Does Patient Sex Affect the Anatomic Relationships Between the Sternoclavicular Joint and Posterior Vascular Structures?

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Abstract

Background Despite increased concern for injury during surgical reconstruction of the sternoclavicular joint, to our knowledge there are few studies detailing the vascular relationships adjacent to the joint.

Questions/purposes We investigated sex differences in the following relationships for sternoclavicular joint reconstruction: (1) safe distance from the posterior surface of the medial clavicle's medial and lateral segments to the major vessels, (2) length of the first costal cartilage and safe distance from the first rib to the internal mammary artery, (3) minimum distance medial to the sternoclavicular joint for optimal hole placement, and (4) safe distance from the manubrium to the great vessels.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

This study was performed at the Keck School of Medicine of the University of Southern California.

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Methods Fifty normal postcontrast CT scans of the chest were reviewed. Means, standard deviations, and 95% CI were calculated for each aforementioned measurement. A t-test was used to determine if a sex difference exists ($p \leq 0.05$).

Results At the medial end of the clavicle, the safe distance from the medial segment (first 10 mm) to the major vessels was greater in males than in females (3.5 mm versus 2.4 mm, respectively; 95% CI, 3 mm–4 mm versus 1.7 mm–3 mm, respectively; $p = 0.014$). For the lateral segment (next 10 mm), the distance also was safer in males than in females (3.3 mm versus 1.7 mm, respectively; 95% CI, 2.7 mm–4 mm versus 1.1 mm–2.3 mm, respectively; $p < 0.001$). The mean length of the first costal cartilage also was greater in males (35.8 mm versus 30.1 mm, respectively; 95% CI, 33.8 mm–37.8 mm versus 28.5 mm–31.9 mm, respectively; $p < 0.001$); the distance from the first costochondral joint to the internal mammary artery was safer in males than in females (19.1 mm versus 15.4 mm, respectively; 95% CI, 16.5 mm–21.8 mm versus 13 mm–17.9 mm, respectively; $p = 0.05$). The minimum distance to avoid inadvertent penetration of the sternoclavicular joint was greater in males than in females (16 mm versus 12.3 mm, respectively; 95% CI, 14.6 mm–17.5 mm versus 11 mm–13.6 mm, respectively; $p < 0.001$). The distance to vessels after penetration of the manubrium was

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not different between males and females (5.6 mm versus 3.9, respectively; 95% CI, 4.4 mm–6.8 mm versus 2.6 mm–5.2 mm, respectively; $p = 0.06$).

Conclusions This study makes apparent the intimate relationships between vessels and the musculoskeletal structures associated with sternoclavicular reconstruction. Based on our findings, we recommend considering the sex of the patient, using caution when drilling, and protecting essential structures posterior to the joint.

Introduction

Dislocation of the sternoclavicular joint is a rare injury, accounting for 2% to 3% of all dislocations of the shoulder girdle [4]. A sternoclavicular joint injury is most common in young adults owing to the nature of the injury, and because the clavicular epiphysis and shaft do not fuse until 23 to 25 years of age [29]. The sternoclavicular joint has poor osseous stability relative to other joints of the body because less than $\frac{1}{2}$ of the medial clavicle articulates with the superior angle of the sternum [7]. Subsequently, it requires stabilization from surrounding ligaments: the intraarticular disc, capsule, costoclavicular ligament, and interclavicular ligament [18]. Although infrequent, these injuries are potentially life threatening because of the proximity of the joint to critical structures. Traumatic and iatrogenic damage to neurovascular structures in the mediastinum is a major concern. Acute posterior dislocation has been associated with limb- or life-threatening injuries such as injury to the great vessels, tracheal compression, and compression of the innominate vein [9, 12, 14, 28]. Chronic, unreduced posterior dislocations have been associated with late complications such as erosion into the great vessels, tracheoesophageal fistulas, thoracic outlet syndrome, and compression of brachial plexus [5, 8, 13, 16]. The more common scenario of a chronic unreduced anterior dislocation occasionally can result in symptomatic chronic instability. Open reduction and reconstruction of the sternoclavicular joint ligaments is indicated for patients with acute irreducible posterior dislocations, chronic posterior dislocations, and symptomatic chronic anterior dislocations [1]. Many of the available reconstruction techniques, including the figure-of-eight technique, require drilling anterior to posterior on the clavicle and sternum (Fig. 1). Drilling holes for tendon passage poses the risk of inadvertent injury to the nearby vascular structures.

The aim of our study was to define the proximity of relevant adjacent major blood vessels during sternoclavicular reconstruction using postcontrast CT scans with three-dimensional (3-D) reconstruction. The precision of CT

Fig. 1 The figure-of-eight technique for sternoclavicular reconstruction is shown. (Reprinted with permission from Sage Publications from Martetschlager F, Warth RJ, Millet PJ. Instability and degenerative arthritis of the sternoclavicular joint: a current concepts review. *Am J Sports Med.* 2014;42:999–1007.)

Fig. 2 The illustration shows the vascular anatomy associated with the sternum, medial clavicle, and medial first rib. (Reprinted with permission from Matthew Skalski DC.)

Fig. 3A–D This is a 4-on-1 image from a 3-D reconstruction of a CT scan for measurements at the medial end of the left clavicle showing (A) the 3-D surface shaded display, (B) oblique sagittal plane, (C) oblique coronal plane along the long axis of the medial clavicle, and (D) the oblique axial plane. Points C1, C2, and C3 are shown. First, using a double oblique technique, (D) the oblique axial plane along the long axis of the medial clavicle was obtained. The reference line is along the long axis of the clavicle in (C) the oblique coronal

plane, and the line on the (B) oblique sagittal plane indicates the oblique axial plane passing midway between the superior and inferior margins of the medial clavicle. Reference point C1 is marked on the oblique axial plane, along the anterior articular margin of the medial clavicle midway between its superior and inferior margins. Points C2 and C3 are marked 10 mm and 20 mm lateral to point C1 along the long axis of the medial clavicle.

scans in showing vascular structures has been reported in studies with detailed observations of the vascular system [20, 26] (Fig. 2). However, although sternoclavicular dislocations occur in men and women, sex differences in proximity to important vascular structures have not been well defined in the region of the sternoclavicular joint. Specifically, we investigated sex differences in the following relationships for sternoclavicular joint reconstruction: (1) safe distance from the posterior surface of the medial clavicle's medial and lateral segments to the major vessels, (2) length of the first costal cartilage and safe distance from the first rib to the internal mammary artery, (3) minimum distance medial to the sternoclavicular joint for optimal hole placement, and (4) safe distance from the manubrium to the great vessels.

Patients and Methods

The institutional review board approved this retrospective comparative study, informed consent was waived, and the study was compliant with the Health Insurance Portability and Accountability Act. Following approval, the radiology database was queried, and 50 normal CT scans of the chest from 2008 through 2011 were selected. The CT scans were performed for staging or restaging of malignancy to evaluate for lung metastasis. A chart review was performed to determine whether patients were in alignment with inclusion and exclusion criteria. Inclusion criteria included: age younger than 50 years and CT studies that were normal or near normal. We chose a cutoff age of 50 years because of the increasing odds of osteoarthritis and calcification of the

Fig. 4A–H This is 4-on-1 image from a 3-D reconstruction of a CT scan for measurements at the medial end of the left clavicle showing (A) the 3-D surface shaded display, (B) the oblique axial plane, (C) the oblique coronal plane and along the long axis of the medial clavicle, and (D) the oblique sagittal plane. The shortest distance between the posterior surface of the clavicle and the major vessel in segment Ca are measured. The reference lines in oblique axial and

oblique coronal planes indicate the site of measurement. This 4-on-1 image showing (E) the 3-D surface shaded display, (F) the oblique axial plane, (G) the oblique coronal plane and along the long axis of the medial clavicle, and (H) the oblique sagittal plane. The shortest distance between the posterior surface of the clavicle and the major vessel in segment Cb are measured. The reference lines in the oblique axial and oblique coronal planes indicate the site of measurement.

costal cartilage in older patients and because of the younger age most commonly associated with this injury. The patients with near-normal CT scans had findings that included changes seen with increasing age, such as atherosclerosis. Normal CT scans were defined as lacking disorders that would affect thoracic anatomy. Exclusion criteria included: noncontrast study, evidence of previous trauma (rib fracture or clavicle fracture, for example), evidence of previous surgery or history of significant thoracic surgery that would alter anatomy of the region of interest, vascular anomaly in the region of interest, patients with portacath, catheter or central lines, or pacemaker or an Automatic Implantable Cardioverter Defibrillator device in the major vessels, and significant pulmonary or mediastinal abnormalities that would alter the anatomy of the region of interest. There were 29 men and 21 women in the study,

with an average age of 38 years (range, 19–50 years); all were skeletally mature. All scans were performed with the patient in the supine position with the arms in the overhead position. The aorta and the major arteries and veins in the region of interest on the side of injection were opacified from the corresponding upper extremity injection. Injection of contrast was made through the right upper extremity in 33 patients and the left upper extremity in 16 patients. For one patient, the side of injection was undetermined, but the arteries and veins were opacified bilaterally. Major vessels were defined as the aorta and its main branches, superior vena cava and its central tributaries, and the internal mammary vessels. CT scans were performed on Phillips Brilliance 64 (Royal Phillips, Amsterdam, The Netherlands), Toshiba Aquilion (Toshiba America, Tustin, CA), and Siemens Somatom 10 CT scanners (Siemens, Munich,

Fig. 4A–H continued

Germany), and slice thickness varied from 2 mm to 3 mm. The images were retrieved on a separate workstation and reconstructed in 3-D with surface shaded display. The measurements were performed using AZE VirtualPlace Fujin Rajin 340 3.4002 (r14038) software (AZE Ltd, Tokyo, Japan) by a musculoskeletal radiologist (DP).

Using a double oblique technique, three points were marked along the anterior surface of the medial clavicle. The first reference point (C1) was marked along the anterior margin of the articular surface of the medial clavicle midway between the superior and inferior margin. Two points then were marked along the anterior surface of the clavicle, along its long axis: One (C2) 10 mm lateral to the reference point and the second (C3) 20 mm lateral to the reference point, dividing the medial clavicle into segment Ca (between C1 and C2) and Cb (between C2 and C3) (Fig. 3). In an oblique sagittal plane, perpendicular to the long axis of the medial clavicle, the closest distance between the posterior surface of the clavicle and the anterior surface of a contrast filled major vessel was measured in segment Ca (Fig. 4A–D) and segment Cb (Fig. 4E–H). This is the distance a drill,

tap, or screw can travel in segment Ca and Cb, after penetration of the posterior surface of the clavicle, at which point it will encounter a major vessel.

Again, using a double oblique technique, the long axis of the first costal cartilage was obtained and two points were marked along the anterior surface, one at the costosternal junction (R1), and the second at the costochondral junction (R2). The length of the first costal cartilage was measured between points R1 and R2 (Fig. 5). A line was drawn along the lateral margin of the internal mammary artery perpendicular to the anterior surface of the first costal cartilage. We measured the closest distance between this line and point R2 (Fig. 6). This is the distance from the costochondral joint, along the first costal cartilage medially, at which the internal mammary artery crosses the posterior aspect of the costal cartilage.

The articular surface of the sternum at the sternoclavicular joint is inclined from anterolateral to posteromedial in the axial plane and from superomedial to inferolateral in the frontal plane. In the axial plane, a reference point (S1) was made along the anterior surface of the sternum at the inferior

Fig. 5A–D This is a 4-on-1 image from a 3-D reconstruction of a CT scan for measurements at the first left costal cartilage showing (A) the 3-D surface shaded display, (B) the oblique sagittal plane, (C) the oblique coronal plane and along the long axis of the left first costal cartilage, and (D) the oblique axial plane. Points R1 and R2 are shown. First, using a double oblique technique similar to that for the medial clavicle, (D) the oblique axial plane along the long axis of the

first costal cartilage was obtained. The reference line along the long axis of the costal cartilage in (C) the oblique coronal plane can be seen. Reference points R1 and R2 are marked at the sternochondral and costochondral junctions midway between the superior and inferior margins. (D) The length of the first costal cartilage is measured between points R1 and R2.

margin of the sternoclavicular joint. A second reference point (S2) was made along the posterior margin of the articular surface of the sternum at the sternoclavicular joint. A line in the sagittal plane of the body was drawn passing through point S2. We measured the distance between S1 and the intersection of the sagittal line with the anterior cortex of the sternum (Fig. 7). This is the minimum distance for placement of an AP drill hole to avoid inadvertent penetration of the sternoclavicular joint. Next, a point (S3) was marked 10 mm medial to point S2 (Fig. 8A–D). In a sagittal plane, between points S2 and S3, the closest distance between the posterior surface of the sternum and the anterior surface of a major vessel was measured (Fig. 8E–H). This is the distance a drill, tap, or screw can travel, after penetration of the posterior surface of the sternum at which point it will encounter a major vessel.

For statistical analysis, Microsoft Excel (Microsoft, Redmond, WA, USA) was used to calculate mean values, SDs, and 95% CIs for each measurement. An unpaired two-tailed t-test was used to determine if a statistically significant difference ($p \leq 0.05$) exists when comparing measurements between females and males, and the measurement of distance between the posterior surface of the clavicle and the major vessel in zones Ca and Cb of the medial clavicle.

Results

At the medial end of the clavicle, the safe distance from the medial segment (first 10 mm) to the major vessels was greater in males than in females (3.5 mm versus 2.4 mm;

Fig. 6A–D This is a 4-on-1 image from a 3-D reconstruction of a CT scan for the measurements at the first left costal cartilage showing (A) the 3-D surface shaded display, (B) the oblique sagittal plane, (C) the oblique coronal plane along the long axis of the first costal cartilage, and (D) the oblique axial plane. The internal mammary artery at the level of the first costal cartilage was identified (white

arrow). In this case, the artery is in contact with the posterior surface of the sternochondral junction. A line is drawn passing along the lateral surface of the artery and perpendicular to the first costal cartilage. (D) The distance between the intersection of this line with the anterior surface of the costal cartilage, and point R2 is measured.

95% CI, 3 mm–4 mm versus 1.7 mm–3 mm, respectively; $p = 0.014$) (Fig. 4A–D). For the lateral segment (next 10 mm), the distance also was safer in males (3.3 mm; 95% CI, 2.7 mm–4 mm) than in females (1.7 mm; 95% CI, 1.1 mm–2.3 mm; $p < 0.001$) (Fig. 4E–H) (Table 1). However, overall, the safe distance in the medial segment was not different than that in the lateral segment (3 mm versus 2.6 mm; 95% CI, 2.6 mm–3.4 mm versus 2.1 mm–3.1 mm; $p = 0.32$).

The mean length of the costal cartilage (between points R1 and R2) was greater in males (35.8 mm; 95% CI, 33.8–37.8 mm) than in females (30.1 mm; 95% CI, 28.5 mm–31.9 mm; $p < 0.001$), (Fig. 5) (Table 1). Along the first costal cartilage, the mean distance between the costochondral reference point (R1), and the junction of anterior costal cartilage with the perpendicular line along the

lateral surface of the internal mammary artery was 19.1 mm (95% CI, 16.5 mm–21.8 mm) for males and 15.4 mm (95% CI, 13 mm–17.9 mm) for females, and there was a significant difference between sexes ($p = 0.05$) (Fig. 6) (Table 1).

Reference points S1 and S2 defined the anterior and posterior margins of the inferior sternoclavicular joint, respectively. The mean distance between point S1 and the sagittal line through point S2 at the intersection with the anterior cortex of the sternum was 16 mm (95% CI, 14.6 mm–17.5 mm) for males and 12.3 mm (95% CI, 11 mm–13.6 mm) for females, and there also was a significant difference in this measurement between sexes ($p < 0.001$) (Fig. 7) (Table 1).

In the 10-mm segment medial to point S2, between points S2 and S3, the mean distance of the major vessel from the posterior surface of the sternum was 5.6 mm

Fig. 7A–D This is a 4-on-1 image from a 3-D reconstruction of a CT scan for the measurements at the sternum showing (A) the 3-D surface shaded display, (B) the sagittal, (C) the coronal, and (D) the axial planes of the sternum. Reference points S1 and S2 are drawn along the anterolateral and posteromedial margins of the articular

surface of the manubrium at the sternoclavicular joint. A sagittal line is drawn through point S2 and perpendicular to the anterior surface of the cortex. (D) The distance between the intersection of this line with the anterior surface of the sternum, and point S1 is measured.

(95% CI, 4.4 mm–6.8 mm) for males and 3.9 mm (95% CI, 2.6 mm–5.2 mm) for females with no difference between sexes with the numbers available ($p = 0.06$) (Fig. 8E–H) (Table 1).

Discussion

Various methods have been described, but biomechanical and clinical evidence [6, 19, 22] suggests that reconstruction of the ligamentous structures of the sternoclavicular joint is imperative for successful fixation. Others have suggested that the costoclavicular ligament represents the vital stabilizing structure [16, 17], while others promote the importance of the capsule for limiting migration of the medial end of the clavicle [2, 21]. Regardless of the technique used for reconstruction, there is a theoretical risk of

iatrogenic injury owing to the joint's close approximation with multiple vascular structures. Therefore, the use of 3-D CT scans allows for detailed and precise observation of the vascular structures associated with ligamentous reconstruction of the sternoclavicular joint. We investigated the vascular relationships of the sternoclavicular joint using postcontrast CT scans to explore safe distances between bony landmarks and the major vessels.

The patients in this study were in the supine position with their arms overhead for the CT scans. This is a weakness of our study as in normal operative circumstances, patients have their arms at their sides. However, we are not aware of any evidence that suggests this change in position would result in different measurements. In addition, patients with sternoclavicular injuries may have altered anatomy and those with acute injuries may have swelling that distorts local anatomy.

Fig. 8A–H This is a 4-on-1 image from a 3-D reconstruction of a CT scan for measurements at the sternum showing (A) the 3-D surface shaded display, (B) the sagittal, (C) the coronal, and (D) the axial planes of the sternum. Point S3 is marked 10 mm medial to point S2 to define the parameters for the zone of drilling. This 4-on-1 image shows (E) the 3-D surface shaded image, (F) the axial, (G) the

coronal, and (H) the sagittal planes of the sternum. (D) The shortest distance between the posterior surface of the sternum in the segment between points S2 and S3 and the major vessel is measured. The reference lines in the (B) axial and (C) coronal planes indicate the site of measurement.

The figure-of-eight technique for reconstruction of the sternoclavicular joint has biomechanical advantages and good clinical outcomes for patients with chronic sternoclavicular instability [19, 22]. The technique involves drilling holes anterior to posterior in the medial clavicle approximately 10 mm from the joint and 10 mm from each other [19]. Based on the results of our study, there is a potential risk for vascular injury when performing this technique owing to the intimate relationship between vascular structures and the sternoclavicular joint. We found a greater safe distance in males for both drill holes. Our results are relatively similar to those of Sinha et al. [20], who looked at vessel relationships of the medial ½ of the clavicle in 26 patients and found a mean distance of 4.77 mm. However, our study is more precise in defining the vascular anatomy in the relevant 20 mm of the medial

clavicle used during the figure-of-eight technique. Both studies are in agreement regarding the imminent danger of an AP screw trajectory in the medial clavicle. Therefore, we posit that localizing a drill hole at any point in the medial 20 mm of the clavicle poses the same risk.

Completing the sternoclavicular joint capsule reconstruction with the figure-of-eight technique also requires drilling a corresponding set of holes in the manubrium [19]. Based on the results of our study, when drilling the manubrium for sternoclavicular joint capsule reconstruction, we recommend drilling 16 mm medial to the joint line for males and 12 mm for females. The figure-of-eight semitendinous autograft has gained traction as the preferred technique for sternoclavicular reconstruction [25], yet some authors promote reconstituting the costoclavicular ligament [10, 17, 24]. Passing suture around the first rib,

Fig. 8A–H continued

Table 1. Comparison between the mean parameters in males and females

Parameter	Males (mm) (95% CI)	Females (mm) (95% CI)	Difference (mm)	p value (t-test)
Distance of the major vessel from the posterior surface of the clavicle				
Medial segment (Ca)	3.5 (3–4)	2.4 (1.7–3)	1.1	*0.014
Lateral segment (Cb)	3.3 (2.7–4)	1.7 (1.1–2.3)	1.6	*< 0.001
Length of the first costal cartilage	35.8 (33.8–37.8)	30.1 (28.5–31.9)	5.7	*< 0.001
Distance of internal mammary artery from medial end of first rib	19.1 (16.5–21.8)	15.4 (13–17.9)	3.7	*0.05
Minimum distance for drill hole at the sternoclavicular joint	16 (14.6–17.5)	12.3 (11–13.6)	3.7	*< 0.001
Distance of the major vessel from the posterior surface of sternum	5.6 (4.4–6.8)	3.9 (2.6–5.2)	1.7	0.06

A negative difference means a higher value in women; (Ca) = 10 mm segment between reference points C1 and C2; (Cb) = 10 mm segment between reference points C2 and C3; * = statistically significant ($p \leq 0.05$).

through holes in the first rib, or through the residual costoclavicular ligament and then securing to the medial end of the clavicle can achieve this [10, 17, 24].

Damaging the internal mammary artery is a concern when performing any of the aforementioned techniques as this vessel has been described as traveling posterior to the

first costal cartilage [3]. Along the anterior surface of the first costal cartilage, the mean distance from the first costochondral junction to the oblique sagittal plane passing through the internal mammary artery was 19.13 mm for males and 15.42 mm for females with a significant difference between sexes. The mean length of the costal

cartilage was 35.76 mm in males and 30.17 mm in females therefore keeping procedures to the medial ½ of the costal cartilage appears safer.

Difficulty can arise when defining the boundary of the posterior medial portion of the sternoclavicular joint thus enhancing the risk of missing the posterior cortex and drilling into the joint. It is biomechanically advantageous to have a bicortical hole for tendon passage [22]. In addition, drilling through the sternum is dangerous because of the vital retrosternal vessels. We determined the distance to these structures was, on average, less than 6 mm. Li et al. [11] reported that the nearest vessel to the posterior aspect of the midpoint of the sternum is the brachiocephalic vein at 23.8 mm. We observed vessel relationships in a 10-mm zone starting at the posterior articular margin of the sternum and moving medially. This area represents the most likely to be perforated during ligamentous reconstruction using the figure-of-eight technique [19]. These measurements highlight the importance of protecting retrosternal structures while drilling into the sternum to prevent serious complications.

The overall optimal surgical technique for sternoclavicular reconstruction remains unclear. However, owing to the concern for vascular compromise it may be advantageous to further develop techniques that avoid anterior to posterior drilling. A recent study using sternocleidomastoid tendon graft had promising clinical results and requires only superior to inferior drilling of the medial clavicle [27]. In addition, several studies have had good clinical outcomes for medial clavicle resection when instability is present in conjunction with osteoarthritis [15, 17, 23]. Tavakkolizadeh et al. [23] described an arthroscopic medial clavicle resection with the perceived advantage of improved observation and minimized risk to mediastinal structures. Short-term followup appears promising for the arthroscopic procedure but, to our knowledge, there are no studies with minimum 2-year followup. Our study showed the intimate relationships between vessels and musculoskeletal structures associated with sternoclavicular reconstruction. Based on our findings, we recommend considering the sex of the patient, using caution when drilling, and protecting essential structures posterior to the joint.

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