Diagnostic Imaging of Ulnar Collateral Ligament Injury

CME

A Systematic Review

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Background: Ulnar collateral ligament (UCL) injuries can be debilitating in overhead athletes. Accurate diagnosis is important; however, several imaging modalities are available for the assessment of UCL injuries.

Purpose: To provide a comprehensive review of published literature regarding the diagnostic capabilities of different imaging modalities for UCL tears.

Methods: PubMed, Medline, and Embase were queried for peer-reviewed literature published between January 1947 and June 4, 2019, pertaining to diagnostic imaging of UCL tears. Articles assessing static and stress radiography, ultrasound, magnetic resonance imaging (MRI), MRI with arthrography (MRA), and computed tomography arthrography of the UCL were included. Studies were excluded if imaging results were not compared with intraoperative diagnosis, as intraoperative findings are generally considered the gold standard for diagnostic comparison. The articles were assessed per the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) guidelines and reviewed with the Quality Assessment of Diagnostic Accuracy Studies, version 2 (QUADAS-2) assessment.

Results: The literature search yielded 2478 articles, of which 15 were included in this review. Potential bias was noted in each QUADAS-2 subsection. Multiple studies demonstrate an association between UCL tears and osseous abnormalities identified on static radiographs; however, the use of static or nonstressed radiographs is not recommended for specific evaluation of UCL injuries. Conventional ultrasound was 81% sensitive and 91% specific, as compared with 96% and 81% for stress ultrasound, respectively. The sensitivity and specificity of MRI ranged from 57% to 100% and 89% to 100%. The sensitivity of computed tomography arthrography ranged from 63% to 86%. The sensitivity and specificity of MRA ranged from 81% to 100% and 91% to 100%.

Conclusion: Of the currently available imaging modalities, MRA provides the best combination of sensitivity and specificity of the evaluation of the UCL. Further research comparing ultrasound with MRA is needed.

Keywords: elbow; baseball; ultrasound; computed tomography; magnetic resonance imaging

The medial ulnar collateral ligament (UCL) is the main stabilizing ligament of the elbow against valgus stress. The UCL can become injured by repetitive, high-velocity movements associated with overhead throwing activities.[16] UCL injuries, if untreated, can become debilitating and significantly impair a patient's ability to participate in athletic activities; however, when promptly treated, patients with UCL injuries are typically able to return to play.[18] While patients with complete UCL tears often require surgical reconstruction, partial UCL tears can be treated successfully through nonoperative measures.[5] Therefore, an accurate diagnosis is important, especially for elite or professional athletes.

As with any diagnosis, a history and physical examination are needed for an initial assessment. A history of insidious onset of medial elbow pain and positive physical

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TABLE 1
Literature Database Search Terms[a]

Search Term 1	AND	Search Term 2	AND	Search Term 3
UCL		Injury		Radiograph
Ulnar collateral ligament		Tear		Computed tomography
Medial collateral ligament		Rupture		Magnetic resonance imaging
		Sprain		Magnetic resonance arthrogram
				Ultrasound
				Sonography
				Arthrography
				Arthrogram

[a]UCL, ulnar collateral ligament.

examination findings can significantly increase a physician's concern for UCL injury; however, diagnostic imaging is usually needed to confirm and classify the diagnosis. A myriad of imaging modalities is available for the assessment of patients with presumed UCL injuries. These modalities include plain radiography, stress radiography, conventional or stressed ultrasound, computed tomography arthrography (CTA), and magnetic resonance imaging (MRI) with or without magnetic resonance arthrography (MRA). Multiple imaging techniques are often used to provide a complete clinical assessment of the patient's injury, with each modality offering specific advantages and disadvantages. Static images such as radiographs, MRI scans, and CTAs allow for the assessment of osseous and soft tissue anatomic structures, while valgus stress radiographs allow clinicians to assess the stability of the elbow while under stress. Finally, the versatility of ultrasound allows physicians to assess the static anatomy, stress stability, and dynamic functionality of the elbow. Radiographic studies have risks associated with exposure to radiation, and arthrography can lead to postinjection pain, which may impair use of the arm for multiple days, affecting immediate return to play in some athletes.[6] With each modality offering various advantages and disadvantages, there is a need for a comprehensive review of imaging modalities and evidence-based recommendations.

The purpose of this systematic review is to investigate the published literature regarding the diagnostic capabilities of different imaging modalities for UCL tears, partial and full thickness. We aim to present the sensitivity and specificity of imaging modalities for UCL tears and report associated findings.

METHODS

Search Strategy

PubMed, Medline, and Embase were queried for peer-reviewed literature published between January 1947 and June 4, 2019. The systematic search was performed by 2 trained orthopaedic researchers (R.E.C., A.N.M.) according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[9] A combination of search terms pertaining to UCL tear imaging was used for the literature search (Table 1). The search was limited to articles published in English. The references of articles describing UCL injury diagnosis or treatment were searched as well.

Study Selection

The study selection process was conducted independently by the 2 orthopaedic researchers. Original peer-reviewed articles were included that discussed the use of static and stress radiography, static and dynamic ultrasound, MRI, MRA, and CTA of the UCL. Exclusion criteria included non-English articles, cadaveric studies, case reports with <5 patients, and review articles. Studies were also excluded if imaging results were not compared with intraoperative findings. After both researchers independently screened the literature, their lists were combined and reviewed until consensus was reached.

Data Extraction

The following data were extracted from each imaging study: number of participants, sex distribution, participant age, participant athletic activities, imaging modality and protocols, and imaging results. Data extraction was performed by the 2 aforementioned researchers.

Study Quality Assessment

The quality of each included article was assessed with a modified Quality Assessment of Diagnostic Accuracy Studies, version 2 (QUADAS-2).[23] The QUADAS-2 assesses risk of bias in 4 domains for each article: patient selection, index test (diagnostic test of interest), reference standard, and flow and timing.

Outcome Reporting

The results were stratified by imaging modality. Where applicable, the sensitivity, specificity, and positive predictive value were calculated per the data reported in each article.

RESULTS

Study Selection

After duplicates were removed, the literature search yielded 2478 articles. Among these, 2353 articles were removed after their titles and abstracts were screened. A total of 125 articles underwent full-text review. The article list was reduced to 12 peer-reviewed articles; however, reference screening of the 125 reviewed articles yielded an additional 3 articles. Overall, 15 articles published between January 1994 and June 2017 were included for qualitative review.

Study Characteristics

Of the 15 articles, 11 were retrospective cohort studies,[2-4,7,8,10-12,15,17,21] and 4 were prospective cohort studies.[14,19,20,22] The studies performed by Joyner et al[7] and Bruce et al[3] comprised the same patient population; however, each article reports different aspects of diagnostic evaluations. With the exception of the study performed by Magee,[8] the patient population of each study consisted mostly of overhead athletes, primarily baseball players. When reported, patient ages ranged from 9 to 59 years old (Table 2).

QUADAS-2 Risk and Qualitative Assessment

Potential bias was evident in each subsection (Table 3). Multiple studies were potentially biased by sample sizes $\leq$10 or by patient populations in which $<$70% of patients underwent the index or reference diagnostic study.[4,11,19,21] In 9 articles, bias was introduced by the inclusion of only patients who underwent surgical reconstruction.[2-4,7,11,12,17,21] Mulligan et al[10] included only patients with heterotrophic calcifications, significantly biasing their patient population.

Multiple studies did not adequately describe the methodology used for the index diagnosis test, making the risk of bias unclear.[2,12,15,17,21,22] Thompson et al[21] performed stress radiographs with manually supplied valgus stress instead of a standardized device. This may have introduced bias if different amounts of stress were placed on the elbow joint. Cain et al[4] and Mulligan et al[10] reported combined MRI and MRA results. Nakanishi et al[11] described imaging observations only.

There were also multiple concerns for applicability to current patients. Valgus stress radiographs are commonly performed with a standardized stress device; this significantly limits the application of the stress radiograph results presented by Thompson et al.[21] Although the specification of the computed tomography imager used by Timmerman et al[22] was not described, it is probable that the imaging system in 1994 is considerably different than the computed tomography imagers currently used.

Static Radiograph

Rijke et al[14] investigated the diagnostic utility of unstressed elbow joint space measurements, obtained via radiographs, for large partial or complete UCL tears in 21 patients. The authors were unable to identify a difference in joint space width between injured and noninjured elbows. Bruce et al[3] also investigated the difference in medial joint space measurements between 226 elbows with UCL injuries and noninjured contralateral elbows. Similar to Rijke et al, they did not identify a significant difference between injured and uninjured elbows.

However, specific findings on plain elbow radiographs may be indicative of UCL injuries. Petty et al[12] identified osseous elbow abnormalities on preoperative radiographs of 33% (9/27) of patients who underwent UCL reconstruction. The most common finding was sublime tubercle avulsions (6 patients). Similarly, Salvo et al[17] identified avulsion fractures of the sublime tubercle in 24% (8/33) of patients treated for UCL injuries. Through retrospective review of 1014 preoperative radiographs, Cain et al[4] identified osseous abnormalities in 57% of patients undergoing UCL reconstruction. The most common findings were olecranon osteophyte formation (148/1014) and ectopic calcification within the UCL (94/1014).[4] Mulligan et al[10] investigated the relationship between heterotopic calcifications and UCL tears. Of 42 patients with heterotopic calcifications, 34 underwent surgical treatment. A total 19% (8/42) had intact UCL ligaments; 14% (6/42), partially torn UCLs; and 48% (20/42), completely torn ligaments. The positive predictive value of heterotopic calcifications for UCL tears was 62%.[10] Joyner et al[7] also identified a 33% prevalence of UCL calcification in patients with partial or complete UCL tears.[7] However, this finding appears to be associated with chronic injuries, as the time between injury and elbow radiograph was approximately 3 months longer in patients with UCL calcifications.

Stress Radiograph

Thompson et al[21] reported stress radiograph findings for 43 of 83 (52%) patients who underwent UCL reconstruction. Of the 43 patients, 88% demonstrated a difference in joint space opening $>$2 mm between the injured elbow and the contralateral elbow. Thompson et al speculated that the lack of stress radiographs in the other 48% of patients was due to obvious diagnosis.

Using the same cohort as cited earlier, Rijke et al[14] demonstrated that elbows with UCL tears exhibited significantly larger valgus-stressed joint space measurements than uninjured elbows (mean $\pm$ SD, 5.3 $\pm$ 1.8 mm vs 3.9 $\pm$ 0.5 mm). The authors also analyzed differences in the increase in valgus-stressed joint space width between the injured and contralateral elbows. Patients with UCL tears exhibited significantly larger increases in joint space measurements than patients without UCL tears (1.1 $\pm$ 0.8 mm vs –0.1 $\pm$ 0.2 mm). The authors concluded that a joint space difference $>$0.5 mm between the injured elbow and contralateral elbow was indicative of a large or complete tear, with a specificity and sensitivity of 100%.[14]

Similar to Rijke et al,[14] Bruce et al[3] demonstrated a significantly larger stressed joint space width in elbows with UCL injuries as compared with uninjured contralateral elbows (5.0 $\pm$ 0.9 mm vs 4.6 $\pm$ 0.8 mm). Injured elbows

TABLE 2
UCL Imaging Study Characteristics[a]

Imaging Modality: First Author[b]	Year	Study Type	No. of Patients	Age, Mean ± SD (Range), y	Index Test Specifications
Static Radiograph					
Rijke[14]	1994	Prospective	21	Not specified	Anteroposterior views
Mulligan[10]	2000	Retrospective	42	22 (16-38)	Anteroposterior, lateral, oblique views
Salvo[17]	2002	Retrospective	33	16.9 (15-19	Not specified
Petty[12]	2004	Retrospective	27	17.4 (15.9-19)	Anteroposterior, lateral, oblique, and olecranon views
Cain[4]	2010	Retrospective	1,014	21.5 (14-59)	Not specified
Bruce[3]	2014	Retrospective	226	20.3 (13-37)	Anteroposterior, lateral, oblique, and reverse axial views
Joyner[7]	2016	Retrospective	264	Not specified	Anteroposterior, lateral, oblique, and reverse axial views
Stress Radiograph					
Rijke[14]	1994	Prospective	21	Not specified	25° of elbow flexion with a 15daN valgus load applied via a Telos stress device
Azar[2]	2000	Retrospective	91	21.6 (15-39)	Anteroposterior views of the elbow with 5, 10, and 15 kPa of valgus stress applied via a fixed arm-holder device
Thompson[21]	2001	Retrospective	83	24.3	Manually applied valgus stress
Petty[12]	2004	Retrospective	27	17.4 (15.9-19)	30° of elbow flexion with a 15-kPa valgus load applied via a Telos stress device
Bruce[3]	2014	Retrospective	226	20.3 (13-37)	20° to 30° of elbow flexion with a 15 daN valgus load
Joyner[7]	2016	Retrospective	302	Not specified	20° to 30° elbow flexion with a 15 daN valgus load. Telos Stress Device
MRI					
Magee[8]	2014	Retrospective	79	23 (14-43)	Coronal (T1 & T2 weighted) and axial (T2 weighted) images 3-tesla imager. 3mm and 4mm section thickness.
Thompson[21]	2001	Retrospective	52	24.3	Not specified
Timmerman[22]	1994	Prospective	25	21.8 (16-34)	Multiplanar MRI with 5-inch general purpose coil.
Petty[12]	2004	Retrospective	27	17.4 (15.9-19)	Not specified
Nakanishi[11]	1996	Retrospective	10	20 (15-27)	Coronal (T1 & T2 weighted) images 1.0-Tesla imager 3mm section thickness
MRA					
Schwartz[19]	1995	Prospective	40	22 (18-36)	Coronal (T1-weighted) multigradient echo images 1.5-Telsa imager 3mm section thickness 3 mL of iopamidol and 7 mL of saline contrast
Nakanishi[11]	1996	Retrospective	10	20 (15-27)	Coronal (T1 & T2 weighted) images 1.0 Tesla imager 3-mm section thickness 10mL saline
Mulligan[10]	2000	Retrospective	30	22 (16-38)	Coronal (T1-weighted) multiplanar gradient-echo images 1.5-Telsa imager 3mm section thickness
Azar[2]	2000	Retrospective	48	21.6 (15-39)	Not specified
Cain[4]	2010	Retrospective	1,281	21.5 (14-59)	Not specified
Magee[8]	2014	Retrospective	79	23 (14-43)	Coronal, sagittal, and axial (fat saturated T1-weighted) 0.075 mL of gadopentetate dimeglumine and 0.925 mL of normal saline
Joyner[7]	2016	Retrospective	240	Not specified	1.5- or 3.0-Tesla imager Gadolinium contrast
Roedl[15]	2016	Retrospective	144	24.5 ± 5.6	1.5-Tesla imager MR imagers gadopentetate dimeglumine
CTA					
Timmerman[22]	1994	Prospective	25	21.8 (16-34)	3mm section thickness 3 mL of contrast and 6 mL of air
Azar[2]	2000	Retrospective	53	21.6 (15-39)	Not specified
Ultrasound					
Tanaka[20]	2017	Prospective	64	12 (9-13)	7.75 MHz linear array transducers
Roedl[15]	2016	Retrospective	144	24.5 ± 5.6	30° of elbow flexion with manually applied valgus stress 13-MHz linear array transducer

[a]CTA, computed tomography arthrography; MRA, magnetic resonance arthrography; MRI, magnetic resonance imaging.
[b]Reference standard per study: intraoperative diagnosis.

also showed a significantly larger increase in joint space width with the addition of valgus stress as compared with the contralateral elbow (1.4 ± 0.7 mm vs 1.0 ± 0.6 mm).[3] These differences remained significant for partial- and complete-tear subgroup analysis. However, contrary to the findings of Rijke et al, only 32% of patients

TABLE 3
QUADAS-2 Literature Assessment[a]

Imaging Modality First Author	Year	Risk of Bias				Applicability Concerns		
		Patient Population	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Static Radiograph								
Rijke[14]	1994		L	M	?	L	L	L
Mulligan[10]	2000	L	?	L	L	L	?	L
Salvo[17]	2002	L	?	L	L	L	?	L
Petty[12]	2004	L	?	L	L	L	?	L
Cain[4]	2010	L	L	L	L	L	L	L
Bruce[3]	2014	L	L	L	L	L	L	L
Stress Radiograph								
Rijke[14]	1994	L	L	L	?	L	L	L
Azar[2]	2000	L	L	L	L	L	L	L
Thompson[21]	2001	M	H	L	L	L	H	L
Petty[12]	2004	L	L	L	L	L	L	L
Bruce[3]	2014	L	L	L	L	L	L	L
Joyner[7]	2016	L	L	L	L	L	L	L
MRI								
Magee[8]	2014	L	L	L	L	L	L	L
Thompson[21]	2001	M	?	L	L	L	?	L
Timmerman[22]	1994	L	?	L	?	L	?	L
Petty[12]	2004	L	?	L	L	L	?	L
Nakanishi[11]	1996	M	L	L	L	L	M	L
MRA								
Schwartz[19]	1995	M	L	L	L	L	L	L
Nakanishi[11]	1996	M	L	L	L	L	M	L
Mulligan[10]	2000	H	M	L	L	L	L	L
Azar[2]	2000	L	?	L	L	L	?	L
Cain[4]	2010	M	M	L	L	L	M	L
Magee[8]	2014	L	L	L	L	L	L	L
Joyner[7]	2016	L	L	L	L	L	L	L
Roedl[15]	2016	L	L	L	L	L	L	L
CTA								
Timmerman [22]	1994	L	L	L	?	L	M	L
Azar[2]	2000	L	?	L	L	L	?	L
Ultrasound								
Tanaka[20]	2017	L	L	M	L	L	L	M
Roedl[15]	2016	L	?	L	L	L	?	L

[a] L: Low Risk, M : Moderate Risk, H :High Risk, ?: Unclear Risk. CTA, computed tomography arthrography; MRA, magnetic resonance arthrography; MRI, magnetic resonance imaging; QUADAS-2, Quality Assessment of Diagnostic Accuracy Studies, version 2.

surgically treated for UCL tears had side-to-side joint space difference >0.5 mm, and only 51% of patients with complete tears had a >0.5-mm difference between elbows.[3]

Unfortunately, multiple subsequent studies have shown that a difference in valgus stress joint width >0.5 mm between the injured and uninjured elbows has low specificity for UCL tear diagnosis. Azar et al[2] observed a valgus stress joint space difference >0.5 mm in 46% of patients surgically treated for UCL tears. Petty et al[12] also reported a difference in valgus-stressed joint space measurements between elbows with UCL injuries and contralateral elbows. Out of 27 patients, 59% had a side-to-side difference in stressed joint width ≥1 mm, while 41% did not.[12]

Expanding on the relationship between stressed joint space width and UCL tears, Joyner et al[7] demonstrated that larger valgus stress joint measurements correlated with worse classification of UCL injuries diagnosed via MRI. Joyner et al also identified the presence of a stress radiographic vacuum sign in 13% (39/302) of patients with UCL injuries, with 97% (38/39) of vacuum signs occurring in patients with a high-grade partial tear or complete tear. The vacuum sign is described as the presence of hypodensity in the trochlear ulnar joint.

Ultrasound

In a study evaluating 64 patients, Tanaka et al[20] examined the relationship between valgus stress ultrasound results and UCL tears diagnosed via MRI. There was no difference in relative (ipsilateral – contralateral) joint space measurements between patients with UCL tears (0.29 ± 1.06 mm) and without (0.08 ± 0.96 mm).[20]

Roedl et al[15] evaluated the diagnostic accuracy of valgus stress and conventional ultrasound for UCL tears as compared with intraoperative observation. An increase in the relative ulnohumeral joint width ≥1.0 mm was defined as a positive valgus stress assessment. The sensitivity and specificity of valgus stress ultrasound for all UCL tears were 96% and 81%, respectively. When full-thickness tears were predicted, a relative gapping of 2.5 mm yielded a sensitivity of 95% and a specificity of 89%. The sensitivity and specificity of conventional ultrasound for all tears, interpreted by one of two trained musculoskeletal radiologist (L.N.N. or a second radiologist), were 81% and 91%. The sensitivity for partial tears and complete tears was 77% and 79%, with a specificity of 94% and 98%.[15]

Computed Tomography Arthrography

In a study evaluating 25 patients, Timmerman et al[22] demonstrated that CTA can diagnose UCL injuries with a sensitivity of 86%. The sensitivity for full-thickness tears and partial tears was 100% and 71%, respectively. The overall specificity was 91%. The only false-positive CTA finding indicated a possible partial undersurface UCL tear, which was found to be intact. Azar et al[2] retrospectively reviewed 56 CTAs in 53 patients who underwent UCL repair or reconstruction. CTA had a sensitivity of 62.5% for all UCL tears.

Magnetic Resonance Imaging

In a study evaluating 52 patients who underwent UCL reconstruction, Thompson et al[21] demonstrated that MRI is 79% sensitive for UCL tears. In a similar study evaluating 27 patients, Petty et al[12] found that MRI is 96% sensitive for UCL tears. Nakanishi et al[11] also indicated that a high-intensity signal in the UCL on T2-weighted MRI sequences was 100% sensitive for the presence of a UCL tear in 10 patients.

The CTA study performed by Timmerman et al[22] also demonstrated that MRI could diagnose UCL injuries with an overall sensitivity of 57%. In this cohort, MRI sensitivity increased to 100% for full-thickness tears but was 14% for partial tears. The overall specificity of MRI was 100%.

Finally, Magee[8] published a study in 2015 investigating the diagnostic accuracy of 3-T MRI for UCL injuries. This study examined 79 patients and had the lowest risk of bias among MRI studies. The results indicate that 3-T MRI was 100% sensitive and 89% specific for the diagnosis of full-thickness UCL tears.

Magnetic Resonance Arthrography

Nakanishi et al[11] correlated extracapsular contrast leakage on MRA scans with intraoperative observations in 10 cases. All cases with intraoperative avulsion fractures demonstrated MRA extracapsular contrast leakage. Extracapsular leakage was also observed in the only case to show complete rupture of the UCL. MRAs without extracapsular leakage were associated with intact UCLs, mainly consisting of scar tissue.[11] Similarly, Joyner et al[7] noted that the T sign (extension of injected contrast distally from the joint line along the cortical margin of the sublime tubercle) was present only in the MRAs of patients with tears occurring at the insertion of the UCL on the sublime tubercle.

Cain et al[4] correlated MRI and MRA scans with intraoperative observations for 871 of 1281 patients who underwent UCL reconstruction. The majority of images were MRAs; however, MRI and MRA scans were combined into 1 analysis. The sensitivity of MRI/MRA for partial tears, complete tears, or insufficient ligaments was 84%.[4] Other MRI/MRA findings associated with UCL injury included olecranon osteophytes, ectopic UCL calcification, flexor muscle tendinopathy or edema, medial epicondylitis, and an olecranon stress fracture.[4] Mulligan et al[10] similarly correlated intraoperative observations with combined MRI/MRA scans (79% MRA) in 30 patients. The overall sensitivity of MRI for UCL injury was 96%; however, 3 complete tears were misdiagnosed as partial tears. The sensitivity for partial and complete tears was 83% and 82%, respectively.

Azar et al[2] reported MRA findings for 48 patients who underwent UCL repair or reconstruction. MRA resulted in a sensitivity of 84% for all UCL tears. In a study assessing 40 patients, Schwartz et al[19] found that MRA can diagnose UCL tears with an overall sensitivity of 92% and a specificity of 100%. The sensitivity for partial and complete tears was 86% and 95%, respectively. Similarly, in a cohort of 144 patients, Roedl et al[15] found MRA to have a sensitivity of 81% and a specificity of 91% for all UCL tears in their patient cohort, which was identical to the accuracy of conventional ultrasound in their cohort. The sensitivity for partial tears and complete tears was 74% and 84%, respectively, with a specificity of 92% and 99%. The separate accuracy results for partial and complete tears were similar to the results of ultrasound in their cohort. Interestingly, MRA was more sensitive than ultrasound for the diagnosis of middle and distal tears, with a sensitivity of 96% versus 68%. However, ultrasound was more sensitive that MRA for the diagnosis of proximal tears, with a sensitivity of 96% versus 64%. Finally, Roedl et al showed that a combination of conventional ultrasound, stress ultrasound, and MRA yielded significantly better accuracy than when each modality was used alone. The sensitivity and specificity of the combined method were 96% and 99%, respectively.

Magee[8] investigated the diagnostic accuracy of 3-T MRA for UCL injuries. The results indicate that MRA was 100% sensitive and 100% specific for the diagnosis of full-thickness UCL tears. The authors noted that MRA revealed 3 partial-thickness tears that were not evident on corresponding MRI scans. MRA also correctly identified 6 intact UCL ligaments that appeared torn on MRI.

DISCUSSION

The differential diagnosis for medial elbow pain in throwing athletes is broad. Although a thorough history and physical examination are crucial for accurate diagnosis, the addition of diagnostic imaging can provide significant insight into a patient's pathology and aid in diagnosis. The results of this systematic review indicate that MRI, MRA, and ultrasound provide the most diagnostic information regarding UCL tears.

Multiple studies have demonstrated an association between UCL tears and osseous abnormalities identified on static radiographs.[4,7,10,12] Heterotrophic ossification, olecranon osteophyte formation, and sublime tubercle avulsions are common findings among patients with UCL tears. However, the low sensitivities and unknown specificities of these findings preclude the use of static radiographs for evaluation of the UCL. Furthermore, findings such as heterotrophic ossification and osteophyte formation are chronic manifestations of UCL injuries and may not be useful in early diagnosis. Nevertheless, plain radiographs are often obtained to rule out other elbow pathology, and the presence of the aforementioned findings may raise the clinician's suspicion for a UCL tear and indicate the need for further diagnostic testing.

The diagnostic accuracy of valgus stress radiographs for UCL tears is unclear. The sensitivity of valgus radiographs varied from study to study. Rijke et al[14] and Thompson et al[21] demonstrated sensitivities of 100% and 88% for varying joint width thresholds. However, multiple studies have demonstrated that a side-to-side joint space difference >0.5 mm was only 32% and 46% sensitive.[2,3,12] Given the large distribution of published sensitivities, we do not recommend the use of valgus stress radiographs.

There are limited studies evaluating the diagnostic accuracy of CTA images. The sensitivity ranges from 63% to 86%, and a specificity of 91% has been reported.[2,22] However, both studies were published >18 years ago. Computed tomography image quality has significantly improved during the past 2 decades,[1] potentially increasing the diagnostic capabilities of CTA. We recommend the use of CTA only in patients with contraindications to MRI.

The sensitivity of MRI for UCL tears was superior to that of CTA and valgus stress radiographs. With the exclusion of the Timmerman et al[22] study in 1994, the overall sensitivity of MRI for UCL tears ranged from 79% to 100% and appeared to increase for the diagnosis of complete UCL tears.[8,21] The specificity of MRI for UCL tears ranged from 89% to 100%.[8,22] Although MRA is often considered superior to MRI for the diagnosis of UCL tears, the sensitivity of MRA for UCL tears was similar to that of MRI, ranging from 81% to 100%.[8,15] The specificity of MRA was also similar to that of MRI, ranging from 91% to 100%,[8,15] although formal comparison is limited by differences in MRI techniques.

In a direct comparison, Magee[8] found that MRA was more specific than MRI (100% vs 89%) and better suited to identify partial-thickness UCL tears. Despite the need for more head-to-head trials comparing MRI and MRA, we recommend the use of MRA over MRI when available, preferably with a 3-T imager. The added specificity and increased identification of partial tears associated with MRA often offsets the added discomfort of arthrography; however, there are circumstances in which MRI is preferred over MRA (discussed in the diagnostic pathway).

Finally, ultrasound may become an advantageous diagnostic tool for UCL tears; however, there is currently a paucity of published literature evaluating ultrasound's diagnostic accuracy as compared with intraoperative observations. Roedl et al[15] demonstrated that conventional and valgus stress ultrasound was 81% and 96% sensitive and 91% and 81% specific, respectively. However, the lack of significant differences between injured and uninjured elbows reported by Tanaka et al[20] indicates that the utility of valgus stress US may vary among patients or observers. Currently, there is not enough peer-reviewed evidence to support the diagnosis of UCL tears with ultrasound.

On the basis of the results previously discussed, we propose the following diagnostic protocol for patients with a history and physical examination concerning for UCL injuries. Static radiographs should be obtained in all patients to rule out osseous pathology. Ideally, an easily accessible and highly sensitive imaging modality would be used to screen out patients with a low risk of UCL tears.

Ultrasound may eventually serve this purpose; however, there is not sufficient evidence for the use of ultrasound in this role. Ideally, MRI or MRA would be obtained in patients with positive findings on screening imaging. The combination of ultrasound and MRI or MRA may also be a promising evaluation; however, this method should be further investigated. MRA is the preferred imaging modality for patients with concern for UCL tears, although MRI may be preferred in certain circumstances. The decision to proceed with advanced imaging for the in-season athlete is one that the team physician must determine on the basis of history, a physical examination, and the results of preliminary diagnostic tests. Gadolinium contrast can result in an allergic-like reaction in 0.3% of patients, as well as a delayed onset of pain in the injected joint lasting several days.[6,13] This prolonged postarthrography pain may affect athletes' ability to immediately return to play after examination. Patients with previous adverse gadolinium reactions or those would need to continue using the affected arm for work or sports purposes may prefer MRI over MRA. CTA should be obtained in patients with contraindications to MRI. When MRA or MRI scans are obtained, a 3-T MRI scanner should be used when available.

This study has many strengths. It represents a comprehensive review of the diagnostic imaging modalities available for UCL injuries. The data were not combined in meta-analysis format owing to the heterogeneity of the literature and reporting methods, thereby permitting the data to be analyzed as presented. Despite this, there are potential limitations to this review. The majority of articles included in this review were retrospective cohort studies and included small sample sizes. Many of the articles also reported results only for patients who underwent UCL reconstruction or repair, which may bias the conclusions with regard to partial injuries or those who respond to nonoperative treatment. This prevented the assessment of specificity and negative predictive value. There was also considerable heterogeneity of imaging characteristics within each group. For example, studies including 1-, 1.5-, and 3-T MRI scans were included in this review.

While the primary purpose of this systematic review was to report the diagnostic capabilities of different imaging modalities for UCL tears, this study highlights the paucity of evidence supporting the use of these imaging modalities. Orthopaedic surgeons and radiologists would greatly benefit from future research investigating the accuracy of different modalities in assessing different subtypes of tears, such as proximal tears, distal tears, and avulsions, as well as partial and complete tears. Similarly, further research is needed to evaluate the combination method described by Roedl et al.[15]

CONCLUSION

In conclusion, multiple imaging modalities are available for the assessment of UCL injuries. Ultrasound assessment of the UCL may be promising; however, there is not sufficient evidence to recommend its use based on published studies. Of the currently available imaging modalities, MRA provides the best combination of sensitivity and specificity of the evaluation of the UCL.

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