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Research Article

Vascular anatomy of the clavicle: an aid to midshaft clavicle fracture management

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Abstract

Introduction: Clavicle fractures are common across both adults and paediatric populations. Furthermore, gender differences in clavicular anatomy are well-documented, with male clavicles often measuring longer and thicker than their female counterparts. We aimed to elucidate disparities in surrounding vasculature, between genders, as well as within the same patient. The greatest proportion of these fractures occurs within the middle third of the clavicle. These fractures are often treated conservatively and, in some cases, can lead to complications of malunion and more rarely non-union, which may require surgical intervention. However, these surgeries present the risk of iatrogenic complications which include but are not limited to neurovascular deficit, hardware failure and scarring. The aim of this study is to better understand the relationship between major vascular structures surrounding the middle third of the clavicle, to improve patient outcomes following mid-shaft clavicle fracture management.

Methods: Upper-limb 3D CT angiograms were retrospectively retrieved from the PACS Royal Free database. Our search timeframe was set between January to December of 2022. Inclusion criteria comprised of non-orthopaedic referrals and patients of skeletally mature age. Exclusion criteria included any fracture cases or subclavian pathologies which would disrupt normal anatomy. As a result of our search requirements, thirty patient CTAs of the upper limb were retrieved; we noted age, gender, and reason for the scan request for all patients, as well as the number of slices on each of the scans. We measured clavicle length, thickness, distance, and angle with respect to the subclavian artery and vein.

Measurements were collated and analysed using Microsoft Excel 2022, to calculate the mean and range; the means were then compared using an unpaired two-tailed t-test. A linear regression analysis was also conducted on age and clavicle thickness to inform whether these values would prove important to consider pre-operatively.

Results: Thirty patients' upper limb CTAs were retrieved, 15 of which were female and 15 were male. The mean age of all patients was 54 years (ranging from 25 to 85) with males averaging 59 years and females averaging 50 years. Twenty-seven measurements were obtained for the right clavicle and 28 for the left clavicle, due to some CTs only visualising the right or left clavicles.

The mean clavicle length and thickness were 14.7 cm (95% CI: 14.3 to 15) and 11.8 mm (95% CI: 11.1 to 12.5) respectively. Statistically significant gender differences were observed with respect to these parameters, with male clavicles measuring longer (p-value<0.00001) and thicker along the mid-section (p-value<0.00001) when compared with the female mean. No statistically significant right and left differences were observed in length (p-value > 0.05) or thickness (p-value > 0.05 0.685).

The mean distances between the clavicle and subclavian artery and the subclavian vein were 14.2 mm and 15.1 mm respectively. The female clavicle exhibited closer proximity to the subclavian vein at a mean of 13.3 mm (95% CI: 11.5 to 15) which was significantly lower than the male mean of 17.4 (95% CI: 13.8 to 21.1) (p-value < 0.05). Statistically significant gender differences were observed with respect to the subclavian vein (p-value < 0.05).

The mean distance between the right clavicle and the right subclavian artery was 14.5 mm (95% CI: 12.4 to 16.6), compared to the left subclavian artery which was more proximal at 13.9 mm (95% CI: 11.9 to 15.9). This was not a statistically significant difference (p-value > 0.05). No statistically significant differences were observed between right and left clavicles, concerning the angle of the artery (p-value > 0.05), or in the angle of the vein (p-value > 0.05). No statistically significant differences in angles were observed between female (p-value > 0.05) and male clavicles (p-value > 0.05).

Conclusion: Our study found significant gender differences in the parameters of clavicle length, thickness and proximity of the subclavian artery and vein. However, no significant differences were found in vascular angularity or between the right and left clavicular anatomy. Our findings suggested that male clavicles tend to have greater thickness and length, and are therefore less likely to pose a risk of iatrogenic injury during operative intervention when compared with female patients.

Keywords: Clavicular fractures, upper-limb, angiograms, clavicular anatomy

INTRODUCTION

Trauma is a leading cause of morbidity and mortality in the United Kingdom [1]. Clavicular fractures are the most common type of fracture worldwide, making up 5% of all adult fractures and 95% of all fractures in neonates due to birth trauma. Mid-shaft fractures represent 69% of all adult cases, increasing to 95% in children, due to their superficial location and limited muscular support [2-3]. Many major structures, including the subclavian artery, vein and the brachial plexus, can be subject to injury in clavicular fractures, particularly if there is displacement of fracture segments [4]. Around 50% of injuries to the subclavian artery, an otherwise densely protected anatomical landmark, are attributed to clavicular fractures [5]. The mechanism of injury is typically falls, especially on an outstretched hand or lateral fall onto the shoulder, or high-energy trauma directly onto the clavicle. These injuries are most frequently seen in children under 20 years old or adults over 55 years old [6].

While such fractures are usually treated conservatively with a splint or sling, these management methods are being increasingly linked to an elevated risk of malunion between 15%-17% Such patients will then require surgical intervention due to functional complications [5]. Displaced mid-shaft fractures are typically treated via open reduction and internal fixation of the clavicle. These interventions are becoming more common as first-line treatment and are preferred to conservative treatment due to greater functional outcomes and patient satisfaction due to a faster return to regular activities such as work and sports [7]. However, with this rise in surgical intervention comes an increased risk of iatrogenic neurovascular complications, especially as meticulous vascular imaging is not routinely conducted as part of pre-operative planning.

The objective of this study was to determine the distribution of major vascular structures, namely the subclavian artery and vein, between the thorax superiorly and apices of the lungs inferiorly, by conducting a retrospective analysis of CT angiograms of the upper limb, taken at the Royal Free Hospital.

METHODS

Non-orthopaedic-related upper limb CT angiograms were retrospectively reviewed to visualise normal anatomy in situ. Both CT angiograms and MRI were considered for use as the primary imaging modality, however, the former was preferred due to its superior spatial resolution; on average, selected CTAs consisted of 1620 slices. Therefore, CTAs were preferred for visualising arterial and venous vasculature.

The inclusion criteria for patients in this study were those of skeletally mature age, determined as anyone aged over 25, due to excessive variation between clavicular measurements in those without skeletal maturity [8]. Most scans had been conducted for vascular assessments, often following surgery where complications are suspected; patients with traumatic upper limb injuries or pathologies occluding the subclavian vessels were excluded due to disrupted anatomy. In the case where multiple CT scans had been conducted for the same patient, we selected the most recent scan; in the case, all scans were taken on the same date, we selected the CT with the most slices to optimise image resolution.

The mid-shaft region of the clavicle was defined by measuring the overall length and splitting it into thirds for each patient. We then selected the middle point of the mid-shaft as the clavicular marker. We decided to focus on the subclavian artery and vein due to their proximity to the mid-shaft, as well as functional significance; iatrogenic dissection of the artery is associated with high morbidity due to complications of pseudoaneurysm or stenosis to nearby major vessels such as the common carotid [9].

The parameters measured with respect to the subclavian artery and vein were clavicle length, minimum distance, direction relative to the clavicle and angle from the clavicle. Using PACS software, we q-uantrum the minimum distance from the middle third of the clavicle to the subclavian artery and vein. Thickness was calculated at the mid-point, using a straight-line measurement.

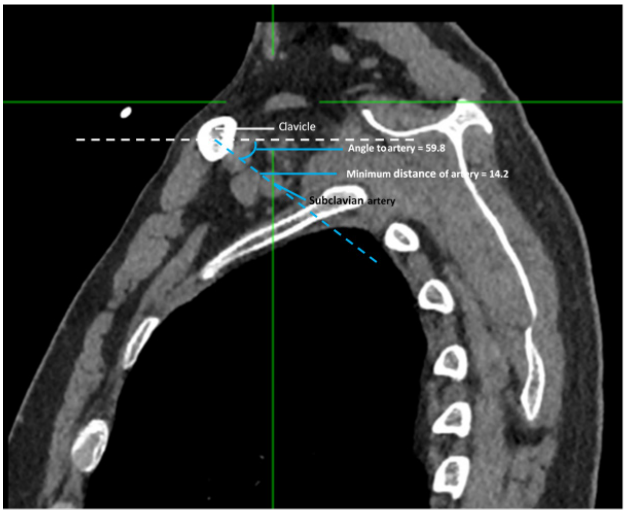

Fig. 1. Method for subclavian artery angle measurement and minimum distance, with means.

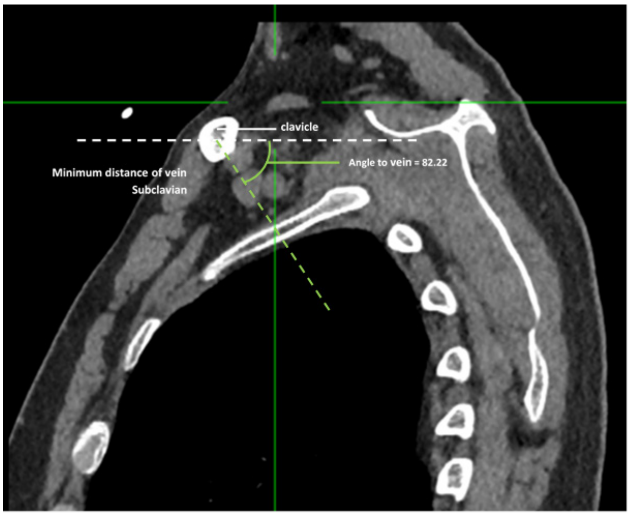

Fig. 2. Method for subclavian vein angle measurement and minimum distance, with means.

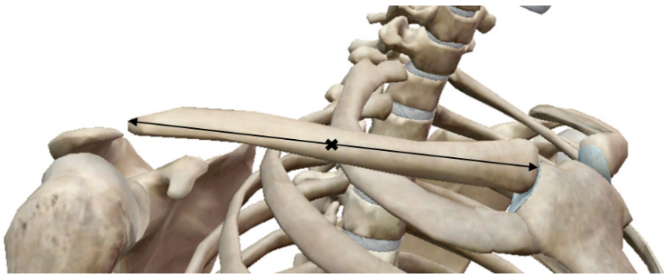

Fig. 3. Method for defining mid-clavicle.

The angle between the vessel of interest and the clavicle was determined in the sagittal plane, by marking the centre of the clavicle and vessel, then using the PACS angle function (Figure 1). The direction was then determined by the angle; for example, an angle over 95 would suggest the vessel is anteroinferior with respect to the clavicle, whereas an angle under 85 means posteroinferior and angles between 85-95 were determined to be inferior.

RESULTS

SUBCLAVIAN ARTERY AND VEIN DISTANCES

With respect to the mid-shaft, both the right and left subclavian arteries lay posteroinferior. All of our mean distances and statistical analyses have been compiled into the tables below, where gender (Table 1) and right and left (Table 2), differences are compared. The overall mean (M) minimum distance between the clavicle mid-point and subclavian artery was 14.2 mm, with right subclavian arteries (M=14.5mm ± 5.4) being located further away than left arteries (M=13.9mm ± 5.2); despite this, there is no statistically significant difference between the minimum distance of right and left subclavian arteries and clavicle mid-shafts [t(51) = -0.41, p = 0.685] (Table 2). There were also no observable significant differences in the venous distance when comparing right (M=17.4mm ± 7.2) and left clavicles (M=13.3mm ± 4.9), (t(50) = 0.547, p = 0.587), but it was significantly more proximal in female anatomy (p-value = 0.022). Subclavian arteries in females (M=12.9mm ± 4.1) were also observed to be significantly closer [t(51) = -2.42, p = 0.048]. to the mid-shaft compared to males (M=15.9mm ± 6.3); significant gender differences were observed in the minimum distance between the clavicle mid-shaft and subclavian arteries (Table 1).

CLAVICLE LENGTH AND THICKNESS

The mean clavicle length overall was 14.7 cm, with right clavicles (M=14.8mm ± 0.9) measuring greater than left clavicles (M=14.6mm ± 1.1) (Table 2); however there is no statistically significant difference between right and left clavicle lengths [t(53) = 0.72, p = 0.473]. Male clavicles (M=15.4mm ± 0.7), compared to female clavicles (M=14.0 ± 0.9) were of significantly greater length (Table 1); so there were, once again, statistically significant gender differences observed in clavicle length [t(54) = -5.55, p < 0.00001].

The mean clavicular thickness overall was 11.8 mm, with right clavicles (M=12.2mm ± 1.6) measuring thicker than left clavicles (M=11.5 ± 2.2), although this is not statistically significant [t(52) = 1.18, p < 0.05]. However, there is a statistically significant gender difference [t(56) = -5.18, p < 0.00001] observed in thickness, with male clavicles (M=13.1mm ± 1.3) measuring 2.3 mm thicker than female clavicles (M=10.9mm ± 1.9). There was no statistically significant correlation between age and clavicle thickness (p-value = 0.928) (Figure 4).

ANGLE

In the mid-shaft, the right subclavian artery (M=63.3 ± 25.6) was located at a more acute angle compared to the vein (M=87.8 ± 22.6), which was always located posteriorly. In contrast with the right subclavian vessels, both the left subclavian artery (M=56.5 ± 22.1) and the vein (M=77.1 ± 20.9) were less angled with respect to the clavicle; however, this difference was not found to be statistically significant between arteries (t(50) = 0.99, p = 0.326) or veins (t(50) = 1.70, p = 0.095). These differences were also not found to be significant when comparing male and female patients' artery (t(24) = -0.01, p = 0.418) or vein (t(24) = 1.08, p = 0.611) angles.

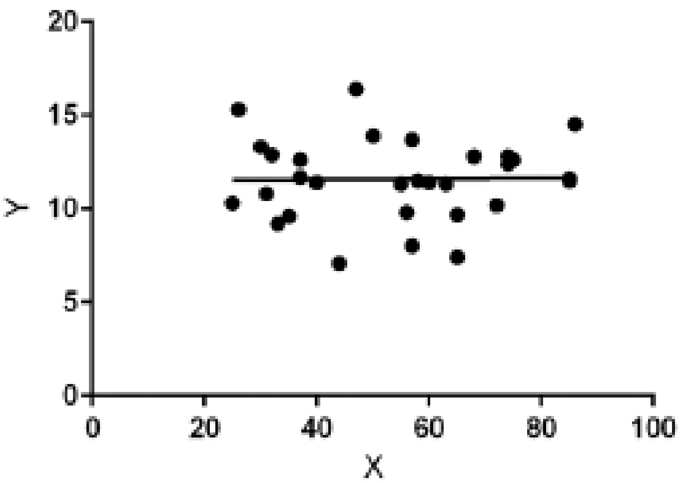

Fig. 4. Linear regression analysis of age and clavicle thickness

Table 1. Age, clavicle length, thickness, and vessel angle with respect to clavicle presented as mean ± SD (2 d.p.)

	Male	Female	Difference	Both	p-value (m vs. f)
Number of participants	15	15	N/A	30	N/A
Age (years)	59 ± 18.0	49.0 ± 17.2	10	54.9 ± 17.8	N/A
Clavicle length (cm)	15.4 ± 0.7	14.0 ± 0.9	1.4	14.7 ± 1.0	<0.00001
Thickness (mm)	13.1 ± 1.3	10.8 ± 1.9	2.3	11.8 ± 2.0	<0.00001
Distance of artery (mm)	15.9 ± 6.3	12.9 ± 4.1	3	14.2 ± 5.3	0.048
Distance of vein (mm)	17.4 ± 7.2	13.3 ± 4.9	4.1	15.1 ± 6.4	0.022
Angle of artery (°)	62.9 ± 27.0	57.2 ± 21.1	5.7	59.8 ± 24.1	0.418
Angle of vein (°)	80.4 ± 22.9	83.7 ± 21.9	-3.3	82.2 ± 22.4	0.611

Table 2. Right and left clavicle differences in clavicle length, distance and angle between midpoint and right subclavian artery presented as mean ± SD (2 d.p.)

	Right	Left	Difference	Both	p-value
Clavicle length	14.8 ± 0.9	14.6 ± 1.1	0.2	14.7 ± 1.0	0.473
Thickness (mm)	12.2 ± 1.6	11.5 ± 2.2	0.7	11.8 ± 2.0	0.244
Distance of artery (mm)	14.5 ± 5.4	13.9 ± 5.2	0.6	14.2 ± 5.3	0.685
Distance of vein (mm)	15.6 ± 6.1	14.6 ± 6.5	1	15.1 ± 6.4	0.587
Angle of artery (°)	63.3 ± 25.6	56.5 ± 22.1	6.7	59.8 ± 24.1	0.326
Angle of vein (°)	87.8 ± 22.6	77.1 ± 20.9	10.7	82.2 ± 22.4	0.095

DISCUSSION

Measurements collected in this study demonstrated a clear, statistically significant difference in clavicle length, thickness, and distance of subclavian artery and vein between male and female patients, but no difference in vascular angling. No statistically significant difference was seen between the right and left clavicular anatomy. Our findings reflected the results of similar studies, with Sinha et al. also finding significant gender differences in artery and vein distance at the mid-shaft, although none were found in clavicular length or thickness [10].

Clavicle fractures are a common injury and their management is not universally agreed upon. Traditionally, non-surgical management has been favoured as the initial treatment modality for most clavicle fractures owing to the high non-union rates reported after operative treatment [11]. However, non-operative management may be optimal for many clavicle fractures, good outcomes of non-surgically treated fractures are not universal [12]. Recent evidence suggests that specific subsets of patients may be at high risk for non-union, shoulder dysfunction, or residual pain after nonsurgical management [12]. In this subset of patients, acute surgical intervention may minimize suboptimal outcomes.

There is increasing literature emerging in support of surgical intervention for clavicular fractures, especially in the case of displacement. Techniques for reduction and fixation are evolving to reduce recovery time and improve cosmetic outcome; for example, intramedullary fixation uses smaller incisions which reduces the risk of soft tissue disruption, although it provides less stability than plate fixation and is therefore accompanied by a greater risk of malunion or non union [13]. Additionally, neurovascular compromise following fracture remains a contraindication to IM fixation [13]. The trajectory taken for IM fixation is laterally from the medial end of the clavicle; this approach targets the scalenus anterior and therefore eliminates any risk of subclavian or brachial plexus damage. However, complications typically arise from implant failure, such as infection or irritation arising from breakage of the IM device [14].

With plate fixation, immediate stability is achieved which allows shorter recovery time due to rapid mobilisation following surgery; however, the use of improperly long screws and angle of approach poses a greater risk of vascular damage. A bridge plate is commonly used which utilised the plate as a reduction mechanism, with proceeding screws fixing the fracture segments in position to support mobilisation. This superior approach presents the advantage of treating all lateral, medial and diaphyseal fractures of the mid-shaft and avoids the risk of subclavian artery damage, which is usually angled postero-inferiorly. However, the subclavian vein may be at risk since it is located at a mean of 82.2°C about the clavicle; in this case, CT angiography would be highly recommended to plan trajectory due to the variation in vein positioning.

The use of a lag screw is indicated in simple fractures as they provide compression and enhance stability. This involves angling the screw perpendicular to the fracture plane and pairing it with a neutralisation plate to enhance stability across the whole clavicle, to promote early mobilisation. An anterior approach is typically taken for lag screw and plate fixation, which Ai et al. found boasts shorter operation time and less blood loss when compared with a superior approach [15]. However, the need for a 90 °C angle jeopardizes the subclavian artery, at a mean angle of 57.96°C about the mid-shaft. It would therefore be advisable to take an anterior-inferior approach when inserting the lag screw, to avoid the trajectory of the infraclavicular vessels. While the trajectory of the approach is highly dependent on the angle of the fracture line, a posteroinferior approach would pose the greatest risk to the subclavian vessels; avoiding an angle between 36°C and 105°C would eliminate this risk, suggesting an anteroinferior approach would be the prudent option. Due to the large standard deviation found in vascular angling, pre-operative imaging would be highly recommended to determine the direction of the vessels and inform the approach in anterior plating.

Additionally, the lag screw would need to be longer in length in comparison to screws in a neutral position, due to its slanted position within the clavicle, which may also allow over-estimations in screw length, again posing a risk to surrounding vasculature. In this instance, gender differences must be considered, as these vessels are in greater proximity to the mid-shaft within the female anatomy; when paired with a thinner clavicle as is seen in females, the risk of vascular tear increases if improperly long pins or plates are used during fixation. Therefore, conservative screw lengths, between 13.7mm and 22.6 mm according to our patient measurements, would be recommended particularly in the case of female patients.

Table 3. Actionable measurements based on this study (2 d.p.)

	Male	Female	Both
Minimum Screw Length (mm)	14.7	13.16	13.7
Maximum Screw Length (mm)	24.36	21.92	22.56
Lag Screw angles of risk (°)	35.88 – 103.24	36.06 – 105.58	35.69 - 104.62

The limitations in this study lie in the sample size and patient positioning. While we are confident in the diversity of our patient population, there is no certainty that type 2 errors did not interfere with our significant findings, which could be minimised by expanding the sample size. Additionally, distance measurements can be subjective; this was combatted by devising detailed boundaries, for example, this must be the minimum, straight-line distance between the clavicular cortex and tunica adventitia of the vessel to minimise the need for subjectivity. Measurements across all parameters were not retrievable for every patient, due to some CT angiograms only visualising half of the patient; however, the comparisons are still valid due to assumed equal variance. Similar studies have been able to describe the relationship between major neurovascular structures and the clavicle without pathology, radiologically or in cadaveric specimen; many of these, including this study, are performed while the cadaver or patient is in a supine position, which does not reflect operative position where the patient's torso would be elevated at around 30°-45° in a 'beach-chair' position [16, 17]. This may result in minor discrepancies in the distribution of vessels. Additionally, the scope of this study did not comprise assessing the impact of screw lengths with neurovascular injury, as the inclusion criteria only included scans that were undertaken for non-orthopaedic reasons; it would therefore be challenging to directly ascertain the interaction between gender and screw length risk, particularly in the case of female patients where clavicular measurements are likely to be narrower and more slender than their male counterparts.

CONCLUSION

The results of this study have shown a clear link between gender and clavicle length, thickness, and proximity to subclavian vessels. No significant differences were observed in the angulation of vessels between genders or right and left clavicles. Future research could be targeted at identifying whether the 'beach-chair' positioning causes significant distortions to measurements.

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