Evaluating the Diagnostic Pathway for Acute ACL Injuries in Trauma Centres: A Systematic Review

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Abstract

Objective: This review sought to evaluate the literature on the initial assessment and diagnostic pathway for patients with a suspected Anterior Cruciate Ligament (ACL) tear.

Methods: MEDLINE, EMBASE, and CINAHL were systematically searched for eligible studies. Studies were included if they used at least one assessment method to assess for ACL injury and participants were assessed at an acute trauma centre within 6-weeks of injury. Article quality was evaluated using the QUADAS-2 checklist.

Results: A total of 353 studies were assessed for eligibility, 347 were excluded for the following reasons: injuries were not assessed in an acute trauma setting, injuries were not acute, participants had previous ACL injuries or chronic joint deformities affecting the knee, participants were under 18, or participants included animals or cadavers. A total of six studies were included in the review. Common assessment methods included: laxity tests, joint effusion, inability to continue activity, and a history of a 'pop' and 'giving way' at the time of injury. Diagnostic accuracy varied greatly between the assessment method and the assessing clinician. Gold standard diagnostics were MRI and arthroscopy. A weighted meta-mean calculated the time to reach diagnosis to be 68.60 days [CI 23.94, 113.24]. The mean number of appointments to reach diagnosis varied from 2-5. Delay to surgery or surgical consultation ranged from 61 to 328 days.

Conclusion: Clinicians in the Emergency Department are not proficient in performing the assessment methods that are used for diagnosis in acute ACL injury. Reliance on specialist assessments or radiological methods inevitably increases the time to reach a diagnosis, which has repercussions on management options. There is an ever-growing demand to improve diagnostic accuracy and efficiency, innovation into new diagnostic methods that require less specialist training would help improve patient care.

1.0 Introduction

Musculoskeletal complaints make up 30% of primary care consultations in the UK(1), with acute knee injuries accounting for approximately 5-8% of all acute injuries seen in the Accident and Emergency unit (A&E) (2, 3). The anterior cruciate ligament (ACL) is a commonly injured, major ligament in the knee preventing tibia-femoral anterior translation. ACL injuries are debilitating; causing a great deal of pain, swelling, gait deviations, and limitations to daily function, not to mention the association of later developing osteoarthritis. For this reason, early diagnosis is key to facilitating efficient treatment outcomes.

Acute ACL injury is renowned to be difficult to assess and it is frequently missed by clinicians, with diagnosis taking on average 21 months to confirm (4, 5). Traditional diagnosis of musculoskeletal (MSK) conditions uses a semi-subjective approach, comprising of visual assessment and joint integrity testing; diagnosis is reached through a process of elimination. These clinical assessments whilst low cost are subject to significant errors; diagnostic accuracy can be as low as 56% (4), and consequently only 14% of ACL injuries diagnosed at initial presentation (4, 5). Most acute ACL injuries present in trauma settings such as A&E departments and minor injury units (3, 6). In the immediate acute injury phase, joint effusion and muscular

compensation often mask ACL injury (3, 6), and excessive joint effusion is postulated to reduce diagnostic accuracy to 12.7% (3).

Some practitioners have addressed diagnostic errors by performing joint aspiration on acute presentation to A&E (7) thereby enhancing the accuracy of laxity tests, such as Lachman's and the pivot shift. Others rely on clinical history and mechanism of injury as a primary diagnostic indicator (8, 9). A clear mechanism of injury that is considered 'suspicious' can be either contact or non-contact twisting, fast velocity changes, landing from a height, hyperextension, or excessive valgus knee strain (6, 10, 11). Other features of clinical history that may indicate ACL injury are an audible pop, (3, 6, 12), effusion onset within 6 hours (3, 6, 12, 13), difficulty weight-bearing (3), pain (13), changes in range of movement (ROM)(13), locking, giving way or catching (3), and a feeling of vulnerability or instability(12). A study conducted by Hardy et al (3) developed an acronym (LIMP) for clinicians to follow when assessing for ACL injury. LIMP is comprised of 4 facets of clinical history including: 'Leg giving way at the time of injury (TOI)', 'Inability to continue activity immediately after Injury', 'Marked effusion within 6 hours after TOI', 'Pop heard or felt at TOI'. However, both clinical history and laxity tests experience issues of sensitivity and specificity (14, 15).

Many clinicians rely on radiological evidence to confirm diagnosis; magnetic resonance imaging (MRI) is currently underpinned as one of the gold standard diagnostic techniques for ACL injury. MRIs are both accurate and reliable at demonstrating the extent and location of trauma. However, they are expensive, costing the NHS 2 billion pounds per annum (16), and are associated with long wait times; between June 2020 and August 2021 the waitlist for an MRI increased by 50%(17). The other gold standard diagnostic verification is for patients to undergo an arthroscopic procedure (18), there are again costly, invasive and have long wait times.

Previous studies have investigated common diagnostic pathways and referral routes for patients with a suspected ACL injury (12). This patient group tends to initially present to A&E, where often bracing is prescribed as a form of precautionary management which leaves the patient immobilised for long periods unnecessarily (6). If acute knee clinics are not established, they are referred to either fracture clinic or physiotherapy. If these clinicians are concerned and suspicious of a more serious injury, then the patient is sent for diagnostic imaging (5). Without this diagnostic confirmation, patients will not have been put on an appropriate management pathway (6). Emergency physicians have poor diagnostic accuracy, as low as 25.9%, compared to more experienced professionals such as sports medicine physicians when assessing acute ACL injury (6, 12). However, Perera's study emphasised that even with specialist training, orthopaedic physicians missed diagnosis in 28% of patients, with knee specialists having a diagnostic rate of 71.8% (6). This reinforces that clinicians cannot ensure diagnostic accuracy with the current clinical assessment methods (6), thus emphasising the importance of more accurate diagnostic tests at acute trauma centres to improve patient outcomes (12).

Early diagnosis is paramount as it can reduce the likelihood of the knee giving way, which is associated with secondary injury, specifically to the meniscus which can result in osteochondral damage (19). ACL deficiencies lead to an increase in anterior and rotary instability, which changes the joint's load pattern creating subsequent damage to the surrounding structures (19). Sadly, up to 50% of ACL injuries lead to post-traumatic osteoarthritis (PTOA) (20, 21). PTOA changes can occur almost immediately post-injury, they are

associated with metabolic alterations from intra-articular inflammatory markers. Although there is no evidence that a reconstruction reduces the chance of PTOA, compensatory changes to knee biomechanics and tibiofemoral contact patterns acutely post ligament injury, significantly expedite the progression in metabolic changes which are associated with the development of arthritis (22). Thus, there is a need for faster surgical or conservative management strategies as there are significant economic and health benefits associated with these approaches (4, 23). The British Orthopaedic Association not only highlights the importance of accurate, fast diagnosis, but it also recommends that any ACL injury is referred to a surgeon as soon as possible to facilitate optimal patient outcomes, be that surgical or conservative management (16).

Understanding current assessment methods and diagnostic pathways for patients with acute ACL tears are paramount to developing more efficient diagnosis recommendations and assessment measures. This article aims to systematically review the literature for assessing patients with suspected ACL tears that come in through the emergency department.

2.0 Materials And Methods

2.1 Search strategy

The databases MEDLINE, EMBASE, and CINAHL were used to conduct the search, published articles up until the 25th of May 2021 were eligible for inclusion in the review. The search terms were either classed as headings or keywords. The Boolean search strategy was used to appropriately combine terms and retrieve the most relevant articles (Table 1). 'ACL' AND 'trauma centre' were the two topic groups, all keywords and subject headings within the topic heading 'ACL' were combined with 'OR', this was repeated with the keywords and subject heading within the topic heading 'trauma centre'. Topic headings were then combined with 'AND'. After the automated search using the terms listed in Table 1, a hand search was undertaken which cross-referenced the terms in Table 1 against the bibliographies of the relevant articles.

2.2 Eligibility criteria

The review scoped the current assessment methods and diagnostic pathways for ACL injury in the emergency department for patients. For articles to be eligible for the systematic review, they had to meet the following inclusion criteria: the assessment had to be completed in an Emergency Department, injury was acute on initial assessment (within 6 weeks), at least one clinical assessment tool was stated, and participants were deemed to have sustained an ACL injury. Articles were excluded if: participants had experienced a previous ACL injury, participants had known chronic joint deformities (such as osteoarthritis), animals or cadavers were included within the sample, the paper was not available in English, and if participants were under the age of 18.

2.3 Selection process

All articles identified from the search from the databases were exported to a reference manager software called Endnote X20 (Clarivate Analytics, Philadelphia, PA, USA). Duplicates were removed, all references were then exported to another reference management software called Covidence (Veritas Health Innovation,

Melbourne, Australia). Articles were first screened by text and abstract, those who were deemed relevant underwent a full-text review. The articles were screened against the inclusion-exclusion criteria by two independent reviewers (N.A and A.M), discrepancies between reviewers were then resolved by a discussion.

Studies that included participants under the age of 18 were contacted asking for data specific to the population of interest. A few articles did not specify whether the injury was acute or chronic, thus the authors of these articles were contacted for further information.

2.4 Data extraction

The following data were extracted from the selected articles: Aim; sample size; study design, time since injury, participant number, clinical assessment tool, reference standard, assessing clinician (profession and experience), time to reach diagnosis, the median number of appointments to reach diagnosis, the meantime to await surgery and diagnostic accuracy.

2.5 Quality appraisal

The QUADAS-2 checklist (Appendix 1) a quality appraisal assessment tool was used to assess papers. The QUADAS-2 is widely used for studies evaluating diagnostic accuracy assessment measures. It is made up of 4 domains: patient selection, index tests, reference standards, and flow and timing. As shown in Table 2, the first 3 domains are split into assessing sections A and B, A) risk of bias, and B) concerns regarding applicability. The 4th domain: flow and timing, did not include section B. The sections were comprised of signalling questions (Table 2) that would ultimately determine the 'risk of bias' and 'concern regarding applicability'. The QUADAS-2 is not designed to give an overall quality score, instead, it provides an overall judgment on the two assessment criteria. If a paper had more than one signalling question that was 'at high risk' (X) it was regarded as 'at risk of bias', the 'concern regarding applicability' was then assessed.

3.0 Results

A total of 673 articles were initially obtained across all three databases. After duplicates were removed, 353 articles were included in the review. Once the titles and abstracts were screened, 64 articles were eligible for a full-text review. Following this, six articles were identified as being appropriate for inclusion, Figure 1 details the PRISMA diagram and the reasons for article exclusion at each stage.

Main characteristics of included studies

Table 3 details the main characteristics of the included studies of the review. All studies used a consecutive sampling method, however the articles varied in sample size and study design. A mixture of prospective and retrospective designs were used and methodology varied amongst studies.

The study completed by Clifford et al (15) included participants with injuries that were outside of the acute timeframe (6 weeks), authors provided raw data for all participants and only the data of those who matched the inclusion criteria (61/82) were included in this review.

Article quality

The QUADAS-2 showed variation between studies, as represented in table 4. The risk of bias in domain 1 was high for 50% of the articles (4, 7, 19), these were negatively impacted due to an insufficient sample size attributable to the absence of power calculations, inappropriate exclusion criteria, and a retrospective design including only patients who underwent arthroscopy. For domain 2, two of the studies were not explicit when describing their assessment methods, thus negatively affecting the risk of bias, and resulting in an unclear concern regarding applicability (4, 19). In domain 3, the article that was at high risk of bias (3) completed a clinical assessment as their 'reference standard' which is not the gold standard for ACL injury diagnosis, another study's (19) risk of bias was unclear as the reference standard was not clearly stated. Domain 4 appeared to be the poorest across all the studies, many articles (4, 7, 19) did not define the time frame between the index test and the reference standard. In addition, participants in two studies did use a consistent reference standard (15, 19). Figure 2 represents the percentage of articles scoring high, low, and unclear for each domain.

Index tests

Table 5 presents the index tests and reference standards used in the studies included in the review. An index test, in this instance, is the initial assessment method(s) used to evaluate the knee. Passive laxity tests such as Lachman's, anterior drawer, and the pivot shift test were used to assess knee instability in two of the articles (7, 15). Lee and Yun (14) used ultrasound and an unspecified clinical assessment as their index test. Joint effusion was part of the initial assessment in 3 of the studies (3, 7, 15), inability to continue activity was also an injury indicator in two of these articles (3, 15). Another study's index tests comprised of palpation, temperature, and joint line tenderness (2), whilst a different article used X-Rays as a means of ruling out fractures (7). Giving way and a 'pop' at the time of injury were a strong indicator of injury in two of the articles (15). The other two studies left their initial assessment method unspecified (7, 15).

Reference standard

A reference standard, in the context of ACL injury, is a verification tool used to measure the accuracy of the respective index test. MRIs were used as a reference standard in many of the studies (3, 14, 15, 24). Whereas other participants were retrospectively recruited from ACL reconstructive surgeries, leaving arthroscopy the designated reference standard (3, 7, 15). In Clifford et al's study(15), only four participants did not have an MRI, of the 62 patients that met the inclusion criteria, 25 were initially diagnosed using MRI alone, another 25 were diagnosed from clinical examination findings, 9 participants diagnoses were confirmed from a combination of MRI and clinical assessments, and two had an arthroscopy. Hardy et al (3) verified their index test with a combination of an unspecified clinical assessment, MRI, or arthroscopy. They did not specify which participants had the respective reference standard (3). Some studies did not specify their diagnosis verification, they simply eluded that ACL injury was confirmed (4, 19).

Time to reach diagnosis

Table 6 represents the time taken to reach diagnosis, this varied between studies. Whilst Ball et al (19) reported that before an acute knee clinic was established, it took 123 days for diagnosis to be confirmed, after the acute knee clinic was formed this reduced to 14 days. Lee and Yun's participants (14) were immediately scheduled for an MRI after their ultrasound on initial presentation to A&E, they reported diagnosis took an average of 3.8 days. Hardy et al (3) observed a considerable increase in the delay to diagnosis when follow-ups were not scheduled. Participants who had a follow-up arranged had a delay of 29 days to diagnosis, when the patients who were diagnosed at initial consultation were removed, the delay increased to 46 days. Participants with no follow-up arranged had a delay of 198 days to diagnosis, when those who were diagnosed at initial consultation were removed, this increased to 229 days. Wang et al's (7) participants were all referred to an out-patient department to be seen by professionals in a specialist knee clinic within 7-14 days of initial presentation to the Emergency Department. It was eluded that confirmation of diagnosis was reached at this outpatient visit, patients who had an aspiration performed on initial A&E presentation took 6.7 days to be diagnosed; those who did not, took an average of 6 days. Parwaiz et al (4) had 48.8% of the participants present to A&E, of these, only 5% were diagnosed on initial presentation, there was no further data on how long diagnosis took to be confirmed. Clifford et al's data revealed diagnosis took on average 115 days (15).

Statistical analysis

A meta-analysis of the weighted mean time to reach diagnosis for all the studies was calculated to be 68.60 days [CI 23.94, 113.24] (figure 3).

Mean number of appointments to reach diagnosis

Three of the papers reported the number of appointments to reach diagnosis, ranging from 2 to 5 (table 6). However, the number of appointments varied depending on the study design, those that only used imaging modalities took less time to reach diagnosis (2 appointments) (14) compared to those that did not (3.3 and 5 appointments) (19) (15).

Assessing clinician

Table 7 displays the assessing clinicians and time until surgery. Ball et al (19) did not specify the assessing clinician before the acute knee clinic was established, however, all participants were assessed in the emergency department. Patients assessed in the acute knee clinic were seen by a 'knee specialist'. The study by Lee and Yun (14) included a board-certified emergency physician with over 5 years of experience, and an MSK radiologist familiar with ultrasonography and diagnosis of ACL injury. The radiologist trained the emergency department practitioner in sonography prior to the study (14). Hardy et al (3) described the assessor in the acute knee clinic as 'a person highly trained in a particular branch of medicine', 22 were included, some of which were surgeons. Wang et al's (7) initial clinical assessment was performed by a

junior orthopaedic surgeon; they were then followed up by a senior orthopaedic surgeon with over 10 years of experience (7). Parwaiz used either an advanced nurse practitioner, a junior emergency department trainee, or a senior emergency department trainee to assess participants (4). Clifford et al (15) used participants that were assessed by a variety of clinicians on initial presentation.

Time until surgery

Not all studies included data about surgery (table 7). Ball et al's (19) participants waited on average 196 days (3-48) to receive their relevant surgery before the acute knee clinic was established, this then decreased to 126 days (8-480) afterwards. Hardy et al (3) did not record the surgical waiting times, however, data was published from the time of injury to when participants had their initial appointment with a surgeon. Initial surgical consultation increased when patients were not arranged a follow-up after their initial consultation. Those who had a follow-up arranged were waiting 61 days (47-80), and those who had a follow-up arranged once patients who received their diagnosis on initial appointment were removed, waited for an average of 69 days (51-93). Those with no follow-up arranged waited an average of 328 days (213-503) and those with no follow-up arranged once patients who received their diagnosis on initial appointment were removed waited for an average of 311 days (210-481).

Diagnostic accuracy

Of the articles that had values published for diagnostic accuracy (Table 8), Lee and Yun (14) recorded high accuracy of both ultrasound performers 1 and 2 of 91.9% and 93.6% respectively. Hardy et al (3) recorded 99.5% of participants reported at least 1 facet of the LIMP index, 95.8% reported 2, 83.9% of participants reported 3, this dropped to 57.8% of participants reporting all 4 variables of the LIMP index. Wang et al and Clifford et al both investigated the pivot shift and Lachman's test. Whilst Wang et al had values for accuracy, Clifford et al only have sensitivity data as a result of the way they sampled their participants. The Lachman's had poor accuracy in Wang et al's study when initially performed in the Emergency Department at the time of injury in both the aspirated and non-aspirated cohort (47.1% and 40.5% respectively). This increased to 76.5% in the aspirated cohort when reviewed 2 weeks later in the outpatient department, this value was similar to the sensitivity reported by Clifford et al (77.4%). Values for the pivot shift test varied massively (9.5-100%), the accuracy increased significantly in the aspirated knee group (from 11.8% to 76.5%). Clifford et al's study revealed an unremarkable sensitivity of 100%, however, this result was only based on 3 participants. Parwaiz et al (4) did not have any data on the diagnostic accuracy of their assessment methods.

Discussion

This literature review evaluated the current diagnostic methods and assessment pathways available to patients presenting themselves to an Emergency Department with a suspected ACL injury. Although numerous papers investigated diagnostic accuracy for ACL tears, only 6 were identified that assess for ACL injury in an acute timeframe (less than 6 weeks), and an acute trauma setting.

A reoccurring theme in the literature is that the time to reach a diagnosis is reliant on a thorough assessment at initial presentation, which is not always guaranteed in current clinical practice. The difficulty arises when inexperienced assessors are presented with an acutely swollen knee(4, 7, 25), indicating a greater need for a recognised, consistent approach amongst non-specialist departments, in order to reduce prolonged and false-negative diagnoses.

Of the 6 papers reviewed, article quality was low, this was primarily due to: (a) absence of power calculations, (b) retrospective design (c), unspecified index tests and reference standards, and (d) undefined timeframes between diagnostic tests and verification. Many studies were insufficiently powered or were retrospective in nature, sampling patients who had undergone reconstruction is not representative of the whole population. Both factors increase the risk of bias for domain 1. Unspecified index tests and reference standards lead to an inability to assess the risk of bias or concern regarding applicability, thus affecting the quality scores of domains 2 and 3. Domain 4 was negatively impacted by undefined timeframes between the initial assessment (index test), and the diagnostic verification (reference standard). If this is not standardised amongst participants, longer wait times between the index test and reference standard will have repercussions on the recorded accuracy of the assessment method. Consequently, this quality review has identified many areas for improvement for studies evaluating diagnostic tests.

A plethora of index tests were used to identify ACL injury. Laxity tests were common and often accompanied by a subjective assessment and a history of the mechanism of injury. Swelling in particular, alluded to a high suspicion of an ACL tear but was also a barrier to accurate assessment, as demonstrated by Wang et al (7). The authors theorised that aspiration reduces Substance P within the joint, which consequently decreases pain and prevents the patient from 'guarding' during joint instability tests (7).

Radiological methods, such as ultrasound and X-rays (14, 15) were popular index tests. Ultrasound allows for fast comparison to the contralateral limb and is not subject to lengthy waitlists (14). Although found useful in this review, ultrasound is not routinely used in the Emergency Department to assess for ACL injury due to the lack of available specialists in front door services(14).

X-rays were used as an assessment adjunct to rule out bony pathology. Nearly all studies used either MRI or arthroscopy to verify injury (12, 13, 26-30) and these were the most popular assessment verification method (3, 7, 14, 15). As such, both are considered as gold standard diagnostic approaches (31, 32), many clinicians within these studies would only confirm a diagnosis on their completion (14, 15), suggesting that many healthcare professionals are not confident in confirming diagnosis based on clinical assessment alone.

When performed by a specialist clinician, the diagnostic accuracy of clinical tests increased significantly (7) this is reflected by the inconsistencies amongst pivot shift test accuracy (9.5-100%) (7, 15). Although Clifford et al reported 100% sensitivity (15), this test was only performed on 3 participants (out of 61), all of which were completed by a 'consultant specialist', which is not reflective of front door assessing clinicians. Diagnostic rates during initial assessment within the emergency department are reported as low as 5% (4), this is attributable to few clinicians performing stability tests during their assessment, often secondary to an unconfident skill set. Instead, patients of concern are triaged to specialist practitioners.

Although this triaging pathway ensures a more accurate assessment, relying solely on specialists to undertake initial assessments relies on Emergency Department clinicians to be able to recognise those suspicious of ACL injury appropriately.

False positives and false negatives are the two obstacles within acute MSK injury assessment, if assessment criteria are too rigid and specific, false negatives occur which is a direct cause of lengthy diagnoses. Contrary to this, if assessment criteria are too comprehensive, although accuracy may be high, false-positive diagnoses will also be in abundance, thus encompassing many other differential diagnoses and overwhelming the service; a prime example of this is within Hardy et al's LIMP index (3).

The varied time periods to reach a diagnosis is attributable to the differences in the study design and the assessing clinician. The meta-mean calculated (68.60 days) for the time to reach diagnosis is not necessarily representative of clinical practice. Diagnostic accuracy was highest in the studies using ultrasound and joint aspiration (7, 14), both of which are unsurprising due to the expertise required to undertake these assessment methods.

There is a clear correlation between faster diagnoses and more efficient diagnostic pathways. Late diagnosis leads to delayed surgical review, as illustrated in table 7 (3, 19); this impacts the optimal management pathways. Those with clinical follow-ups arranged reached diagnosis in a shorter period(3, 7, 19). Lengthy diagnoses were a consequence of prolonged referral times between initial assessment and a specialist review, resulting in multiple appointments before a diagnosis is reached(19)(table 6). This is secondary to ineffective initial assessments and subsequent false negatives on clinical testing. The effects of lengthy diagnosis are exposed over time, ACL deficient knees are associated with an increase in "giving way" episodes and knee instability. Receiving the appropriate management, whether surgical or conservative, aims to prevent "giving way" and to correct gait abnormalities. Which in turn, prevent subsequent injury deterioration and development of PTOA.

Limitations must be considered when analysing the review. Some of the included papers were not of high quality, thus affecting the evidence conclusions. Most of the data outcomes showed heterogeneity, subsequently, meta-analysis calculations could only be completed for the outcome "time to reach diagnosis", for which, confidence intervals could not be demonstrated for each article (due to insufficient statistical data). The time to reach diagnosis is hard to definitively timestamp, clinical impressions and working diagnoses are often made early on, the question therefore arises: when is diagnosis actually reached? Also, it must be considered that the 'time taken until surgery' was noted as an outcome for 2 of the studies, this is not representative of the conservative management group; complexities arise when trying to define a point in time to represent delayed diagnosis within this patient group. The knee is the most commonly injured joint within sport; ACL injuries account for around 40% of all sporting trauma, without considering ACL injuries outside sport. This study only reflects a small proportion of these, more reviews like this must be undertaken for more data to be available and represented in this area. However, it must be recognised that the lack of publications in this area are a consequence of the adversities in setting up trials in acute settings and phases of injury.

Conclusion

The time to reach diagnosis ranged from 3.8-229 days, such variation is attributable to the difference in assessment method and triage pathway. Experience and specialization positively correlate with a higher degree of sensitivity and accuracy within a clinical assessment, shown by the variation within the pivot shift test (9.5-100%), such disparity is unacceptable when seeking fast and accurate diagnosis to allow for optimal management of the associated trauma. For patient care to be improved, clinical assessments need to be quick, accurate, and to be performed with confidence from non-specialist clinicians; such methods should produce an accurate, quantifiable value of knee instability. This would help eliminate the subjectivity clinical assessments currently are faced with and reduce the number of false-negative diagnoses assumed on initial presentation. Thus, speeding up diagnosis without increasing the number of false-positive and subsequent pressures on healthcare services.

Abbreviations

ACL: anterior cruciate ligament

A&E: accident and emergency

ROM: range of movement

TOI: time of injury

PTOA: post-traumatic osteoarthritis

MRI: magnetic resonance imaging

MSK: musculoskeletal

Declarations

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Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data generated or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests

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All authors have read and approved the manuscript. NA: manuscript preparation, study design, statistical analysis database interpretation, and manuscript revision.

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Tables

Table 1: Boolean search strategy

Topic Group	Subject headings		Keywords
ACL	MEDLINE EMBASE	Anterior cruciate ligament/	ACL OR anterior cruciate Adj2 ligament OR anterior adj2 cruciate ligament
		Exp Anterior cruciate ligament rupture/	
		Exp Anterior cruciate ligament injury/	
	MEDLINE OVID	Anterior cruciate ligament/	
	EBSCO CINAHL	MH "anterior cruciate ligament"	
Trauma center	MEDLINE EMBASE	Emergency ward/	Emergency department* OR emergency health service* OR emergency adj2 accident OR first contact practitioner* OR casualty OR triage* OR delay adj2 diagnosis OR late* adj1 diagnos* OR orthop?edic clinic* OR knee clinic* OR Emergency ward*
		Exp emergency health service/	
		Delayed diagnosis/	
	MEDLINE OVID	EXP Emergency medical services/	
		Delayed diagnosis/	
	EBSCO CINAHL	MH "emergency medical services+"	
		MH "diagnosis, delayed"	

Table 2: Signalling questions for QUADAS-2 quality assessment

Signaling questions for QUADAS-2 quality assessment	
Domain 1: patient selection	
A: risk or bias	Was a consecutive or random sample of patients enrolled?
	Did the study have appropriate exclusions?
	Was the study retrospective?
	Was a sufficient sample size used?
	Could the selection or patient have introduced bias?
B: concerns regarding applicability	Are there concerns that the included patients do not match the review question?
Domain 2: index test(s)	
A: risk or bias	Were the index test results interpreted without knowledge of the results of the reference standard?
	Were all the index tests specified and clearly explained?
	Could the conduct or interpretation of the index test have introduced bias?
B: concerns regarding applicability	Is there concern that the index test, its conduct, or interpretation differ from the review question?
Domain 3: reference standard	
A: risk or bias	Is the reference standard the 'gold standard' for ACL diagnosis?
	Were the reference standard results interpreted without knowledge of the results of the index test?
	Could the reference standard, its conduct, or its interpretation, have introduced bias?
B: concerns regarding applicability	Is there concern that the target condition as defined by the reference standard does not match the review question?
Domain 4: flow and timing	
A: risk of bias	Was there an appropriate interval between the index test and the reference standard?
	Was the time frame defined where the initial consultation (index test) and/or reference standard was completed? /Unclear
	Did all patients receive a reference standard?
	Did all patients receive the same reference standard?

	Were all patients included in the analysis?
	Could the patient flow have introduced bias?

Table 3: Main characteristics of included studies

Author	Article title	Aims	Participants	Protocol
Ball et al	The impact of an Acute Knee Clinic	Evaluate the impact of an acute knee clinic on diagnosis and treatment for acute knee injuries	100	Design: <ul style="list-style-type: none"> • Prospective study • Consecutive sampling Methods: <ul style="list-style-type: none"> • Audit or timeframes and assessment process
Clifford et al	Acute knee clinics are effective in reducing delay to diagnosis following anterior cruciate ligament injury	Investigate the impact of an acute knee clinic compared to the standard A&E pathway	61 (that matched the inclusion criteria)	Design: <ul style="list-style-type: none"> • Prospective study • Consecutive sampling Methods: <ul style="list-style-type: none"> • Physical examination • Imaging • Arthroscopy
Hardy et al	The use of history to identify anterior cruciate ligament injuries in the acute trauma setting: the 'LIMP index'	To investigate what clinical history features indicate ACL injuries	194 (163 available)	Design: <ul style="list-style-type: none"> • Prospective study • Consecutive sampling Methods: <ul style="list-style-type: none"> • Survey • Questionnaire • Physical examination • Imaging
Lee and Yun	Feasibility of point-of-care knee ultrasonography for	To evaluate the use of ultrasound compared to	62	Design:

	diagnosing anterior cruciate and posterior cruciate ligament tears in the ED	MRI to diagnose ACL injury		<ul style="list-style-type: none"> • Prospective study • Consecutive sampling <p>Methods:</p> <ul style="list-style-type: none"> • Physical examination • Imaging
Parwaiz et al	Anterior cruciate ligament injury: A persistently difficult diagnosis	To investigate if there has been an improvement in ACL diagnosis over the last 20 years	160	<p>Design:</p> <ul style="list-style-type: none"> • Retrospective design • Consecutive sampling <p>Methods:</p> <ul style="list-style-type: none"> • Retrospective data extraction
Wang et al	Efficacy of knee joint aspiration in patients with acute ACL injury in the emergency department	To evaluate the impact of joint aspiration on the sensitivity of joint laxity tests on patients with ACL injuries through the emergency department	60	<p>Design:</p> <ul style="list-style-type: none"> • Retrospective design • Consecutive sampling <p>Methods:</p> <ul style="list-style-type: none"> • Retrospective data extraction • Physical examination • Imaging

Table 4: Methodological quality summary

STUDY	RISK OF BIAS				APPLICABILITY OF CONCERNS		
	Domain 1: PATIENT SELECTION	Domain 2: INDEX TEST	Domain 3: REFERENCE STANDARD	Domain 4: FLOW AND TIMING	Domain 1: PATIENT SELECTION	Domain 2: INDEX TEXT	Domain 3: REFERENCE STANDARD
Ball et al 2010	X	X	?	?	P	?	?
Hardy 2017	P	P	X	X	P	P	P
Lee and Yun 2020	P	P	P	P	P	P	P
Wang 2016	X	P	P	?	P	P	P
Parwaiz 2016	X	X	P	?	P	?	P
Clifford et al 2021	P	P	P	X	P	P	P

KEY:

P = LOW

X = HIGH

? = UNCLEAR

Table 5: Assessment methods

Table 6: Time to reach diagnosis

Table 7: tabulation of assessing clinician and delay to surgery

AIM	TEST	INDEX TEST	REFERENCE STANDARD
Laxity	Lachman's	(7, 15)	(15)
	INSTABILITY'	-	-
	Lever sign	-	-
	Pivot shift	(7, 15)	(15)
	Anterior drawer	(7, 15)	(15)
	KT1000	-	-
Range of movement	Active range of movement	(7)	-
	Passive range of movement	-	-
Swelling	Time delay swelling	(15)	-
	Joint effusion	(7, 15)	(15)
Functional ability	Weight bare	-	-
	Inability to continue activity	(15)	-
	Gait	-	-
Pain	Palpation	(7)	-
	Temperature	(7)	-
	Joint line tenderness	(7)	-
	Pain	-	-
Imaging	X-RAY	(15)	(15)
	Ultrasound	(14)	-
	CT	-	-
	MRI	-	(3, 14, 15)
Subjective assessment	Mechanism of Injury	-	-
	Lysholms functional score	-	-
	Locking	-	-
	Unspecified clinical history	(3, 4)	-
	Clicking	-	-
	Giving way	(15)	-
	Popping sound	(15)	-
	Limp index	(3, 15)	-

Unspecified assessment	Unspecified clinical assessment	(4, 14)	(3)
	Physicians' agreement	-	-
	Unspecified	(19)	(4, 19)
	Orthopaedic surgeon exam	-	-
Surgery	Anaesthetic eval	-	-
	Arthroscopy	-	(3, 7, 15)

Author	Study components	Study reference number	Meantime to reach diagnosis (days)	Sample size	Mean number of appointments to reach diagnosis
Ball et al 2010	Before acute knee clinic (AKC)	1	123	100	5
	Post-AKC	2	14	100	1
Lee and Yun 2020	Ultrasound	3	3.8	62	2
Hardy et al 2017	Follow up arranged	4	29	120	-
	Follow up arranged with initial diagnosis removed	5	46	101	
	No follow up arranged	6	198	43	
	No follow up arranged with initial diagnosis removed	7	229	40	
Wang et al 2016	Aspirated knee group`	8	6.7	18	-
	Non-aspirated	9	6.0	42	
Parwaiz et al 2016	Those presenting to an Emergency Department	-	Not documented – although only 5% reached initially	78	-
Clifford et al 2021	Whole Participant sample	10	115	61	3.3
Meta Mean		11	68.60	-	-

Author	Assessing clinician	Time until surgery	
Ball et al	Unspecified	196	
	'specialist'	126	
Lee and Yun	Board-certified emergency physician with over 5 years of experience	-	
	AND		
	specialist MSK radiologist		
Hardy et al	22 specialists	Follow up arranged	61
		Follow up arranged with initial diagnosis removed	69
		No follow up arranged	328
		No follow up arranged with initial diagnosis removed	311
Wang et al	In the ED	junior orthopaedic surgeon	-
	In the OPD follow-up	senior orthopaedic surgeon	
Parwaiz et al	advanced nurse practitioner	-	
	OR		
	A junior ED trainee		
	OR		
	A senior ED trainee		
Clifford et al	triaged by an A&E Sister and assessed by an A&E physician	1	-
	A&E registrar	1	
	triaged by nurses and assessed by	4	

an A&E Physician	
normal adult triage route and then assessed by an A&E physician	53
adult triage and was then assessed by an emergency nurse practitioner	1
orthopaedic doctor	1

Table 8: Diagnostic accuracy of index tests

Authors	Diagnostic accuracy					
Ball et al	Unspecified					
Lee and Yun	Ultrasound performer 1			91.9%		
	Ultrasound performer 2			93.6%		
Hardy et al	All 4 facets			57.8%		
	3 facets			83.9%		
	2 facets			95.8%		
	1 facet			99.5%		
Wang et al	Group 1- Aspirated knee			Group 2- non-Aspirated knee		
	ED	Lachman's	47.1%	ED	Lachman's	40.5%
		Pivot shift	11.8%		Pivot shift	9.5%
	OPD	Lachman's	76.5%	OPD	Lachman's	47.5%
		Pivot shift	76.5%		Pivot shift	31.0%
Parwaiz et al	Unspecified					
Clifford et al				Sensitivity		
	Lachman's			77.4%		
	Anterior Drawer			64.3%		
	Pivot Shift			100%		

Figures

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Figure 1

PRISMA diagram detailing the selection process

Figure 2

a and b: methodological quality graph summary: Bar chart representing the percentage of studies that are rated low, high, and clear for each domain for both sections A (risk of bias) and B (concerns regarding applicability).

Figure 3

Scatter Diagram showing the 'meantime to reach diagnoses for individual sub-sample groups, and meta mean with 95% confidence intervals (table 6).