A Cadaveric Model Evaluating the Influence of Bony Anatomy and the Effectiveness of Partial Scapulectomy on Decompression of the Scapulothoracic Space in Snapping Scapula Syndrome

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Background: Snapping scapula syndrome (SSS) is caused by bony and/or soft tissue impingement in the scapulothoracic articulation. Surgical resection of the superomedial angle (SMA) plus bursectomy can provide relief in most cases; however, the amount needed to achieve adequate scapulothoracic space decompression (SSD) is unknown.

Purpose: The aim of this study was to evaluate the effectiveness of partial scapulectomy and the influence of bony anatomy on SSD. It was hypothesized that the anterior offset and costomedial angle would correlate with the amount of bony resection needed to achieve adequate SSD.

Study Design: Controlled laboratory study.

Methods: Twenty pairs (n = 40) of shoulder specimens (mean age, 58 years [range, 41-64 years]; 10 male and 10 female specimens) were included. The scapula shape, medial scapula corpus angle (MSCA), anterior offset, and costomedial angle were obtained from computed tomography scans. Specimens were dissected, and each bare bony scapula was rigidly mounted. Points were collected using a 3-dimensional measuring arm. An SMA point and theoretical resection points (incremental 1-cm points up to 3 cm) proceeding laterally and medially were collected. The scapular plane was interpolated using points from the posterior scapular body. The horizontal distances of the anterior offset and each resection point to the scapular plane were calculated. The difference between the native anterior offset and the offset after resection represented the SSD. Adequate SSD was set at 5 mm. One-way analyses of variance and Pearson correlations were used with statistical significance set at $P < .05$.

Results: The maximum SSD with 3-cm resection was significantly correlated with the anterior offset ($R = 0.83$, $P < .001$) as well as the costomedial angle ($R = -0.43$, $P = .006$) but not the MSCA ($R = -0.11$, $P = .495$) or scapula shape ($F_{2,37} = 0.39$, $P = .681$). For the 5 scapulae with an anterior offset of less than 20 mm, a 5-mm SSD was not achieved. For 18 of 30 (60%) scapulae with an anterior offset between 20 mm and 35 mm, 3-cm resection provided at least a 5-mm SSD. For the 5 scapulae with an anterior offset of greater than 35 mm, 2-cm resection resulted in at least a 5-mm SSD in all cases.

Conclusion: The anterior offset of the scapula appeared to be the most important bony parameter to consider during preoperative planning and the evaluation of SSD with partial scapulectomy.

Clinical Relevance: The results of this study may help surgeons with preoperative planning of surgical decompression of the scapulothoracic space for patients with symptomatic SSS.

Keywords: snapping scapula syndrome; partial scapulectomy; scapulothoracic space; anterior offset; arthroscopic surgery

Snapping scapula syndrome (SSS) is characterized by a “snapping” sensation of the scapulothoracic articulation caused by bony and/or soft tissue impingement. When symptomatic, SSS is usually accompanied by bursal inflammation.[9,21] While obvious bony abnormalities such as osteochondromas can lead to bony impingement and SSS, these cases are rare. SSS is mostly seen in normal-appearing scapulae without obvious bony abnormalities and is often associated with trauma or participation in

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546516687755

sports leading to muscular imbalances and abnormal scapula positioning.[4,6,9,21] Nonoperative management is the initial treatment choice and is successful in approximately 75% of cases.[8,9,21] If nonoperative measures fail to provide a sufficient relief of symptoms, then surgery consisting of bursectomy and partial scapulectomy of the superomedial angle (SMA) is indicated. Initial surgical procedures were performed open[12] but have been widely replaced by minimally invasive arthroscopic techniques because of the advantages of faster recovery time, less cosmetic defects, and preservation of muscular attachments.[3,7,11,13,16,17,19] The majority of patients are satisfied with the outcomes of partial scapulectomy; however, occasionally, recurrent symptoms warrant revision surgery with additional scapular resection.[3,7,11,13,16,17]

To date, the amount of scapular resection of the SMA needed to achieve adequate scapulothoracic space decompression (SSD) is not known. There are varying amounts of resection noted in the literature; 2-cm (superior to inferior) by 3-cm (medial to lateral) triangular resection is commonly performed but may vary depending on the size of the scapula and the experience of the surgeon.[10,12,15,16,21] The bony anatomy of a scapula varies among the population, and recent studies have shown a possible relationship of several bony parameters to the development of SSS in patients. The scapula shape, medial scapula corpus angle (MSCA), costomedial angle, and anterior offset have all been implicated in disease occurrence and severity.[1,2,14,20] Despite the identification of these bony parameters, it remains unclear if, and how, these influence the effect of bony resection. While only certain types of the scapula shape and MSCA seem to affect the scapulothoracic space, as these measurements reflect the bony architecture below the scapula spine, the anterior offset and costomedial angle appear to have a direct relationship with the anatomy that determines the scapulothoracic space.[2,14,20]

The aim of this study was to evaluate the effectiveness of partial scapulectomy and the influence of the scapula shape, MSCA, costomedial angle, and anterior offset on SSD using a cadaveric model. It was hypothesized that the anterior offset and costomedial angle would correlate with the amount of bony resection needed to achieve adequate SSD. Furthermore, it was hypothesized that the MSCA and scapula shape, despite being predictors of the occurrence of SSS, would not affect the SSD achieved.

METHODS

Twenty pairs (n = 40) of fresh-frozen shoulder cadaveric specimens (mean age, 58 years [range, 41-64 years]; 10 male and 10 female specimens) with no history of rotator cuff injuries, surgery, or other definitive shoulder injuries were included in this study. The cadaveric specimens utilized in this study were donated to a tissue bank for the purpose of medical research and then purchased by our institution.

Imaging

Each shoulder specimen underwent clinical-grade computed tomography (CT) (Aquilion Premium; Toshiba America Medical Systems) with a 0.5 × 80−mm slice thickness, 120-kVp voltage, 150-mA current, and 750-millisecond exposure time using helical scans. Mimics computational modeling software (Materialise) was then used to create a 3-dimensional (3-D) bone model from the CT data. Using the CT scans and 3-D models on the Mimics software, the shape of the scapula was classified (straight, concave, or S-shaped) (Figure 1), and the MSCA was measured for all specimens by an orthopaedic surgeon (J.C.K.).[20] The MSCA was measured using a similar technique as described by Spiegl et al[20] that was modified for the use with CT instead of magnetic resonance imaging (MRI). Using the axial-plane images scrolling from superior to inferior, the angle of the costal surface of the medial scapula border was measured when the scapular body was seen sharply. Additionally, the costomedial angle and anterior offset were measured for all specimens.[2,14] The costomedial angle was measured as described by Mozes et al,[14] defined as the angle between the superior and inferior scapula wings along the medial border of the scapula (Figure 2). The anterior offset was measured using the sagittal-plane images in which the SMA point was identified as the most anterior superior point. A best-fit straight line was then imposed on the scapular body to represent the scapular body plane, and from this straight line, a perpendicular line was drawn directly across to the SMA point. The distance of this perpendicular line from the scapular body plane to the SMA point was used to measure the anterior offset (Figure 3).

Data Collection

Specimens were thawed for 24 hours at room temperature and then dissected free of all soft tissue, leaving the bare bony scapula. Each scapula was mounted by rigidly clamping the inferior aspect of the scapula to a custom shoulder clamp. Theoretical SMA resection was simulated by collecting points in 3-D space using a portable measuring arm with a manufacturer-reported point repeatability of 0.025 mm (Romer Absolute Arm; Hexagon Metrology) and Rhinoceros software (Rhinoceros 5.0; Robert McNeel & Associates).

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One or more of the authors has declared the following potential conflict of interest or source of funding: P.J.M. receives royalties from and is a paid consultant for Arthrex Inc, owns stock or options in Game Ready and VuMedi, and receives research support from Arthrex, Ossur, Siemens, and Smith & Nephew. J.C.K.'s research position was sponsored by Arthrex.

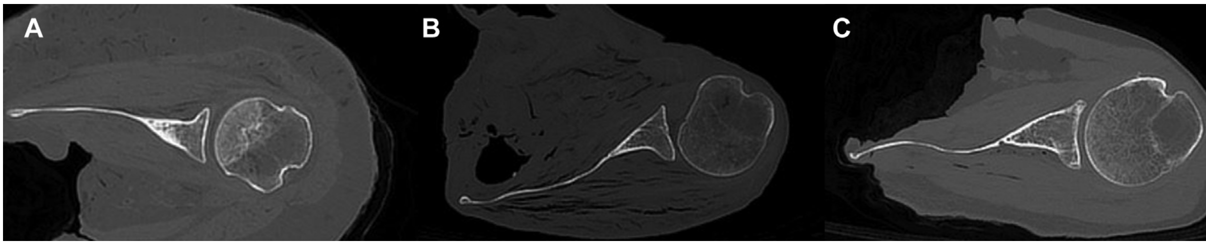

Figure 1. The different shapes of the scapula as determined when the scapular body first becomes sharp scrolling from superior to inferior in the axial plane of the computed tomography scan: (A) straight, (B) concave, and (C) S-shaped.

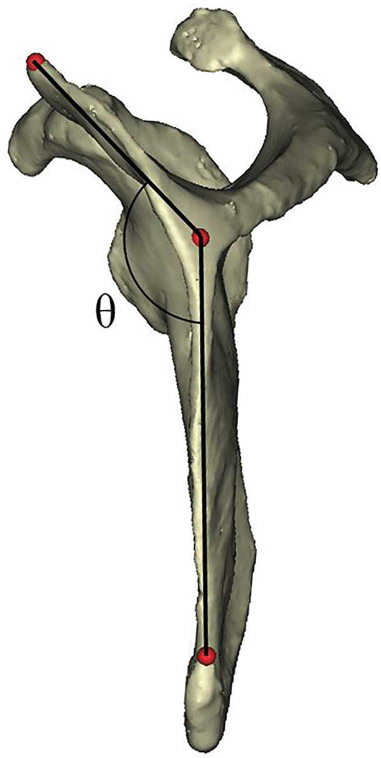

Figure 2. Schematic demonstrating the measurement of the costomedial angle (θ) as the angle between the superior and inferior scapula wings along the medial border of the scapula.

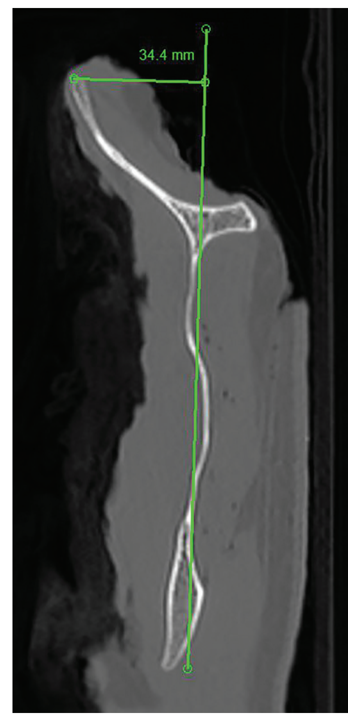

Figure 3. Measurement of the anterior offset of the scapula using a standard computed tomography scan in the sagittal plane. The horizontal distance from an estimated scapular body plane to the superomedial angle (SMA) point of the scapula represented the anterior offset.

The SMA point (the most anterior point along the SMA) and 1-cm incremental points up to 3 cm proceeding both laterally (L1, L2, L3) and medially (M1, M2, M3) from the chosen SMA point were collected for each scapula (Figure 4A). The SMA point represents the most anterior point closest to the posterior thorax and therefore is potentially the most clinically relevant point to dictate the scapulothoracic space.[2] Each incremental 1-cm point on either side of the SMA point represented different amounts of theoretical partial scapulectomy. In addition, approximately 70 points were collected from the posterior scapular body below the scapula spine for each scapula (Figure 4A). These points from the scapular body were used to re-create the scapular body plane, from which the horizontal distance to the SMA point (anterior offset) and to the boundary points of the theoretical triangular-shaped resections (L1, M1, etc) was measured (Figure 4B). The horizontal distance of the SMA point to each boundary point represented the SSD achieved with that particular amount of resection.

A 5-mm SSD was set as the minimal clinically relevant SSD with consideration of the previous measurements relating to the scapulothoracic space and for easy reproducibility intraoperatively because a typical burr has a 5-mm width.[2] The suprascapular notch was identified in each scapula, and its proximity to point L3 (Figure 4A) was noted to assess the risk of possible suprascapular nerve injuries with resection at L3.

Computational Analysis

The points collected with the measuring arm were imported from the Rhinoceros software to MATLAB (MathWorks) for

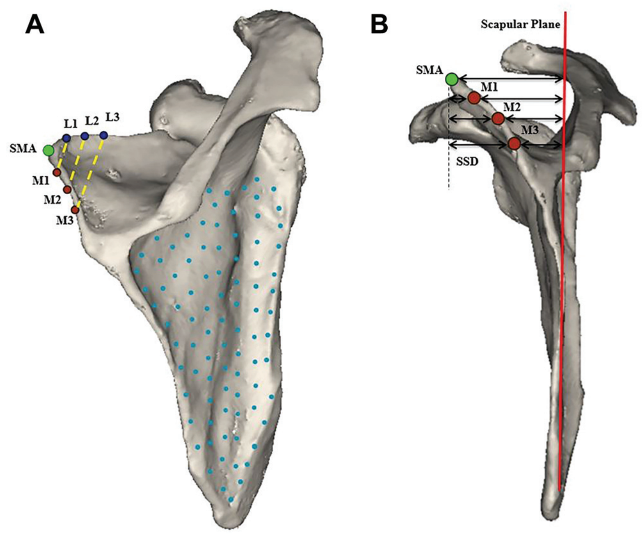

Figure 4. Schematic depiction of a right scapula (A) from a posteromedial view showing the points collected on each scapula (superomedial angle [SMA] = green; medial resection points = red; lateral resection points = deep blue; posterior scapular body = light blue; theoretical resection lines = yellow dashed lines) using the portable measuring arm and (B) from a medial view demonstrating the calculation of scapulothoracic space decompression (SSD) for each resection point.

analysis. The scapular body plane was established by interpolating a surface from the points collected on the posterior scapular body surface. Next, the anterior offset was measured, followed by the distance of each resection point to the scapular plane. The difference between the anterior offset and the distance for each resection point was calculated and represented the theoretical SSD achieved with that particular resection boundary point. The maximum SSD was then determined by taking the smaller SSD (more anterior point) achieved at either the medial or lateral side for each 1-cm, 2-cm, and 3-cm resection.

Statistical Analysis

All statistical analyses and graphics were produced using the statistical programming language R version 3.2.3 (R Development Core Team).[18] Continuous measurement data were not observed to be skewed or overdispersed, so parametric testing methods were used. A 1-way analysis of variance model was used to compare averages between the scapula shape groups. Associations between continuous variables were assessed with Pearson correlations and visualized with scatterplots and linear regression lines with 95% CIs for the regression relationship and 95% prediction intervals for individual observations. Intermethod measurement reliability was assessed using a 2-way random-effects model to calculate the absolute agreement definition of the intraclass correlation coefficient (ICC). Statistical significance was set at $P < .05$.

RESULTS

All measurements and analyses were performed on 40 scapulae in total (20 left, 20 right).

CT Measurements

Of the 40 scapulae, 15 were classified as straight, 15 concave, and 10 S-shaped.[20] The mean MSCA was found to be 3.2° ± 15.1°. The mean costomedial angle was found to be 144.1° ± 9.6°. The mean anterior offset measured by CT was 28.0 ± 6.1 mm.

Scapulothoracic Space Decompression

The mean anterior offset measured in the cadaveric model was 27.2 ± 8.6 mm. After theoretical resection at points L1, L2, and L3, the mean SSD was 0.9 ± 1.7 mm, 3.9 ± 3.2 mm, and 6.5 ± 4.4 mm, respectively. After theoretical resection at points M1, M2, and M3, the mean SSD was 3.2 ± 1.5 mm, 8.0 ± 2.9 mm, and 13.4 ± 3.5 mm, respectively. The maximum SSD with 1-cm lateral and medial resection, 2-cm lateral and medial resection, and 3-cm lateral and medial resection was 0.7 ± 1.4 mm, 3.4 ± 2.8 mm, and 6.1 ± 3.9 mm, respectively.

Determining the Maximum SSD

The maximum SSD for 36 of 40 (90%) scapulae was determined by the decompression achieved at the lateral border to the SMA, as it was more anterior than the medial border. On the other hand, the maximum SSD for 4 of 40 (10%) scapulae was determined at the medial border to the SMA, as it was more anterior than the lateral border.

Relationship of Bony Parameters and SSD

The maximum SSD with 3-cm resection was significantly correlated with the native anterior offset (R = 0.83, $P <$ .001) as well as with the costomedial angle (R = −0.43, P = .006) but not the MSCA (R = −0.11, P = .495). It was also not significantly associated with the scapula shape ($F_{2,37}$ = 0.39, P = .681). Thus, the maximum SSD with 3-cm resection was more strongly correlated with the anterior offset than with the costomedial angle (Figure 5).

Resection and Maximum SSD

From the correlation of the anterior offset and maximum SSD, a few patterns were noted. For the 5 scapulae with an anterior offset of less than 20 mm, a 5-mm SSD was not achieved with 1-cm, 2-cm, or 3-cm SMA resection. For 18 of 30 (60%) scapulae with an anterior offset between 20 and 35 mm, 3-cm resection achieved at least 5 mm of SSD (7.4 ± 1.2 mm). For the 5 scapulae with an anterior offset of greater than 35 mm, 2-cm resection resulted in at least 5 mm of SSD in all 5 cases (7.8 ± 0.9 mm). For the same group, 3-cm resection resulted in a mean SSD of 13.1 ± 1.0 mm.

No scapula with a costomedial angle greater than 157.9° was able to achieve a 5-mm SSD with 3-cm resection. All

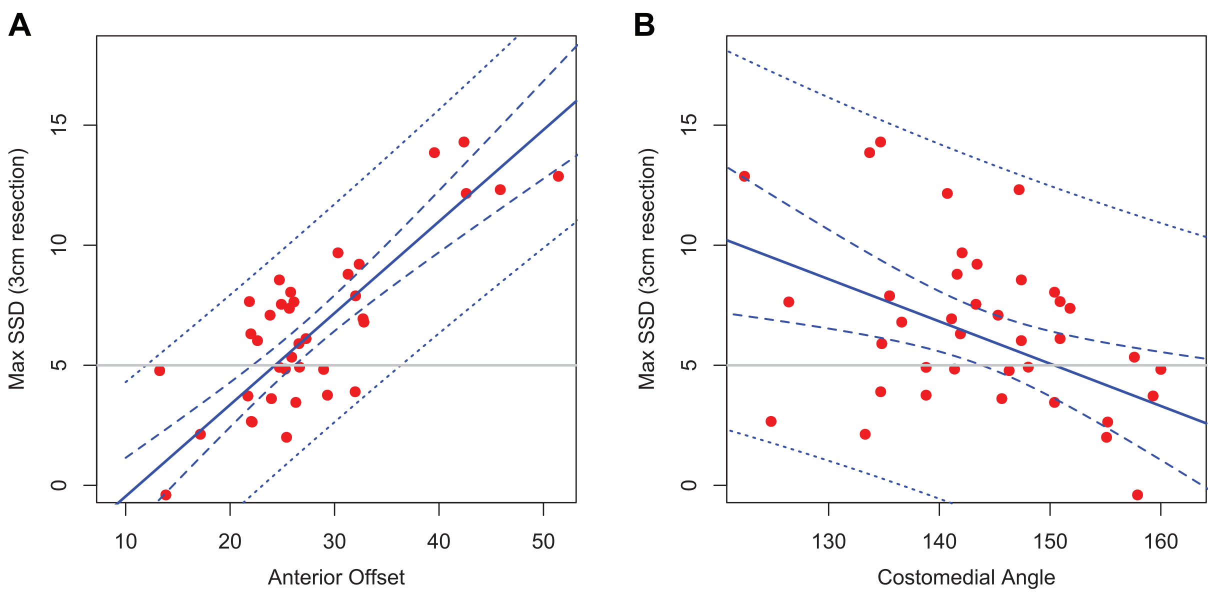

Figure 5. Correlation of the maximum scapulothoracic space decompression (SSD) (3-cm resection) with the (A) anterior offset and (B) costomedial angle (solid lines = regression relationship; large dashed lines = 95% CI for regression line; small dashed lines = 95% prediction interval for individual points).

scapulae with a costomedial angle less than 126.4° were able to achieve at least a 5-mm SSD with 2-cm resection.

Measuring the Anterior Offset With CT

The anterior offset as measured in the cadaveric model (27.2 ± 8.6 mm) and as measured by CT (28.0 ± 6.1 mm) showed strong intermethod reliability (ICC, 0.91; 95% CI, 0.86-0.96).

Resection and Scapular Notch

The suprascapular notch was not interrupted by L3 points (theoretical resection at 3 cm lateral to the SMA) in any scapula specimens. The L3 point was close to the suprascapular notch in smaller scapula specimens, but in larger scapula specimens, it was theoretically possible to perform an additional resection of 1 to 2 cm. Thirty-one of 40 (77.5%) scapulae presented a distance of at least 4 cm between the SMA and the suprascapular notch. Nine of 40 (22.5%) scapulae had a distance of at least 5 cm between the SMA and the suprascapular notch.

DISCUSSION

The main finding of this study is that the anterior offset and costomedial angle were identified as the 2 most important bony parameters to evaluate the effectiveness of partial scapulectomy during preoperative planning for patients with SSS. The anterior offset appeared to be more important to consider as it is a direct participant in the scapulothoracic space, and a reduction in this offset with scapulectomy results in decompression of the scapulothoracic space. The MSCA and scapula shape may have a role in the development of SSS but did not appear to be important to consider when planning surgical SSD. Intuitively, the MSCA or angulation of the scapular body has a role in the position of the SMA relative to the posterior thorax, but the MSCA is not altered with partial scapulectomy. Additionally, resection of 3 cm on the superior border lateral to the SMA did not come into contact with the suprascapular notch in any specimen and is potentially safe for avoiding injuries to the suprascapular nerve.

The amount of resection of the SMA required to completely treat or significantly reduce the symptoms of SSS is not exactly known, and this is reflected in the literature. Variable and sometimes unclear resection amounts are mentioned in the literature of scapulectomy techniques and outcomes.[3,7,11,13,16,17,19] Recommendations vary between 1 cm and 7 cm of scapular bone to be resected,[10,15] with others recommending the removal of the entire superomedial corner that shows excessive anterior angulation.[12,16,19] While it is clear that scapulae with obvious bony abnormalities, such as osteochondroma, require resection of these for symptom resolution, the majority of patients with SSS have normal-appearing scapulae without obvious bony abnormalities, making judgment of the adequate resection amount difficult to determine. This may be a potential explanation for the inconsistency in outcomes after partial scapulectomy.[3,7,11,13,16,17] Other explanations of these outcomes include anterior angulation of the scapular body, type III scapulae, and incomplete bursectomy. This study used standardized triangular resections with the medial border and superior border lateral to the SMA both equal in length. The results showed that a standard resection may not be appropriate for the surgical treatment of SSS because of wide variations in scapular bony anatomy among the patient population, particularly the anterior offset and costomedial angle but also the inward or outward bending of the borders medial and lateral to the SMA. Partial resection would have to be discussed with patients without a pathological SMA and with normal thoracic anatomy.

Bell et al[2] used 4-D CT scans to demonstrate that SSS usually occurs because of contact of the SMA with the posterior thorax, but contact can also occur at a point medial or lateral to the SMA, which seems important to consider when planning resection. The results of this current study support the possibility of a point along the lateral or medial border being more anterior than the SMA, causing contact with the posterior thorax. This partially depends on the thoracic anatomy, which was not considered in this study. Thus, a more medial resection might be necessary dependent on the patient's complaints and anatomy. The border lateral to the SMA seems to be more anterior in most cases (90%), whereas the border medial to the SMA is much less commonly more anterior (10%). Judging which border of the scapula is more anterior is better assessed by visual analysis with preoperative imaging as opposed to intraoperatively through arthroscopic visualization because of fluid insufflation of the scapulothoracic space and limited viewing angles. In the ideal scenario, 4-D CT scans preoperatively would give the exact source of bony contact, but these are not always available.[2] With the knowledge of which border is more anterior, an asymmetric resection can be planned with greater bony resection from the problematic, more anterior border.

The anterior offset of the scapula should be the first measurement performed during preoperative planning for patients with SSS. In this study of cadaveric specimens with an unknown history of SSS, the mean anterior offset was 27.2 ± 8.6 mm. Bell et al[2] reported the mean anterior offset of asymptomatic and symptomatic scapulae to be 27.8 ± 9.8 mm and 28.5 ± 7.9 mm, respectively, with no significant difference between them. These anterior offsets are similar to those of this study, supporting the occurrence of SSS in normal-appearing scapulae and also supporting the applicability of this study's findings to patients with SSS. Patients' scapulae with an anterior offset less than 20 mm seem unlikely to achieve adequate SSD with $\leq$3-cm resection. It is possible that a larger resection could provide this adequate SSD, but the safety of this additional resection would have to be assessed as the lateral 3-cm resection point of these scapulae was sometimes observed to be in close proximity to the suprascapular notch and nerve on the scapulae tested. More work is warranted to evaluate the surgical options for scapulae with a low anterior offset, which may have a reduced chance of presenting symptomatic SSS. Patients with an anterior offset between 20 mm and 35 mm have an approximate 60% success rate for adequate SSD with 3-cm resection. Detailed preoperative planning is recommended in this medium anterior offset group to ensure a safe amount of resection that will achieve the necessary SSD. Other factors such as the medial scapula and thoracic anatomy, which can likely influence the outcomes, should also be considered in preoperative planning. For patients with an anterior offset greater than 35 mm, 2-cm resection is likely to achieve adequate SSD. As shown in this study, CT is a reliable tool for estimating the anterior offset of scapulae and can be used as a part of preoperative planning for patients with SSS. Future work is advised to validate the reliability of MRI versus CT for this measurement.

Limitations

This cadaveric study has several limitations. First, the cadaveric model used to measure SSD did so in an indirect manner without the presence of a posterior thorax, which defines the scapulothoracic space and is in contact with the scapula during SSS. The role played by the thoracic anatomy with regard to SSS and decompression of the scapulothoracic space remains unclear. Additionally, soft tissue such as muscles and bursa were not studied. Instead, the posterior scapular body was used to create a plane that would allow distance measurements to the SMA and resection points on the scapula. However, the main interest of the study was decompression, which depended only on changes in the scapula bony anatomy after resection, and this technique was able to effectively measure the SSD. Second, a 5-mm SSD was arbitrarily set as the minimal clinically relevant SSD, with consideration that a typical burr has a 5-mm width, that bony contact occurs at approximately 2 mm of the scapulothoracic space because of bursa and periosteum, that 1.5 mm has been shown to be the difference in the scapulothoracic distance between asymptomatic and symptomatic patients with SSS, and that dynamic movement may alter the scapulothoracic space.[2] Third, 3-cm resection was chosen as the limit in this study, even though in some cases it was possible to perform larger resections. Evaluating the risks and effects of larger resections could be an area for future work. Fourth, the safety of the resection was evaluated based on the assumptions that the suprascapular nerve was located in the notch and that the superior transverse scapular ligament was not damaged, keeping the nerve in place.[5] Lastly, it was unknown whether the cadaveric specimens included in the study presented SSS. However, this study's focus was to measure the effects of bony anatomy on the magnitude of SSD introduced by scapulectomy, with the aim of applying the knowledge gained to better treat patients suffering from SSS.

CONCLUSION

The anterior offset of the scapula appeared to be the most important bony parameter to consider during preoperative planning and the evaluation of SSD with partial scapulectomy.

ACKNOWLEDGMENT

The authors thank David M. Civitarese, BA, for his assistance with specimen acquisition and organization.

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