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Sex Differences in Shoulder Anatomy and Biomechanics: A Systematic Review and Meta-Analysis

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BACKGROUND: Studies analyzing sex-related differences in anatomy, biomechanics, and injury patterns have burgeoned in recent years. While the majority of these manuscripts have highlighted differences about the knee, there remains a paucity of descriptions of the sex-related differences about the shoulder. Herein we summarize the sex-related differences of shoulder 1) osteology, 2) soft tissue anatomy, and 3) neuromuscular function.
METHODS: A systematic review of literature was performed querying manuscripts from Medline, Web of Science, Embase, and Google Scholar databases according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. All articles investigating shoulder differences by sex were included. Metrics of the sex-related differences in osteology, soft-tissue anatomy, and neuromuscular function were recorded. Meta-analysis was performed when metrics were available from 3 or more studies.
RESULTS: Sixteen articles were included for analysis. There were 7 cadaveric studies, 1 review article, and 8 studies with Level-III or IV evidence. Glenoid height and width were significantly smaller in females (4.57 mm, $p<0.001$) compared to males (4.60mm, $p=0.001$), respectively. There was no significant sex-related difference in glenoid retroversion. Females demonstrated significantly less dynanomotor shoulder strength and greater shoulder range of motion than males. There were no significant sex-related differences in shoulder proprioception, and the results for shoulder instability were variable.
CONCLUSION: Significant interactions of sex were found in both glenoid and humeral osteology, functional shoulder strength, and shoulder range of motion. Further study is warranted to determine proper conceptualization and treatment of shoulder injuries among sexes.

INTRODUCTION

Descriptions of sex-related differences encountered in orthopaedic surgery have burgeoned in recent years.[1-3] Perhaps the most illustrative example is in knee anatomy, biomechanics, injury patterns, and injury prevention, where studies have highlighted important anatomic differences between sexes that have created a better understanding of knee pathology in men and women. These, in turn, have aided in tailoring therapy, injury prevention programs, and surgical management for anterior cruciate ligament (ACL) injuries.[4-6]

While studies of sex-related differences have yielded tangible gains in the prevention and management of common knee injuries, studies regarding sex-related differences of the shoulder remain in relative infancy. Preliminary descriptions of anatomic relationships about the shoulder have demonstrated differences between men and women.[7-10] Sex has been shown to affect patterns of soft tissue injury and the biomechanics of certain pathologies, such as shoulder instability.[11,12] Expectations and outcomes following shoulder surgery are also impacted by sex.[13,14] As such, an understanding of sex-related differences in

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shoulder anatomy and biomechanics may be of great importance to orthopedic surgeons and their patients in guiding treatment decisions and optimizing patient outcomes.

While preliminary descriptions of sex-related differences of the shoulder exist, a comprehensive review of the literature is absent. The purpose of this systematic review was therefore to summarize the sex-related differences in shoulder (1) osteology, (2) soft tissue anatomy, and (3) neuromuscular function.

MATERIALS AND METHODS

Research Framework

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. Prior to data extraction, a study protocol was registered in the PROSPERO database (PROSPERO ID CRD42020211937).

Eligibility Criteria

English-language articles reporting sex-related differences in at least one of the following measures were considered for study inclusion: (1) shoulder osteology, (2) shoulder soft tissue anatomy, and (3) shoulder neuromuscular function.

Information Sources and Search Strategy

In October 2020, electronic searches for published literature were conducted by a medical librarian using EMBASE (1947-2020), Ovid MEDLINE (1946-2020), Google Scholar using Publish or Perish software, and Web of Science (1900-2020). With the aim of indentifying studies primarily illustrating gender/sex differences, a search strategy incorporating controlled vocabulary and free-text synonyms for the concepts of sex and gender differences and shoulder surgeries was developed. No additional search filters (e.g., language) were applied. The full database search strategies are documented in **Appendix 1**. All identified studies were combined and de-duplicated in a single reference manager (EndNote).

Study Selection and Assessment

Articles retrieved by the computerized search were uploaded into Covidence systematic review software (Covidence, Veritas Health Innovation, Melbourne, Australia). The manuscripts were then independently reviewed by two authors (S.P.M. and E.A.O.) to determine study eligibility, and any disagreements were resolved by discussion. The quality of included studies were assessed using the Oxford Center for Evidence Based Medicine Levels of Evidence.[15]

Data Collection

Information on study design, methods, population, and outcome measures pertaining to shoulder osteology, soft tissue anatomy, and neuromuscular function was collected using a custom data extraction form. All data were extracted by a single reviewer and verified by a second.

Meta-Analysis

Meta-analyses were performed for sex differences in shoulder anatomy for which data was available from three or more studies. Inverse variance random-effects meta-analysis was performed using the DerSimonian-Laird method to generate pooled effects and estimate between study variance.[16] Forest plots were created to depict mean differences (MD) with 95% confidence intervals (CIs). Heterogeneity was assessed using Higgins & Thompson's I^2, DerSimonian-Laird $\tau 2$, and Cochran's Q test of heterogeneity.[17,18] Analyses were performed in Jamovi version 1.2.27.0 with the MAJOR package. The level of significance was set at $p < 0.05$.

RESULTS

Study Selection

The database search retrieved 484 articles as potentially relevant. After removing duplicates, 394 were screened according to title and abstract, and 54 were retained for full-text review. After excluding 37 for failure to satisfy inclusion criteria, 16 were included in this review (**Figure 1**). Specifically, 8 studies addressed components of glenohumeral osteology, 5 discussed soft tissue elements of the shoulder, and 4 pertained to shoulder biomechanics and neuromuscular function. There were 7 cadaveric studies, 1 review article, and 8 studies with Level III or IV evidence. A complete summary of individual study characteristics is included in **Table 1**, and results are synthesized in **Table 2**.

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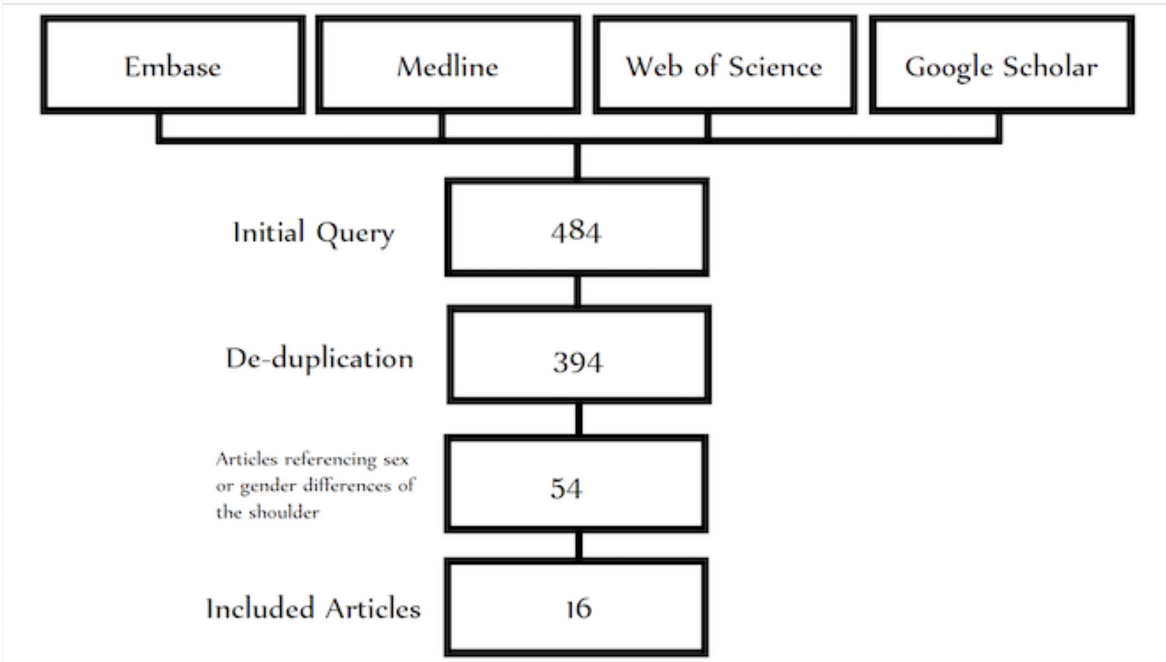

Figure 1. PRISMA flowchart depicting literature search for included articles in the systematic review.

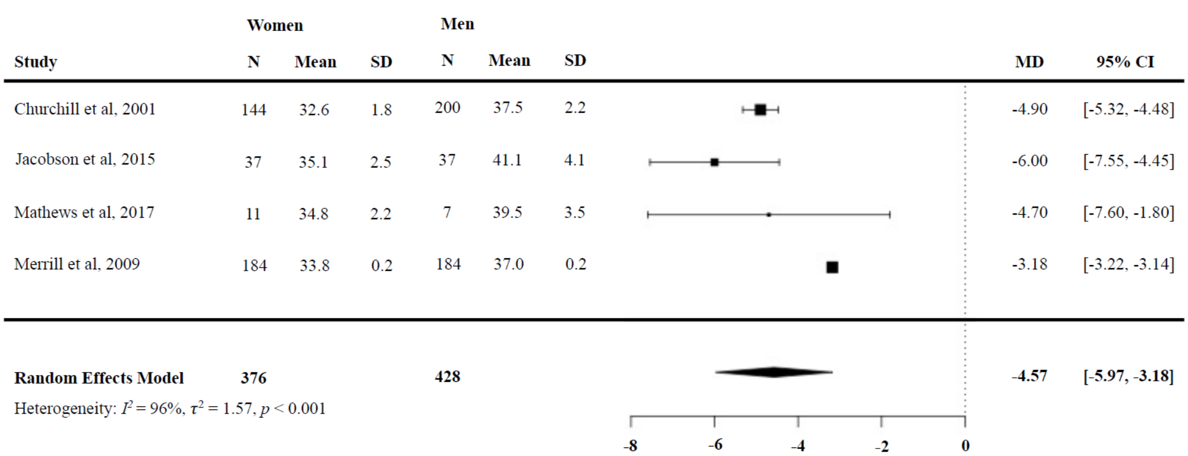

Figure 2. Mean differences (MD) in glenoid height of women compared to men.
CI, confidence interval; SD, standard deviation

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Table 1. Tabulated representation of studies included in this systematic review.

AUTHOR	YEAR	TITLE	TOPIC	TYPE OF STUDY	SUBJECTS (N)	LEVEL OF EVIDENCE
MERRILL ET AL[7]	2009	Gender differences in glenoid anatomy: an anatomic study	Anatomic differences in size of glenoid features between sexes	Cadaveric Study	363	IV
JACOBSON ET AL[8]	2015	Glenohumeral anatomic study. A comparison of male and female shoulders with similar average age and BMI	Differences in glenohumeral joint spatial relationships between sexes	Cadaveric Study	74	IV
MATHEWS ET AL[9]	2017	Glenoid morphology in light of anatomical and reverse total shoulder arthroplasty: a dissection- and 3D-CT-based study in male and female body donors	Variance in glenoid measurements and glenohumeral relationships between sexes	Cadaveric Study	36	IV
WEST ET AL[19]	2018	A 3D comparison of humeral head retroversion by sex and measurement technique	Humeral head version variability between sexes	Cadaveric Study	52	IV
SOLTANMOHAMMADI ET AL[20]	2019	Investigating the effects of demographics on shoulder morphology and density using statistical shape and density modeling	Bone density and scapular/humeral morphology differences between sexes	Cadaveric Study	75	IV
CHURCHILL ET AL[21]	2001	Glenoid size, inclination, and version: an anatomic study	Glenoid size, inclination, and version differences between sexes and races	Cadaveric Study	344	IV
CHECROUN ET AL[10]	2002	Fit of current glenoid component designs: an anatomic cadaver study	Shoulder arthroplasty study of component fit by design	Cadaveric Study	412	IV
ACHENBACH ET AL[22]	2019	The throwing shoulder in youth elite handball: soft-tissue adaptations but not humeral retrotorsion differ between the two sexes	Shoulder range-of-motion and humeral retrotorsion differences between sexes in youth handball athletes	Cross-sectional Study	138	IV
HUXEL ET AL[23]	2005	Gender differences in muscle recruitment and stiffness regulation strategies of the shoulder	Differences in glenohumeral joint muscle recruitment and stiffness regulation for shoulder protection between sexes	Case Control Study	40	III
KÄLIN ET AL[24]	2018	Shoulder muscle volume and fat content in healthy adult volunteers: quantification with DIXON MRI to determine the influence of demographics and handedness	Analysis of shoulder muscle volume and fat-signal fraction on MRI between sexes	Cross-sectional Study	76	IV
BROWN ET AL[25]	2000	The lax shoulder in females. Issues, answers, but many more questions	Review of literature on glenohumeral instability across age and sex	Clinical Review	74 referenced studies	III
SHAHRAKI ET AL[26]	2020	Comparison of some intrinsic risk factors of shoulder injury in three phases of menstrual cycle in collegiate female athletes	Evaluation of shoulder joint stability factors throughout menstrual cycle	Cross-sectional Study	15	IV
SUTTON ET AL[27]	2003	Shoulder proprioception in male and female athletes	Proprioceptive differences between sexes and athletes vs. non-athletes	Cross-sectional Study	56	III
HOSSEINIMEHR ET AL[28]	2015	The comparison of scapular upward rotation and scapulohumeral rhythm between dominant and non-dominant shoulder in male overhead athletes and non-athletes	Analysis of scapular motion and rhythm between male athletes and non-athletes between dominant and non-dominant shoulders	Cross-sectional Study	34	III
LIRIO-ROMERO ET AL[29]	2018	Implications on older women of age- and sex-related differences in activation patterns of shoulder muscles: A cross-sectional study	Analysis of neuromotor attributes of shoulder muscles between age groups and sexes to understand related functional disorders	Cross-sectional Study	60	III
BALCELLS-DIAZ ET AL[30]	2018	Shoulder strength value differences between genders and age groups	Shoulder strength variability between sex and age	Cross-sectional Study	381	III

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Table 2. Summary of pertinent findings identified in systematic review of sex-based differences of the shoulder.

Topic	Conclusion
Bony Anatomy	Men have significantly larger and denser bony anatomical structures (e.g. glenoid, scapula, humerus)[7-10,20,21] Glenohumeral spatial distances are longer in men (e.g. glenoid to acromion, glenoid to tuberosity)[8] No differences in glenoid version between sexes, but males have greater humeral head version[9,19-22]
Soft Tissue Anatomy	Men have significantly greater shoulder girdle strength[23,24,29,30] Dominant-side shoulder has significantly greater muscle volume and lower fat-signal fraction[24] Age correlates indirectly with shoulder muscle volume[29] EMG contractility force correlates indirectly with age in men, but force levels remained unaffected by age in women[29]
Biomechanics	No conclusive data regarding difference in prevalence of shoulder laxity between sexes[25,27] No changes in shoulder laxity throughout menstrual cycle in women, though proprioceptive and strength differences were noted between phases of the menstrual cycle[26] Athletes may have less proprioceptive sense than the general public at mid-range shoulder motion[27] Athletes have greater scapula rotational and scapulohumeral rhythm asymmetry between shoulders than non-athletes[28]

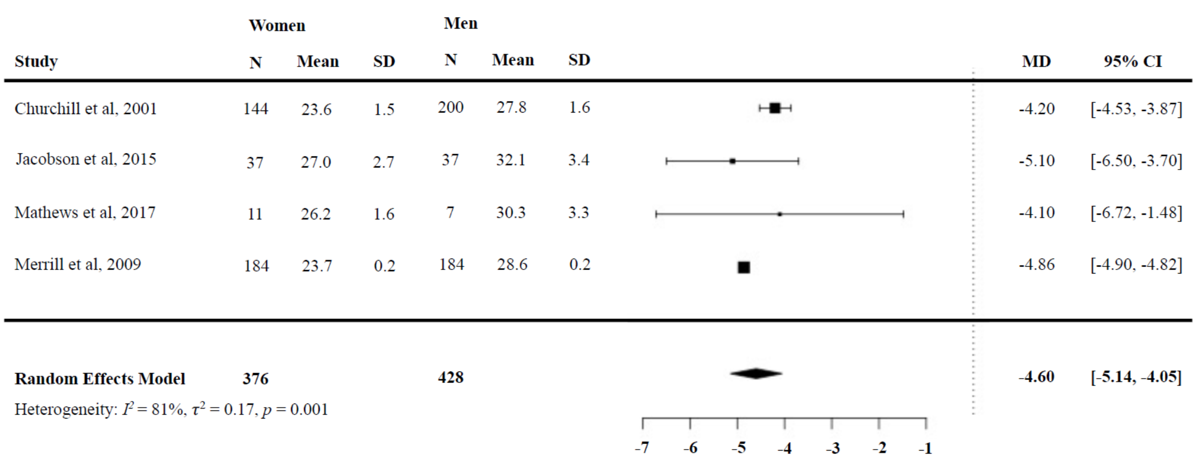

Figure 3. Mean differences (MD) in glenoid width of women compared to men.
CI, confidence interval; SD, standard deviation

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Synthesis of Results

Osteology

Glenohumeral osteology was the topic of 8 included studies.[7-10,19-22] Five studies reported glenoid size measurements for comparison between sexes, with each noting sex differences in glenoid height and width. In a meta-analysis of four studies, glenoid height was 4.57 mm less in females than in males on average (95% CI: -5.97 - -3.18; **Figure 2**). Data pooled across the same four studies revealed similar differences in glenoid width, with female measures 4.60 mm smaller on average compared to those of males (95% CI: -5.14 - -4.05; **Figure 3**). Similarly, Checroun et al noted female glenoids to be 10% smaller compared to males in terms of both height and width, though specific measures were not reported.[10] Only Merrill et al investigated sex differences in glenoid depth, which was 36% shallower in females (1.21 mm) than males (1.88 mm, $p < 0.0001$) in an equally distributed cohort of 368 patients.[7]

Glenoid retroversion and inclination were each reported by three[9,20,21] and two[20,21] studies, respectively. In a meta-analysis of retroversion across the three studies, females demonstrated on average 1.54° greater retroversion compared to males, though this difference was not statistically significant (95% CI: -2.32° - 5.39°; **Figure 4**). Of note, however, humeral head anteversion was found to be significantly greater in females (females 30.4˚, males 37.7˚, $p = 0.029$).[19] Neither of the two studies assessing glenoid inclination demonstrated differences based on sex.[20,21] Specifically, Churchill et al measured inclination to be 4.5° in females and 4.0° in males, while Soltanmohammadi et al measured 0.8° in females and 4.9° in males ($p = 0.15$).

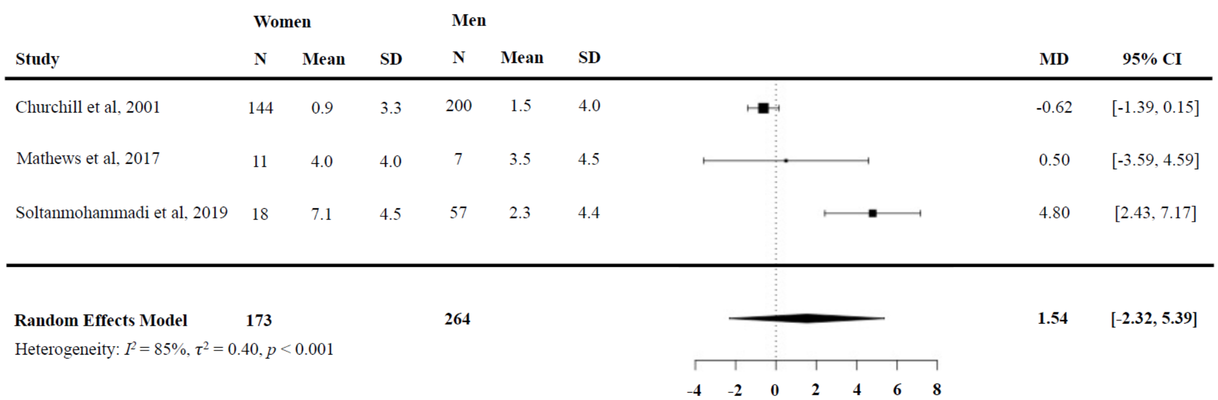

Figure 4. Mean differences (MD) in glenoid retroversion of women compared to men.
CI, confidence interval; SD, standard deviation

Three studies evaluated sex-related differences in scapular shape and density.[7,9,20] In a computed tomography (CT)-based study of gross morphology using cadaveric specimens, Merrill et al observed female glenoids to exhibit an oval shape, whereas male glenoids were rounder.[7] Soltanmohammadi et al found the medial/inferior border of scapulae, as well as the coracoid, to be qualitatively shorter in females than in males, though values were not reported in the study.[20] Mathews et al found the measured distance between the supraglenoid tubercle and scapular notch to be shorter in females than males on average (32.0 mm vs. 33.9 mm, $p < 0.05$).[9] Anatomy of the glenoid notch also varied by sex, as the structure was present in most females (80.4%) but was absent in the majority of males (42.4%). When present, however, the most common glenoid notch morphology was curved in both females and males, as opposed to notched or scalloped.[7] With regard to density, female scapulae were less dense in the tuberosities and subarticular region of the humeral head than those of males.[7]

Three studies investigated sex differences in humeral anatomy.[8,19,22] Only Jacobson et al assessed humeral size, determining the female

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humerus to be smaller than males in terms of distance from the center of the humeral head to the greater tuberosity (21.1 ± 2.5 mm vs. 23.8 ± 2.1 mm, $p < 0.0001$), humeral head diameter (43.7 ± 2.3 mm vs. 49.9 ± 3.3 mm, $p < 0.0001$), and humeral length (307.1 ± 15.8 mm vs. 335.1 ± 16.3 mm, $p < 0.0001$).[8] With regard to humeral version, West et al reported females to exhibit less retroversion than males by a margin of 7° using flexion-extension and transepicondylar axis techniques.[19] Results of a study by Achenbach et al support these findings, as retroversion was similarly less in females than males.[22] Lastly, Jacobson et al explored variation between males and females in terms of glenohumeral relationships, and found women to have significantly shorter distances from the center of the glenoid to the lateral greater tuberosity (females: 51.3 ± 3.3 mm, males: 59.0 ± 3.9 mm, $p < 0.0001$) and from the center of the humeral head to the lateral acromion (females: 31.2 ± 2.3 mm, males: 36.6 ± 4.5 mm, $p < 0.0001$).[8]

Soft Tissue Anatomy

The soft tissue composition of the shoulder was assessed in only one included study.[24] A prospective MRI-based study by Kälin et al demonstrated women to have a significantly higher fat-signal fraction of the subscapularis muscle compared to men (6.8% vs. 7.5%, $p = 0.001$), though no differences were observed between sexes for the supraspinatus, infraspinatus, teres minor, or deltoid muscles.[24] The authors also found significantly lower shoulder muscle volumes for all rotator cuff muscles (supraspinatus: 14.9 vs 20.3 ml/cm^2, infraspinatus: 31.3 vs 45.0 ml/cm^2, subscapularis: 40.2 vs 60.4 ml/cm^2, teres minor: 6.8 vs 9.7 ml/cm^2), and for the deltoid (82.8 vs 125.6 ml/cm^2) amongst females compared to males when normalized to body height. Further examination revealed lower fat-signal fractions and greater muscle volumes on the dominant side in all patients, with age directly correlating with muscle volume.

Two studies researched sex-related differences in shoulder laxity and stability.[25,27] The studies evaluated shoulder stability with anterior and posterior drawer examinations, as well as generalized laxity with elbow hyperextension, knee hyperextension, finger hyperextension, ability to touch the thumb to the forearm, and/or sulcus sign. Combined, the two studies had six total studies contained within them addressing shoulder laxity, of which three studies showed increased laxity among females.[31-33] Two of the studies found no difference in global or shoulder laxity[34,35] and one noted a difference in global laxity between sexes without a difference in shoulder laxity.[36] In the latter study, Marshall et al evaluated a cohort of 124 patients according to 13 parameters of global joint laxity (including 2 shoulder-specific measures) and determined shoulder laxity did not differ between sexes, though females did demonstrate increased looseness in several other joints.[36] Conversely, however, more recent studies included in the analysis noted greater laxity among females in both anterior[27,31] and posterior planes[32] compared to men.

Research indicates that increased joint laxity among females may be both a passive and active process.[23] Investigating how sex differences in static joint stability can influence neuromuscular strategies for stiffness regulation and dynamic restraint of the shoulder, Huxel et al found that males exhibit significantly greater passive (39%) and active stiffness (53%) than females, with females accordingly displaying a significantly higher prevalence of generalized joint laxity.[23] Maximum internal rotation (IR) strength and generalized joint laxity were significant predictors of shoulder stiffness. Females elicited more infraspinatus (47%) and less subscapularis (37%) muscle activity than males when preparing for dynamic testing, which the authors postulated may be the result of increased generalized joint laxity.

Neuromuscular Function

Sex differences in shoulder proprioception were evaluated by two studies.[26,27] Shahraki et al found women to experience significantly heightened proprioception during the luteal phase as measured by passive joint position sensation in flexion, IR, and external rotation (ER). Conversely, strength of abduction, IR, and ER were greatest in the ovulatory phase.[26] In a prospective study of 56 college-aged volunteers, Sutton et al found that female proprioception was not significantly different than that of males, nor were there any differences between the dominant and non-dominant shoulders or between fatigued and non-fatigued states.[27] The authors of this study noted athletes possessed significantly less proprioceptive acuity than the general population at the middle

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range of motion, indicating proprioceptive ability at the glenohumeral joint is more influenced by athletic training than sex.

Sex differences in shoulder strength were evaluated by two studies, which similarly demonstrated that strength of the upper extremity girdle differed by sex.[29,30] In a prospective analysis of shoulder strength in over 400 individuals, Balcells-Diaz et al determined female participants achieved significantly lower dynamometer strength scores than their male counterparts (9.9 units vs. 19.5 units, as measured by a digital processor-driven isometric dynamometer attached by a cuff to the patient's forearm in an extended and mid-pronated position).[30] Additionally, males under 40 years of age were significantly stronger than those over age 40 (22 units vs. 18 units); no such difference was observed within the female cohort. A more recent electromyography (EMG)-based study by Lirio-Romero et al investigating shoulder function corroborates these findings. The authors found young adult males (age 20-42yr) achieved greater force in maximum isometric voluntary contraction than females, though females achieved greater amplitudes within the serratus anterior muscle.[29] The authors similarly observed male strength to decrease with age whereas female strength remained almost unaffected, leading to older females (age >68yr) demonstrating greater shoulder functionality than similarly aged males. During middle-age (age 43-67yr), females displayed greater range of motion (flexion, IR, abduction).

DISCUSSION

Multiple anatomic and biomechanical sex differences exist in the shoulder. Bony anatomy, including glenohumeral size, morphology, and version, varies between men and women. This systematic review and meta-analysis found average glenoid height and width are roughly 12% and 15% smaller in females as compared to males, respectively. Humeral head anteversion is approximately 7° greater in females, while glenoid retroversion is similar between the sexes. In addition to osseous dimorphism, females and males also exhibit differences in shoulder soft tissue anatomy, with females exhibiting higher fat-signal fractions and lower muscle volumes relative to males. Differences in shoulder laxity and stability remain controversial. Finally, biomechanical differences between the sexes are inconsistent across the literature. While females and males did not differ in proprioceptive ability, sex differences were apparent in measures of strength as young- and middle-aged males achieved greater isotonic force, though patient age appears to also play a role in mediating this relationship. Considering shoulder anatomy and function directly influences injury risk and rehabilitation, understanding sex differences is critically important to clinicians and may aid in determining diagnoses and tailoring treatment approaches to optimize patient outcomes.

Differences in shoulder osteology between the sexes – i.e. glenoid height, glenoid width - were consistently reported across studies included in this review, with meta-analysis serving confirmation of significance. Such differences may have important clinical correlations with respect to both shoulder pathology and treatment approaches. For example, in their prospective cohort study of 714 young athletes, Owens et al found glenoid index, or the height-to-width ratio, to be a significant risk factor for anterior glenohumeral instability in multivariate analyses (HR 8.12; 95% CI 1.07-61.72; p = 0.043).[37] Prior literature has shown that overhead throwing may have an impact on glenoid version, as Drakos et al noted significantly greater retroversion in professional baseball players as compared to their age-matched non-throwing control subjects. Though this study found no significant differences in version between sexes, this may be an opportunity for future investigation.[38] Knowledge of sex differences related to shoulder osteology are imperative for surgeons performing shoulder arthroplasty. In the treatment of proximal humerus fractures, greater tuberosity height is utilized to guide the vertical position or height of the humeral stem when anatomy is distorted. Surgeons performing shoulder arthroplasty and medical device implant companies must also be aware of sex differences in glenoid width. Recent studies performed outside of the United States have noted a mismatch between the average size of the female glenoid and commercially-available glenoid baseplates.[39-42]

Our review demonstrates soft tissue laxity remains controversial in literature pertaining to sex differences of the shoulder. Similar discordance was reported in a prior review by Brown et al in 2000.[25] Some included studies observed no sex differences in generalized joint laxity among

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children and adolescents[34,35], while others determined females to have greater laxity.[32,33] Similar to research regarding the ACL, recent research has focused on elucidating biochemical pathways related to increased shoulder laxity in females. Relaxin, for example, a hormone responsible for increasing pelvic ligamentous laxity and cervical ripening to support childbirth, has been implicated in ACL injuries among female athletes.[43,44] Recently, studies have demonstrated a potential impact on shoulder laxity, as well. In a nested case-control analysis of 106 young athletes, Owens et al found each 1 pg-mL increase in relaxin concentrations increased the odds ratio of shoulder instability by 2.18 (95% CI 1.01-4.76).[37]

Recent research has also sought to elucidate a relationship between shoulder laxity and the female menstrual cycle. In a study of 15 healthy collegiate female overhead athletes with normal menstrual cycles, Shahraki et al observed no significant differences in shoulder laxity or functional stability across the three phases of the menstrual cycle (menses, ovulation, midluteal).[26] However, given these physiologic processes are specific to the female sex, these findings are unique to women and no studies have examined potential fluctuations in male laxity to date. Further investigation into genetic, biomechanical, and biochemical factors impacting sex-related shoulder laxity is warranted.

The results of our review substantiate sex-related differences between female and male shoulder strength, though the relationship is complex. While analysis of muscle composition and strength shows females have less muscle volume and lower strength than males, females are less affected by age-related reduction in muscle strength of the shoulder girdle. As has been well-established at this point, shoulder strength is an important component in many clinical outcomes measures, including objectively in the CONSTANT shoulder score and more subjectively in the DASH score.[45,46] Proprioception has also become a topic of recent interest as it relates to susceptibility to injury and to therapy with a focus on neuromuscular control.[47] Additionally, it may prove to have value as a post-operative metric; Walecka et al demonstrated in a recent study that joint position sense after reverse TSA was comparable to healthy population shoulders and superior to non-operated contralateral shoulders.[48] However, in line with the findings of this study, perhaps sex-related proprioceptive differences of the shoulder do not exist. A comprehensive understanding of proprioceptive differences of the shoulder between sexes may inform specific protocol development as it relates to rehabilitation and risk after a procedure. The use of anatomically-based literature has the potential to standardize or, at the very least, to create a more nuanced understanding of expected outcomes after injury or intervention.

Limitations

This study has several important limitations to consider. As with any systematic review, the strength of this study is dependent upon the quality of evidence of included studies. Although multiple databases were searched for eligible articles, only those published in peer-reviewed journals were considered for inclusion, potentially bypassing unpublished works. The search methodology was employed in particular to assess those studies which primarily sought sex or gender differences in the aforementioned shoulder categories. There are many studies which report gender or sex differences, however, these findings are incidental to the primary outcomes measured, and thus, are likely to be fraught with bias (such as lack of power). The authors recognize that a single metric to compare cadaveric, imaging, and functional measurement study quality is lacking. Reporting a variety of metrics may prove difficult to interpret among studies of varying methodologies. Meta-analyses were performed, when possible, but pooling of data was restricted by limited and variable reporting of outcome measures. Moreover, small numbers of subjects within the identified studies as well as the overall paucity of studies to include must be recognized as a limitation, and the interpretation of the findings should be influenced as such. Taken together, these limitations demonstrate need for further research on the topic of sex differences in shoulder anatomy and biomechanics as well as the implications of sex differences in injury predisposition, prevention, and rehabilitation. Future work may focus on translating the interactions between osteology, soft tissue anatomy, and neuromuscular function into meaningful clinical implications directed towards focused patient care. For example, does glenoid shape influence over/underestimation of glenoid bone loss or reaming, or does glenoid depth

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influence shoulder laxity? Despite these weaknesses, this review presents a comprehensive overview of sex-related differences in shoulder bony and soft tissue anatomy and neuromuscular function that can be used to inform clinician decision-making and refine operative and nonoperative therapeutic techniques.

CONCLUSION

This systematic review and meta-analysis demonstrate multiple sex-related differences in shoulder anatomy and biomechanics. Compared to males, females exhibit smaller glenoids, less humeral head retroversion, and decreased muscle volume and strength in young and middle-aged patients. Differences in shoulder laxity remain controversial. Taken together, these findings can be used by clinicians and researchers within the purview of the limitations of this systematic review to better understand glenohumeral injury risk and tailor management to patients.

Conflict of Interest Statement

The authors report no conflict of interest with the contents of this manuscript.

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REFERENCES

1. Oliphant JG, Drawbert JP. Gender differences in anterior cruciate ligament injury rates in wisconsin intercollegiate basketball. *J Athl Train.* 1996;31(3):245-247.
2. Anderson AF, Dome DC, Gautam S, Awh MH, Rennirt GW. Correlation of anthropometric measurements, strength, anterior cruciate ligament size, and intercondylar notch characteristics to sex differences in anterior cruciate ligament tear rates. *Am J Sports Med.* 2001;29(1):58-66.
3. Charlton WP, St John TA, Ciccotti MG, Harrison N, Schweitzer M. Differences in femoral notch anatomy between men and women: a magnetic resonance imaging study. *Am J Sports Med.* 2002;30(3):329-333.
4. Dimitriou D, Wang Z, Zou D, Helmy N, Tsai TY. Do Sex-Specific Differences Exist in ACL Attachment Location? An MRI-Based 3-Dimensional Topographic Analysis. *Orthop J Sports Med.* 2020;8(11):2325967120964477.
5. Mountcastle SB, Posner M, Kragh JF, Jr., Taylor DC. Gender differences in anterior cruciate ligament injury vary with activity: epidemiology of anterior cruciate ligament injuries in a young, athletic population. *Am J Sports Med.* 2007;35(10):1635-1642.
6. Ireland ML. The female ACL: why is it more prone to injury? *Orthop Clin North Am.* 2002;33(4):637-651.
7. Merrill A, Guzman K, Miller SL. Gender differences in glenoid anatomy: an anatomic study. *Surg Radiol Anat.* 2009;31(3):183-189.
8. Jacobson A, Gilot GJ, Hamilton MA, et al. Glenohumeral Anatomic Study. A Comparison of Male and Female Shoulders with Similar Average Age and BMI. *Bull Hosp Jt Dis (2013).* 2015;73 Suppl 1:S68-78.
9. Mathews S, Burkhard M, Serrano N, et al. Glenoid morphology in light of anatomical and reverse total shoulder arthroplasty: a dissection- and 3D-CT-based study in male and female body donors. *BMC Musculoskelet Disord.* 2017;18(1):9.
10. Checroun AJ, Hawkins C, Kummer FJ, Zuckerman JD. Fit of current glenoid component designs: an anatomic cadaver study. *J Shoulder Elbow Surg.* 2002;11(6):614-617.
11. Magnuson JA, Wolf BR, Cronin KJ, et al. Sex-related differences in patients undergoing surgery for shoulder instability: a Multicenter Orthopaedic Outcomes Network (MOON) Shoulder Instability cohort study. *J Shoulder Elbow Surg.* 2019;28(6):1013-1021.
12. Owens BD, Campbell SE, Cameron KL. Risk factors for anterior glenohumeral instability. *Am J Sports Med.* 2014;42(11):2591-2596.
13. Jawa A, Dasti U, Brown A, Grannatt K, Miller S. Gender differences in expectations and outcomes for total shoulder arthroplasty: a prospective cohort study. *J Shoulder Elbow Surg.* 2016;25(8):1323-1327.
14. Friedman RJ, Cheung EV, Flurin PH, et al. Are Age and Patient Gender Associated With Different Rates and Magnitudes of Clinical Improvement After Reverse Shoulder Arthroplasty? *Clin Orthop Relat Res.* 2018;476(6):1264-1273.
15. Group OLoEW. The Oxford Levels of Evidence 2. In: Oxford Center for Evidence Based Medicine; 2011.
16. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials.* 1986;7(3):177-188.
17. Cochran WM. Some Methods for Strengthening the Common χ2 Tests. *Biometrics.* 1954;10(4):35.
18. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med.* 2002;21(11):1539-1558.
19. West EA, Knowles NK, Athwal GS, Ferreira LM. A 3D comparison of humeral head retroversion by sex and measurement technique. *Shoulder Elbow.* 2018;10(3):192-200.

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20. Soltanmohammadi P, Elwell J, Veeraraghavan V, Athwal GS, Willing R. Investigating the Effects of Demographics on Shoulder Morphology and Density Using Statistical Shape and Density Modeling. *J Biomech Eng.* 2020;142(12).
21. Churchill RS, Brems JJ, Kotschi H. Glenoid size, inclination, and version: an anatomic study. *J Shoulder Elbow Surg.* 2001;10(4):327-332.
22. Achenbach L, Clement AC, Hufsky L, Greiner S, Zeman F, Walter SS. The throwing shoulder in youth elite handball: soft-tissue adaptations but not humeral retrotorsion differ between the two sexes. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(12):3937-3943.
23. Huxel KC. *Gender differences in muscle recruitment and stiffness regulation strategies of the shoulder*, Temple University; 2005.
24. Kalin PS, Crawford RJ, Marcon M, et al. Shoulder muscle volume and fat content in healthy adult volunteers: quantification with DIXON MRI to determine the influence of demographics and handedness. *Skeletal Radiol.* 2018;47(10):1393-1402.
25. Brown GA, Tan JL, Kirkley A. The lax shoulder in females. Issues, answers, but many more questions. *Clin Orthop Relat Res.* 2000(372):110-122.
26. Forouzandeh Shahraki S, Minoonejad H, Moghadas Tabrizi Y. Comparison of some intrinsic risk factors of shoulder injury in three phases of menstrual cycle in collegiate female athletes. *Phys Ther Sport.* 2020;43:195-203.
27. Sutton ZL. *Shoulder proprioception in male and female athletes*, University of Tennessee; 2003.
28. Hosseinimehr SH, Anbarian M, Norasteh AA, Fardmal J, Khosravi MT. The comparison of scapular upward rotation and scapulohumeral rhythm between dominant and non-dominant shoulder in male overhead athletes and non-athletes. *Man Ther.* 2015;20(6):758-762.
29. Lirio-Romero C, Anders C, De La Villa-Polo P, Torres-Lacomba M. Implications on older women of age- and sex-related differences in activation patterns of shoulder muscles: A cross-sectional study. *J Women Aging.* 2019;31(6):492-512.
30. Balcells-Diaz E, Daunis IEP. Shoulder strength value differences between genders and age groups. *J Shoulder Elbow Surg.* 2018;27(3):463-469.
31. Borsa PA, Sauers EL, Herling DE. Patterns of glenohumeral joint laxity and stiffness in healthy men and women. *Med Sci Sports Exerc.* 2000;32(10):1685-1690.
32. McFarland EG, Campbell G, McDowell J. Posterior shoulder laxity in asymptomatic athletes. *Am J Sports Med.* 1996;24(4):468-471.
33. Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. *Ann Rheum Dis.* 1973;32(5):413-418.
34. Carter C, Wilkinson J. Persistent Joint Laxity and Congenital Dislocation of the Hip. *J Bone Joint Surg Br.* 1964;46:40-45.
35. Emery RJ, Mullaji AB. Glenohumeral joint instability in normal adolescents. Incidence and significance. *J Bone Joint Surg Br.* 1991;73(3):406-408.
36. Marshall JL, Johanson N, Wickiewicz TL, et al. Joint looseness: a function of the person and the joint. *Med Sci Sports Exerc.* 1980;12(3):189-194.
37. Owens BD, Cameron KL, Clifton KB, Svoboda SJ, Wolf JM. Association Between Serum Relaxin and Subsequent Shoulder Instability. *Orthopedics.* 2016;39(4):e724-728.
38. Drakos MC, Barker JU, Osbahr DC, et al. Effective glenoid version in professional baseball players. *Am J Orthop (Belle Mead NJ).* 2010;39(7):340-344.
39. Jha SC, Fukuta S, Wada K, et al. Optimizing baseplate position in reverse total shoulder arthroplasty in small-sized Japanese females: technical notes and literature review. *J Med Invest.* 2016;63(1-2):8-14.
40. Matsuki K, Sugaya H, Hoshika S, et al. Three-dimensional measurement of glenoid dimensions and orientations. *J Orthop Sci.* 2019;24(4):624-630.
41. Matsumura N, Oki S, Ogawa K, et al. Three-dimensional anthropometric analysis of the glenohumeral joint in a normal Japanese population. *J Shoulder Elbow Surg.* 2016;25(3):493-501.
42. Slocum AMY, Siu YC, Ma CM, Lui TH. The study of 2-dimensional computed tomography scans of the glenoid anatomy in relation to reverse shoulder arthroplasty in the Southern Chinese population. *JSES Int.* 2021;5(4):714-721.
43. Dragoo JL, Castillo TN, Braun HJ, Ridley BA, Kennedy AC, Golish SR. Prospective correlation between serum relaxin concentration and anterior cruciate ligament tears among elite collegiate female athletes. *Am J Sports Med.* 2011;39(10):2175-2180.
44. Dragoo JL, Lee RS, Benhaim P, Finerman GA, Hame SL. Relaxin receptors in the human female anterior cruciate ligament. *Am J Sports Med.* 2003;31(4):577-584.
45. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res.* 1987(214):160-164.
46. Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand) [corrected]. The Upper Extremity Collaborative Group (UECG). *Am J Ind Med.* 1996;29(6):602-608.
47. Salles JI, Velasques B, Cossich V, et al. Strength training and shoulder proprioception. *J Athl Train.* 2015;50(3):277-280.
48. Walecka J, Lubiatowski P, Consigliere P, Atoun E, Levy O. Shoulder proprioception following reverse total shoulder arthroplasty. *Int Orthop.* 2020;44(12):2691-2699.

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APPENDIX

Supplemental Table 1. Full Search Strategy for Ovid (MEDLINE)

1	'exp Sex Characteristics/ OR (Gender difference*).ti,ab OR (Sex difference*).ti,ab OR (Sex-related difference*).ti,ab OR (Sex related difference*).ti,ab OR (Gender-associated difference*).ti,ab OR (Gender associated difference*).ti,ab OR (Sex associated difference*).ti,ab OR (Sex-associated difference*).ti,ab OR (Gender related difference*).ti,ab OR (Gender-related difference*).ti,ab OR (Sex specific).ti,ab OR (Sex-specific).ti,ab OR (Sexual dimorphism).ti,ab OR (Sexually dimorphic).ti,ab OR (Sex-dependent).ti,ab OR (Sex dependent).ti,ab OR (Sexual characteristic*).ti,ab OR (Sex characteristic*).ti,ab OR (Gender characteristic*).ti,ab
2	(exp Shoulder/ OR shoulder.ti,ab) AND (surgery.fs. or surgery.ti,ab. OR exp General Surgery/ or exp Surgical Procedures, Operative/ OR exp Orthopedic Procedures/)
3	("biceps tenodesis" OR "biceps tenotomy" OR "shoulder replacement" OR "shoulder arthroplasty" OR "arthroscopic capsulorrhaphy").ti,ab OR (arthroscopic adj3 repair).ti,ab
4	#1 AND (#2 OR #3)

Supplemental Table 2. Full Search Strategy for Web of Science

1	TS=("Sexual Characteristics" OR "Gender difference*" OR "Sex difference*" OR "Sex-related difference*" OR "Sex related difference*" OR "Gender-associated difference*" OR "Gender associated difference*" OR "Sex associated difference*" OR "Sex-associated difference*" OR "Gender related difference*" OR "Gender-related difference*" OR "Sex specific" OR Sex-specific OR "Sexual dimorphism" OR "Sexually dimorphic" OR Sex-dependent OR "Sex dependent")
2	TS=("arthroscopic rotator cuff repair" OR "arthroscopic resection" OR "biceps tenodesis" OR "shoulder replacement" "OR shoulder arthroplasty" OR "biceps tenotomy" OR "arthroscopic capsulorrhaphy")
3	TS=(arthroscopic NEAR/2 repair)
4	TS=("shoulder")
5	TS=("surgery" OR "General Surgery" OR "Orthopedic surgery" OR "Joint surgery")
6	#4 AND #5
7	#1 AND (#2 OR #3 OR #6)

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Supplemental Table 3. Full Search Strategy for EMBASE.com

1	'Sexual Characteristics'/exp OR 'gender differences'/exp OR 'sex differences'/exp OR 'Gender difference*':ti,ab OR 'Sex difference*':ti,ab OR 'Sex-related difference*':ti,ab OR 'Sex related difference*':ti,ab OR 'Gender-associated difference*':ti,ab OR 'Gender associated difference*':ti,ab OR 'Sex associated difference*':ti,ab OR 'Sex-associated difference*':ti,ab OR 'Gender related difference*':ti,ab OR 'Gender-related difference*':ti,ab OR 'Sex specific':ti,ab OR 'Sex-specific':ti,ab OR 'Sexual dimorphism':ti,ab OR 'Sexually dimorphic':ti,ab OR 'Sex-dependent':ti,ab OR 'Sex dependent':ti,ab
2	'arthroscopic rotator cuff repair'/exp OR 'arthroscopic resection'/exp OR 'biceps tenodesis'/exp OR 'shoulder replacement'/exp OR 'shoulder arthroplasty'/exp OR 'biceps tenodesis':ti,ab OR 'biceps tenotomy':ti,ab OR 'shoulder replacement':ti,ab OR 'shoulder arthroplasty':ti,ab OR 'arthroscopic capsulorrhaphy':ti,ab
3	(Arthroscopic NEAR/3 repair):ti,ab
4	'Shoulder'/exp OR 'shoulder':ti,ab
5	surgery:lnk OR surgery:ti,ab OR 'General Surgery'/exp OR 'Orthopedic surgery'/exp
6	#4 AND #5
7	#1 AND (#2 OR #3 OR #4 OR #6)

Supplemental Table 4. Full Search Strategy for Google Scholar

TITLE WORDS:	shoulder
KEYWORDS:	"Gender differences" | "sex differences" AND arthroscopy | arthroplasty | tenotomy | tenodesis | resection | replacement

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