Clin Orthop Relat Res (2019) 477:2761-2768
DOI 10.1097/CORR.0000000000000902

Clinical Orthopaedics and Related Research®
A Publication of The Association of Bone and Joint Surgeons®

Basic Research

Patient Position Is Related to the Risk of Neurovascular Injury in Clavicular Plating: A Cadaveric Study

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Received: 25 March 2019 / Accepted: 2 July 2019 / Published online: 31 July 2019

Abstract

Background Fixation of clavicle shaft fractures with a plate and screws can endanger the neurovascular structures if proper care is not taken. Although prior studies have looked at the risk of clavicular plates and screws (for example, length and positions) to vulnerable neurovascular structures (such as the subclavian vein, subclavian artery, and brachial plexus) in the supine position, no studies to our knowledge have compared these distances in the beach chair position.

Questions/purposes (1) In superior and anteroinferior plating of midclavicle fractures, which screw tips in a typical clavicular plating approach place the neurovascular structures at risk of injury? (2) How does patient positioning (supine or beach chair) affect the distance between the screws and the neurovascular structures?

Methods The clavicles of 15 fresh-frozen cadavers were dissected. A hypothetical fracture line was marked at the midpoint of each clavicle. A precontoured six-hole 3.5-mm reconstruction locking compression plate was applied to the superior surface of the clavicle by using the fracture line to position the center of the plate. The direction of the drill bits and screws through screw holes that offer the greater risk of injury to the neurovascular structures were identified, and were defined as the risky screw holes, and the distances from the screw tips to the neurovascular structures were measured according to a standard protocol with a Vernier caliper in both supine and beach chair positions. Anteroinferior plating was also assessed following the same steps. The different distances from the screw tips to the neurovascular structures in the supine position were compared with the distances in the beach chair position using an unpaired t-test.

Results The risky screw holes were the first medial and second medial screw holes. The relative distance ratios compared with the entire clavicular length for the distances from the sternoclavicular joint to the first medial and second medial screw holes were 0.46 and 0.36 in superior plating and 0.47 and 0.37 in anteroinferior plating, respectively. The riskiest screw hole for both superior and anteroinferior plates was the second medial screw hole in

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Each author certifies that his or her institution approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.
This work was performed at Prince of Songkla University, Songkhla, Thailand.

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both the supine and beach chair positions (supine superior plating: 8.2 mm ± 3.1 mm [minimum: 1.1 mm]; beach chair anteroinferior plating: 7.6 mm ± 4.2 mm [minimum: 1.1 mm]). Patient positioning affected the distances between the riskiest screw tip and the nearest neurovascular structures, whereas in superior plating, changing from the supine position to the beach chair position increased this distance by 1.4 mm (95% CI -2.8 to -0.1; supine 8.2 ± 3.1 mm, beach chair 9.6 ± 2.1 mm; $p = 0.037$); by contrast, in anteroinferior plating, changing from the beach chair position to the supine position increased this distance by 5.4 mm (95% CI 3.6 to 7.4; beach chair 7.6 ± 4.2 mm, supine 13.0 ± 3.2 mm; $p < 0.001$).

Conclusions The second medial screw hole places the neurovascular structures at the most risk, particularly with superior plating in the supine position and anteroinferior plating in the beach chair position.

Clinical Relevance The surgeon should be careful while making the first medial and second medial screw holes. Superior plating is safer to perform in the beach chair position, while anteroinferior plating is more safely performed in the supine position.

Introduction

In clavicular plating, plates are commonly applied to the superior and anteroinferior surfaces of the clavicle. Superior plating involves less soft-tissue dissection with stronger biomechanical testing, and it is easy to apply [3, 6, 8], while anteroinferior plating has less implant irritation, good cosmesis, supposedly lower risk of damage to the neurovascular structures (such as the subclavian vein, subclavian artery, and brachial plexus), and lower reoperation rates [4, 11]. The patient's position is important for successful clavicular plating outcomes in the operating room. The most widely used patient positions are the supine and beach chair positions, depending on surgeon preference. In fixation of clavicular fractures, the fixation plate screws can endanger the neurovascular structures if proper care is not taken. Iatrogenic neurovascular complications such as air embolism of the subclavian vein, pseudoaneurysm or thrombosis of the subclavian artery, and thoracic outlet syndrome have been reported after fixation with these plates [1, 2, 9, 10, 13]. Many studies have examined the relationship between the clavicle and the adjacent neurovascular structures. Werner et al. [15] reported that there were no differences in the distance between the screw tip and the neurovascular structures based on the plate's position, but with the arm in abduction, the distance between the neurovascular structures and bone was greater. Lo et al. [12] studied the locations of vital structures related to anteroinferior clavicular plating in fresh cadaveric specimens and found that the distance to the subclavian artery was 15 mm to 22 mm from the posterior aspect of the medial half of the clavicle. In superior plating, the neurovascular structures at risk were the subclavian vein, the subclavian artery, and the brachial plexus, of which the subclavian vein was the riskiest. Hussey et al. [7], Werner et al. [15], and Sinha et al. [14] reported that the average distances from the screw tip or the far cortex to the subclavian vein were 9.2, 17.0, and 12.5 mm, respectively. Moreover, anatomically, the neurovascular structures are medial to the midshaft of the clavicle. As the surgeon applies the clavicular plate, there is danger of injuring the neurovascular structures while the surgeon is drilling any holes located medially to the midshaft of the clavicle.

All of these studies only evaluated the proximity of the screw tips and far clavicular cortex to the neurovascular structures in patients in the supine position; however, not all surgeons use the supine position in clavicle fixation, as some surgeons prefer to do the surgery in the beach chair position. Not all screw holes have the same risk, and it would be advantageous to know which hole positions offer greater risk of neurovascular injury in those positions, as well as the distances between the far clavicular cortex and neurovascular structures to help the surgeon understand the safety margins.

Therefore, we asked: (1) In superior and anteroinferior plating of midclavicle fractures, which screw tips place the neurovascular structures at risk of injury? (2) How does patient positioning (supine or beach chair) affect the distances between the screws and the neurovascular structures?

Materials and Methods

For the study, 15 adult fresh-frozen, full-body cadavers of seven men and eight women with a mean age at death of 67 ± 12 years were obtained from the Anatomy Department of the Faculty of Science of Prince of Songkla University. The average height of the cadavers was 162 ± 9 cm, and the average length of the clavicle was 152.3 ± 8.4 mm. Each cadaver was thawed at room temperature overnight before use. Each cadaver was placed in the supine position with both arms adducted to the side.

The surgical approaches were performed by one experienced microneurovascular orthopaedist (PS), who made a longitudinal incision along the clavicle from the sternoclavicular joint to the acromioclavicular joint that was distally curved to the proximal humerus (Fig. 1A). The surgeon folded back the skin and subcutaneous tissue distally to expose the pectoralis major, anterior deltoid muscles, and clavicular bone. The pectoralis major and anterior deltoid muscles were sharply dissected and detached from their clavicular origins (Fig. 1B). The neurovascular tethers to the pectoralis major and anterior deltoid

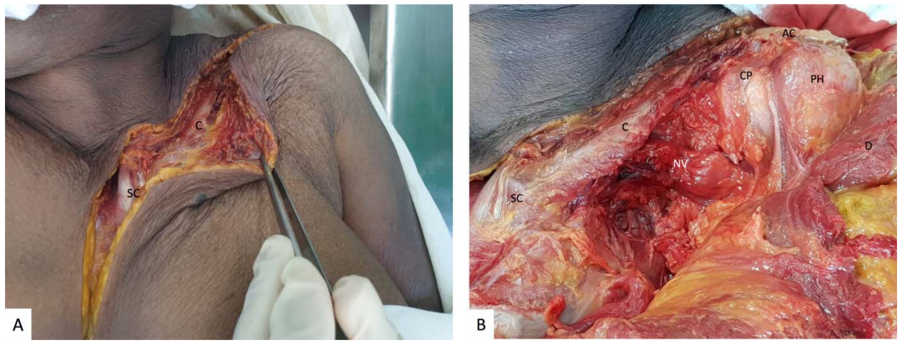

Fig. 1 A-B The surgical approach to the left clavicle is shown. **(A)** A curved skin incision was created for the anterior approach to the clavicle. **(B)** The deltoid muscle and pectoralis major were detached from the clavicular and acromial origins to expose the neurovascular structures. SC = sternoclavicular joint; C = clavicle; CP = coracoid process; AC = acromioclavicular joint; PH = proximal humerus; D = deltoid muscle.

muscles were preserved to maintain the normal relationship of the neurovascular structures. The surgeon removed the clavipectoral fascia from the clavicle but preserved the coracoid attachment. The neurovascular structures (the subclavian vein, subclavian artery, and brachial plexus) were exposed. In this step, the surgeon did not dissect the vessels and the brachial plexus from the bundle because this would compromise the accuracy of the measurements. The sternoclavicular and acromioclavicular joints were identified. A large straight surgical needle was inserted into the midpoint of each of the sternoclavicular and acromioclavicular joints, and a 2-0 silk thread was stretched between the needles. The clavicular length was measured between the midpoint of the sternoclavicular and acromioclavicular joints using a Vernier caliper with a precision of 0.001 mm (Insize, Suzhou New District, China). The midpoint of the clavicle then was marked with a surgical pen, and the mark was considered to be a fracture line. A six-hole, 3.5-mm reconstruction LCP® (DePuy Synthes, Oberdorf, Switzerland) was contoured until it matched the upper surface of the clavicle. The surgeon applied the plate to the superior surface of the clavicle by using the fracture line to position the center of the plate. The plate was secured with bone clamps at the proximal and distal sections. Before a locking screw was inserted, a cortical screw was inserted to secure the plate to the clavicle and align the plate snugly with the bone.

We defined the screw hole positions by numbering them in two directions moving outward from the midpoint of the clavicle. The hole closest to the midpoint in the sternoclavicular direction was called the first medial screw hole, the next hole in that direction the second medial screw hole, and the last one the third medial screw hole. For the screw holes on the side toward the acromioclavicular joint, we called the hole closest to the midline the first lateral screw hole, the next one the second lateral screw hole, and the last one the third lateral screw hole (Fig. 2). There is an advantage to using this numbering approach. This nomenclature is consistent regardless of how many screw holes are in the plate. Plates can contain between six and 10 screw holes. Even with an odd number of holes, with the system of numbering from the midpoint of the clavicle in each direction, the holes nearest the midpoint will always have the same numbers.

In normal practice, each hole will use a combination of locking and cortex screws, but in this study, we inserted screw only in the locking hole. A drill was used to make the holes. The screw holes exiting nearest to the neurovascular structures and thus offering the greatest risk to the neurovascular structures were identified as the risky screw holes. Focusing on these holes, we measured the distances from the sternoclavicular joint to these holes. For each hole we measured the distances from the plate to the neurovascular structures (Fig. 3A) and from the plate to the far clavicular cortex (screw length) (Fig. 3B) through the plate by using a depth gauge. After that, the screw was inserted, and the

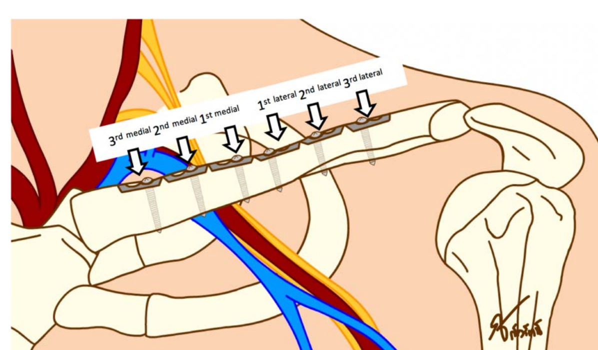

Fig. 2 The position of the screw holes in the six-hole contoured 3.5-mm reconstruction LCP implant (DePuy Synthes® Oberdorf, Switzerland) is shown here.

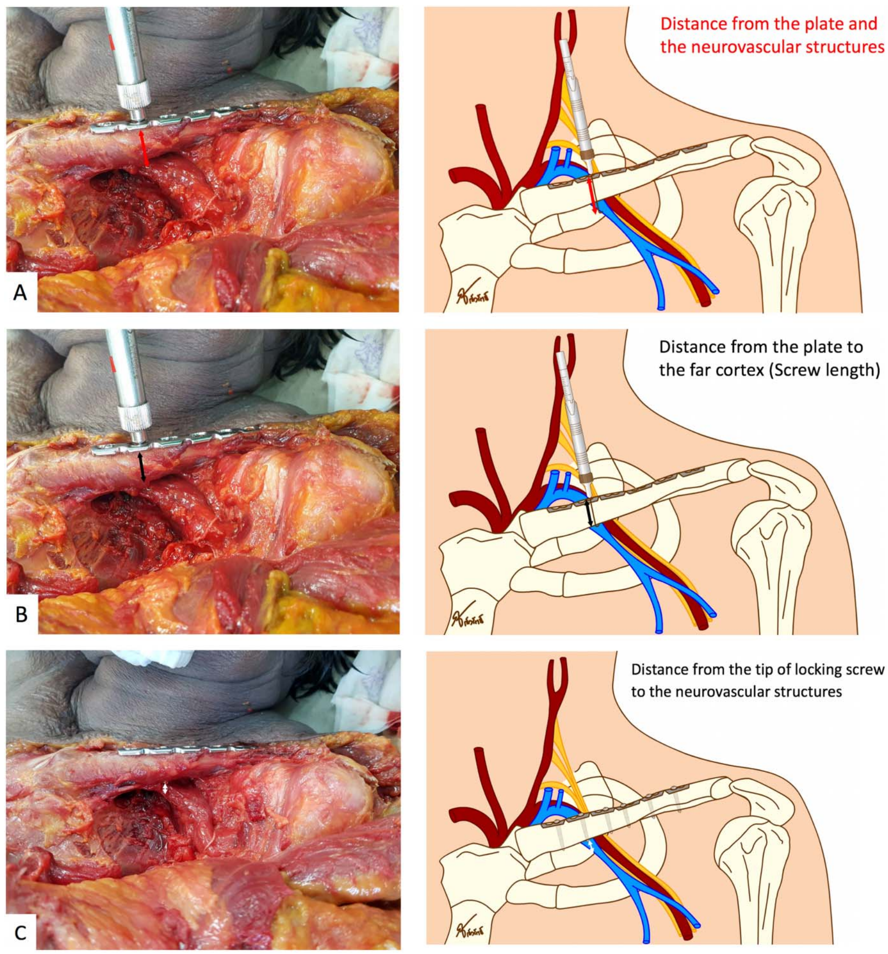

Fig. 3 A-C The measurement of **(A)** the distance from the plate to the neurovascular structures (red arrow), **(B)** the distance from the plate to the far clavicular cortex (black arrow) using a depth gauge and **(C)** the distance from the tip of the locking screw to the neurovascular structures (white arrow) in the risky screw hole.

distance from the tip of the locking screw to the neurovascular structures was measured with a Vernier caliper (Fig. 3C). The holes next to the risky screw holes medially and laterally were called the less risky screw holes, and a drill bit was inserted in these holes until the tip was as close as possible to the neurovascular structures. Then, the distances between the drill tip and the neurovascular structures were measured (Fig. 4). The same procedure was followed to assess the risky screw holes, the less risky screw holes, and the distances between the screw tips and the neurovascular structures in the beach chair position. For the second part of the study, the same procedure was followed to assess the screw holes in anteroinferior plating. The cadavers were placed in the beach chair position at a 60° upright angle with 40° of hip flexion and 30° of knee flexion. We used a goniometer to standardize the angles. All cadavers were dissected and measured according to a standardized protocol.

To decrease measurement bias, one orthopaedist (CC) measured all distances three times, and the mean ± SD was calculated. The statistical analysis was performed with the R program and “epicalc” package (version 3.4.3; R Foundation for Statistical Computing, Vienna, Austria). The different distances were determined using unpaired t-test. A p value of 0.05 was considered significant. The intraobserver reliability was calculated by intraclass correlation coefficients.

Results

In both the superior and anteroinferior plating parts of the study, the risky screw holes were the first medial and second medial screw holes, and the less risky screw holes were the third medial and the first lateral screw holes (Fig. 5). The relative distance ratios compared with the entire

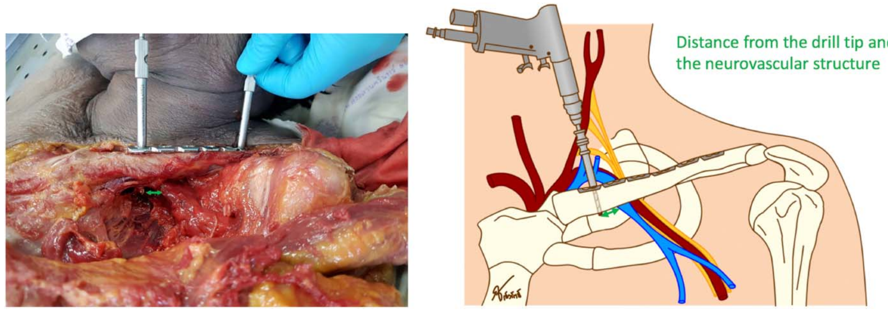

Fig. 4 The measurement of the distance from the drill tip to the neurovascular structure (green arrow) in the less risky screw hole is shown here.

clavicular length for the distances from the sternoclavicular joint to the first and second medial screw holes were 0.46 and 0.36 in superior plating and 0.47 and 0.37 in anteroinferior plating, respectively. The average screw lengths in the first and second medial risky screw holes were 15.3 ± 1.8 mm and 14.0 ± 3.3 mm in superior plating and 13.8 ± 1.2 mm and 15.7 ± 3 mm in anteroinferior plating, respectively. The average distances from the plate to the neurovascular structures, in the first and second medial screw holes in superior plating were 25.6 ± 3.2 mm (minimum 20.4 mm) and 22.4 ± 4.2 mm (minimum 15.3 mm) in the supine position and 26.0 ± 4.0 mm (minimum 18.3 mm) and 23.4 ± 4.6 mm (minimum 18.1 mm) in the beach chair position, respectively. These distances in anteroinferior plating were 25.7 ± 3.5 mm (minimum 19.8 mm) and 27.0 ± 4.3 mm (minimum 21.3 mm) in the supine position and 23.6 ± 1.9 mm (minimum19.6 mm) and 25.0 ± 2.2 mm (minimum 21.4 mm) in the beach chair position, respectively. In the supine position, the shortest distance from the screw tip to the neurovascular structures was the second medial screw hole of the superior plate, which was 1.1 mm (Table 1). The shortest distance from the screw tip to the neurovascular structures in the beach chair position was 1.1 mm for the second medial screw hole in the anteroinferior plate (Table 2).

Patient positioning affected the distances between the screw tips and the neurovascular structures as it related to the riskiest screw; in superior plating (Table 1), changing from the supine position to the beach chair position increased this distance by 1.4 mm (95% CI -2.8 to -0.1; supine 8.2 ± 3.1 mm, beach chair 9.6 ± 2.1 mm; p =

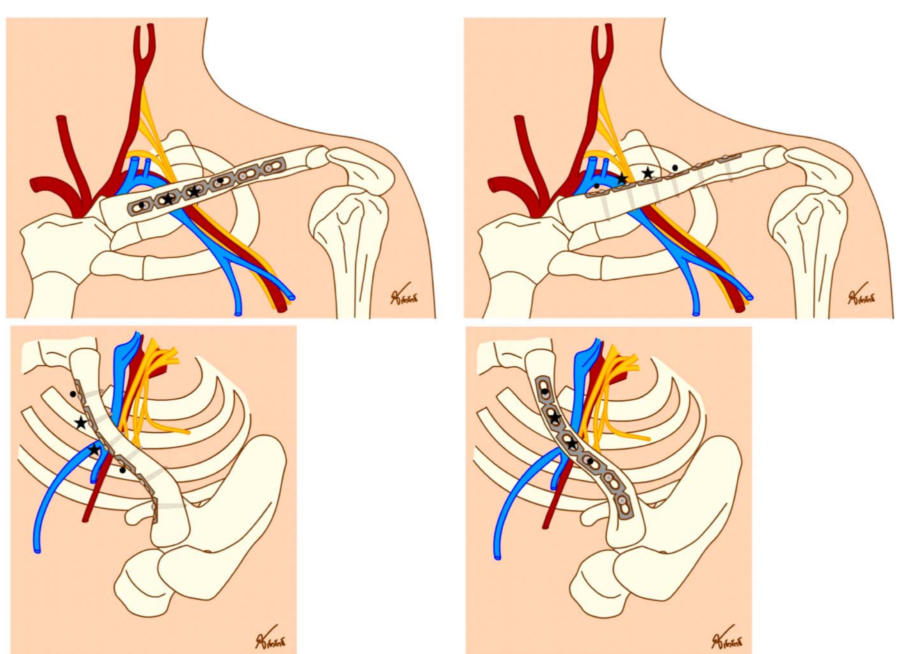

Fig. 5. The risky screw holes (black stars) and less risky screw holes (black circles) of the superior and anteroinferior plates are shown from the front and top.

Table 1. Distances from the screw tips to the neurovascular structures in risky and less risky screw holes in superior plating

	Supine position (mm)		Beach chair position (mm)			
Screw holes	Mean ± SD	Minimum	Mean ± SD	Minimum	Mean difference (95% CI)	p value
Medial 3[a]	13.0 ± 4.5	3.0	14.2 ± 4.8	3.0	-1.0 (-3.6 to 1.2)	0.328
Medial 2[b]	8.2 ± 3.1	1.1	9.6 ± 2.1	6.5	-2.1 (-2.8 to -0.1)	0.037[c]
Medial 1[b]	10.9 ± 2.7	6.1	9.9 ± 4.4	3.2	1.1 (-0.9 to 2.9)	0.301
Lateral	9.5 ± 3.9	3.8	9.5 ± 4.5	3.8	0.0 (-2.2 to 2.1)	0.972

[a]Less risky screw hole.
[b]Risky screw hole.
[c]Significant difference (p value < 0.05).

Table 2. Distances from the screw tips to the neurovascular structures in the risky and less risky screw holes in anteroinferior plating

	Supine (mm)		Beach chair (mm)			
Screw holes	mean ± SD	Minimum	mean ± SD	Minimum	Mean difference (95% CI)	p value
Medial 3[a]	11.6 ± 5.4	3.0	7.4 ± 3.8	2.9	3.5 (1.8 to 6.6)	0.001[c]
Medial 2[b]	13.0 ± 3.2	7.3	7.6 ± 4.2	1.1	5.7 (3.6 to 7.4)	< 0.001[c]
Medial 1[b]	12.0 ± 3.1	8.3	9.8 ± 2.5	3.8	3.1 (0.8 to 3.7)	0.003[c]
Lateral 1[a]	14.5 ± 3.8	8.8	12.3 ± 3.8	6.5	2.2 (0.2 to 4.1)	0.029[c]

[a]Less risky screw hole.
[b]Risky screw hole.
[c]Significant difference (p value < 0.05).

0.037). On the other hand, the distance from the screw tip of the first medial screw hole to the neurovascular structures in superior plating was no different in the beach chair position (95% CI -0.9 to 2.9; supine: 10.9 mm ± 2.7 mm; beach chair: 9.9 mm ± 4.4 mm; p = 0.301) (Fig. 6). In anteroinferior plating (Table 2), changing from the beach chair position to the supine position increased this distance by 5.4 mm (95% CI 3.6 to 7.4; beach chair 7.6 ± 4.2 mm, supine 13.0 ± 3.2 mm; p < 0.001). Similarly, the distance from the screw tip of the first medial screw hole to the neurovascular structures was safer in the supine position (95% CI 0.8 to 3.7; beach chair: 9.8 mm ± 2.5 mm; supine: 12.0 mm ± 3.1 mm; p < 0.003) (Fig. 7). Each distance was measured three times by a single surgeon (CC); the intraobserver reliability ranged from 0.83 to 0.99.

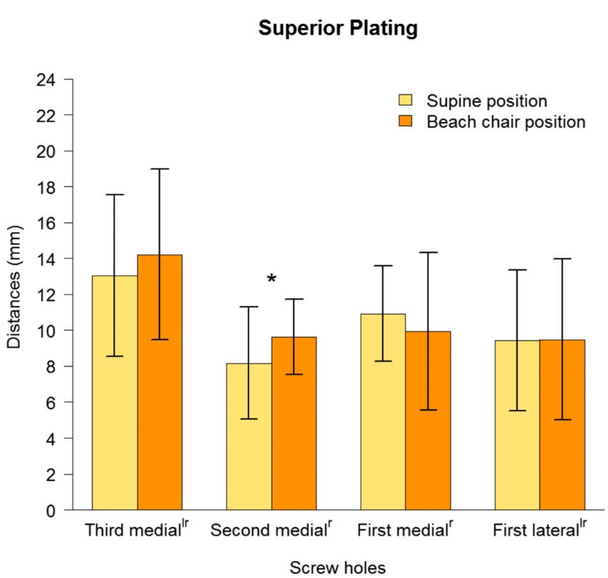

Fig. 6 This column chart shows the distances from the screw tips to the neurovascular structures in the risky and less risky screw holes in superior plating. ([lr] = less risky screw hole, [r] = risky screw hole. *p < 0.05).

Discussion

Fixation of clavicular shaft fractures with a plate and screws can endanger the neurovascular structures (the subclavian vein, the subclavian artery, and the brachial plexus) if proper care is not taken. The surgeon should be particularly careful when making the first and second medial screw holes during both superior and anteroinferior clavicular fixation. Superior plating is more safely applied in the beach chair position, while anteroinferior plating is more safely applied in the supine position.

The study should be interpreted in light of its limitations. First, the different cadaver heights may have affected the clavicle length, the screw length, and the proximity of the screw tips to the neurovascular structures.

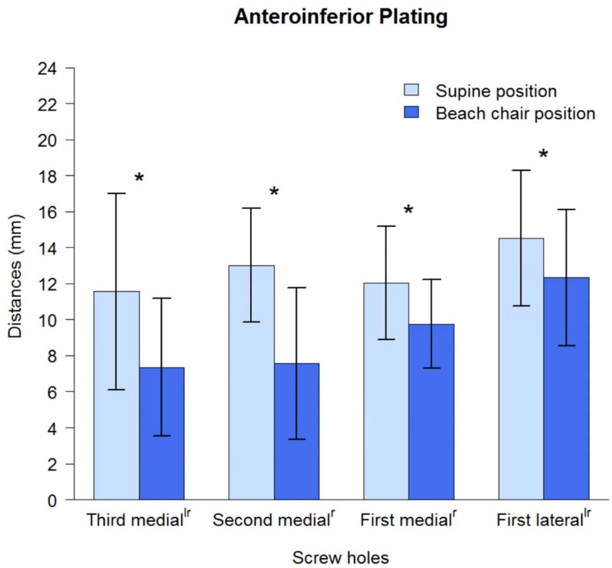

Fig. 7 This column chart shows the distances from the screw tips to the neurovascular structures in the risky and less risky screw holes in anteroinferior plating. ([lr] = less risky screw hole, [r] = risky screw hole. *$p < 0.05$).

In our study, we reported the positions of the risky screw holes that can be applied in the average-size patient, and we also reported the relative distance ratios of the risky screw holes that can be applied in extremely short or tall patients. Second, the anatomic relationship between the neurovascular structures and the clavicle may have been slightly changed during dissection. We attempted to minimize this problem by exploring only the medial and lateral borders of the neurovascular bundle to maintain the natural relationship as closely as possible. Third, this study used plates from one manufacturer to study the risk of iatrogenic neurovascular injury. In surgical practice, there are many types of plates that can be used in clavicular fixation. Each plate has a specific design and length that are different from this study. However, the surgeon can use the results from this study to avoid iatrogenic neurovascular injury. Screw holes that are located medially to the center of the clavicle might be at risk during drilling holes and inserting screws. As a result, the surgeon should be careful while doing this process. Additionally, the surgeon can use the relative distance ratios of the risky screw holes to predict the positions of screws at risk in the other types of plates. Fourth, in actual clavicular fractures, the distances from the plate and screws to the neurovascular structures may be different from the distances in this study, depending on the patient's age, degree of soft tissue injury, alignment of reduction, and normal circulation of blood vessels. Fifth, this study measured the distances from the screw tips to the neurovascular structures in three dimensions, which could have led to measurement errors. We minimized this problem by using a high-precision Vernier caliper (0.001 mm). Sixth, we had no way of knowing if there were pre-existing conditions of the shoulder and clavicle of the cadavers, but any cadavers with obvious lesions of the acromioclavicular joint, sternoclavicular joint, and neurovascular structures or deformities of the clavicle were excluded from the study.

The riskiest area for screw placement is the area that is medial to midline. When the surgeon applies the clavicular plate, drilling screw holes and measuring the screw length using the depth gauge may cause an iatrogenic neurovascular injury. The surgeon should be careful when drilling any holes located medially to the midshaft of the clavicle, especially the first and second medial screw holes (Fig. 5). For plates from other manufacturers or the same manufacturer with different lenghts and designs, the results of the relative distance ratio helps to determine the risky screw holes. Additionally, the surgeon can decrease the likelihood of neurovascular injury by having a clear understanding of the depth of the screw holes and the distances from the plate to the nearby neurovascular bundle to control the drilling depth. There is a risk of iatrogenic neurovascular injury if the drill bit passes the plate in the first or second medial holes more than 18.3 mm and 15.3 with superior plating and 19.6 mm and 21.3 mm in anteroinferior plating. In our study, the average depths of the drill bit and screw length in the first and second medial risky screw holes were 15.3 ± 1.8 mm and 14 ± 3.3 mm in superior plating and 13.8 ± 1.2 mm and 15.7 ± 3 mm in anteroinferior plating, respectively. Another technique that has been suggested to reduce the chance of possible injury is unicortical far-cortex abutting screw fixation during clavicle fixation. One study has shown through biomechanical testing that this technique achieved equivalent mechanical properties to bicortical fixation in axial and torsional loading [5]. The surgeon can further apply the results from our study to assist with the insertion of abutting screws in the risky screw holes (the first and second medial screw holes).

With superior plating, we found the beach chair position was safer, whereas in anteroinferior plating, the supine position was safer. In anteroinferior plating, the distances from the screw tips to the neurovascular structures of the first and second medial screw holes in the beach chair position were closer than those in the supine position. However, with superior plating in the supine position, the second screw hole had shorter clearance than in the beach chair position. In anteroinferior plating, because the neurovascular structures cross the clavicle from the posterior to inferior direction, the neurovascular structures that are posterior to the clavicle are in the risky position. On the other hand, the neurovascular structures located inferior to the clavicle are at risk of iatrogenic injury in superior plating. Many earlier studies only evaluated the distances from the screw tips to the neurovascular structures in the supine position. Most recommended anteroinferior plating to treat clavicular fractures because in the supine position, the screws are far away from the neurovascular structures [4, 7, 12]. In our study, we found that there was a risk of neurovascular injury with both anteroinferior and superior clavicular plating. For anteroinferior plating, we recommend performing the operation in the supine position, while we found the beach chair position to be safer with the superior clavicular plate. This is because gravity assists in shifting the neurovascular structures more posteriorly in the supine position and more inferiorly in the beach chair position.

In both superior and anteroinferior plating, the area medial to the midclavicle is the riskiest area for drilling and screw placement. In the supine position, the distances from the screws and plate to the neurovascular structures were farther in anteroinferior plating, but these distances were closer in superior plating. We recommend that surgeons use anteroinferior plating in the supine position and superior plating in the beach chair position. The surgeon should exercise appropriate caution while drilling holes and inserting the first and second medial screws.

Acknowledgments We thank Stephen Durako for his assistance with methodology advice; Uraporn Vongvatcharanon, PhD, head of the Anatomy Department of the Faculty of Science, Prince of Songkla University as well as Kosol Puriwattanakul and her assistants in the Anatomy Department for supplying the cadavers; Nannapat Pruphetkaew, MSc, of the Epidemiology Unit, Faculty of Medicine, for providing statistical support; Konwarat Ninlachart for his assistance with drawing the illustrations; and Dave Patterson for his assistance with English proofreading.

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