Clinical Article

A morphometric study of the clavicle

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Abstract

Recognition of unfavourable outcomes in displaced fractures of the clavicle in its middle third has stimulated global interest in the fixation of these fractures. The design of fixation devices is dependent on in-depth knowledge of the dimensions and morphology of the clavicle in order to optimise the configuration and fixation points of such a device.

In this study 100 dry clavicles were obtained from the Anatomy Department for assessment of the dimensions, angular deviations and gross morphology. The clavicle could be divided into distinct regions according to its muscle and ligament attachments and the cross-sectional morphology was typified for each region. The physical data presented can be utilised to inform fracture or osteotomy fixation-device design.

Introduction

Clavicle fractures are common and occur most frequently (80-85%) in the middle third. Although usually treated conservatively, there is increasing recognition of the morbidity associated with displaced fractures, and also of the increased rate of non-union of fractures in this zone. The improved benefits derived from fixation have resulted in renewed interest in fixation of clavicle fractures. While plating and nailing have been popularised, an external fixation device can also be effectively employed for the mid-third fractures as reported by Schuind,[1] Demiralp,[2] Tomic[3] and others. This renewed interest in fixation has stimulated closer scrutiny of the anatomy of the clavicle

The design of fixation devices depends to a large extent on the anatomical and physical characteristics of this bone. In order to get data on the normal variation of the dimensions of the clavicle to assist with design, a search of the literature was undertaken. Most studies reporting the physical characteristics and appearance of the clavicle are published in the forensic medicine literature in order to capture data to assist with gender identification and size (length) of the deceased individual.[4,5]

Few anthropometric studies address this bone from a biomechanical perspective. Ahmad *et al* examined the morphometric properties of the clavicle in 88 subjects in the UK, by using a 3D reconstruction of CT images[6] with particular reference to the diameter of the intramedullary canal, and Gumina *et al*, in a study of the prevalence of a coraco-clavicular joint, reported only on the length of 509 dry clavicles of Italian origin as measured on radiographs.[7] In a study of 100 pairs of clavicles by Huang *et al*, they record the medial and lateral angle and the clavicular bow angle with specific relevance to screw and plate fixation.[8] A study by Daruwalla *et al*[9] (UK) described a technique by which they examined 15 clavicles by 3D CT reconstruction. They concluded that the use of CT and 3D statistical shape analysis is advantageous because it rules out observer variability and uses 'live' clavicles, the dimensions of which have been shown to differ appreciably from dry bone.[10]

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To date, no published study on the morphology and dimensions has been adequate enough to permit the calculation of the forces that are transmitted through the clavicle during activity. To obtain the precise data that we required to investigate the range in size and morphological features of the human clavicle we undertook a survey of dry cadaver clavicles which had been sourced from the Anatomy Department.

Due to cost constraints we were not able to gain access to radiographic images for the morphological and dimensional assessment.

The purpose for undertaking this study was to obtain baseline data on length, cross-sectional morphology, medial and lateral angles and the clavicular bow in the transverse plane. Such information can be used for the theoretical calculation of the forces and stresses that are transmitted through the clavicle during low grade activity, such as elevating or abducting the arm, and to assist with the design of clavicle fracture fixation devices so that they are able to withstand the applied forces.

Materials and methods

One hundred clavicles collected between 1987 and 1994 were obtained from the Anatomy Department for analysis. Forty-five were left-sided and 55 right-sided. Age, race and gender differentiation were unknown.

Initial scrutiny revealed that the clavicle could be divided into five distinct zones as determined by the surface markings of its muscle and ligament attachments (as demonstrated in *Figure 1*) and the cross-sectional morphology. The reason for considering these landmarks was based on the theoretical assumption that fixation points on the clavicle for a fixation device would be best achieved in such a way that the muscles or ligaments would not be affected adversely by the fixation device.

Figure 1.
The superior (top) and inferior surfaces of the clavicle showing muscle and ligament attachments. SCM: sternocleidomastoid ligament; PM: pectoralis major muscle; D: deltoid; T: trapezius; SC: subclavius muscle; CL: conoid ligament; TL: trapezoid ligament

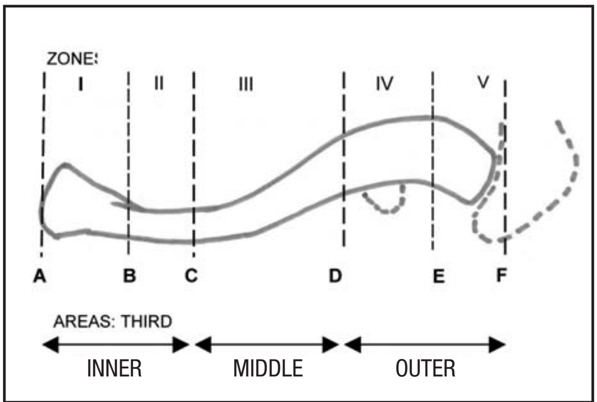

Figure 2.
This diagram indicates the upper surface of the left clavicle. Transition points (A to F) were determined mainly by muscle or ligament attachments. For example, A/B = distance to lateral aspect of sternoclavicular ligament and sternocleidomastoid muscle attachments; point D = medial extent of deltoid ligament insertion.
The zones (I to VI) are the areas between the points, and their cross-sectional profiles were determined at the midpoint of each zone.

The clavicle was divided at the following sites as shown in *Figure 2*:

- **Point A** and **F** represent the medial and lateral ends of the clavicle.
- **Point B** which represents the lateral most extent of the insertion of the sternocleidomastoid muscle superiorly, and sternoclavicular ligament inferiorly; A/B represents zone I and B/C represents zone II.
- **Point C** is the junction of the medial and middle thirds of the clavicle, so that A/C represents the medial third.
- **Point D** is the junction of the middle and lateral thirds of the clavicle so that C/D represents the middle third of the clavicle. Inferiorly subclavius attaches roughly between points C/D which represents zone III.
- **Point E** is the midpoint of the outer third where a significant change of cross-sectional profile occurs between zones IV and V.
- D/F represents the outer third of the clavicle; D/E represents zone IV, and E/F is zone V.

The following measurements were made:

1. **Dimensions**
   Using Vernier callipers, the overall length of the clavicle and length of each zone were measured. The cross-sectional dimensions at the designated sites were measured perpendicular to the bone in the midsection of each zone.

2. **Cross-sectional morphology**
   The cross-sectional morphology for each zone was assessed by visual inspection and was typified as recorded in *Figure 3*. These findings represent an 'impression' rather than an absolute or accurate rendition of the bone.
3. **Angles**
   The angle of deviation between the sternoclavicular end and the shaft (SC/S∞), and the angle between the acromio-clavicular end and the shaft (AC/S∞) were captured by digital photographs and measurement by protractor (*Figure 3*).
   The clavicular bow as measured in the transverse plane was measured directly from the clavicles with a protractor (*Figure 4*).

Figure 3.
The superior surface of the clavicle showing the medial sternoclavicular angle (left) and the lateral acromioclavicular angle (right)

Figure 4.
An AP view of the clavicle demonstrating the superior bow

Results

The results were recorded on a spreadsheet for ease of analysis. Minimum and maximum values for length and the cross-sectional dimensions are shown in *Table I*.

There were 44 left and 56 right clavicles. Age and gender were not known.

Length of clavicle

The mean length of the clavicles assessed was 150.1 mm with a range of 121.0–183.0 mm. The right was 151.6 mm (129 mm–174 mm) and the left side was 148.2 mm (121 mm–183 mm).

Length of each zone

The values for each 'third' of the clavicle was determined by simple mathematical division of the overall length into 3 and is recorded in *Table I*.

Morphology

Cross-sectional profile

The sternal portion of the clavicle varied from a circular to quadrangular or prismatic profile in cross-section. Zones I and II were found to have predominantly tubular, either faceted or ovoid. Only in two instances was the AP dimension appreciably less than the superior/inferior dimension. Zone III, the central third, tended to have a circular to ovoid profile becoming more flattened at its lateral extent. Zones IV and V, the acromial portion or outer third, became flattened with the narrower dimension being supero-inferior. *Figure 5* illustrates the different profiles encountered, and graphically orientates the dimensions superiorly and inferiorly. *Table II* illustrates the prevalence for each profile type in the five zones.

The measurements of the minimum and maximum cross-sectional dimensions of its narrowest and widest parts for each zone are recorded in *Table III*. The narrowest measurement was 6.8 mm and the widest 33 mm.

Clavicle angles

Medial and lateral axis deviations

The angle of deviation between the sternoclavicular end and the shaft (SC/S), and the angle between the outer acromial clavicular end and the shaft (AC/S) were measured and recorded in *Table IV*. The SC/S angle was 25.2º with an SD of 7.3º and the AC/S angle was 38.6º with an SD of 9.8º.

Clavicular bow

The clavicle was found to have an angulation directed superiorly in all but one case. The bow angle mean value was 13.5°, (0° to 29°) and a SD of 8.5°. A comparison with the measurements of Huang *et al* are shown in *Table V*.

Table I.
Measurements of 100 clavicles reflecting the minimum and maximum dimensions and the overall length average. The dimensions of the 'thirds' was calculated by simple division of each dimension into three equal parts (i.e. A/F divided by 3). Measurements are in mm.

Length	Min	Max	Average
Overall clavicle length	121.0	183.0	150.1
Dimensions of thirds	40.3	61.0	50.0

Profile 1
Mostly rectangular with facets in transverse and longitudinal planes

Profile 2
Oval with long axis in longitudinal plane

Profile 3
Mostly circular

Profile 4
Mostly triangular with flat surface superiorly and long axis in longitudinal plane

Profile 5
Mostly rectangular with facets in transverse and longitudinal planes

Profile 6
Oval with long axis in transverse plane

Profile 7
Mostly triangular with flat surface superiorly and short in longitudinal plane

Profile 8
Flattened with widest dimension in transverse plane

Figure 5.
Variations of cross-sectional profiles of 100 clavicles. The top of each profile represents the superior aspect and the bottom the inferior aspect of the clavicle.

Table II.
The occurrence of the cross-sectional profile types of the clavicle in the five zones as illustrated in *Figure 2.*

Profile type	Zone I	Zone II	Zone III	Zone IV	Zone V
1	42	13	3	0	0
2	14	20	4	1	0
3	25	7	6	0	0
4	17	50	19	0	0
5	0	1	47	3	2
6	1	7	18	3	20
7	1	2	3	91	10
8	0	0	0	2	68

Table III:
Measurements of 100 clavicles. The minimum and maximum cross-sectional dimension at the intervals illustrated in Figure 1 were recorded (measured values are in mm)

Cross-section dimensions		Min	Max	Average
Zone I:	Narrowest	7.9	20	14
	Widest	11	33	18
Zone II:	Narrowest	7	15	10
	Widest	10	26	13.6
Zone III:	Narrowest	6.8	14	10
	Widest	11	22	14
Zone IV:	Narrowest	8.2	17	11
	Widest	13	27.6	19.3
Zone V:	Narrowest	7.6	14	11
	Widest	15	31	23

Discussion

Clavicle fractures are common and occur most frequently (80-85%) in the middle third. Although usually treated conservatively, there is increasing recognition of the morbidity associated with displaced fractures.[11,12] The choice of the sites at which the clavicles were measured was determined by the desire to acquire information about those areas where a fixation device, particularly an external fixator could be applied with the least interference of the soft tissues attached to or around the clavicle. The surface markings caused by the attachments of muscles and ligaments were identified as the extent of such structures.

The overall length of the clavicle measured in this study (150.1 mm) by direct dry bone measurement differed from those published by Ahmad *et al* who recorded a mean length of 136.2 mm (range: 112.6–172.0 mm) in a radiographic study, and by Gumina *et al* who recorded a mean of 138 mm ± 12.3 (SD) and Galley *et al* 138.4 (113.8–167.6) in wet cadaver dissections. The results reported by Huang (145.0 mm) in a CT study (USA), that of Daruwalla *et al* (144.3 mm) in the 3D CT (UK) and that of Nalla *et al*[13] (143.3 mm) (RSA), also dry bone measurement, were all marginally less than the Cape Town study but reasons for our increased average length are not clear. While gender has been shown to play a role, gender identity of the specimens in our group was not known. This difference may reflect a true difference between different regions in the world, although discrepancies due to the differing methods of measurement cannot be excluded. In all reported series there is wide variation demonstrated in the dimensions, which reflects size variation in the general population.[5]

It can be seen that the traditional practice of dividing the clavicle into 'thirds' does not correspond completely with anatomical parameters. Although such a division is reasonable in a clinical setting for fracture configurations, a more rational approach when considering implant design is to take into account the soft tissue attachments to the clavicle.

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Table IV.
In this study the values for the medial (SC/C) angle and the lateral (AC/C) angle were assessed by measurement of a digital photograph taken perpendicular to the superior surface of the clavicle. The values obtained by Huang *et al* are shown for comparison.

	SC/C			AC/C		
	Min	Max	Average (SD)	Min	Max	Average (SD)
Walters *et al*	6°	43°	25.2° ± 7.3	14º	58°	38.6° ± 9.8
Huang *et al*			36.6° ± 7.4			51.8° ± 12.7

Table V.
The maximal bow angle was measured directly from the clavicle using a protractor. The values obtained by Huang *et al* is shown for comparison.

	Superior bow
	Average
Walters *et al*	13.5° ± 8.5°
Huang *et al*	12° ± 7.4°

The dimensions of each zone have not been previously recorded and this has been done so here. We believe the zone categorisation used here to be relevant in order to define the ideal area for the attachment and design of a fixation device. Knowledge of the appropriate area for fixation and the length of bone available for application of a fixation device are vital to optimal design of an external fixation device. In this study we found that the average length available for application of a device is 40 to 60 mm, but laterally this may be limited to 40 to 55 mm as defined by zones I and II and zones IV and V respectively.

The cross-sectional profile will also influence the ease or difficulty with which an external fixation device can be securely applied. From the cross-sectional profile it can be seen that zones I and II, the medial end, can be consolidated into one group with the profile being overwhelmingly tubular or somewhat quadrilaterally faceted, lending it to a variety of fixation options and inclinations. At the other end, the lateral end is flattened supero-inferiorly and fixation is more intuitively restricted to perpendicular to the superior/ inferior surfaces. In its mid portion the clavicle undergoes a transition from a faceted surface to a more rounded or ovoid profile which favours anterior and superior placement of a fixation device.

The angular change that occurs across the length of the clavicle in the transverse and coronal planes must be accommodated by the implant used for fracture fixation. For an exoskeletal device sufficient inherent adjustability is required to accommodate the curves and in addition it should have the versatility for application on the right and left sides, if the methods for bone attachment on the medial and lateral sides differ in accordance with the bone morphology.

Although not measured in this study it is of interest to note the cortical thickness variation. In a study by Ahmad *et al* they reported the central third of the clavicle to have the thickest cortex. In this study the mean cortical thickness (mean 3.37 mm) was greatest at a point 60% from the sternal end with the mean thinnest cortex (1.37 and 1.15 mm) found at the extreme sternal and acromial ends of the bone respectively. The reason for not conducting these measurements in our study was that the primary objective was to examine and record the external morphological characteristics, and furthermore the gender and age of the clavicles were not known: both of which influence cortical thickness.[6,9] Caution should be exercised when interpreting measurements from dry bones because change in dimensions may occur during preparation.[10]

The mean angle differences between the medial and lateral ends of the clavicle to the shaft were 25.2° and 35.8° for the medial and lateral angles respectively which differs somewhat from the findings of Huang. It is possible that the technique of measurement may have varied between the two studies because the precise reference points for these measurements are not mentioned in the Huang study. In the study by Huang there was no significant difference between the angles in males or females or between black or white subjects.

The morphometric values obtained from this study can assist in the mathematical calculation or finite element analysis of the stress and forces that are transmitted through the clavicle during various activities, such as lifting the arm, thereby assisting with device design and fixation method for each specific area of the clavicle.

A potential weakness of this study is the sample size of 100 clavicles only that may not represent the full spectrum of variations encountered in the clavicle. This applies in particular to the upper and lower ends of the spectrum.

Conclusion

The practical value of this study has been to provide physical data regarding the dimensions and morphology of the clavicle. There is wide variation in the dimensions and morphology of the clavicles assessed. It can be seen that attachment of a fixation device can be easily achieved to the medial end. The morphology of this region permits application in a variety of orientations and inclinations.

Laterally however the narrowness of the supero-inferior dimension restricts options for application of fixation devices.

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