Surgical and Radiologic Anatomy (2019) 41:365–372
https://doi.org/10.1007/s00276-018-2132-z

ORIGINAL ARTICLE

Redefining the morphometry of subclavian vessels for clavicle fracture treatments

Alper Vatansever[1] · Deniz Demiryürek[2] · Burcu Erçakmak[2] · Hakan Özsoy[3] · Tuncay Hazirolan[4] · Yunus Emre Şentürk[4]

Received: 7 April 2018 / Accepted: 31 October 2018 / Published online: 3 November 2018

Abstract

Purpose Clavicle fractures are common injuries in adults and children. Although neurovascular damage is rarely seen, acute subclavian artery pseudoaneurysms and injuries to subclavian vessels were reported for closed fractures of the clavicle. The aim of this study was to identify the morphological details of the subclavian vessels and their relation to the sternoclavicular joint and body of the clavicle.

Methods 127 patients (66 females and 61 males) were evaluated using reconstructed three-dimensional computed tomographic angiographies. The point at which the subclavian artery crossed posterior to the clavicle was detected as a landmark. The medio-lateral distance between the sternal end of the clavicle, landmark, antero-posterior distance between the clavicle and the subclavian artery, diameter of the artery and vein, angle between the subclavian artery and vein, distance of the subclavian vein to the subclavian artery and the clavicle at the landmark were measured. Measurements were compared according to gender and right and left sides, and age correlation was determined.

Results Morphometric relationship between the subclavian vessels and clavicle presented differences between genders. We measured the antero-posterior distance between the subclavian artery and the clavicle to be less than 1 cm (0.91 cm).

Conclusion The subclavian artery travelled longer distances in men than women to reach the point that it crossed the clavicle. Our results demonstrated that the subclavian artery does not pass from the inferior margin of the clavicle, thus, superior plate osteosynthesis does not have any risk to injury against the subclavian vessels during the management of the clavicle fractures.

Keywords Subclavian vessels · Clavicle · Computed tomography · 3D reconstruction

Introduction

Clavicle fractures are very common and constitute up to 10% of all fractures [13]. Most of these fractures can be treated by close reduction with satisfactory outcomes [16]. However, the malunion or non-union of fractures after non-operative treatment sometimes occurs. In these situations, operative reduction methods can prevent unexpected results [1]. During surgical treatment, surgeons should avoid iatrogenic damage to the neurovascular bundle [3]. Since the subclavian artery plays a crucial role in the arterial supply of the upper extremities and the head and neck regions, any trauma to it could cause serious disorders. Furthermore, complications caused by clavicular fractures have been reported in many cases [5, 24]. Recent studies have demonstrated great interest in determining safe zones for preventing neurovascular damage while treating clavicular fractures with plate osteosynthesis to avoid postoperative complications [22, 23].

Radiological and cadaveric studies have been used to identify the anatomical relation of the neurovascular bundle and the clavicle [16, 18]. A reconstructed three-dimensional (3-D) computed tomographic angiography (CTA) study performed with 26 patients showed that there was no difference between the left and right sides for defining the relationship between the clavicle and the subclavian vessels [18].

✉ Alper Vatansever
alpervatansever@yahoo.com

[1] Department of Anatomy, Faculty of Medicine, Balikesir University, Balikesir, Turkey

[2] Department of Anatomy, Faculty of Medicine, Hacettepe University, Ankara, Turkey

[3] Department of Orthopaedic and Traumatology, Memorial Hospital, Ankara, Turkey

[4] Department of Radiology, Faculty of Medicine, Hacettepe University, Ankara, Turkey

In another anatomical study on five cadavers, the closest antero-posterior distance between the clavicle and subclavian artery was found to be 18.6 mm [16].

A number of techniques have been used to describe the anatomy of the shoulder region. The principal aim of this study was to determine the anatomical relationship between the subclavian vessels and the clavicle to define the safest zone that avoids vascular damage during surgery. This was achieved by analysing the morphometric measurements of healthy individuals using 3-D reconstructed CTA images.

Methods

Patient selection

In our study, 127 patients (66 females and 61 males) were retrospectively evaluated using 3-D reconstructed CTA images of the neck and shoulder region. The mean age of the patients was 59.8 (range 26–90). Patients that had undergone the CTA for a reason other than an orthopaedic disorder or had no history of surgery in the shoulder or chest regions were included in the present study. Patients that had undergone surgery or had any fracture in the shoulder or chest regions were excluded. Furthermore, patients were grouped according to age. There were 8, 14, 20, 17, 24, 35, and 9 patients in age groups 1 (0–30), 2 (31–40), 3 (41–50), 4 (51–60), 5 (61–70), 6 (71–80) and 7 (81–90), respectively.

Image acquisition

A 64-detector-row dual-source CT scanner (SOMATOM Definition, Siemens Healthcare, Erlangen, Germany) was used for CTA imaging. Only arterial phase imaging was performed. The protocol was as follows: 64 × 0.6 collimation, 1.4 pitch, 0.5-s rotation time, 100 kV (peak) and 180 effective mAs. The area between the upper mediastinum, including the ascending aorta, and vertex was scanned. The timing of the CTA was determined by the test-bolus technique. Dual injectors were used. A 10-mL saline chaser was injected before and after contrast material administration. Contrast material (70 ml) was injected at a rate of 4 mL/s. The source images were reconstructed into 1-mm slice thicknesses in axial view, and coronal and sagittal images were reformatted. All patients' CT angiograms were obtained from the Picture Archiving and Communication System (PACS) of the Hacettepe University Hospital. All measurements were completed by a 20-year-experienced anatomy professor, a 20-year-experienced radiology professor, a 20-year-experienced orthopaedic surgeon using OsiriX-Lite version 8 (Pixmeo, SARL, Switzerland).

Morphometric parameters

All CTA procedures were completed while patients were in the supine position. To standardise measurements across patients, the point at which the subclavian artery crosses from the posterior border of the clavicle was chosen as our landmark, and all measurements were completed according to this point. The bilateral distances between the sternal end of the clavicle and the landmark and the lengths of the clavicles were evaluated on anterior-oriented 3-D reconstructed images (Fig. 1). We also measured the antero-posterior distance between the clavicle and the subclavian artery, the antero-posterior thickness of the clavicle and the diameter of the subclavian vessels in sagittal sections at the landmark on both sides (Fig. 2). In addition, the angles of the transverse plane between the subclavian artery and the subclavian vein as well as the distance between this vein and the subclavian artery and clavicle on each side were measured according to the landmark in sagittal sections (Fig. 3).

Statistical analysis

Statistical analyses were performed using SPSS version 23. All variables were investigated using histograms, probability plots, the Kolmogorov–Smirnov test and the Shapiro–Wilk test to define of their normal or non-normal distribution. Descriptive analyses were presented using the means and standard deviations for all variables. The Student's *t* test was used for

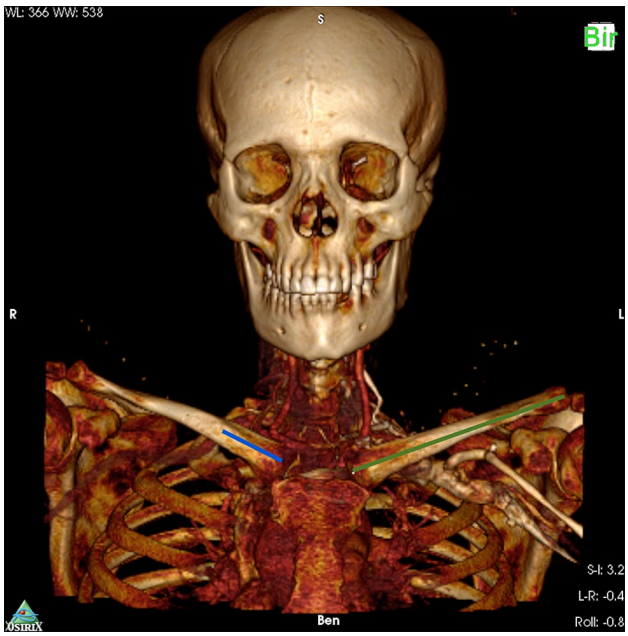

Fig. 1 Measurements of medio-lateral distance (blue line) and length of clavicle (green line)

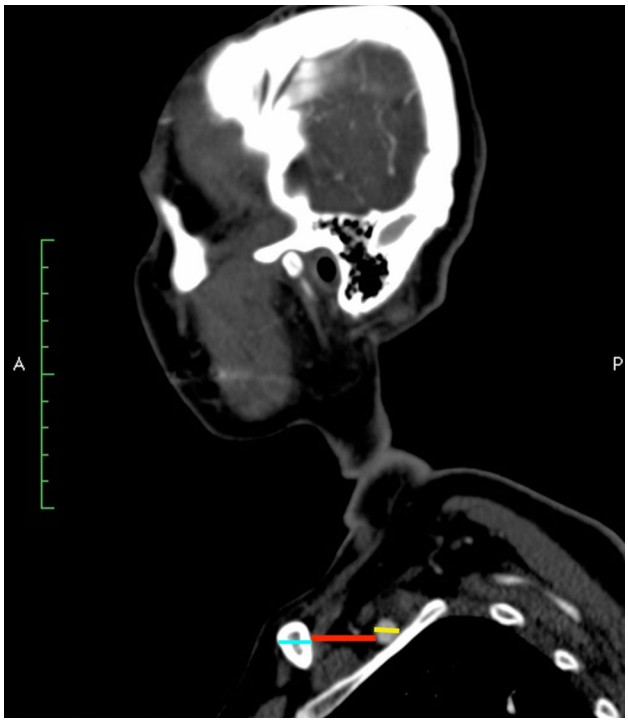

Fig. 2 Measurements of antero-posterior distance between clavicle and subclavian artery (red line), diameter of the subclavian artery (yellow line) and thickness of the clavicle (blue line)

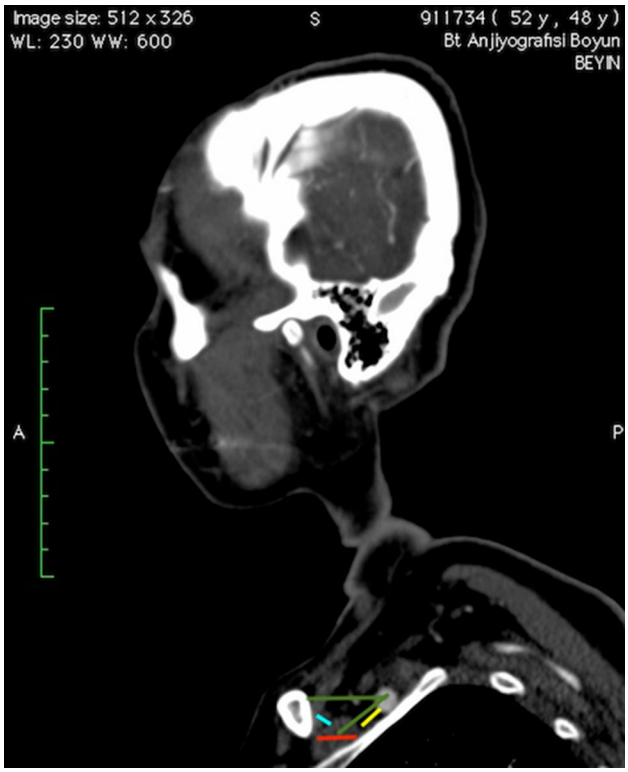

Fig. 3 Morphological measurements of the subclavian vein, angle between the subclavian artery and vein (green line), distance between the subclavian artery and vein (yellow line), distance between the clavicle and the subclavian vein (blue line) and diameter of the subclavian vein (red line)

normally distributed variables, and the Mann–Whitney *U* test was used for non-normally distributed variables for comparison between genders. The paired Student's *t* test was utilised to compare measurements between right and left sides. While investigating the associations between age and the measured variables, the Spearman's rho test was used to calculate the correlation coefficients and their significance at a 5% Type-I error level. Since the medio-lateral distances of the landmark and clavicle lengths were normally distributed, the Pearson test was used to compute the correlation coefficients and their significance at a 5% Type-I error level. Variables with a *p* value of less than 0.05 were considered statistically significant. A one-way ANOVA test was used to compare all morphometric data among the age groups. An overall *p* value of less than 0.05 was considered to show a statistically significant result.

Ethical approval

This study began after the approval from Hacettepe University's Ethical Board (decree no. GO 18/13-35).

Results

Morphometric measurements

Table 1 summarises the details of the measurements, including their mean values, standard deviations and minimum and maximum values.

The closest distance between the subclavian artery and vein was less than 1 mm, while the angles between the subclavian vessels had a wide range. On the right side, the mean distances between the subclavian artery and vein were 5.58 ± 3.83 mm (0.74–16.6) in women and 5.25 ± 3.71 mm (0.59–19.9) in men, while on the left side, they were 6.17 ± 3.96 mm (0.76–18.6) in women and 6.6 ± 3.96 mm (1.1–20.2) in men.

The subclavian artery followed a longer course until the landmark on the right side from the medial end of the clavicle. The mean values of distances between the medial end of the clavicle and the landmark were 38.1 ± 0.56 mm (23.3–49.6) in women and 42 ± 0.6 mm (31.1–55) in men on the right side, whereas they were 36.6 ± 0.62 mm (22.7–48.9) in women and 39.8 ± 0.64 mm (23.5–53.4) in men on the left side.

Table 1 Results of morphological measurements. Mean values with standard deviations, minimum and maximum values

Parameter	Women		Men	
	Right	Left	Right	Left
Medio-lateral distance (mm)	38.1 ± 0.56 (23.3–49.6)	36.6 ± 0.62 (22.7–48.9)	42 ± 0.6 (31.1–55)	39.8 ± 0.64 (23.5–53.4)
Antero-posterior distance (mm)	24.9 ± 0.49 (13.6–35.2)	26.3 ± 0.57 (14.2–35.8)	25.3 ± 0.64 (9.1–42.4)	26.1 ± 0.64 (13.4–43)
Diameter of subclavian artery (mm)	7.37 ± 1.11 (4.54–10.5)	7.04 ± 1.02 (5.38–10.8)	8.01 ± 1.15 (6.11–10.9)	7.6 ± 1.23 (5.47–11.5)
Length of clavicle (cm)	10.81 ± 1.02 (8.91–12.99)	10.79 ± 0.99 (8.49–12.98)	11.57 ± 1.18 (9.4–14.68)	11.51 ± 1.26 (8.96–14.83)
Thickness at landmark point (cm)	1.15 ± 0.15 (0.88–1.63)	1.12 ± 0.16 (0.86–1.58)	1.31 ± 0.16 (0.88–1.75)	1.32 ± 0.16 (0.94–1.72)
Angle between subclavian artery and vein	29.42 ± 11.67 (8.03–84.34)	27.45 ± 8.22 (13.61–54.57)	27.48 ± 8.49 (6.52–48.67)	26.14 ± 8.88 (9.43–48.06)
Distance between subclavian artery and vein (mm)	5.58 ± 3.83 (0.74–16.6)	6.17 ± 3.96 (0.76–18.6)	5.25 ± 3.71 (0.59–19.9)	6.6 ± 3.96 (1.1–20.2)
Distance between subclavian vein and clavicle (mm)	6.72 ± 2.69 (1.53–13.8)	6.41 ± 2.33 (1.19–13.1)	6.48 ± 3.19 (0.46–15.7)	7.37 ± 2.68 (1.9–14)
Diameter of subclavian vein (mm)	15.09 ± 3.29 (7.9–22)	13.47 ± 2.67 (7.15–19.8)	15.22 ± 3.35 (7.33–22.2)	13.73 ± 2.94 (7.92–19.3)

The antero-posterior distances between the clavicle and the subclavian artery at the landmark are also important. We measured 24.9 ± 0.49 mm (13.6–35.2) and 25.3 ± 0.64 mm (9.1–42.4) on the right side in women and men, respectively. On the left side, the distances between the clavicle and the subclavian artery at the landmark were 26.3 ± 0.57 mm (14.2–35.8) in women and 26.1 ± 0.64 mm (13.4–43) in men.

Morphometric measurements did not demonstrate any differences among the age groups.

Gender differences

Comparing the measured parameters between genders was one of the objectives of this study. Table 2 shows the results of the comparisons of the parameters measured between genders. Variables that showed statistically significant differences tended to be longer in male patients than in female patients.

Table 2 Comparison of measurement between genders

Parameters	*p* value	Test	Comment
Right medio-lateral distance	$p < 0.001$	Student's *t* test	Longer in men and statistically significant
Left medio-lateral distance	$p = 0.006$	Student's *t* test	Longer in men and statically significant
Right antero-posterior distance	$p = 0.67$	Student's *t* test	No significance
Left antero-posterior distance	$p = 0.85$	Student's *t* test	No significance
Diameter of right subclavian artery	$p = 0.006$	Student's *t* test	Wider in men and statistically significant
Diameter of left subclavian artery	$p = 0.005$	Mann–Whitney *U*	Wider in men and statistically significant
Length of right clavicle	$p < 0.001$	Student's *t* test	Larger in men and statistically significant
Length of left clavicle	$p < 0.001$	Student's *t* test	Larger in men and statistically significant
Thickness of right clavicle at landmark	$p < 0.001$	Student's *t* test	Thicker in men and statistically significant
Thickness of left clavicle at landmark	$p < 0.001$	Student's *t* test	Thicker in men and statistically significant
Angle between right subclavian artery and vein at landmark	$p = 0.55$	Mann–Whitney *U*	No significance
Angle between left subclavian artery and vein at landmark	$p = 0.35$	Mann–Whitney *U*	No significance
Distance between right subclavian artery and vein at landmark	$p = 0.72$	Mann–Whitney *U*	No significance
Distance between left subclavian artery and vein at landmark	$p = 0.5$	Mann–Whitney *U*	No significance
Distance between right subclavian vein and clavicle at landmark	$p = 0.77$	Mann–Whitney *U*	No significance
Distance between left subclavian vein and clavicle at landmark	$p = 0.03$	Student's *t* test	Longer in men and statistically significant
Diameter of right subclavian vein at landmark	$p = 0.82$	Student's *t* test	No significance
Diameter of left subclavian vein at landmark	$p = 0.6$	Student's *t* test	No significance

The distances between the medial end of the clavicle and the landmark were longer in men than women on the right ($p < 0.001$) and left ($p = 0.006$) sides. On the other hand, the antero-posterior distances between the clavicle and the subclavian artery at the landmark were not statistically different between genders on either side. Furthermore, the clavicle was thicker in men than women on both sides at the landmark ($p < 0.001$).

Differences between right and left sides

As demonstrated in Table 3, most of the measured parameters showed statistically significant differences between the right and left sides.

We considered all measurements between the right and left sides without considering gender. According to our results, the subclavian artery had a longer course from the medial end of the clavicle to the landmark on the right side ($p < 0.001$). The antero-posterior distance between the clavicle and the subclavian artery ($p = 0.005$) and the distance between the subclavian artery and vein ($p = 0.002$) were longer at the landmark on the left side. The diameters of the subclavian artery ($p = 0.001$) and vein ($p < 0.001$) were wider on the right side.

Furthermore, there were no statistically significant differences in the length or thickness of the clavicle, the angle between the subclavian artery and vein or the distance between the subclavian vein and the clavicle between the two sides.

Age correlation

As a result of correlation analyses, it was revealed that morphometric measurements, with the exception of the diameter of the subclavian arteries, did not show any statistically significant correlation with age (Table 4). However, there was a weakly significant correlation between the diameter of the subclavian arteries and the age of patients.

In addition to these results, when we considered the correlation between the clavicle length and landmark, there was a significant correlation on both sides ($r = 0.27$, $p = 0.002$ on the right side; $r = 0.37$, $p < 0.001$ on the left side).

Discussion

The use of 3-D CTA images allowed for the highly detailed examination of the subclavian vessels.

Iatrogenic neurovascular injury as a result of osteosynthesis with plating or the screwing of the shaft fractures of the clavicle could cause serious clinical issues. Studies have shown that mistaken instrumentation of clavicle fractures has given rise to thoracic outlet syndrome and function losses in the upper extremities [26]. Therefore, recent studies have been designed to describe safe zones for preventing iatrogenic injuries to neurovascular structures while managing clavicle fractures.

In a previous cadaveric study, using five cadavers, Robinson et al. showed that the closest distance between the medial third of the clavicle and the subclavian artery was 18.6 mm. They also showed that this distance increased through the lateral end of the clavicle [16]. According to our results, the point at which the sternal end of the clavicle and the subclavian artery were closest measured 22.7 mm. This difference may be caused by the usage of different material and the limited 'n' number in the previous study. We have completed our study with in vivo measurements of a larger population.

In another radiological study, the subclavian artery was evaluated in relationship to the clavicles of 26 patients. In that study, the clavicle was separated into three parts, with one point selected for each part. However, the selection criteria for these points are unknown. According to their

Table 3 Comparison of measurement between left and right sides (paired-sample *t* test)

Parameters	Mean values ± SD	*p* value	Comment
Medio-lateral distance between landmark point and medial end of clavicle	0.18 ± 0.57	$p < 0.001$	Longer on right side and statistically significant
Antero-posterior distance between clavicle and subclavian artery	0.11 ± 0.44	$p = 0.005$	Longer on left side and statistically significant
Length of clavicle	0.04 ± 0.45	$p = 0.29$	No significance
Thickness of clavicle at landmark	0.01 ± 0.11	$p = 0.29$	No significance
Diameter of subclavian artery	0.36 ± 1.17	$p = 0.001$	Wider on right side and statistically significant
Angle between subclavian artery and vein	1.66 ± 9.72	$p = 0.06$	No significance
Distance between subclavian artery and vein at landmark	0.95 ± 3.4	$p = 0.002$	Longer on left side and statistically significant
Distance between subclavian vein and clavicle at landmark	0.26 ± 3.37	$p = 0.37$	No significance
Diameter of subclavian vein at landmark	1.55 ± 3.51	$p < 0.001$	Wider on right side and statistically significant

Table 4 Correlation summary of all parameters with the age

Parameter	Correlation coefficient (*r*)	Significance (*p*)	Comment
Right medio-lateral distance	−0.02	0.81	No significant correlation
Left medio-lateral distance	−0.13	0.12	No significant correlation
Right antero-posterior distance	0.01	0.85	No significant correlation
Left antero-posterior distance	−0.01	0.94	No significant correlation
Diameter of right subclavian artery	0.18	0.04	Weak correlation and statistically significant
Diameter of left subclavian artery	0.2	0.02	Weak correlation and statistically significant
Right clavicle length	−0.84	0.34	No significant correlation
Left clavicle length	−0.08	0.35	No significant correlation
Right clavicle thickness	0.12	0.16	No significant correlation
Left clavicle thickness	0.13	0.13	No significant correlation
Right angle between subclavian artery and vein	−0.11	0.18	No significant correlation
Left angle between subclavian artery and vein	0.05	0.58	No significant correlation
Distance between right subclavian artery and vein	−0.05	0.52	No significant correlation
Distance between left subclavian artery and vein	0.06	0.49	No significant correlation
Distance between right subclavian vein and clavicle	0.03	0.72	No significant correlation
Distance between left subclavian vein and clavicle	0.08	0.32	No significant correlation
Diameter of right subclavian vein	−0.04	0.64	No significant correlation
Diameter of left subclavian vein	0.01	0.83	No significant correlation

results, the closest antero-posterior distance between the subclavian artery and the clavicle was 5.4 mm, and they found no difference between the right and left sides [18]. In contrast, our results showed that the closest antero-posterior distance was 9.1 mm at the landmark. Additionally, we found a difference in the distance between the sternal end of the clavicle and the landmark between genders. When we compared the distances between the right and left sides, the difference was statistically significant in favour of the right side for all patients. These differences may be caused by the origin and course of the subclavian artery and/or dominant hand use. Further studies may be required to determine the reasons for these differences.

As our results showed, most parameters demonstrated statistically significant differences between the right and left sides. Thus, statistical differences are incontrovertible while designing surgery protocols. On the contrary, age had no effect on the morphological organization of the relationship between the subclavian vessels and the clavicle.

Plenty of reports demonstrate neurovascular damage in clavicular fracture cases [5, 7, 11, 17, 19–21, 25]. Furthermore, the subclavian artery could be damaged during surgery or the postoperative period [3, 4, 6, 14].

Recent studies have focused on the most suitable treatment technique for clavicular fractures. Choosing a surgical technique requires the consideration of various criteria, and therefore, there is still no consensus on the best method. On the other hand, the mutual aim of these studies is to prevent damage to and complications in neurovascular structures during and after surgery [2, 10, 13, 15, 22, 23, 26]. Furthermore, variations in the subclavian artery have been reported [8, 9, 12].

Statistically different measurements between the right and left sides indicated that an asymmetry was present between the two sides. The main reasons for the asymmetry were not clear. However, this might be formed as a result of the route of the vessels or dominant hand usage. A prospective study may be designed to investigate these relationships.

According to our results, the antero-posterior distance was as close as 9.1 mm, and the closest medio-lateral distance from the medial end of the clavicle was 22.7 mm. These close relations must be considered while arranging the screw holes of the plates. Furthermore, during anterior plate osteosynthesis, screw lengths should not exceed 5 mm beyond the clavicle thickness, because the antero-posterior distance was less than 1 cm. However, anterior plate osteosynthesis is not a safe trajectory for mid-shaft fractures of the clavicle and may only be applied in lateral end fractures of the clavicle. On the other hand, to our knowledge, the subclavian artery never passes from the inferior surface of the clavicle, and therefore, superior plate osteosynthesis may be used to achieve a safe trajectory.

Our results showed that the subclavian artery may be as close as 1 cm to the clavicle and crosses the clavicle at various lengths. The results also showed a gender difference regarding the distance between the sternal end of the clavicle and the landmark.

Conclusion

Surgeons should pay special attention in clavicular fracture cases to the prevention of iatrogenic and postoperative neurovascular disorders. While doing so, they should be aware of the anatomy of the subclavian vessels, their variations and the relationships between neighbour structures. Our results had indicated that the subclavian vessels had not passed from the inferior surface of the clavicle. Therefore, applying the superior plate osteosynthesis to manage clavicular fractures would not pose any injury risk to subclavian vessels. Finally, each patient should be assessed individually to choose an appropriate surgery protocol. Further studies evaluating the subclavian vessels in clavicle fractures should be conducted to compare anatomical changes in these cases.

Limitations

Since the study was designed retrospectively, the somatometric characteristics of the patients such as body mass index or dominant hand usage could not be obtained.

Author contributions DD; study development and design, manuscript preparation. BE; study development and design, manuscript preparation. TH; data collection and management, data analysis, manuscript preparation. HÖ; study development and design, data analysis, manuscript preparation. YEŞ; data collection and management, data analysis, manuscript preparation. AV; study development and design, data collection and management, data analysis, statistical analysis, manuscript preparation.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Bernstein J (2007) Nonoperative treatment compared with plate fixation of displaced midshaft clavicular fractures. J Bone Jt Surg Am 89:1866 **(author reply 1866–1867)**
2. Calbiyik M, Zehir S, Ipek D (2016) Minimally invasive implantation of a novel flexible intramedullary nail in patients with displaced midshaft clavicle fractures. Eur J Trauma Emerg Surg 42:711–717. https://doi.org/10.1007/s00068-015-0567-z
3. Ding M, Hu J, Ni J, Lv H, Song D, Shu C (2012) Iatrogenic subclavian arteriovenous fistula: rare complication of plate osteosynthesis of clavicle fracture. Orthopedics 35:e287–e289. https://doi.org/10.3928/01477447-20120123-21
4. Evans T, Roy S, Rocker M (2015) Subclavian artery pseudoaneurysm formation 3 months after a game of Rugby union. Case Rep Emerg Med 2015:346192. https://doi.org/10.1155/2015/346192
5. Fatimi SH, Anees A, Muzaffar M, Hanif HM (2010) Acute traumatic subclavian artery thrombosis and its successful repair via resection and end-to-end anastomosis. Chin J Traumatol 13:255–256
6. Gieger J, Beeres F, Birrer K, Babst R (2016) Misalignment of the clavicle after intramedullary fixation of a midshaft fracture with a titanium elastic nail results in acute neurovascular thoracic outlet syndrome. J Shoulder Elbow Surg 25:e110–e114. https://doi.org/10.1016/j.jse.2015.12.014
7. Gullo J, Singletary EM, Larese S (2013) Emergency bedside sonographic diagnosis of subclavian artery pseudoaneurysm with brachial plexopathy after clavicle fracture. Ann Emerg Med 61:204–206. https://doi.org/10.1016/j.annemergmed.2012.05.037
8. Kohli S, Yadav N, Prasad A, Banerjee SS (2014) Anatomic variation of subclavian artery visualized on ultrasound-guided supraclavicular brachial plexus block. Case Rep Med 2014:394920. https://doi.org/10.1155/2014/394920
9. Natsis K, Didagelos M, Gkiouliava A, Lazaridis N, Vyzas V, Piagkou M (2017) The aberrant right subclavian artery: cadaveric study and literature review. Surg Radiol Anat 39:559–565. https://doi.org/10.1007/s00276-016-1796-5
10. Naveen BM, Joshi GR, Harikrishnan B (2017) Management of mid-shaft clavicular fractures: comparison between non-operative treatment and plate fixation in 60 patients. Strateg Trauma Limb Reconstr 12:11–18. https://doi.org/10.1007/s11751-016-0272-4
11. Nishimura K, Hamasaki T, Yamamoto S, Kawai T, Sugiura K (2015) Endovascular treatment of left subclavian artery pseudoaneurysm after clavicle fracture in an elderly adult with a 40-year history of Behcet's disease. Ann Vasc Dis 8:328–330. https://doi.org/10.3400/avd.cr.15-00082
12. Ocaya A (2015) Retroesophageal right subclavian artery: a case report and review of the literature. Afr Health Sci 15:1034–1037. https://doi.org/10.4314/ahs.v15i3.44
13. Omid R, Kidd C, Yi A, Villacis D, White E (2016) Measurement of clavicle fracture shortening using computed tomography and chest radiography. Clin Orthop Surg 8:367–372. https://doi.org/10.4055/cios.2016.8.4.367
14. Perera KG, Clifford C, Maddock L (2015) Subclavian artery injury secondary to clavicular plate fixation: a novel operative approach. J Surg Case Rep. https://doi.org/10.1093/jscr/rjv044
15. Qin D, Zhang Q, Zhang YZ, Pan JS, Chen W (2010) Safe drilling angles and depths for plate-screw fixation of the clavicle: avoidance of inadvertent iatrogenic subclavian neurovascular bundle injury. J Trauma 69:162–168. https://doi.org/10.1097/TA.0b013e3181bbd617
16. Robinson L, Persico F, Lorenz E, Seligson D (2014) Clavicular caution: an anatomic study of neurovascular structures. Injury 45:1867–1869. https://doi.org/10.1016/j.injury.2014.08.031
17. Rodriguez-Merchan EC, Gomez-Cardero P (2010) Delayed union of a fracture of the middle third of the clavicle presenting with a late subclavian pseudoaneurysm. Musculoskelet Surg 94:89–92. https://doi.org/10.1007/s12306-010-0076-5
18. Sinha A, Edwin J, Sreeharsha B, Bhalaik V, Brownson P (2011) A radiological study to define safe zones for drilling during plating of clavicle fractures. J Bone Jt Surg Br 93:1247–1252. https://doi.org/10.1302/0301-620X.93B9.25739
19. Sodhi KS, Arora J, Khandelwal N (2007) Post-traumatic occlusion of subclavian artery with clavicle fracture. J Emerg Med 33:419–420. https://doi.org/10.1016/j.jemermed.2007.02.054
20. Stefanczyk L, Czeczotka J, Elgalal M, Sapieha M, Rowinski O (2011) A large posttraumatic subclavian artery aneurysm complicated by artery occlusion and arteriobronchial fistula successfully treated using a covered stent. Cardiovasc Intervent Radiol 34(Suppl 2):S146–S149. https://doi.org/10.1007/s00270-010-9959-y
21. Stella M, Santolini E, Briano S, Santolini F (2015) Late recurrent peripheral upper limb ischemia after non-union of a clavicle

fracture. Injury 46(Suppl 7):S3–S7. https://doi.org/10.1016/S0020-1383(15)30035-8
22. Stillwell A, Ioannou C, Daniele L, Tan SL (2017) Osteosynthesis for clavicle fractures: how close are we to penetration of neurovascular structures? Injury 48:460–463. https://doi.org/10.1016/j.injury.2016.10.044
23. Sukur E, Ozturkmen Y, Akman YE, Gungor M (2016) Clinical and radiological results on the fixation of Neer type 2 distal clavicle fractures with a hook plate. Acta Orthop Traumatol Turc 50:489–493. https://doi.org/10.1016/j.aott.2016.08.012
24. Tachtsi MD, Pitoulias GA, Fycatas P, Kalogirou T, Papadimitriou DK (2011) Subclavian artery aneurysm due to clavicle fracture. Ann Vasc Surg 25:984e985–984987. https://doi.org/10.1016/j.avsg.2011.04.005
25. Watanabe K, Matsumura T (2005) Late-onset brachial plexus paresis caused by subclavian pseudoaneurysm formation after clavicular fracture. J Trauma 58:1073–1074
26. Werner SD, Reed J, Hanson T, Jaeblon T (2011) Anatomic relationships after instrumentation of the midshaft clavicle with 3.5-mm reconstruction plating: an anatomic study. J Orthop Trauma 25:657–660. https://doi.org/10.1097/BOT.0b013e3182112d7b