodology, outcome measures, gold standard applied, and study findings [12]. Quality assessment of studies, including assessment of population bias and clinical applicability, was based on the QUADAS-2 checklist for diagnostic studies [55].

Results

Search findings

The article selection process is shown in Fig. 1. The search identified 2241 articles, and 2 were identified from other sources. Examination of titles and abstracts produced

182 remaining articles. Following application of the eligibility criteria, the full text revision yielded 4 studies to be included in the subsequent review processes of quality assessment and data extraction. Reasons for exclusion of the other 178 articles are shown in Fig. 1.

Quality assessment

Table 1 shows the quality assessment scores, based on the QUADAS-2 [55] checklist, of the 4 included studies, indicating potential sources of bias. Three articles had population bias [28, 30, 36], and all [28, 30, 36, 39] were of questionable applicability. No articles excluded subjects from analysis.

Study characteristics

Table 2 summarises the data extracted from the included studies. All studies adopted a case–control design and

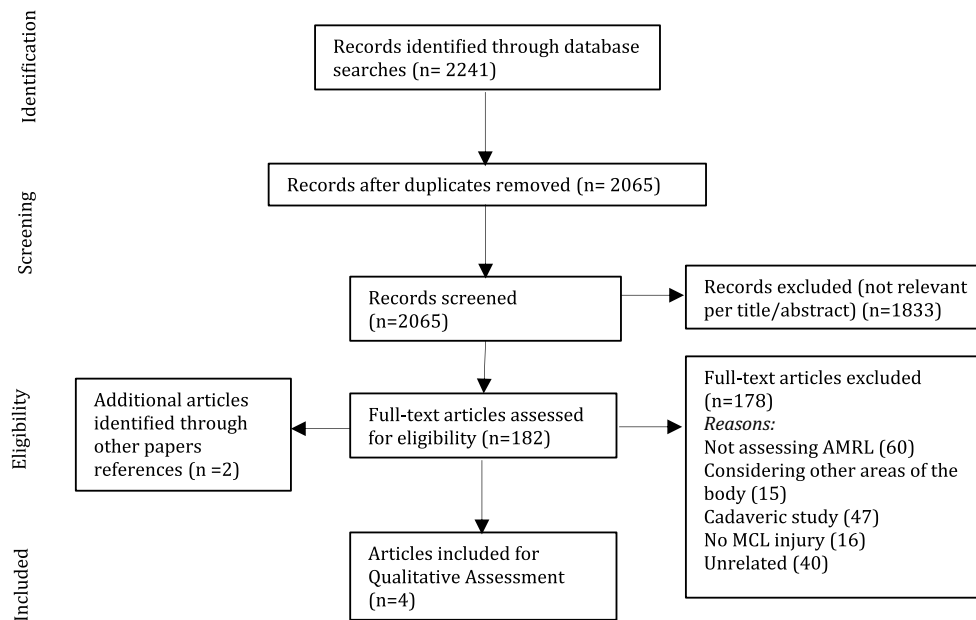


Fig. 1 Outline of review process

Table 1 Qualitative analysis of articles included in the final review

References	QUADAS-2 Domain						
	Patient selection		Index test		Reference standard		Flow and timing
	Bias	Applicability	Bias	Applicability	Bias	Applicability	
Kennedy and Fowler [28]	High	Low	N/A	N/A	N/A	N/A	Low
Kurimura et al. [30]	High	Low	N/A	N/A	N/A	N/A	Low
Mayr et al. [36]	High	Low	N/A	N/A	N/A	N/A	Low
Nordt et al. [39]	Low	Low	Unclear	Unclear	Unclear	Unclear	Low

For each category, articles were judged as to whether there were concerns regarding introduction of bias (LOW/HIGH/UNCLEAR) and for the first three categories, concerns regarding applicability (LOW/HIGH/UNCLEAR)

considered combined ACL/MCL injuries [28, 30, 36, 39]. None considering an MCL injury in isolation were available for inclusion. Three studies also included healthy controls for comparison [28, 30, 36]. All four employed specialised medical devices to assess knees [28, 30, 36, 39], but two also employed the KT-1000 arthrometer (MEDmetric, San Diego, CA), either as part of their experimental method for assessing AMRL [36] or as a validation tool [39]. The KT-1000 arthrometer is commonly employed as a tool for quantifying anterior laxity following ACL injury and not for rotational assessments. One study employed Computerised tomography (CT) to produce images from which measurements were taken [39], while the remaining three relied on non-imaging modalities [28, 30, 36]. None employed a physical/clinical examination technique to assess AMRL.

Devices used for assessment and related findings

Kennedy and Fowler [28] developed a clinical stress machine to produce rotational movement around the knee using a gas-driven footplate controlled with rolling drums. Most medial movement (mm) was identified in subjects with an ACL/MCL injury, whereas it was less in healthy subjects and negligible with isolated ACL injuries (Table 2).

The ‘Laxitester’ [36] produces rotational torque along the long axis of a flexed knee (Fig. 2). No significant difference in rotational ($^{\circ}$) movement was identified between the study groups, but anterior displacement (mm) in the externally rotated position was greatest in subjects with an ACL/MCL injury (Table 2).

Kurimura et al. [30] used a foot-level rotating plate and electronic displacement sensors to measure displacement (mm) and stiffness [angle ($^{\circ}$)] around the knee (Fig. 3). In subjects with an ACL/MCL injury, displacement (20° : 5.0 ± 2.4 mm, 90° : 3.5 ± 1.8 mm) and stiffness (20° : $-28.7 \pm 36.2^{\circ}$, 90° : $-18.0 \pm 10.1^{\circ}$) increase significantly compared to healthy subjects and those with an isolated ACL injury (Table 2).

Nordt et al. [39] used a modified force transduction apparatus (Telos Co., Hungen-Obbornhofen, Germany) and Computerised tomography (CT) imaging (Fig. 4) to study post-operative patients with unilateral ACL or ACL/MCL injuries. Displacement ($^{\circ}$), measured from CT images, was significantly greater for combined ACL/MCL injuries in a neutral and anteriorly displaced conditions compared to healthy knees and those with an isolated ACL pathology (Table 2).

Discussion

The most important finding of the present study was the absence of an easily applicable method for clinically

assessing AMRL in the context of a dMCL injury. This systematic review aimed to examine methods for assessing the AMRL in vivo following a medial knee injury, but as none were available, those who studied a combined ACL/MCL pathology were included.

The search yielded four studies, all of which employed specialised medical equipment to produce rotational forces and record movements. This included a gas-driven system [28], the ‘Laxitester’ [36], customised frames [28, 30], and torque wrench systems [39]. In addition, some utilised more conventional systems such as the KT-1000 [36, 39] and CT imaging [39] to analyse the movements.

While the authors report that their individual systems provide a method for assessing rotational laxity in the knee, a glaring drawback is the need for specialised equipment that may not be commercially available. Without being more widely accessible, it almost negates any generalizable benefits from each of these examinations and leaves their methods only applicable in the respective institution. Equally, needing time to set up, calibrate, and then analyse the results limits the practical applicability of these systems in a real-world fast-paced clinical setting where real-time feedback would be also preferable. With consultation time pressures and clinical loads, time taken to use these systems would require specialised clinical settings or personnel; otherwise, they remain only an option in research environments. Moreover, in situations where repeated CT imaging [39] is needed, it brings patients’ safety issues into question with repeated high-dose radiation.

A key limitation of the studies included in the review is the small population sample sizes, particularly the subjects with an ACL/MCL injury. This implies that the generalizability of the findings to situations where only the dMCL is affected is particularly challenging, but given the paucity of studies examining this phenomenon, an exclusion criterion for study power could not be set. As such, while the combined ACL/MCL injury subjects did demonstrate greater movement than healthy knees and those with an isolated ACL pathology, it is a significant assumption that the MCL injury was the contributing factor. Further studies involving isolated MCL injured patients are needed to address this question.

Another limitation of the systems employed is the rotational movement being generated at the foot and taken to represent the rotated position of the knee [30, 36]. In a cadaveric study of ankle-level knee AMRL measurements, foot and tibial recordings taken to represent knee movement were analysed using inclinometers at 30° and 90° knee flexion. Significantly, greater movement was recorded at the ankle level at both positions [1]. Given that rotational positions of the foot were taken to represent those at the knee, an element of error is certainly possible in the methods reviewed. Indeed, similar studies in the past that have

Table 2 Summary of key findings and analysis of studies from each study

References	Study type	Subjects	Apparatus	Outcome measures	Standard applied	Blinding	Methodology	Findings	P value
Kennedy and Fowler [28]	Case-control	<i>Healthy subjects:</i> 110 ACL/MCL: 42 ACL alone: 11	Stabilising metal frame Freon-Driven footplate Rotating cylindrical drum Cassette holder and marker templates	Displacement of tibia relative to femur (mm)	None	No	Femur stabilised in frame while footplate to produces rotational movement Calf sling kept taught against the lower leg and adjacent to drum Freon gas through the drums was used to control movement and markings are made the adjacent cassettes with marker templates Measurements taken from these using callipers	Medial laxity measurements <i>Healthy subjects:</i> Full extension 0.3–1.7 mm 20° flexion 0.8–3.5 mm ACL/MCL: 20° flexion 3.0–8.5 mm ACL alone: No medial laxity was identified	N/A
Kurimura et al. [30]	Case-control	<i>Healthy subjects:</i> 30 (15 M:15 F)ACL alone: 18 (9 F:11 M)ACL/MCL: 10 (6 M: 4F)	Examination device consisting of adjustable femoral stabiliser, foot holder, loading device and electronic displacement sensor	Detection of tibial and tibial tuberosity anterior displacement (mm) relative to patellaSide-to-side and intra-cohort differences compared	None	No	Femur stabilised in metal frame with knee in 20° and 90° flexion Foot strapped in holder attached to rotating plate with up to 30° rotational movement Electronic measure attached to tibial tuberosity and patella 100 N anterior force applied using loading device in 30° external rotation. Anterior movement measured from electronic sensor displacement Bilateral examinations performed for each group and knees compared for individual	Difference in movement between knees <i>Healthy subjects:</i> 20° flexion 0.3 ± 1.0 mm 90° flexion 0.1 ± 1.1 mm ACL alone: 20° flexion 2.4 ± 2.4 mm* 90° flexion 0.0 ± 1.4 mm ACL/MCL: 20° flexion 5.0 ± 2.4 mm* 90° flexion 3.5 ± 1.8 mm*	$P < 0.05$

Table 2 continued

References	Study type	Subjects	Apparatus	Outcome measures	Standard applied	Blinding	Methodology	Findings	P value
Mayr et al. [36]	Case-control	Healthy subjects: 10ACL alone: 10ACL/MCL: 1018 F;22 M	LaxitesterKT1000	Angular external rotation of the lower leg (°) and anterior displacement (mm) of tibia when in this position	Arthroscopy performed to determine injuries to the knee	Yes Clinical examiner was blinded to operative findings and vice versa	Knee held in 30° flexion with Laxitester, a 2 NM external rotational force was applied with torque wrench at foot An anterior translation force was then applied with the KT-1000	Healthy subjects: External rotation: 9.0° ± 6.6° Anterior movement in external rotation: 0.29 ± 0.30 mm ACL alone: External rotation: -1.0° ± 5.7° Anterior movement in external rotation: 2.50 ± 1.71 mm* ACL/MCL: External rotation: -4.5° ± 8.6° Anterior movement in external rotation: 3.73 ± 1.65 mm*	P < 0.05
Nordt et al. [39]	Case-control	ACL alone: 13ACL/MCL: 8(16 M;5 F)	Force translation apparatus ankle foot orthotic with torque wrench KT-1000 CT	External rotation of knee (°) in neutral and with anterior force applied	None	No	Knee stabilised by transduction apparatus in 20° flexion. Anterior force applied with the KT-1000 and 5 N torque applied via digital torque wrench attached to foot-plate to produce tibial rotation CT images obtained in normal alignment and rotated positions under anterior force and neutral	Non-injured knee: Mean external rotation (neutral): 7.4° Mean external rotation (anterior force): 5.5° ACL alone: Mean external rotation (neutral): 9.1°* Mean external rotation (anterior force): 5.5° ACL/MCL: Mean external rotation (neutral): 9.5°* Mean external rotation (anterior force): 6.0°*	P < 0.05

* Significant difference

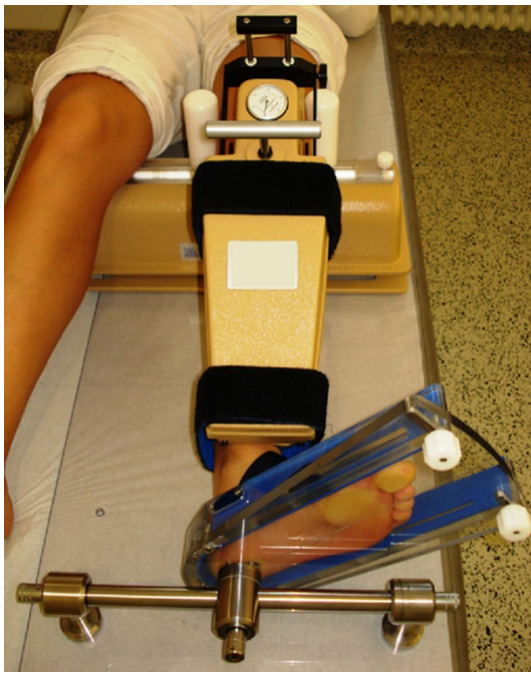


Fig. 2 Laxitester produced rotational movement at the foot and measured the maximal angle ($^{\circ}$) of movement. Simultaneously, an anterior force was applied using the KT-1000 to measure anterior displacement (mm) in the rotated position [36]

focused exclusively on ACL pathologies and measured knee rotational laxity at the ankle have also made this same assumption, bringing into question the outcomes of otherwise more applicable systems [3, 4, 16, 25, 26].

Equally, a further limitation of the studies reviewed were the physical parameters measured; some recorded movement in mm [28, 30, 36], while others took angular measurements [36, 39]. This limits direct comparison of the studies, and also, for an individual patient assessed by one method, reassessment via an alternative might produce different results.

During the review process, it was evident that several studies have considered AMRL in the context of an isolated ACL injury. While these were excluded from the review process based on the eligibility criteria, several of these also employed a medical device to produce rotational movement [2–4, 16, 20, 21, 25, 26, 29, 30, 36, 39, 48, 53], used imaging modalities to record movements [3, 16, 20–22, 25, 26, 39, 41, 42, 52, 53] or attempted to perform this assessment functionally [11, 22].

As with the studies included in the review process, many of these methods required specialised medical apparatus, most of which are not commercially available, technical expertise, extensive time, and patients' exposure to radiation. Some, such as the Vermont knee laxity device (VKLD), was used in repeated studies to determine the degree of rotational movement in healthy [48, 53],

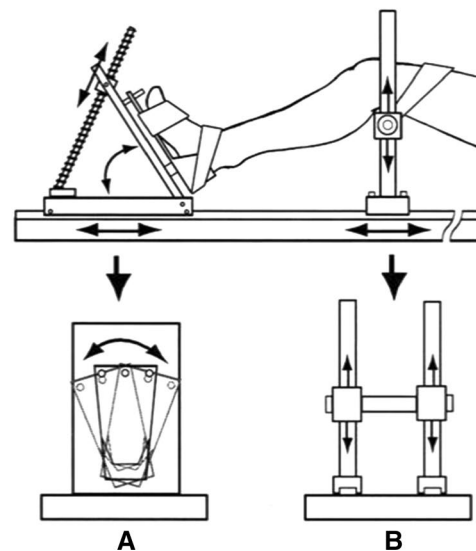
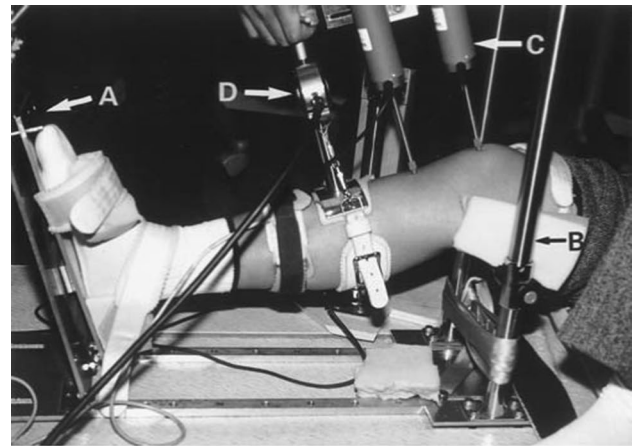


Fig. 3 Rotational device using electronic displacement system employed by Kurimura et al. [30]. Their devices enabled differing degrees of knee flexion and produced rotational movement at the foot. Electronic displacement devices placed along the tibia and at the patella detected movement (mm)

ACL-deficient [20], and post-ACL repair subjects [29]. This implies that it was available to different groups for research purposes and that also the design held a degree of versatility, such that a non-metallic version could be manufactured and applied in another study [20]. However, it still remains impractical in the clinical setting due to time taken in setting up the system; moreover, it was only tested in patients with an isolated ACL injury.

The generalizability and results of this review are limited by the paucity and quality of studies focussing on the MCL/dMCL and its role in controlling for AMRL. One of the challenges is in the variability of methodology in recording the rotational movement and the actual measurement taken as displacement in mm or angular displacement in degrees, making direct comparison and extrapolation

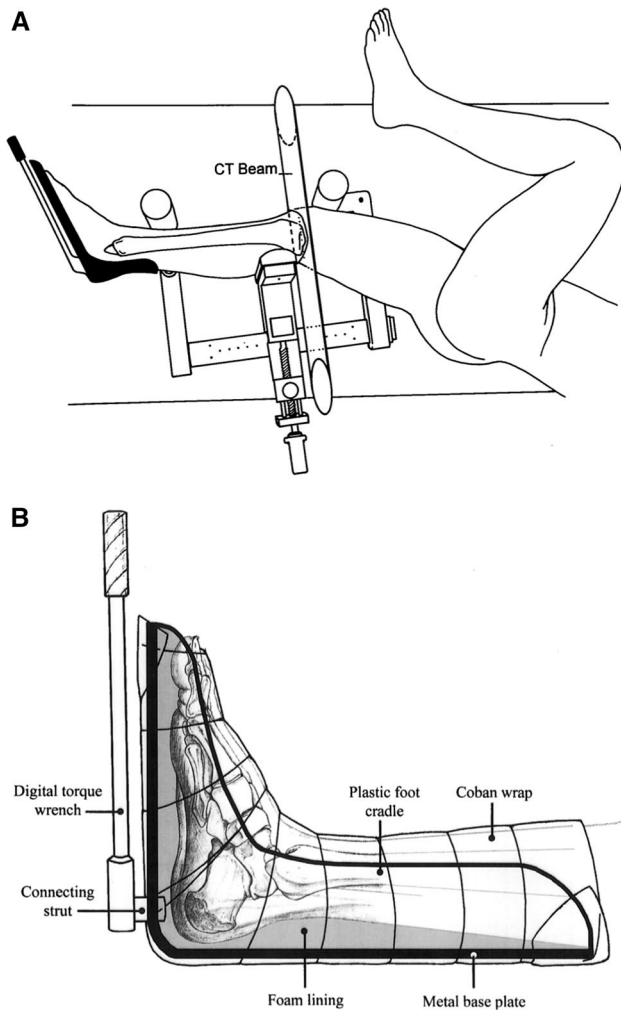


Fig. 4 Force translation apparatus used by Nordt et al. [39]; it produced an anterior force behind the knee while an external rotation moment was produced at the foot. CT images were obtained and from these external rotation ($^{\circ}$) of the knee was calculated

of results more challenging. The exclusion of studies that were not in vivo or did not consider an MCL injury limited the number of studies included in the review process. While AMRL could have been considered more generally, with the aim of the review being to assess AMRL in the context of an MCL pathology, it would not have been in keeping with the review process. However, it does not mean that these studies could not have been applied in the situations of suspected MCL injury, either in isolation or as a combined pathology.

Moreover, the following limitations should be acknowledged about this review: agreement statistics were not included as part of the methods, as on only one occasion did authors disagree. Only studies published in English were considered due to unavailability of translated sources, representing a language bias to study selection.

Rotational laxity of the knee associated with a dMCL injury can cause a delayed return to activity for professional and amateur athletes and those in physically challenging professions [24, 38]. The aim of being able to effectively assess this in the clinical setting would be to limit the impact this injury has on performance and increase participation in activities. Moreover, by having a readily applicable assessment method, it could highlight the need for focussed treatments at an earlier stage, rather than when there was a failure to progress.

Conclusion

Deep MCL injury and AMRL remain an enigma in medicine that is not routinely examined by clinicians. While we understand more about the anatomical subtleties of this structure, this knowledge is of limited use without a reliable clinical assessment. This review highlights the paucity of methodologies when examining AMRL in association with a medial ligament injury. Even when investigated, specialised equipment was needed to generate rotational movement or record movements produced. Further work is clearly required to identify a clinically valid and reproducible examination technique.

Authors' contribution DS conceived the review, participated in designing and conducting the review, drafted the manuscript, and took it through the final editing process. EP participated in designing and conducting the review, drafted the manuscript, and took it through the final editing process. ET conceived the review, participated in designing and conducting the review. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest Sirisena D, Papi E, and Tillett E declare that they have no conflict of interest.

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Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent This was a systematic review and there were no participants included.

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