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Title: **Variability in Quantifying the Hill-Sachs Lesion: A Systematic Review**

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Background

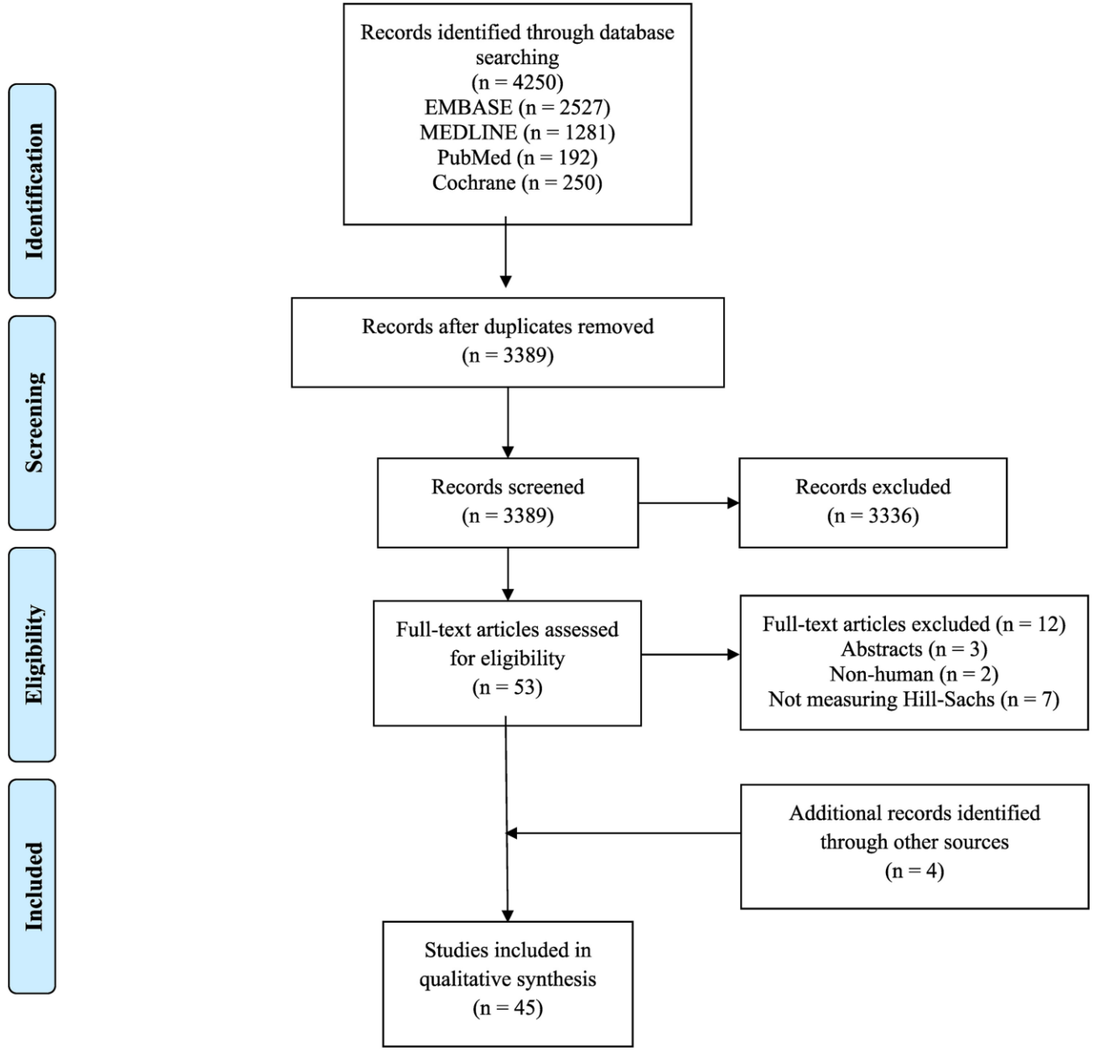
- Hill-Sachs lesion (HSL) is categorized as a bony defect of the posterosuperolateral humeral head, often caused by prior episodes of anteroinferior glenohumeral dislocation.[1,2]
- Measurement of the HSL has been an area of interest for clinicians as quantification of bone loss is crucial in treatment decisions for patients with shoulder instability.
- Despite the various modalities and methods available to measure the HSL, challenges still exist upon evaluation related to its 3D aspect of the humeral sphere and conflicting visibility during imaging, with each method having its own pros and cons along with varying degrees of reliability.[13–16]
- The purpose of this review is to provide an overview of the imaging modalities and techniques to measure the HSL and to assess their diagnostic properties

Methods

- The search terms included “shoulder,” “Hill-Sachs,” “bone loss,” and similar phrases (Appendix Table 1). PUBMED, EMBASE, MEDLINE, and COCHRANE databases were searched for literature on the reliability of imaging modalities and measurement techniques for quantifying the HSL from database inception to 20 November 2021
- Inclusion criteria: (1) HSL; (2) quantification by imaging modalities; (3) present a method for measuring HSLs; (4) human studies; and (5) English language
- Exclusion criteria: (1) measurement of other major shoulder pathologies (e.g. glenohumeral, Bankart lesions) without mention of an HSL; (2) review articles; (3) non-imaging studies; (4) cadaver studies; (5) case reports and editorials
- Systematic screening was in compliance with Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) and Revised Assessment of Multiple Systematic Reviews (R-AMSTAR) guidelines.[17,18]

Results: Study Characteristics

- Systematic screening process yielded 45 articles that met inclusion criteria (Figure 1)
- One study was found upon reviewing references of included studies
- Of the included studies, there were 19 retrospective cohort (42%), 18 prospective cohort (40%), and seven other studies (16%)
- One of the included studies was a conference abstract (2%)



Results

Study Quality

- There was substantial agreement between the reviewers for title and abstract screening (κ = 0.759; 95% CI 0.461–0.877), and almost perfect agreement for full-text screening (κ = 0.838; 95% CI 0.662–1.000)
- The majority of the studies (44%; n = 19) were level II evidence, whereas 15 studies (42%; n = 18) were level III evidence, and six studies (14%; n = 6) were level IV evidence

Distribution of modalities used and reference tests

- Index test: MRA (23%), MRI (23%), 3D-CT (13%), CT (11%), computerized arthrotomography (CTA) (9%), ultrasound (US) (9%), radiography (5%), 3D-magnetic resonance (3D-MRI) (2%)
- Twenty-seven out of the 42 studies (64%) reported using a reference test
- Reference test: arthroscopy (n = 23; 63.8%), surgical techniques (n = 7; 19.4%), radiographs (n = 3; 8.3%), MRI (n = 2; 5.5%), and arthro-CT (n = 1; 2.8%)

Patient Characteristics

- Total of 3413 patients and 3431 shoulders were included in this review. Of the included patients, 74% (1974 out of 2672) were male; nine studies (21%) did not report on gender distribution.[8–10,12,13,20–59]
- Mean age: 28.8 ± 6.3 years, calculated from 37 studies (82%); eight studies (18%) did not report on age.[13,21,24,25,45,49,50,55]

Results

Reported measurement techniques varied amongst the studies as well as modalities

Computed Tomography (CT)

- Reported techniques: humeral residual articular arc and percentage of articular arc loss, HSL width and depth, percentage of anterior glenoid defect, bare area, on-track and off-track, Franceschi grading, Calandra classification, Richards grading, Hall grading, Rowe grading, Flatow percentage, linear-based and area-based methods.[10,31,39,52]
- Sensitivity: between 20% and 65%, specificity: between 41.7% and 87%.[25,39]
- Accuracy, positive predictive value (PPV), and negative predictive value (NPV) were not reported amongst the CT studies.
- Intrarater agreement was only reported in one study, where there was 33% agreement for on-track measurements.56 Interrater agreement ranged between 41% and 76% (Table 2).[10,25,40,52,56]
- Reference tests: Radiographs.[25]

3D CT

- Reported techniques: circle area, height, and length of humeral head, HSL length and depth, anatomical neck width, on-track and off-track, and clock-face methods.[8,9,21,22,28,38,57]
- Only one study included data on sensitivity, specificity, PPV, and NPV values using the Calandra method.[22] The values reported were 76.3%, 100%, 100%, and 46.2%, respectively.[22]
- One study reported intrarater agreement ICC values ranging from 0.92 and 0.99, and interrater agreement, ranging from 0.77 and 0.99.[28]
- Reference tests: Arthroscopy.[9,21,22,28]

Results

Computed Arthrotomography (CTA)

- Reported techniques: HSL depth, P/R (notch defect/radius) index calculation, and normal base area measurement.[13,27,42]
- Sensitivity: between 20% and 93%, specificity: between 90% and 95%
- Accuracy, PPV, and NPV were reported in only one study, where it was 90%, 67%, and 98%, respectively.[30]
- Intrarater and interrater agreements were only reported in one study, where it was $\kappa = 0.71$, and $\kappa = 0.30$, respectively.[13]
- Reference tests: arthroscopy and AP radiographs.[13,27,30]

Magnetic resonance imaging (MRI)

- Reported techniques: on-track and off-track, linear-based and area-based methods, and a modified Cetik method.[12,20,40,51,56,58]
- Sensitivity: between 16.7% and 96.3%, specificity: between 67% to 100%.[12,29,37,48,58]
- Accuracy: ranged from 67% to 88%.[37,48,58]
- PPV: ranged from 14% to 65%, NPV: ranged from 85% to 91%.[12,58]
- Intrarater agreement: ranged from 41% to 86%.[58]
- Interrater agreement ranged from ICC = 0.33 to 1.00.[43]
- Reference tests: arthroscopy, radiographs, and surgical techniques.[23,29,33,37,43,48,51,58]

Results: Measurement Techniques

Magnetic Resonance Arthrography (MRA)

- Reported techniques: method described by O'Brien et al. where measurements of the humeral circumference, as well as the depth of the HSL were used in analysis of the lesion as the most accurate reflection of Hill-Sachs volume.[45]
- Sensitivity: ranged from 69% to 100%.[24,26,30,32,34,41,46,47,49]
- Specificity: ranged from 0% to 100%.[24,26,30,32,34,41,46,47,49]
- Accuracy: varied from 81% to 100%, PPV from 45% to 100%, and NPV from 88% to 100%.[24,30,32,34,41,46,47]
- Intrarater agreement: ICC = 1.00, and interrater agreement to be ICC = 0.97.[45]
- Reference tests: arthroscopy and surgical techniques.[23,24,26,30,32,34,35,41,46,47,49]

Ultrasound (US)

- For US, only one method was reported as a calculation of the Hill-Sachs volume using V = 4/3 π 1/2a 1/2bc, where a, b, and c represent the width, length, and depth of the lesion, respectively.[50]
- Only one study reported values for sensitivity (95.6%), specificity (92.8%), and accuracy (95.0%).[36]
- There were no reported values for both intrarater and interrater agreement
- Reference tests: arthroscopy, arthro-CT, and surgical techniques.[23,36,42,47,50]

Discussion

- There is significant variability in imaging modality and measurement techniques, with MRI and depth being the most prevalent
- Current literature on the assessment of HSL demonstrates a wide range of measurement techniques and imaging modalities with support for MRI and MRA
- However, results should be taken with caution due to the small number of included studies with each modality, the variability in study designs, and the lack of high-quality and comparative studies
- Variety of measurement techniques corroborate the lack of standardization and agreement regarding the best modality and measurement method, suggesting that at this point there is no clear superiority of one imaging modality or measurement technique above the other
- MRA showed the highest sensitivity and specificity values amongst the different imaging modalities, accuracy, intra-rater and inter-rater agreement was highest amongst MRA compared to all other modalities
  - MRA is reliable in diagnosing various shoulder pathologies such as intra-articular cartilage and ligaments injuries, labral tears, and rotator cuff disease amongst others.[63]
- Effective in measuring HSLs in adolescent patients and can help address bony complications of HSLs to accurately assess the lesion.[59]

There exists a need to conduct analyses to directly compare imaging modalities not only regarding accurate measuring of HSLs, but also their safety profile and potential exposure risks to patients.

Discussion (cont.)

- An analysis of the quantification methods for HSLs identified in the included studies shows that measurement of the depth of the lesion is most prevalent
- Given the limited quantitative data and variability in modalities used among all different techniques, difficulties arise in identifying a “gold standard” for quantifying HSLs
- To address the discrepancies between preoperative and intraoperative measurements of HSLs, a precise method for quantification of HSL needs to be established amongst clinicians and radiologists
- For current surgeons, it is equally important that each technique's benefits and drawbacks are extensively studied and considered for each unique patient presentation to achieve the most accurate and best diagnosis of the HSL to dictate intervention planning
- There is a need to establish the role of imaging modalities to optimize the decision-making process while reducing the economic burden of the healthcare system when using these resources

Limitations

- Meta-analysis was not performed as there was high statistical and methodological heterogeneity among the studies and.
- Lack of a good quality and quantity of evidence available in the literature for each modality and technique
  - Thus, our ability to comprehensively comment on a “gold-standard” and provide meaningful recommendations is limited

Conclusion

- MRA and MRI are reliable imaging modalities with good test diagnostic properties for assessment of HSLs
- There is a wide variety of measurement techniques and imaging modalities for HSL assessment, however a lack of comparative studies exists
- Thus, it is difficult to comment on the superiority of one technique over another
- High-quality comparative studies with large sample sizes should be conducted in the future to determine an optimal imaging modality and to identify the best and more effective measurement technique
- Future studies should directly compare the accuracy and reliability of imaging modalities and measurement while also conducting cost-benefit analyses

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