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HIP

The dimensions of the hip capsule can be measured using magnetic resonance imaging and may have a role in arthroscopic planning

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Abstract

Purpose The purpose of this study was to systematically evaluate the dimensions and thickness of the hip joint capsule. Secondarily, the study assessed whether there were any described correlations between capsule thickness and stability of the hip joint.

Methods Four databases (PubMed, Ovid [MEDLINE], Cochrane Database, and EMBASE) were searched from database inception to May 2018, and two reviewers independently and in duplicate screened the resulting literature. Methodological quality of all included papers was assessed using the Methodological index for non-randomized studies (MINORS) criteria. Mean differences were combined in a meta-analysis using a random effects model when possible.

Results A total of 14 studies (1 level I, 1 level II, 4 level III, 5 level IV) were identified including 796 patients (1013 hips) with a mean age of 39.5 years (range 2–95). Of the included patients, 55.2% were female and they were followed up for a mean of 7.6 months (range 1–12.5 months). The thickness of the capsule was measured in cadaveric specimens, ultrasound, and magnetic resonance imaging (MRI), with MRI measurements reported most consistently and with the least variation. Mean thickness of the anterior capsule in patients without hip disease on MRI ranged from 4.4 and 4.7 mm. Mean thickness of the anterior capsule in patients with FAI ranged between 4.9 and 5.0 mm. Males had significantly thicker capsules than females (mean difference = 1.92 mm, 0.35–3.49, $P = 0.02$). Clinical laxity of the hip joint, as well as female gender was correlated with thinner anterior joint capsules.

Conclusion The thickness of the anterior hip capsule can be measured consistently using MRI. A thinner anterior capsule may be associated with clinical laxity of the hip joint. The relevance of capsular thickness on postoperative instability following hip arthroscopy is poorly understood and warrants further investigation. The thickness of the anterior hip capsule, as measured on MRI, has the potential to be used as part of the clinical decision-making in capsular management strategies.

Level of evidence IV.

Keywords Hip · Capsule · Thickness · Arthroscopy

Introduction

The capsule functions as a critical component of both the function and stability of the hip joint [32, 43]. The importance of the capsule on stability of the hip is magnified when

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there is an underlying bony or soft-tissue abnormality that contributes to instability of the hip joint. Soft tissue laxity can be caused by injuries such as repetitive microtrauma, or due to collagen disorders such as Ehlers–Danlos syndrome. Osseous abnormalities that may contribute to instability of the hip include acetabular dysplasia, and borderline acetabular dysplasia [32]. However, instability of the hip is multifactorial, and patients without collagen disorders or osseous deformities can have symptomatic laxity of the hip joint. Microinstability of the hip is a relatively new clinical entity, often defined as pathological laxity that causes symptomatic and abnormal motion of the hip [41].

Biomechanical evidence supports the role of the capsule in stability of the hip joint [27, 32]. The ischiofemoral ligament, zona orbicularis, and iliofemoral ligament are important components of the capsule, with the later thought to be most important in conforming stability at the anterior aspect of the hip joint [12]. The iliofemoral ligament forms the anterior aspect of the capsule with its origin on the anterior inferior iliac spine and its insertion consisting of two parts, the lateral arm which inserts on the anterior greater trochanteric crest, and the medial arm which inserts on the distal intertrochanteric line [26, 47]. A cadaveric motion analysis study has found that capsular laxity significantly increased joint rotation, and femoral head translation, leading to abnormal movement paths of the femoral head center. These abnormal motions of the hip are thought to be part of the mechanical origin of the pain and instability associated with microinstability of the hip [13].

Femoroacetabular impingement syndrome (FAIS) is a relatively recently documented etiology of hip and groin pain in young, active patients [5]. Arthroscopic surgical correction of bony deformities and associated chondrolabral pathology is a treatment modality for patients with FAIS that is being used increasingly more often [6, 18]. Although rare, postoperative instability remains a feared complication by surgeons due to the potential for a catastrophic outcome [40, 51]. Intraoperative capsular management strategies include leaving the capsule unrepaired, partial repair, complete closure, and capsular plication [33]. While stability postoperatively is an important consideration, plication is not indicated in all patients as adhesive capsulitis of this hip can cause patients significant morbidity [39]. Indications for particular management strategies have not yet been established, however, it is thought that capsular closure may be indicated in patients considered to be "at-risk" for postoperative instability [11, 32].

Patient characteristics including ligamentous laxity, hip dysplasia, and female sex have been implicated as risk factors for postoperative instability [51]. Another factor that may be related to the stability of the hip postoperatively relates to the dimensions and thickness of the hip capsule. However, standard dimensions and thickness of the hip capsule have not clearly been established and the relationship to the stability of the hip joint remains unclear.

The purpose of this study was to systematically evaluate the dimensions and thickness of the hip joint capsule. Secondarily, the study assessed whether there were any described correlations between capsule thickness and stability of the hip joint.

Materials and methods

Search strategy

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement was used for the reporting of study selection [29]. Four online databases (EMBASE, PubMed, Cochrane Database and Ovid [MEDLINE]) were searched for literature from database inception until May 22, 2018 investigating the dimensions of the hip capsule. The search was designed to be broad and captive including the terms: "hip", "arthroscopy", and "capsule" (Supplementary Appendix Table).

Study screening

The titles, abstracts, and full-text articles were screened by two reviewers independently and in duplicate. Disagreements during the title and abstract screening moved onto the next stage for more in-depth review. Any disagreements were discussed between reviewers, and a senior author was consulted for any remaining discrepancies. The references of the included studies were subsequently manually screened for additional articles that may have eluded the initial search strategy.

Assessment of study eligibility

The research question and study eligibility criteria were established a priori. The inclusion criteria were English language studies, studies investigating humans, studies with level of evidence I–IV, cadaveric studies, and those assessing the dimensions of the hip capsule were included. Exclusion criteria were animal studies, commentaries, book chapters, review articles, and technical studies.

Data abstraction

Data were collected by two reviewers and recorded them in a Microsoft Excel spreadsheet (Version 2007, Microsoft, Redmond, WA, USA). Abstracted data included the authors, year of publication, study design, sample sizes, sex ratio, mean age, method of capsular measurement, capsular width, capsular thickness, and any clinical correlations.

Quality assessment

The methodological quality of the included studies was assessed using the Methodological Index for Non-Randomized Studies (MINORS) instrument. This tool was designed to assess the methodological quality of comparative and non-comparative, non-randomized surgical studies [42]. Using the MINORS checklist, non-comparative studies are assigned a maximum score of 16, and comparative studies can achieve a maximum score of 24. The quality of included cadaveric studies was assessed using the QUACS (Quality Appraisal for Cadaveric Studies) scale [50]. Using the QUACS checklist, cadaveric studies are assigned a maximum score of 13. Randomized studies were assessed using the Cochrane Bias Assessment Tool [15]. This tool was developed to assess for bias in studies included in the well-established protocol for Cochrane reviews. Categorizing involves deconstructing and assessing the methodology and reporting of the data in seven evidence-based domains. Risk of bias was summarized for each randomized study as "high", "moderate" or "low".

Assessment of agreement

To assess the inter-reviewer agreement, a kappa (κ) statistic was calculated for the title, abstract, and full-text screening stages. An intra-class correlation coefficient (ICC) was calculated for the quality assessment using the MINORS criteria. Agreement was categorized a priori as follows: κ/ICC of 0.61 or greater was considered substantial agreement; κ/ICC of 0.21 to 0.60, moderate agreement; and κ/ICC of 0.20 or less indicating slight agreement [20].

Statistical analysis

The primary outcome was the thickness of the anterior hip capsule. Where possible, a meta-analysis of the comparative studies was performed using the Review Manager software (RevMan) (Version 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). The I^2 tests was used to assess the heterogeneity across the reported results of the included studies. Non-comparative studies were not included in the pooled analyses. The mean differences were then combined using a random effects model, and I^2 values < 50% was considered as low statistical heterogeneity [25]. Given the non-uniform nature of many of the studies included in this systematic review in terms of techniques and outcome reporting, the results are presented in a narrative summary fashion when pooling was not possible. Although agreement of many of the capsule measurement strategies was not assessed by the majority of the included studies, reliability of the measurements was estimated by calculating the standard error of the mean (SEM) values. Descriptive statistics including means, proportions, standard deviations, and 95% confidence intervals (CI) were calculated using Minitab® statistical software (Version 17, Minitab Inc., State College, USA).

Results

Search strategy

The initial search of the online databases resulted in 2032 total studies. A systematic screening and assessment of eligibility identified 14 full-text articles that satisfied the inclusion and exclusion criteria (Fig. 1). The reviewers reached substantial agreement at the title ($\kappa = 0.828$; 95% CI 0.771–0.885), abstract ($\kappa = 0.861$; 95% CI 0.829–0.893), and full-text ($\kappa = 1.00$) screening stages.

Study quality

Overall, there was one randomized controlled trial (level I), one prospective comparative study (level II), four retrospective comparative studies (level III), five case series (level IV), and three cadaveric studies. The randomized controlled trial was considered to have "low" risk of bias, with a low risk of bias in randomization procedure, allocation concealment, selective outcome reporting, among other categories. The MINORS score for the five comparative studies ranged from 16/24 to 19/24. The majority of these studies lacked a prospective collection of data, sample size/power calculation, and contemporary groups. The MINORS score for the five non-comparative studies ranged from 9/16 to 13/16. The studies lacked a prospective collection of data, had high low-to-follow-up numbers, and did not include consecutive patients. The QUACS scores of the cadaveric studies ranged from 9/13 to 11/13. These studies all had insufficient samples sizes, and were not designed to directly address the research question (Table 1).

Study characteristics

Overall, 796 patients (1013 hips) with a mean age of 39.5 years (range 2–95) were included in this systematic review. Of the included patients, 55.2% were female and they were followed up for a mean of 7.6 months (range 1–12.5) (Table 1). In total, 5 studies investigated patients with FAIS, 2 studies investigated patients with isolated chondro-labral injuries, 2 studies investigated patients with synovitis, 1 study investigated patients with developmental dysplasia of the hip, 1 study investigated patients with adhesive capsulitis, 1 study investigated patients with clinical hip impingement, and 6 studies investigated control patients without diagnosed hip pathology (Table 1).

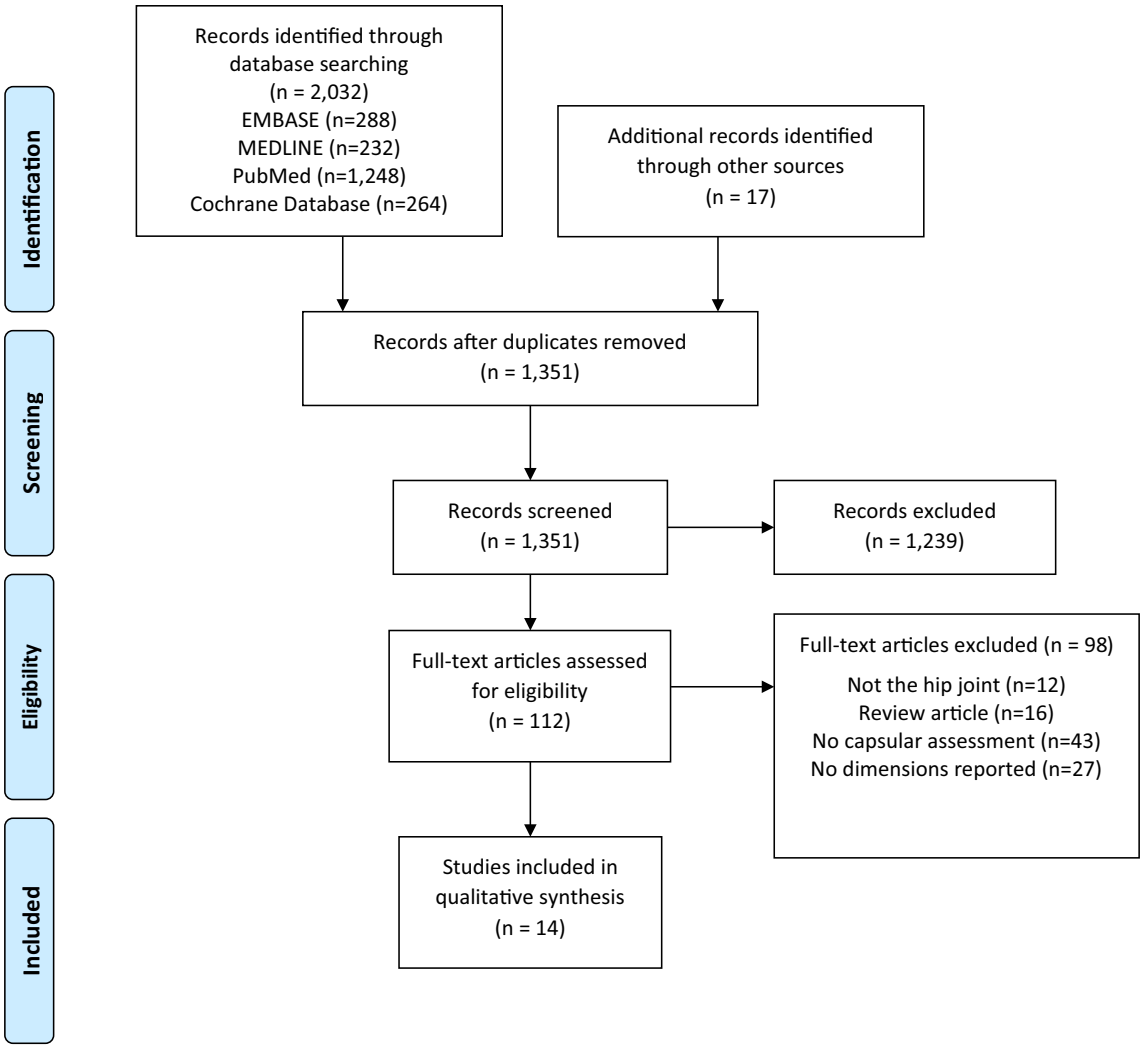

Fig. 1 PRISMA Flow diagram demonstrating the systematic review of the literature for the dimensions of the hip capsule

Techniques of measuring capsular dimensions

The majority of studies (5) used magnetic resonance imaging (MRI) to measure capsular dimensions, with the remainder of studies using magnetic resonance arthrography, open cadaver dissection, ultrasound imaging, and arthroscopically. The capsular dimensions were routinely measured in multiple anatomy reference points using the various aforementioned techniques to record capsular thickness and capsular width. The technical protocols of capsular dimension measurement are summarized in Table 2.

Capsular width in cadaveric specimens

Two studies assessed capsular width in cadaveric specimens [7, 34]. The mean (range) width of the anterior capsule was measured as 5.4 (2.6–10.2) mm at a distance of 5.3 (0.0–10.8) mm from the bony acetabular rim, and 5.6 (1.1–8.7) mm at a distance of 26.5 (17.0–36.0) mm from the chondral head–neck junction by Cooper et al. [7] Cooper et al. also measured the mean (range) width of the superior capsule, which was reported as 8.8 (5.4–12.7) mm at a distance of 4.6 (0.0–9.7) mm from the bony acetabular rim, and 3.7 (3.0–4.5) mm at a distance of 22.1 (14.8–31.5) mm from the chondral head–neck junction. Philippon et al. measured a mean (95% CI) width of the anterior capsule of 10.8 (9.2, 12.3) mm and superior capsule of 11.8 (9.2, 14.4) mm [35].

Capsular thickness on ultrasound

One study assessed the thickness of the capsule using ultrasound measurements [37]. The mean (± SD) thickness of the joint capsule of the asymptomatic hip on children with transient tenosynovitis was measured as 4.90 (3.88–5.92) mm, with SEM of 0.14 mm. In healthy, asymptomatic children, the mean thickness was 4.70 mm [37]. (Table 3).

Table 1 Study characteristics

Authors (year)	Cadaveric/clinical	Study design (level of evidence)	Quality	Number of patients (hips)	% female	Follow-up time (range), months	Mean age (range), years
Cooper et al. (2015) [7]	Cadaveric	Laboratory controlled (level V)	QUACS = 10/13	11 (11)	NR	NR	79.2 (67–95)
Devitt et al. (2017) [8]	Clinical	Case series (level IV)	MINORS = 12/16	100 (100)	55	NR	32 (18–45)
Joo et al. (2014) [16]	Clinical	Retrospective comparative (level III)	MINORS = 17/24	10 (10)	70	4.4 (1–12)	44.4 (28–64)
				20 (20)	65	NR	47.1 (21–72)
Le Bouthillier et al. (2018) [1]	Clinical	Retrospective comparative (level III)	MINORS = 19/24	17 (17)	65	NR	35.1 (19.6–53.6)
				20 (20)	85	NR	38.4 (15.2–62.1)
				20 (20)	55	NR	38.8 (18.9–51.2)
Magerkurth et al. (2013) [24]	Clinical	Case control (level III)	MINORS = 18/24	27 (27)	63	NR	33 (15–61)
Philippon et al. (2014) [34]	Cadaveric	Laboratory controlled (level V)	QUACS = 9/13	14 (14)	14	NR	58 (47–65)
Philippon et al. (2015) [35]	Cadaveric	Laboratory controlled (level V)	QUACS = 11/13	13 (13)	NR	NR	58
Rakhra et al. (2016) [36]	Clinical	Retrospective comparative (level III)	MINORS = 18/24	16 (16)	44	NR	39 (22–58)
				25 (25)	84	NR	40 (18–63)
				15 (15)	33	NR	62 (33–77)
Robben et al. (1999) [37]	Clinical	Case series (level IV)	MINORS = 9/16	58 (116)	36	NR	6.7 (1.7–12.5)
				105 (210)	30	NR	6 (2-12.8)
Soini et al. (2003) [44]	Clinical	Prospective comparative (level II)	MINORS = 16/24	40	55	NR	44 (18–76)
				13	54	NR	39 (27–51)
Strickland et al. (2018) [45]	Clinical	Randomized controlled trial (level I)	"Low" risk of bias	15 (30)	66	6	29.2
Weber et al. (2016) [48]	Clinical	Case series (level IV)	MINORS = 13/16	39 (78)	59	12.5	31.7
Weidner et al. (2012) [49]	Clinical	Case series (level IV)	MINORS = 12/16	30 (30)	50	NR	35 (19–52)
Zhang et al. (2018) [52]	Clinical	Case series (level IV)	MINORS = 13/16	188	66	NR	32 (8–66)

NR not reported

Capsular thickness intraoperatively

The thickness of the capsule was measured intraoperatively by one study using an arthroscopic hook probe (3-mm; Smith & Nephew) calibrated with 5-mm laser etching. The hook was placed on the internal surface of the capsule at the most extreme anterior margin of the capsulotomy, which corresponded with the location of the iliofemoral ligament [8]. The mean (± SD) thickness of the capsule in males was measured as 12.5 (9.8–15.2) mm, with SEM of 0.4 mm, while that in females was 7.8 (5.0–10.6) mm with SEM of 0.38 mm.

Capsular thickness in cadaveric specimens

Two studies assessed the capsular thickness in fresh-frozen cadaveric specimens [7, 35]. Cooper et al. used a hemiquadrant system to measure capsular thickness with a pair of digital calipers (Neiko Tools; Ontario, CA) [7]. The mean (± SD) thickness of the anterior capsule was measured as 1.3 (0.7–2.1) mm; SEM = 0.18 mm, 2.3 (1.0–4.2) mm; SEM = 0.39 mm, and 2.4 (0.9–5.4) mm; SEM = 0.45 mm at the acetabular origin, center, and femoral insertion, respectively [7]. Philippon et al. measured mean (± SD) thicknesses of the anterior capsule of 5.9 (5.0–6.7) mm;

Table 2 Surgical details

Authors (year)	Study population within the study	Method of capsule measurement	Description of technique
Cooper et al. (2015) [7]	Control	Cadaveric	Capsule circumferentially divided at the midpoint between acetabular origin and femoral insertion Capsular thickness measured at eight locations at the midpoint, 5 mm from the acetabular origin and femoral insertion
Devitt et al. (2017) [8]	NR	Arthroscopic	Arthroscopic hook probe (3-mm; Smith & Nephew) calibrated with 5-mm laser etching used to measure the capsular thickness Hook was placed on the internal surface of the capsule at the most extreme anterior margin of the capsulotomy, which corresponded with the location of the iliofemoral ligament
Joo et al. (2014) [16]	Idiopathic adhesive capsulitis of hip	Magnetic resonance arthrography	T1 weighted image chosen where femur head was widest and coronal cut taken at the center of the femur head Capsular thickness measured in the anterior and posterior and inferior recess T1 weighted images showing femur head as widest was cut in the axial plane at the center of the femoral head Capsular thickness was measured in the superior and inferior recess
Le Bouthillier et al. (2018) [1]	Developmental dysplasia of the hip, isolated labral tears, cam-type femoroacetabular impingement	Magnetic resonance arthrography	Hip capsule thickness measured superiorly (12 o'clock) on oblique coronal sequence through mid-acetabulum and anteriorly (3 o'clock) on oblique axial sequence through the mid-femoral neck Capsule measured along its short axis that is the shortest dimension/thickness
Magerkurth et al. (2013) [24]	Capsular laxity of the hip joint	Magnetic resonance arthrography	Minimal anterior hip joint capsule thickness (lateral to the zona orbicularis) measured
Philippon et al. (2014) [34]	Control	Cadaveric	Coordinate measuring device (MicroScribe MX; GoMeasure3D, Amherst, Virginia, USA) used with a needle-point tip to collect anatomical locations Data points were collected circumferentially and along the superomedial border of the greater trochanter, the intertrochanteric crest, the head–neck junction of the femur, and along the vastus tubercle

Table 2 (continued)

Authors (year)	Study population within the study	Method of capsule measurement	Description of technique
Philippon et al. (2015) [35]	Control	Cadaveric	Coordinate measuring device (MicroScribe-MX, Go-Measure3D, Amherst, VA, USA) used to perform quantitative measurements of the capsule 1-mm ruby-tipped spherical probe (GoMeasure3D, Amherst, VA) used for measurement to minimize indentation into the soft tissue Capsule was held in position with Allis clamps to ensure there was no movement during measurement, and care was taken to avoid placing the capsule under tension Thickness of the capsule was determined starting at the incision adjacent to the free edge of the acetabular labrum and at 5-mm intervals (5, 10 and 15 mm) projecting orthogonally from the edge Capsule thickness was compared individually between the 0 and 5 mm distances at each clock-face position between 9 and 3 o'clock
Rakhra et al. (2016) [36]	Cam-FAI Non-FAI chondrolabral pathology Control	3 T MRI	Capsule thickness measured at the thickest point using electronic calipers on 2 images Oblique axial image through the level of the mid-femoral neck and an oblique coronal image through the level of the mid acetabulum Capsular thickness measured anteriorly and superiorly
Robben et al. (1999) [37]	Cadaveric Control Transient synovitis	Ultrasound	Thickness of the capsule assessed by measuring the maximal distance between the anterior surface of the femoral neck and the posterior surface of the iliopsoas muscle
Soini et al. (2003) [44]	Synovitis	1.5 T MRI	Measured on oblique sagittal and axial slices
Strickland et al. (2018) [45]	FAI	3 T MRI	Hip capsular thickness measured in the mid-coronal plane to the femoral head on the coronal proton density sequence at 3 sites: at the level of the femoral head–neck junction (midcapsular thickness), at a point midway between the midpart of the capsule and the labrum (proximal capsular thickness), and at a point equidistant toward the greater trochanter (distal capsular thickness) Capsular thickness assessed by measuring low-signal-intensity substance of the capsule from articular side to the muscular side

Table 2 (continued)

Authors (year)	Study population within the study	Method of capsule measurement	Description of technique
Weber et al. (2016) [48]	Postoperative FAI and asymptomatic contralateral hip	1.5 T MRI	Capsular thickness measured on T2-weighted fat-saturated coronal sections through the iliofemoral ligament at the site of routine capsulotomy and subsequent closure
Weidner et al. (2012) [49]	FAI	MRA	On radial MR images around the axis of the femoral neck, hip capsule thickness measured Thickness of the joint capsule measured at the thickest part of the capsule
Zhang et al. (2018) [52]	Clinical hip impingement	1.5 T MRI	At a level where femoral head–neck junction and any lesion was well-visualized, maximum capsular thickness anteriorly measured on axial, axial oblique, and/or sagittal oblique sequences Capsular thickness also measured on axial sequences at the point of offset in the anterior femoral head–neck junction (axial midline capsular thickness)

NR not reported

SEM = 0.25 mm, 6.9 (5.8–8.1) mm; SEM = 0.31 mm, and 7.3 (6.2–8.4) mm; SEM = 0.31 mm at the acetabular origin, center, and femoral insertion, respectively [35]. This study used a coordinate measuring device (MicroScribe MX; GoMeasure3D, Amherst, Virginia, USA) with a needle-point tip [35].

Capsular thickness on MRI

Plain MRI was used in 5 studies (1.5-T in 3 studies, 3-T in 2 studies) to assess capsular thickness [36, 44, 45, 48, 52]. The mean (± SD) thickness of the anterior capsule was measured as 4.4 (3.3–5.5) mm; SEM = 0.15 mm, 4.5 mm (2.3–6.7) mm; SEM = 0.30 mm, 4.6 (3.2–6.0) mm; SEM = 0.16 mm, and 4.7 (3.5–5.9) mm; SEM = 0.09 mm, respectively in groups of healthy controls [36, 44, 48, 52] (Fig. 2).

Capsular thickness was assessed on Magnetic Resonance Arthrography (MRA) in four studies [1, 16, 24, 49]. The mean (± SD) thickness of the anterior capsule was measured as 2.61 (1.81–3.41) mm; SEM = 0.09 mm, and 3.3 mm (2.8–3.8) mm; SEM = 0.10 mm, respectively in groups of healthy controls [16, 24].

In patients with FAIS, the mean (± SD) thickness of the anterior capsule was measured as 5.0 (3.6–6.4) mm, 5.0 (3.8–6.2) mm, 5.0 (3.7–6.3) mm, and 4.9 (3.4–6.4) mm [36, 48, 49, 52] (Fig. 3). One study assessed patients with FAIS postoperatively with MRI and found those without a capsular repair had a mean (± SD) capsular thickness of 3.76 (2.53–4.89) mm, while those with a capsular repair had a capsular thickness of 3.42 (2.20–4.64) mm [45].

Factors affecting capsular thickness

Six studies measured capsular thickness by gender [8, 16, 36, 48, 49, 52]. Males had significantly thicker mean capsule thickness than females with a pooled mean difference of 1.92 mm [95% confidence interval (CI) 0.35–3.49, $P = 0.02$, $I^2 = 96\%$] (Fig. 4). Three studies that compared capsular thickness by gender did so using MRI [36, 48, 49].

Rakhra et al. compared both patients with FAIS and those without FAIS in males and females. In patients with FAIS there was no difference in mean thickness (± SD) between male which measured 5.0 (3.5–6.5) mm and female which measured 5.0 (4.0–6.0) mm. Non-FAIS patients had similar figures for both males at 5.0 (3.1–6.9) mm and females at 4.9 (3.5–6.3) mm [36].

One study assessed the relationship between range of motion and capsular thickness and reported a negative correlation between increased thickness and flexion (− 0.196), extension (− 0.0962), abduction (− 0.0260), internal rotation (− 0.143) as well as external rotation (− 0.0434) [52].

Association between laxity and thickness of capsule

Two studies assessed the correlation between the thickness of the joint capsule and the degree of laxity in the patient, and both reported significant thinner capsules in those with

Table 3 Capsular thickness and width

Authors (year)	Capsular thickness at various locations in control group (mean ± SD mm unless specified) Specify location	Capsular thickness at various locations in study group (if applicable)	Capsular width at various locations
Cooper et al. (2015) [7]	Anterior = 1.3 (0.7–2.1) [acetabular origin]; 2.3 (1.0–4.2) [center of capsule]; 2.4 (0.9–5.4) [femoral insertion] Superior = 3.7 (1.7–9.6) [acetabular origin]; 3.5 (1.4–6.3) [center of capsule]; 1.3 (0.6–2.6) [femoral insertion]	NR	Anterior = 5.4 (2.6–10.2) at 5.3 (0.0–10.8) from bony acetabular rim; 5.6 (1.1–8.7) at 26.5 (17.0–36.0) from chondral head–neck junction Superior = 8.8 (5.4–12.7) at 4.6 (0.0–9.7) from bony acetabular rim; 3.7 (3.0–4.5) at 22.1 (14.8–31.5) from chondral head–neck junction
Devitt et al. (2017) [8]	NR	NR	NR
Joo et al. (2014) [16]	Anterior: 2.61 ± 0.8 mm $P = 0.112$ Posterior: 1.94 ± 0.5 mm $P = 0.006$ Superior: 1.88 ± 0.5 mm $P = 0.0009$ Inferior: 1.84 ± 0.5 mm $P = 0.121$	Anterior: 3.14 ± 0.7 mm $P = 0.112$ Posterior: 2.61 ± 0.5 mm $P = 0.006$ Superior: 2.78 ± 0.5 mm $P = 0.0009$ Inferior: 2.13 ± 0.4 mm $P = 0.121$	NR
Le Bouthillier et al. (2018) [1]	NR	DDH: Superior = 0.24 (0.06) $P < 0.05$ Anterior = 0.18 (0.07) $P < 0.05$ LT: Superior = 0.15 (0.04) $P < 0.05$ Anterior = 0.13 (0.03) $P < 0.05$ FAI: Superior = 0.16 (0.04) $P < 0.05$ Anterior = 0.15 (0.05) $P > 0.05$	NR
Magerkurth et al. (2013) [24]	No laxity Anterior capsule: thickness (mm) 3.3 (95% CI 2.8–3.8) $P = 0.0043$	Laxity Anterior capsule: thickness (mm) 2.5 (95% CI 2.3–2.8) $P = 0.0043$	NR
Philippon et al. (2014) [34]	NR	NR	12:00 = 11.8 (9.2, 14.4) 1:00 = 12.1 (10.1, 14.1) 2:00 = 10.1 (8.6, 11.7) 3:00 = 10.8 (9.2, 12.3) 4:00 = 12.9 (10.3, 15.5) 5:00 = 14.4 (12.2, 16.6) 6:00 = 18.9 (14.5, 23.2) 7:00 = 12.2 (7.9, 16.6) 8:00 = 5.6 (3.9, 7.3) 9:00 = 4.8 (3.3, 6.4) 10:00 = 5.5 (3.7, 7.3) 11:00 = 10.2 (7.9, 12.5)
Philippon et al. (2015) [35]	Anterior = 5.9 [5.0, 6.7] (0 mm distance from labral edge); 6.9 [5.8, 8.1] (5 mm); 7.0 [5.9, 8.2] (10 mm); 7.3 [6.2, 8.4] (15 mm) Superior = 6.4 [5.1, 7.7] (0 mm distance from labral edge); 6.9 [5.3, 8.5] (5 mm); 6.4 [4.8, 8.0] (10 mm); 5.6 [4.6, 6.6] (15 mm)	NR	NR

Table 3 (continued)

Authors (year)	Capsular thickness at various locations in control group (mean ± SD mm unless specified) Specify location	Capsular thickness at various locations in study group (if applicable)	Capsular width at various locations
Rakhra et al. (2016) [36]	Anterior (3:00) 4.4 (sd 1.1) (2.6–6.1) Superior (12:00) 5.3 (sd 2.3) (2.0–9.0) $P = 0.026$	Hip disease (cam- and non-FAI) ($n = 41$) Anterior (3:00) 5.0 (sd 1.4) (2.3–9.0) Superior (12:00) 6.8 (sd 1.6) (3.2–10.2) Cam-FAI ($n = 16$) Anterior (3:00) 5.0 (sd 1.3) (3.5–7.5) Superior (12:00) 7.0 (sd 1.4) (4.0–9.5) Non-FAI ($n = 25$) Anterior (3:00) 4.9 (sd 1.5) (2.3–9.0) Superior (12:00) 6.7 (sd 1.7) (3.2–10.2)	NR
Robben et al. (1999) [37]	Asymptomatic hip in patients with transient tenosynovitis: Joint capsule 4.90 (sd 1.02) Anterior layer 2.51 (sd 0.63) Posterior layer 2.10 (sd 0.58) Healthy children volunteers: 4.7 mm	Joint capsule 9.91 (sd 1.71) Anterior layer 2.38 (sd 0.66) Posterior layer 2.14 (sd 0.44)	NR
Soini et al. (2003) [44]	4.5 mm (SD 2.2) $P < 0.001$	2.9 mm (SD 2.2) $P < 0.001$	NR
Strickland et al. (2018) [45]	NR	6 weeks No repair = proximal 5.60 (1.50); middle 0.86 (1.92); distal 8.66 (1.63) Repair = proximal 5.75 (2.08); middle 2.93 (2.83); distal 8.93 (3.17) 24 weeks No repair = proximal 4.15 (1.21); middle 3.76 (1.23); distal 7.00 (2.12) Repair = proximal 4.57 (1.86); middle 3.42 (1.22); distal 5.92 (1.89)	NR
Weber et al. (2016) [48]	4.6 ± 1.4 mm; $P = 0.02$	5.0 ± 1.2 mm; $P = 0.02$	NR
Weidner et al. (2012) [49]	NR	12:00 = 4.2 0:45 = 4.7 1:30 = 6.2 2:15 = 6.2 3:00 = 4.9 3:45 = 3.7 4:30 = 2.8 5:15 = 2.7 6:00 = 2.6 6:45 = 3.0 7:30 = 2.4 8:15 = 1.8 9:00 = 2.0 9:45 = 2.3 10:30 = 3.1 11:15 = 3.9	NR

Table 3 (continued)

Authors (year)	Capsular thickness at various locations in control group (mean ± SD mm unless specified) Specify location	Capsular thickness at various locations in study group (if applicable)	Capsular width at various locations
Zhang et al. (2018) [52]	No FAI morphology: axial midline (mm ± SD, range) 4.7 ± 1.2 (3.0–8.6)	Summary: axial midline (mm ± SD, range) 5.0 ± 1.3 (3.0–9.5) Cam FAI: axial midline (mm ± SD, range) 5.3 ± 1.3 (3.0–9.5) Pincer FAI: axial midline (mm ± SD, range) 4.0 ± 0.5 (3.4–4.7) Mixed FAI: axial midline (mm ± SD, range) 6.2 ± 2.1 (3.6–8.0)	NR

NR not reported

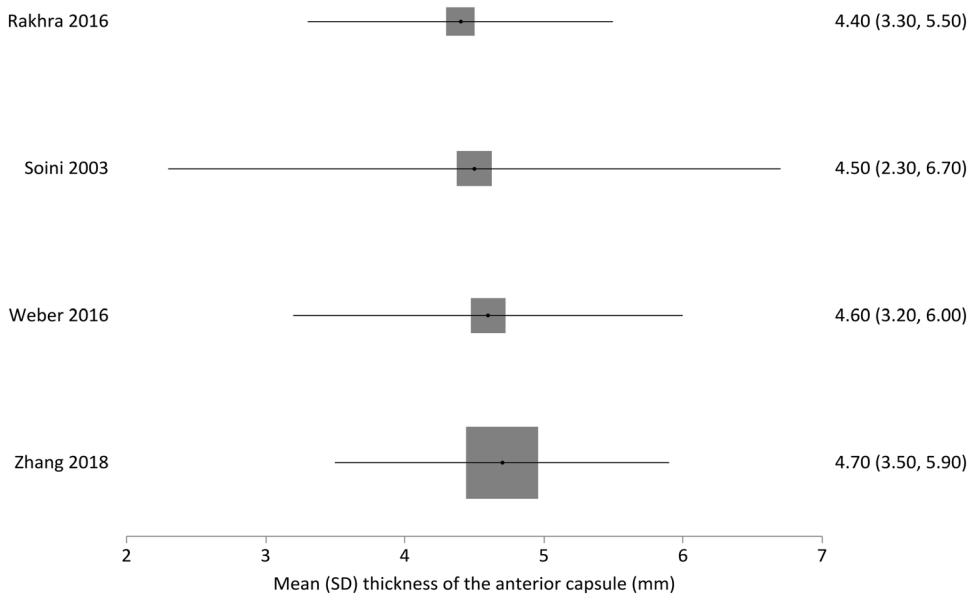

Fig. 2 Mean (SD) anterior capsule thickness of patients without hip disease as measured on MRI in mm

lax joints [8, 24]. Devitt et al. reported significantly higher mean (SD) Beighton scores in patients with capsular thickness less than 7.5 mm [5.3 (1.3)] in comparison to those with capsular thickness greater than 7.5 mm [0.8 (1.1)] ($P < 0.0001$) [8]. Similarly, Magerkurth et al. reported that the mean thickness of the anterior capsule, as measured on MRA, was significantly thinner in patients with laxity [2.5 (95% CI 2.3–2.8)] than those without [3.3 (95% CI 2.8–3.8)] ($P = 0.0043$) [24].

Discussion

The most important finding of the present study was the identification of various methods that have been used to measure the thickness of the hip capsule. While inter-method variability of capsular thickness measurement exists whether measured via ultrasound, intra-operatively, or in cadaveric specimens, the thickness measured on MRI was consistent across studies. Clinical laxity of the hip joint was associated with a thinner anterior capsule. Females had thinner capsules than males, with a difference of approximately 2 mm

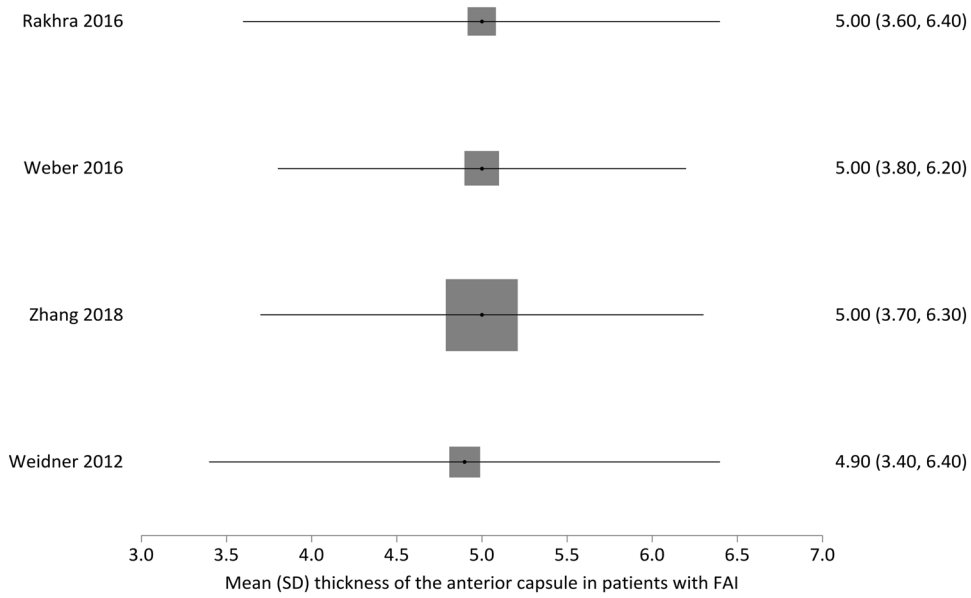

Fig. 3 Mean (SD) anterior capsule thickness of patients with FAIS as measured on MRI in mm

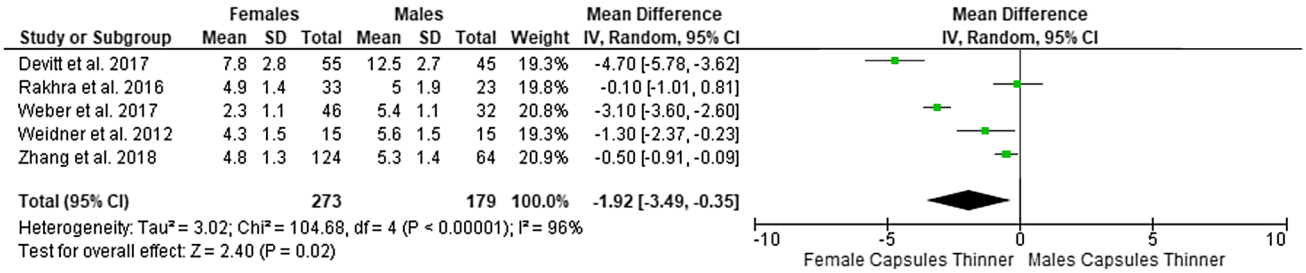

Fig. 4 Forest plot demonstrating the mean difference (mm) in capsular thickness between males and females

between genders. Mean thickness of the anterior capsule measured on MRI was between 4.4 and 4.7 mm for healthy controls and between 4.9 and 5.0 mm for patients with FAIS.

One study included in the current systematic review specifically assessed the interobserver reliability of the capsule measurements with intraclass-correlation coefficient or other similar techniques [36]. The intra-reader intra-class correlation coefficient (ICC) of anterior capsule thickness measured on MRI was reported as a near perfect 0.948 [36]. Furthermore, the mean capsular thicknesses measured on MRI that was reported in each of the studies were within 0.2 mm. Moreover, SEM values of capsular thickness in studies using MRI ranged from 0.09 to 0.3 mm. These findings provide support to the notion that MRI measurements of capsular thickness provides a reliable estimate of the true capsular thickness. In a study on shoulder capsular thickness in patients with adhesive capsulitis, Lefevre-Colau et al. similarly reported that interobserver reliability of capsular thickness measured on T1-weighted MRI images were good with ICC values of 0.84 in the coronal plane and 0.80 in the sagittal plane [23]. On the other hand, there was increased variability and higher SEM reported in other capsular measurement methods included in the current review such as that in cadaveric specimens and intraoperative assessment.

Instability of the hip joint is a clinical diagnosis causing significant disability in patients, and can often be caused by traumatic events which may disrupt the joint capsule [30]. On the other hand, instability may be present without the occurrence of a traumatic event. Microinstability of the hip is a relatively new clinical entity, often defined as functional laxity that causes symptomatic and abnormal motion of the hip [41]. Such instability is thought to occur secondary to both incompetence of soft tissues about the hip joint, including ligamentous or capsular laxity and weakness of muscles about the hip and pelvic girdle, as well as repetitive hip joint loading with sport or exercise [2, 46]. Biomechanical evidence supports the role of the capsule in stability of the hip joint [27, 32]. In a recent cadaveric motion analysis study, capsular laxity was found to significantly increase joint rotations, and femoral head translations leading to abnormal movement paths of the femoral head center. These abnormal motions of the hip are thought to be the mechanical origin

of the pain and instability associated with microinstability of the hip [13]. This systematic review found that thinner anterior hip capsules was correlated with female gender, increased hip laxity, as well as increased generalized joint hypermobility. Such correlations are thought to be attributed to the effect of hormonal variation on composition and healing [14]. Furthermore, there was an association identified between thicker anterior capsules and decreased hip flexion and internal rotation in patients with FAIS. In a cadaveric study, Martin et al. found that the lateral arm of the iliofemoral ligament has important contributions of flexion and internal rotation of the hip [26]. The clinical relevance of these correlations and differences in capsule thickness have not yet been determined and warrants further investigation.

On the other end of the spectrum, adhesive capsulitis of the hip can cause patients significant pain and morbidity when the capsule and other soft tissues about the hip are overly tight [39]. To date, adhesive capsulitis of the hip remains a poorly defined entity with a difficult diagnosis [39]. The diagnosis of adhesive capsulitis is typically achieved by clinical assessment, where patients are noted to have a progressive decrease in global range of motion of the hip [39]. While most studies have reported no significant findings on MRI in patients with adhesive capsulitis,[39] a recent series found capsular hypertrophy on MRI in a subset of patients with clinical adhesive capsulitis [17]. The present study found an inverse correlation reported between capsular thickness and range of motion of the hip joint. Given these findings, the role of capsular thickness, as measured on MRI, as part of a comprehensive strategy to predict which patients may be at risk of developing adhesive capsulitis of the hip warrants further investigation.

Arthroscopic surgical correction of bony deformities and associated chondrolabral pathology is a treatment modality for patients with FAIS that is being used increasingly more often [6, 18]. The most common cause of failure following arthroscopic treatment of FAIS with osteochondroplasty is inadequate bony resection [21, 39]. To achieve adequate exposure of the bony deformities, the hip capsule is often opened via the initial capsulotomy and subsequent extensions. Interportal and T-shaped capsulotomies are the two most commonly used techniques [19], with the former sufficient for diagnostic arthroscopy and resection of small lesions [51], while the latter may be required for larger or more distal CAM lesions [4]. Due to its devastating nature with long-term consequences, instability following arthroscopic hip surgery is a feared, albeit rare, complication among surgeons [51]. A recent systematic review identified 10 cases of gross hip instability following arthroscopic surgery [51]. Factors that were related to increased risk of postoperative instability included female sex and general ligamentous laxity [51]. The role of capsular thickness in postoperative hip instability is not yet understood. Intraoperative capsular management strategies include leaving the capsule unrepaired, partial repair, complete closure, and capsular plication [33]. Although not definitively understood, it is postulated that unrepaired capsulotomies could contribute to postoperative instability [51]. McCormick et al. studied 25 patients that required revision surgery following arthroscopic management of FAIS, and identified capsular abnormalities in 9 of these patients [28]. However, the absolute necessity to repair the capsule is controversial as several studies have reported strong outcomes following hip arthroscopy without capsular repair, including no reports of postoperative instability [3, 31]. Furthermore, adhesive capsulitis of the hip is being recognized more frequently as a cause of significant morbidity in patients with overly stiff hip joints. There is little consistency with respect to indications for specific capsular management strategies [11]. In a systematic review of 36 studies detailing capsular closure techniques following hip arthroscopy, Ekhtiari et al. reported that 22% of these studies left the capsule without repair, 6% routinely performed partial repair, and 50% used complete repair of the capsule [11]. No clinically important differences in outcomes or stability were reported with the routine use of any specific capsule management technique in comparison to another [11].

While the routine use of a particular capsule management strategy following hip arthroscopy has not definitively demonstrated superiority, capsular repair may be indicated in patients at increased risk for postoperative instability such as those with generalized laxity or dysplasia. Larson et al. found that patients with Ehlers-Danlos syndrome and instability of the hip being managed with hip arthroscopy have significant improvements in functional outcomes including stability when capsule plication techniques were used for capsular closure [22]. Similarly, Domb et al. found that patients with borderline dysplasia undergoing arthroscopic correction demonstrate strong improvements in functional outcomes without postoperative instability when the capsule is closed using plication [10]. This systematic review found that those with increased hip laxity may have a thinner anterior hip capsule. However, there were no studies that assessed outcomes and stability following hip arthroscopy with capsule management strategies guided by preoperative capsule thickness.

Several limitations exist within the present systematic review. The study designs were cadaveric or retrospective, therefore, no causative inferences can be made with respect to the thickness of the hip capsule and the incidence of laxity or instability of the hip joint. The effect of capsular thickness on the risk of developing postoperative instability following hip arthroscopy must be specifically investigated before capsular thickness is used clinically. Furthermore, the overall sample size of the patients included in this review was relatively small, and therefore, does not yet warrant widespread

application based on the current results alone. The various techniques used to measure capsular thickness were not specifically assessed via agreement statistics, and therefore, the reliability of these techniques may be uncertain. Lastly, there were significant differences across the included studies with respect to the method of assessing capsular dimensions, and the population of individuals assessed.

The present study provides baseline characteristics that have been reported in terms of capsular thickness across various populations. Moreover, there may be an association between the thickness of the capsule and the degree of laxity of the hip joint. While this data alone does not provide sufficient support for the use of capsular thickness as part of the capsular management decision-making algorithm, the preliminary findings serve as a source of hypothesis generation and background data to study the role of capsular thickness in capsular management strategies. Although more definitive research is required, recent biomechanical studies may support the notion that capsular laxity causes abnormal motions of the hip responsible for symptomatic microinstability. A randomized controlled trial aimed to assess whether capsular closure should be performed as a standard procedure during hip arthroscopy is currently underway in Denmark [9]. The results of this and other similar studies will provide important information regarding the utility of capsular closure, and possible contribution to instability or stiffness postoperatively. Future studies that prospectively prognosticate patients with various capsular thicknesses in combination with other relevant clinical information such as gender, ligamentous laxity-with objective and validated criteria, and acetabular retroversion in terms of risk for postoperative instability following hip arthroscopy is warranted. The findings of such a study could have an important role in understanding an optimal and individualized capsule management strategy.

Conclusion

The thickness of the anterior hip capsule can be measured consistently using magnetic resonance imaging. A thinner anterior capsule may be associated with clinical laxity of the hip joint. The relevance of capsular thickness on postoperative instability following hip arthroscopy is poorly understood and warrants further investigation. The thickness of the anterior hip capsule, as measured on MRI, has the potential to be used as part of the clinical decision-making in capsular management strategies.

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Compliance with ethical standards

Conflict of interest ORA is a paid consultant for ConMed. SNJ is a paid consultant for Ossur and Stryker, is a board/committee member of American Orthopaedic Society for Sports Medicine, Arthroscopy Association of North America and American Journal of Orthopedics and receives research support from Allosource, Arthrex, Athletico, DJ Orthopaedics, Linvatec, Miomed, Smith & Nephew and Stryker. ELB is a paid presenter for Smith & Nephew, Stryker, ConMed, Victhom and Pendopharm and receives research grants, institutional support from Stryker, Zimmer-Biomet, Depuy-Synthes and Medtronic. The authors have no other potential conflicts of interests to declare.

Ethical approval This is a systematic review of the literature and no ethical approval is required.

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