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Biomechanical Comparison of Surgical Techniques for Resection Arthroplasty of the Sternoclavicular Joint

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Background: The optimal location and extent of medial clavicle resection for sternoclavicular (SC) joint resection arthroplasty are unknown.

Hypothesis: Resection of the intra-articular disc alone cannot reliably decompress the SC joint, and a parallel resection technique will decompress the SC joint significantly more compared with the same amount with an oblique resection technique.

Study Design: Controlled laboratory study.

Methods: Force transmission through the SC joint was measured in 7 matched-pair human cadaveric SC joints in a dynamic tensile testing machine. The specimens were randomized to either a parallel or an oblique resection technique. An 80-N axial load was applied on the lateral clavicle toward the SC joint in each of the following 4 conditions: (1) intact joint, (2) after resecting the intra-articular disc, (3) after resecting 5 mm of the medial clavicle, and (4) after 10-mm resection.

Results: Complete discectomy of all SC joints resulted in a significant reduction of force transmitted through the SC joint (P = .002). However, the varying anatomy of the disc was accompanied by a varying amount of joint decompression (95% CI, 29.8%-65.4%). Resecting 5 mm of the SC joint with the parallel technique decompressed the SC joint by a mean (±SD) of 76.7 ± 22.1 N compared with 37.8 ± 24.8 N with the oblique technique (P = .02). Decompression did not significantly differ between the groups after 10-mm resection (P = .18) using the parallel technique (89.4 ± 24.1 N) compared with the oblique technique (68.2 ± 31.6 N). Furthermore, 5-mm resection of the medial end of the clavicle with the parallel technique decompressed the SC joint by an amount similar to 10-mm resection with the oblique technique.

Conclusion: Resection of the disc alone did not reliably decompress each SC joint. Resection of 5 mm of the medial end of the clavicle with the parallel resection technique reliably decompressed the SC joint better than with the oblique resection technique.

Clinical Relevance: This study provides baseline data on SC joint resection techniques and their mechanical effects. This knowledge can be implemented in clinical practice to treat patients with symptomatic posttraumatic arthritis of the SC joint.

Keywords: sternoclavicular joint; resection arthroplasty; discectomy

Injuries of the sternoclavicular (SC) joint are rare and are usually caused by high-energy impacts experienced during sports or motor vehicle accidents.[13,22,24] Symptomatic instability of the SC joint is best treated with surgical reconstruction.[7,13,18,19,23] Painful posttraumatic osteoarthritis and degenerative conditions of the SC joint without instability can be successfully treated with resection arthroplasty.[§] Discectomy in the early stages after a traumatic disc tear is a treatment option for patients with ongoing posttraumatic joint pain.[6,20,30]

Diverse techniques of SC joint resection arthroplasty have been published, with varying amounts of medial clavicle resection ranging from a few millimeters up to 4 cm.[‖] A frequently used resection line runs oblique in relation to the SC joint from superolateral to inferomedial.[5,14,18,23] Recently published arthroscopic SC joint resection techniques decompressed the

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§References 1, 5, 9, 14, 18, 21-23, 25, 28, 31, 35.

‖References 1, 5, 7, 14, 18, 21, 23, 28, 31, 35.

SC joint with discectomy and resection of 6 to 10 mm of the medial end of the clavicle parallel to the joint line.[28,31,35] Independent of the resection technique, most authors agree that preservation of ligamentous joint stability is essential for successful outcomes.[¶] Current anatomic and biomechanical studies have suggested that minimizing bony resection may be advantageous for preservation of the joint stabilizers.[10,16,29,33] Furthermore, it was observed that only the anteroinferior end of the medial clavicle is covered by articular cartilage and that the appearance and shape of the articular disc vary among patients.[2,10,33] The authors of a recent anatomic investigation concluded that further studies are needed regarding the location and extent of medial clavicle resection necessary to adequately decompress the joint and maintain stability.[10]

Therefore, the purpose of this study was to evaluate (1) if resection of the intra-articular disc alone can reliably decompress the SC joint and (2) if resection of the medial end of the clavicle parallel to the joint line decompresses the SC joint similar to the oblique resection technique. We hypothesized that resection of the intra-articular disc alone would not reliably decompress the SC joint and that the parallel joint-line resection technique would decompress the SC joint significantly more compared with the same amount of resection using the oblique technique.

METHODS

Seven fresh-frozen, human breastplate cadaveric specimens with bilateral SC joints (mean age, 54 years [range, 38-65 years]; 5 male, 2 female) with no history of SC injuries, surgery, or other obvious deformities were included in this study. Each specimen was thawed at room temperature for 24 hours and meticulously dissected to include full clavicles, the first rib, and the sternum just distal to the third rib.[26,27] The sternum was potted with casting resin (polymethyl methacrylate; Fricke Dental International Inc) from the base of the cut sternum up to the first rib so as not to disturb the costoclavicular ligament.[26,27] Testing was always performed on the right SC joint first; thus, 5 cm of the distal right clavicle was also potted before testing. One of 2 resection techniques was randomly assigned to the right SC joint. The oblique resection technique had a resection line running from superolateral to inferomedial in relation to the SC joint (Figure 1A). The oblique resection technique was chosen as it is commonly used for conventional open SC joint resection.[5,14,18,23] The parallel resection technique had a resection line running parallel to the cartilage joint line, which runs from inferolateral to superomedial in relation to the SC joint (Figure 1A). The parallel resection technique has been described in recent literature mostly for arthroscopic SC joint resection.[21,28,31,35]

The potted ends of each specimen were rigidly fixed to a dynamic tensile testing machine (ElectroPuls E10000; Instron) with the clavicle fixed to the actuator in the predefined "locked" position of maximal protraction and depression relative to the SC joint. Next, a pressure sensor

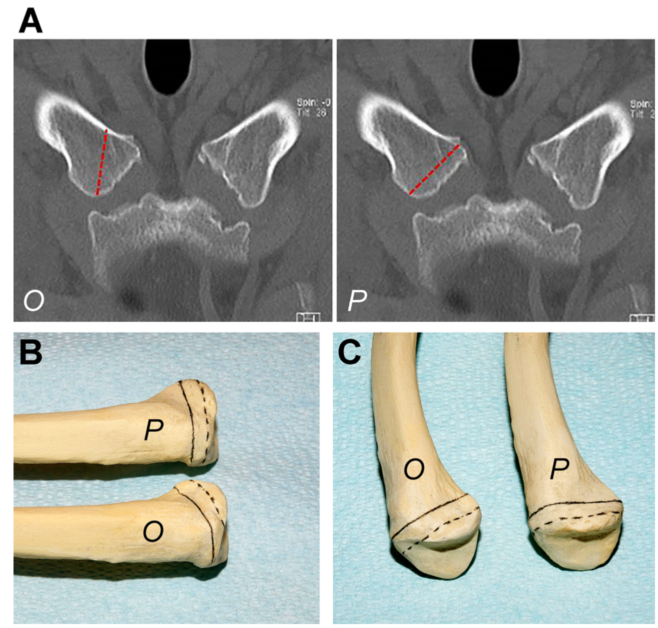

Figure 1. (A-C) *O* indicates the oblique resection technique, and *P* indicates the parallel resection technique. (A) Coronal computed tomography image of an osteoarthritic sternoclavicular joint illustrating both techniques (dotted line). (B) Anteroposterior view of the medial ends of Sawbones clavicle models with illustration of the 2 different resection techniques. Dotted line = 5-mm resection; continuous line = 10-mm resection. (C) Mediolateral view of the medial ends of Sawbones clavicle models. Dotted line = 5-mm resection; continuous line = 10-mm resection.

(Model 4000; Tekscan Inc) was positioned in the intact SC joint between the medial end of the clavicle and the intra-articular disc using a minimally invasive incision of the capsule without releasing the periosteum (Figure 2). A new sensor was used for each SC joint, and correct positioning of the sensor between the medial end of the clavicle and the disc was confirmed visually. Before testing, the sensors were calibrated with a 2-point loading profile (10 and 150 N, with a standard sensitivity of 21) according to manufacturer specifications with a rubber indenter of approximately the same surface area as the SC joint. Markers were placed in the sternum and the clavicle (Figure 2), and the distance between the markers was measured with a digital caliper (SPI Part Number 14-792-6; Swiss Precision Instruments Inc) before testing (Figure 3).

The predetermined load of 80 N was applied axially to the distal clavicle in each of the following 4 conditions: (1) intact joint, (2) after resecting the intra-articular disc, (3) after resecting 5 mm of the medial clavicle with the allocated technique (Figure 1, B and C), and (4) after 10-mm resection with the allocated technique (Figure 1, B and C). The disc was removed using a scalpel without affecting the bone. Subsequent bony resections were performed with an oscillating saw. Each step was carried out under visual control without damaging the stabilizing structures.[10] In each of the loaded conditions, the force transmitted

[¶]References 1, 5, 14, 18, 21, 23, 28, 31, 35.

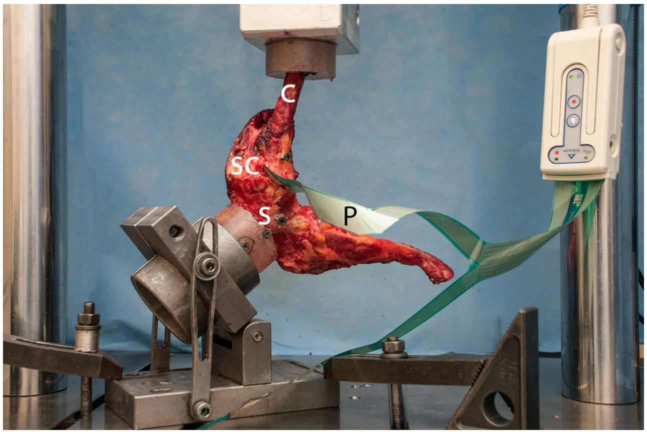

Figure 2. A specimen fixed in the testing machine with the pressure sensor (*P*) placed within the sternoclavicular joint (*SC*). Screws were placed as markers in the proximal clavicle (*C*) and the sternum (*S*). The sternum and the distal third of the clavicle were potted and fixed rigidly to the testing machine.

Figure 3. Measurement of the ''native'' distance between the marker screws with a digital caliper before testing of the joint pressure within the intact sternoclavicular joint.

through the SC joint was determined with the pressure sensor, and the distance between the markers was measured with a digital caliper. The amount of medialization of the medial clavicle was calculated for each step of bony resection by subtracting the distance measured in the loaded state from the baseline distance measured before testing. The amount of decompression generated by each step of bony resection was calculated by subtracting the force measured after each step from the baseline force measured during loading of the intact joint. After testing of the right SC joint, 5 cm of the left distal clavicle was then potted, and the test protocol was repeated again for the left SC joint using the opposite surgical resection technique. After the last step of mechanical testing, each SC joint was manually inspected for instability, and the integrity of the costoclavicular ligament was verified.

Statistical analysis was performed using SPSS (version 23.0; IBM Corp). Normal distribution of the variables was not found as tested with the Kolmogorov-Smirnov test. Two different states of the same specimens (intact joint vs discectomy) were compared with the Wilcoxon test. The results of 2 groups (reduction of force transmission and medial migration of the clavicle) were compared using the Mann-Whitney test. The level of significance was set at $P = .05$.

RESULTS

The application of 80 N of axial force to the lateral potted end of the clavicle resulted in an average ($\pm$SD) force transmission within the intact SC joint of 84.9 $\pm$ 28.9 N. There was no significant difference between forces measured within the intact SC joints of the groups treated with the parallel resection technique (92.0 $\pm$ 24.8 N) compared with the oblique resection technique (77.8 $\pm$ 32.9 N) ($P = .36$) before resection.

Complete discectomy of all SC joints resulted in a significant reduction of force transmitted through the SC joint by an average of 48% $\pm$ 34% compared with the intact joint ($P = .002$). The varying appearance and shape of the disc were accompanied by a varying amount of joint decompression (95% CI, 29.8%-65.4%).

The average decompression achieved with 5-mm resection of the medial end of the clavicle was significantly higher with the parallel technique (76.7 $\pm$ 22.1 N) than with the oblique technique (37.8 $\pm$ 24.8 N) ($P = .02$). After discectomy and 5-mm resection with the parallel technique, the clavicle migrated medially by an average of 6.6 $\pm$ 2.0 mm. Medial migration was significantly less ($P = .03$) after discectomy and 5-mm resection with the oblique technique (4.3 $\pm$ 1.7 mm) compared with the parallel technique.

The mean amount of decompression did not significantly differ between the 2 groups ($P = .18$) after 10-mm resection with the oblique technique (68.2 $\pm$ 31.6 N) compared with the parallel technique (89.4 $\pm$ 24.1 N). Also, medial migration after 10-mm resection did not significantly differ between the 2 groups (parallel: 8.9 $\pm$ 2.8 mm; oblique: 7.3 $\pm$ 3.6 mm; $P = .4$).

Interestingly, there was no significant difference between the mean amount of decompression achieved by 5-mm resection with the parallel technique (76.7 $\pm$ 22.1 N) compared with 10-mm resection with the oblique technique (68.2 $\pm$ 31.6 N) ($P = .65$). All SC joints remained stable after the final step of resection and testing. The integrity of the costoclavicular ligament was not disturbed in any case.

DISCUSSION

The most important finding of this study was that 5-mm resection of the medial end of the clavicle with the parallel technique decompressed the SC joint significantly more than 5-mm resection with the oblique technique. Moreover, 5-mm resection with the parallel technique decompressed the SC joint by a similar amount as 10-mm resection with the oblique technique. These findings are relevant for clinical practice as less bony resection makes it less likely to injure the capsular attachments and the costoclavicular ligaments and helps to maintain stability. Although removal of the entire intra-articular disc decompressed the SC joint significantly with an average reduction of force transmission of 48%, resection of the intra-articular disc alone did not reliably decompress each SC joint.

Isolated resection of the intra-articular disc has successfully been performed in patients with a proven traumatic tear of the disc with ongoing joint pain.[6,30] The theory that arthritic changes can be prevented in such a setting is supported by the finding that discectomy alone reduced force transmission through the joint by an average of almost 50%. However, the varying appearance and shape of the disc were accompanied by a varying amount of joint decompression in this study. Resection of the intra-articular disc alone does not seem to reliably decompress each SC joint and should therefore be restricted to patients with symptomatic tears of the disc.

The diversity of different published techniques of SC joint resection arthroplasty with varying amounts of medial clavicle resection demands clarification for which location and extent of resection are needed to gain adequate decompression and also maintain stability. There are strong arguments to limit the amount of bony resection of the medial end of the clavicle. On one hand, the safe distance between the clavicle and the great vessels in posterior proximity to the clavicle was found to be greater in more medial segments.[15] On the other hand, ligamentous stability can better be preserved with less bony resection, especially the posterior SC ligaments, which are primary restraints of anterior and posterior translation.[10,16,27] Although the distance between the inferior articular cartilage and the costoclavicular ligament, which is a principal stabilizer of the SC joint, averaged 12.6 mm in anatomic studies, it has been observed that the ligament can extend as far as the inferior articular surface.[4,10] The findings of this study suggest that the anteroinferior part of the medial end of the clavicle seems most involved in load transmission through the SC joint. Resection of this region of the medial clavicle appeared most important for SC joint decompression. This finding is in accordance with those of recent anatomic studies that found that the anteroinferior part seems to be mainly involved in SC articulation.[10,33] The anteroinferior region of the medial end of the clavicle was effectively removed by 5-mm resection with the parallel technique but only by 10-mm resection, and not by 5-mm resection, with the oblique technique (Figure 1, B and C).

Current case reports of arthroscopic SC joint resection demonstrated good to excellent clinical outcomes after 6- to 10-mm resection of the medial end of the clavicle parallel to the joint line.[28,31,35] Furthermore, Pingsmann et al[21] found similar outcomes after open resection of 8 to 10 mm of the medial end of the clavicle with a comparable resection line. Patients with instability after SC joint resection experience significantly inferior clinical outcomes compared with patients with stable joints after resection arthroplasty.[18,23] In consideration of the anatomic findings, stability of the SC joint can best be preserved by keeping the amount of bony resection limited.[4,7,10,29,33] The findings of this study suggest that more bone is resected than is necessary with the oblique resection technique to decompress the SC joint. Although the findings of this study cannot be transferred one-to-one into the clinical situation, oblique resection techniques with resection of 15 mm and more should be looked upon critically. Resection of 5 to 10 mm of the medial end of the clavicle with a parallel resection technique seems to reliably decompress the SC joint and additionally seems to best preserve the anatomy of the medial clavicle.

It has previously been stated that it is “difficult to extrapolate in vitro data of the clinical situation”[26(p98)] for the SC joint.[26] Biomechanical evaluations of the SC joint have focused on the ligamentous stabilizers and on reconstruction techniques so far.[16,26,27] No biomechanical test setup for the evaluation of SC joint resection techniques has been published to date, and the 2 different testing modes published to date do not seem useful for testing SC joint resection techniques. Therefore, in planning for this investigation, pilot studies were performed (1) to identify the SC joint position in which the highest native contact force transmitted through the joint can be observed and (2) to determine a reasonable magnitude of force transmitted through the SC joint in the investigated position.

The distal ends of 2 unpaired, intact human clavicles were manually moved from the joint's neutral position[12] to the maximal range of motion for depression, elevation, protraction, retraction, and posterior rotation of the clavicle.[8,11,12] The highest native contact force transmitted through the SC joint was measured with pressure sensors in both specimens and was noted in a position with maximal combined protraction and depression of the clavicle. This reproducible “locked” position has previously been used for the investigation of the SC capsule.[3] In vivo, this position of the clavicle seems to be present in a person lying in a lateral decubitus position. The locked position of the clavicle, which is imitated with the test setup used, is the clavicle that is in the lateral decubitus position.

The true forces transmitted through the SC joint remain unknown. Few studies have attempted to calculate SC forces that could act during different load-bearing tasks.[17,32] To define the approximate in vivo force transmitted through the SC joint in the aforementioned position, pressure sensors were placed underneath the anterolateral edge of the acromion of specimens lying in a lateral supine position during pilot testing. The force acting on the anterolateral edge of the acromion was assumed to equal the force acting through the clavicle at the SC joint. An average contact force of 80 N was measured underneath the anterolateral acromion of 2 specimens (body mass index, 20 and 27 kg/m^2). The force applied in our test setup was within the lower range of forces that are expected to act within the SC joint during load-bearing activities of daily living.[17,32] This time-zero bench test comprehensibly imitates the situation of a person lying in a lateral supine position of an ipsilateral SC joint–resected shoulder.

Arthritic SC joints have been found to be of significantly greater dimensions than native SC joints and tend to subluxate.[34] The fact that SC joints without a history of osteoarthritis have been used for this study may be considered a further limitation as the mechanical behavior of anatomically different SC joints may be dissimilar. The fact that other ligaments (ie, coracoclavicular ligaments) and muscle forces acting on the clavicle (ie, of the sternocleidomastoid, deltoid, and trapezius) are not taken into account must be considered a limitation of this test setup. The complex range of combined motion that the clavicle undergoes in the SC joint during glenohumeral elevation of the arm is well known.[8,11,12] Imitation of this multifaceted motion might better be reproduced within a robotic test setup with full upper-body specimens. To date, no test setup or test protocol has been published for biomechanical, robotic in-motion testing of the SC joint.

CONCLUSION

Resection of the intra-articular disc alone did not reliably decompress each SC joint. Resection of 5 mm of the medial end of the clavicle with the parallel resection technique reliably decompressed the SC joint better than with the oblique resection technique in a cadaveric biomechanical model.

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