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ORIGINAL ARTICLE

Anatomy of the clavicle and its medullary canal: a computed tomography study

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Abstract
Background With recent literature indicating certain clavicle shaft fracture types are best treated surgically, there is renewed interest in the anatomy of the clavicle. Intramedullary fixation of clavicle fractures requires an adequate medullary canal to accommodate the fixation device used. This computed tomography anatomical study of the clavicle and its medullary canal describes its general anatomy and determines the suitability of its medullary canal to intramedullary fixation.
Description of methods Four hundred and eighteen clavicles in 209 patients were examined using computed tomography imaging. The length and curvatures as well as the height and width of the clavicle and its canal at various predetermined points were measured. The start and end of the medullary canal from the sternal and acromial ends of the clavicle were determined. The data was grouped according to age, gender and lateralization.
Summary of results The average length of the clavicle was 151.15 mm with the average sternal and acromial curvature being 146° and 133°, respectively. The medullary canal starts on average 6.59 mm from the sternal end and ends 19.56 mm from the acromial end with the average height and width of the canal at the middle third being 5.61 and 6.63 mm, respectively.
Conclusion The medullary canal of the clavicle is large enough to accommodate commonly used intramedullary devices in the majority of cases. The medullary canal extends far enough medially and laterally for an intramedullary device to adequately bridge most middle third clavicle fractures. An alternative surgical option should be available in theatre when treating females as the medullary canal is too small to pass an intramedullary device past the fracture site on rare occasions.

Keywords Clavicle · Anatomy · Medullary · Canal · Computed tomography

Background

The anatomy of the clavicle has been widely studied using cadaver and bone bank specimens with anatomical variations between different age, gender and race groups found [1]. These anatomical variations can make the use of extramedullary fixation devices for the treatment of clavicle fractures challenging [2]. Various devices have been designed taking these variations into account, but no single plate and screw configuration has been able to address all variations. Intramedullary devices are less reliant on standard anatomy, but an adequate medullary canal is needed for the implant to be used.

The clavicle consists of cancellous bone, enveloped by cortical bone, which is much thicker in the middle 3/5 of the clavicle than in the lateral and medial fifths [3]. The configuration of the clavicle presents a double curvature—a convex anterior curve in the medial half and a concave anterior curve in the lateral half. It has an apex superior curvature located in the medial half of the clavicle [2]. The cross-sectional anatomy of the clavicle differs in shape

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along its length. Distally, the outer third is virtually flat, the medial third is prismatic and the middle third is circular in shape [1]. The clavicle has a distinct medullary canal that is variable in shape and size, but limited literature is available describing its anatomy [4].

This study determines the general anatomy of the clavicle and its medullary canal in living subjects using computed tomography imaging. The data was used to determine whether the anatomy of the clavicle and its medullary canal is amendable to intramedullary fixation in case of a shaft fracture.

Materials and methods

Patients who had computed tomography imaging of their upper trunk were identified using the PACS radiology system. The patients all had computed tomography studies done for unrelated reasons as part of their diagnostic workup and were randomly selected. Examination protocols reviewed included standard CT chest, CT angiogram of the neck, CT angiogram of the pulmonary arteries and standard CT of the neck. All examinations were performed on either a Siemens SOMATOM Sensation 40-slice, a Siemens SOMATOM Emotion 6-slice or a Toshiba Aquilion 4-slice CT scanner. Slice thickness according to clinical indication and scan protocol varied between 1.25 and 2.5 mm. A standard soft tissue kernel was used for image reconstruction. Raw scan data was transferred to a Philips PACS server. Data were then loaded into Philips Brilliance Workspace Portal v 2.6.0.18, a dedicated CT software package. Images were reviewed in a bone window (window width 2,000–2,500 and window level 450–800). Clavicles were reviewed in true axial, coronal and sagittal planes and measurements performed. In patients with marked clavicular angulation or curvature, in which true anatomical planes could not be obtained, curved reconstructions were used. All measurements were performed by a single final-year radiology resident. The shape of the clavicle was described by a radiology and an orthopaedic surgery resident, in agreement.

Inclusion criteria

1. Minimum of 15 years of age
2. Computed tomography imaging done that includes imaging of both clavicles.

Exclusion criteria

1. Congenital malformation of the clavicle.
2. Previous surgery to the clavicle.
3. Previous clavicle fracture.

The group was divided according to age, gender and lateralization.

The clavicle length was determined utilizing a 3-point measuring system on axial images to obtain the true length. It's sternal and acromial curvature was measured in the axial plane by determining the angle between lines drawn paralleling the proximal, middle and distal portions of the clavicle. The coronal curvature was obtained by measuring the angle between lines drawn paralleling the proximal and distal clavicle ends (Figs. 1, 2, 3, 4).

Three points were taken as reference points on each clavicle. This was done by dividing each clavicle in 3 equal parts. These thirds were each halved to determine three points that were used as reference points—the middle of the sternal third, the middle of the middle third and the middle of the acromial third. At each of these points, the height and width of the clavicle and its medullary canal were measured.

The difference in densities of the sponge bone and the medullary canal at the lateral and medial ends were utilized to measure the distance from the medial and lateral ends to the start of the medullary canal (Fig. 5).

The shape of the clavicle and its medullary canal was determined at the 3 reference points. Sagital images of the clavicle were reviewed at the midpoint of the proximal, middle and distal segments, respectively, in order to determine and describe the visualized shape of the clavicle as well as the medullary canal. The shape was described using a predetermined template as described by Walters et al. during an anatomical study of dry bone clavicles (Fig. 6).

Results

Two hundred and nine patients with 418 clavicles were included in the review of which 108 were female and 101 males. The patients had an even distribution of ages with a mean of 49 years (16–84).

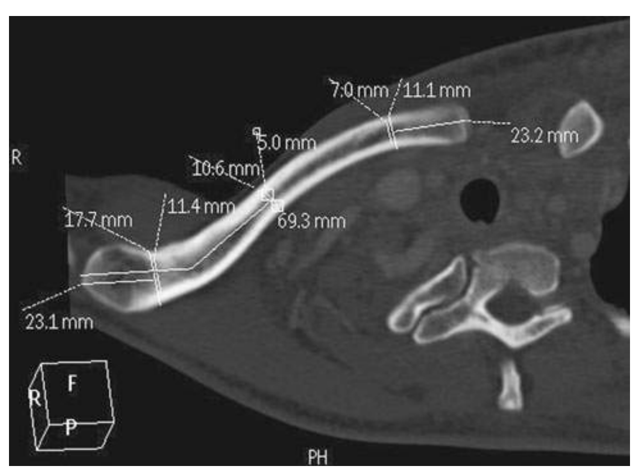

Fig. 1 Determining reference points

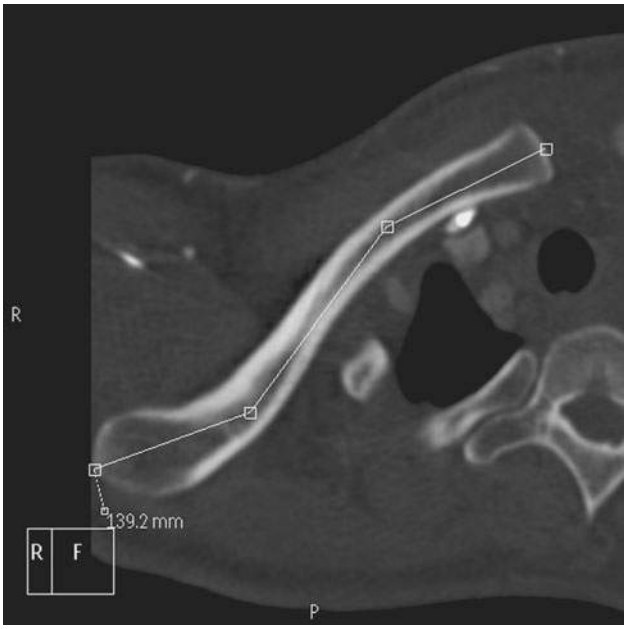

Fig. 2 Measuring the length of the clavicle

Fig. 3 Measuring the sternoclavicular and acromioclavicular angles

The average length of the clavicle was 151.15 mm (121.5–183.3). Male clavicles were 156.87 mm and female clavicles 145.79 mm in length on average. The average length difference between the left and right clavicles in men were 4.55 mm with the left clavicle being longer than the right in 66 of 101 (65 %) cases. In women, the difference between the left and right clavicles were 3.14 mm on average with the left clavicle being longer than the right in 72 of 108 (67 %) cases.

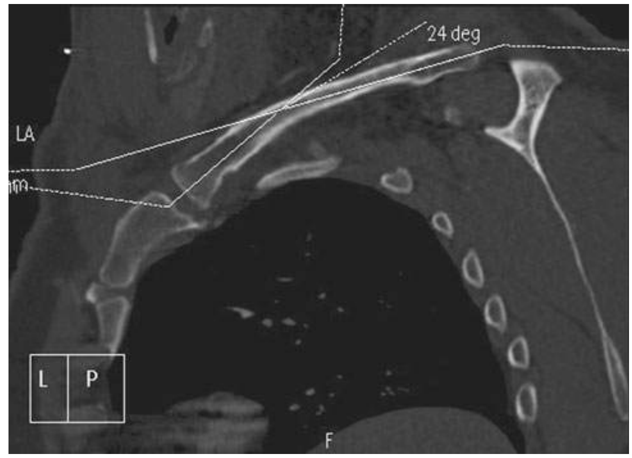

Fig. 4 Measuring the coronal curvature of clavicle

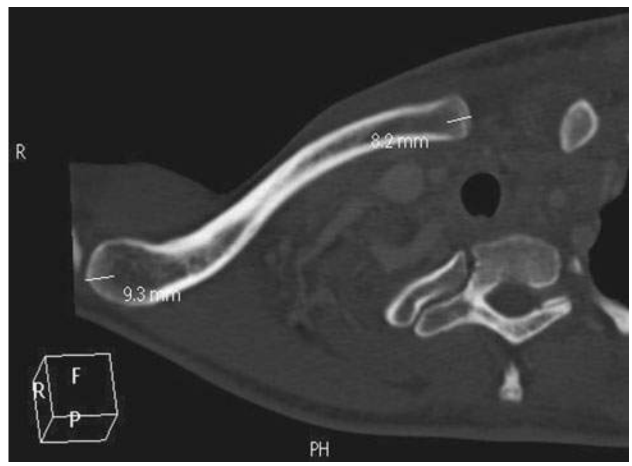

Fig. 5 Determining the start and finish of the medullary canal

	1. Mostly rectangular with facets in transverse and longitudinal planes
	2. Oval with long axis in longitudinal plane
	3. Mostly circular
	4. Mostly triangular with flat surface superiorly and long axis in longitudinal plane
	5. Mostly triangular with flat surface posteriorly and long axis in transverse plane
	6. Oval with long axis in transverse plane
	7. Mostly triangular with flat surface superiorly and short in longitudinal plane.
	8. Flattened with widest dimension in transverse plane

Fig. 6 Clavicle shape template

The medullary canal at the medial reference point had an average width and height of 9.14 and 9.34 mm, respectively. At the middle reference point, the dimensions were 6.63 by 5.61 mm. At the lateral reference point, the width of the canal was 11.93 mm and the height 5.91 mm. The dimensions in females were consistently smaller and the dimensions varied widely across the clavicles studied.

The start of the medullary canal at the medial end of the clavicle was on average 6.59 mm (2.8–30.3) from the sternal end. The medullary canal ends on average 19.56 mm (11.7–42) from the acromial end of the clavicle.

Three (1.4 %) male clavicle canals had a height or width smaller than 4.5 mm at the middle third reference point. The smallest measured 3.6 by 5 mm. Sixty six (31 %) female medullary canals had a width or height smaller than 4.5 mm. The average width of the medullary canal of these clavicles was 5.2 mm and the average height 4.05 mm. These females had an average age of 45.5 years with 59 % being the left clavicle. The clavicles had an average length of 145.9 mm. In only 12 (5 %) clavicles, the height and width of the canal measured less than 4.5 mm.

The average sternal curvature of the clavicle was 146° (126–164) with the average acromial curvature 133° (95–164).

The patients reviewed showed a wide variation in coronal curvatures. It varied from apex superior, apex inferior and even s-shaped curves. Ten clavicles had apex inferior curvatures ranging from 3° to 17°. Twenty four clavicles displayed s-shaped curves with the medial end of the clavicle having an apex superior curve and the lateral end having an apex inferior curve. The remaining 384 clavicles had an apex superior curve ranging from 2° to 35°. The average apex superior curvature was 17° (Fig. 7; Tables 1, 2).

The medial third of the clavicle had a rectangular shape in 103 (25 %) cases, an oval shape in 128 (31 %) cases, 116 (28 %) clavicles were circular and 60 (14 %) had a triangular shape. The middle third of the clavicle had a circular shape in 346 (83 %) of cases and an oval shape in 45 (11 %) of cases. The lateral third was oval in 126 (30 %), flat in 121 cases (29 %), triangular in 89 (21 %) and rectangular in 63 (15 %).

The shape of the medullary canal only very rarely (1 %) differed from the shape of the clavicle at the corresponding reference point.

Fig. 7 S-shaped in coronal plane clavicle

Table 1 Males

Variable	Valid *N*	Mean	Minimum	Maximum	SD
Age	202	49.31	16.00	84.00	16.63
Length	202	156.87	121.50	183.30	9.75
SC-curve	202	146.34	126.00	164.00	7.12
AC-curve	202	134.03	95.00	164.00	12.38
Clavicle width: medial	202	14.55	9.40	23.00	2.25
Clavicle width: middle	202	12.71	9.00	25.50	1.71
Clavicle width: lateral	202	18.26	10.80	26.80	3.04
Clavicle height: medial	202	14.55	9.40	21.80	2.77
Clavicle height: middle	202	10.97	8.00	14.70	1.25
Clavicle height: lateral	202	10.56	6.30	18.60	1.96
Canal start: medial	202	6.77	2.90	30.30	3.48
Canal start: lateral	202	20.67	13.80	42.00	3.97
Canal width: medial	202	10.24	5.90	18.60	2.15
Canal width: middle	202	7.34	4.10	12.00	1.43
Canal width: lateral	202	13.47	5.70	23.50	3.14
Canal height: medial	202	9.82	4.60	17.70	2.62
Canal height: middle	202	6.26	3.60	9.50	1.08
Canal height: lateral	202	6.23	2.70	12.10	1.76

Discussion

This series accurately describes the anatomy of the clavicle and in particular its medullary canal. Wide variations in dimensions across different age and gender groups were found. This is in keeping with previous studies done [1, 3, 5, 6]. Computed tomography imaging has been shown to be

Table 2 Females

Gender = Female					
Descriptive statistics (spreadsheet in analysis—26Oct2012.stw)					
Variable	Valid *N*	Mean	Minimum	Maximum	SD
Age	216	48.39	17.00	82.00	16.70
Length	216	145.79	126.90	168.70	7.95
SC-curve	216	146.56	128.00	164.00	6.79
AC-curve	216	132.96	98.00	160.00	11.69
Clavicle width: medial	216	12.27	7.60	18.40	1.85
Clavicle width: middle	216	11.08	8.80	14.50	1.14
Clavicle width: lateral	216	15.14	8.20	21.70	2.53
Clavicle height: medial	216	13.57	9.30	22.30	2.25
Clavicle height: middle	216	9.36	7.10	13.10	1.06
Clavicle height: lateral	216	9.74	4.60	16.20	1.65
Canal start: medial	216	6.42	2.80	24.10	2.85
Canal start: lateral	216	18.53	11.70	30.00	2.84
Canal width: medial	216	8.12	4.20	12.40	1.67
Canal width: middle	216	5.97	2.90	10.90	1.30
Canal width: lateral	216	10.49	5.10	16.80	2.58
Canal height: medial	216	8.88	4.90	15.80	2.04
Canal height: middle	216	5.00	3.00	8.60	0.97
Canal height: lateral	216	5.62	2.90	11.80	1.48

an accurate method of describing the anatomy of the clavicle [5, 7, 8]. The dimensions of the clavicle and its canal were determined in living subjects avoiding possible post-mortem changes in the dimensions secondary to the preservation process [9].

As in previous series, a marked difference between the dimensions of male and female clavicles was found [5, 7]. The female clavicle is generally shorter and its cross-sectional dimensions smaller than the clavicles of males. The difference in length between the left and right clavicles in the same individual is significant and difficult to explain. It might be explained by hand dominance and different workloads of the respective upper limbs during growth. Whether a longer clavicle holds mechanical advantage is unknown. The curvatures of the clavicle in the coronal and axial plane differ only marginally between gender groups and between left and right. This differs from previous groups studied where more significant differences were found [1, 5, 7]. However, a wide spectrum of curvatures was found similar to previous findings reported on [4, 6].

Intramedullary fixation of midshaft clavicle fractures is an effective mode of treatment [10–13]. However, the size of the canal can be a prohibiting factor to the use of intramedullary devices. If the canal is too small to allow reamers or nails to be inserted, the fixation of the fracture by means of an intramedullary device is impossible. Another prohibiting factor is absence of an adequate medullary canal at the far medial and lateral sides of the clavicle. This causes problems passing the intramedullary device far enough past the fracture site to give adequate fracture stability [10]. Various intramedullary devices are available with different sizes and fixation methods. These include the Hagie pin (Du Puy), 4 mm in diameter, the Rockwood nail (Du Puy), sizes 2.5–4.5 mm, the Acumed clavicle pin, sizes 3 and 3.8 mm, the Sonoma CrX system (4 mm) and flexible titanium nails (Synthes), 2–4 mm. Logic dictates that the medullary canal should at least be of similar size or larger to allow the device to be passed into the canal.

This study shows that the clavicle's anatomy is suitable for intramedullary fixation. The canal is large enough to accommodate above-mentioned intramedullary devices in the majority of cases. The canal extends far enough medial and lateral to allow middle third clavicle fractures to be bridged adequately by an intramedullary device. The medullary canal at the middle third of the clavicle is relatively small in approximately a third of women. Only very rarely is the canal smaller than 4.5 mm in both the coronal and axial planes. Passing an intramedullary device into these medullary canals will prove difficult or even impossible. It is advisable to have a second surgical option available in theatre when treating females by intramedullary means. If the canal is too small to insert the intramedullary device into the canal, the surgeon can revert to plating the clavicle with an anatomically contoured locked plate.

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Conflict of interest Authors declare that they have no conflict of interest.

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