

## CLAVICULAR FUNCTION\*

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This is a survey of the functional variation of the clavicle, in particular with regard to its adaptability, the bone being an essential link in the shoulder girdle. The presence of a clavicle, and its shape, size and position are discussed from the point of view of stability and mobility, and the rôle of the bone regarding circulation, pulmonary ventilation and muscular tension is pointed out. It is stated that the clavicle contributes significantly to the stability of the shoulder girdle, and that in man the presence of this bone represents an increase in the degree of freedom of the upper extremity mobility pattern, dependent on the transversal shape of the thoracic diameter. The precondition for the clavicle to function appropriately is that its curvature fits in with the ligamentous pull.

*Key words:* axes; clavicle; function; mobility; stability

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The human clavicle is the only bone of the shoulder girdle forming a synovial joint with the trunk. The bone is connected strongly to a number of muscles, and accordingly to fascies. Through the fascies of the neck and the pectoral region the clavicle is functionally joined with the internal and external jugular veins as well as with the subclavian vein. By intermittent contraction of the muscles related to the fascies, and by movement of the clavicle, the structures mentioned work jointly as a circulation and ventilation pump for the arm, head and neck.

The word "clavicula" is a diminutive of "clavis", key, but its meaning may equally well be door handle. Medially the clavicle has a ventrally-directed convexity, laterally a dorsally-directed one. The latter shows the greatest curvature and is located in the lateral third of the bone (Figure 1).

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In man the clavicle is one of the bones showing the highest variability in shape (Grant 1971). Its curvatures and thickness to a high degree vary according to the attachments of muscles and ligaments. Muscular individuals are found to exhibit thick and curved clavicles, and males have thicker and more curved clavicles than females (Cunningham 1931, Martin & Saller 1959). In accordance with the usually greater force and higher activity of the right-side extremity in right-handed people, the right-side clavicle is as a rule thicker and more curved than the left-side one (Martin & Saller 1959, Grant 1971).

### *Stabilization of the shoulder*

The medial two-thirds of the clavicle are approximately circular or triangular in cross section, a shape consistent with axial pressure or pull. Its lateral third, corresponding to the acromion, has a relatively flat superior and inferior surface, a shape compatible with pull from muscles and ligaments.

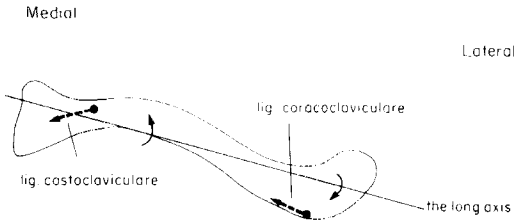


Figure 1. The right-side human clavicle in cranio-caudal view. The estimated long axis of the bone, as well as two of its most important ligaments, are drawn according to observations from dissected specimens. The clavicular attachments of the ligaments are indicated by circular areas, their directions by thick, stippled arrows, expressing their location caudal to the bone. Regarding the long axis of the clavicle, the costoclavicular ligament has a ventrally directed moment, the coracoclavicular ligament a dorsally directed moment.

The clavicle is connected to several ligaments, most of which are essential for the stability of the shoulder girdle. In this presentation only the costoclavicular and coracoclavicular ligaments are dealt with (Figure 1). Because of their clavicular attachments (near to the ventral and dorsal convexity, respectively) and because of their orientation, the moments of the forces represented by the two ligaments are oppositely directed as regards the estimated long axis of the clavicle (Figure 1). In this way equilibrium may be maintained in the plane perpendicular to the axis; i.e. in an approximately sagittal plane. Because of their course and attachments the ligaments increase stability in other planes as well.

The clavicle slopes mediocaudally (Figure 2). Thus, the mass of the arm is transmitted to the clavicle (to a high degree through the coracoclavicular ligament), and through the clavicle to the sternoclavicular joint and to the sternum. The resultant vector  $W$  (Figure 2) is resolved into one component in the direction of the long axis of the clavicle ( $N$ ), giving normal stress on the sternal two-thirds of the bone, and into a second component ( $T$ ), perpendicular to the first one, tending to move the clavicle laterally and

caudally. As is shown in Figure 2, the axially running vector  $N$  increases when the acromial part of the clavicle is elevated. This gives an increased normal stress in the sternal two-thirds of the bone and increased stability of the sternoclavicular joint, owing to the shape and orientation of the clavicular joint surface of the sternum. In this way stability increases as the mass of the arms increases.

This theory is in harmony with the results of electromyographic examination. Thus, Bearn (1961) did not notice electrical activity in the upper part of the trapezius muscle during static loading. The clavicle is predominantly stabilized by passive structures. The unit formed by the sternum and the two attached clavicles has been compared to a yoke; accordingly, the latin word "jugulum". With reference to what is stated above only the sternal two-thirds of the clavicle is

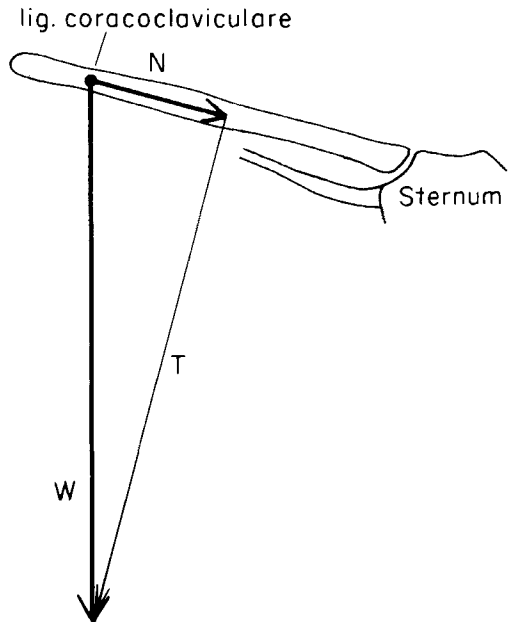


Figure 2. A model showing some stabilizing elements of the clavicle. Parts of the right shoulder girdle in ventrodorsal view. The point of action of the vector  $W$  (the mass of the arm) is the clavicular attachment of the coracoclavicular ligament. For further explanation see the text.

included in the ventral yoke. As the clavicle is cranio-laterally as well as cranio-dorsally directed, the sternal part of the bone is able to lift the acromial part, as well as the acromion and the shoulder joint, up from the thorax, and keep these structures in a lateral position. Accordingly the clavicle acts as a prop. This is illustrated by the tendency for an adducted and inwardly rotated position of the shoulder girdle in the rare congenital anomaly cleido-cranial dysostosis, where among other bones, the clavicles are missing, totally or partly. However, according to Inman & Saunders (1946), partial or complete resection of the clavicle in adults results in only slight deformation of the shoulder region and negligible dysfunction.

According to the authors referred to above, instability and a feeling of weakness during heavy work, especially when pushing above head level, are the only difficulties of importance noted after excision of the clavicle in adults. This is compatible with the notion that the act of carrying, when pushing in a cranial direction, causes pressure in the direction of the long axis of the clavicle. On the other hand, the clavicle will be exposed to pull in its longitudinal direction in hanging, when the arms are above the head, as they are in hanging on a bar or on a rope, as well as when supporting oneself on the arms on a table or on crutches.

In accordance with function some mammals exhibit a clavicle in regression. In the carnivores the bone is reduced, in the ungulates it has vanished (Boas & Thomson 1961). The transmitting of weight from the upper extremity to the trunk, through the coracoclavicular ligament and the sternal part of the clavicle, is a superfluous mechanism in these animals. Because they are quadruped and because of the relatively large antero-posterior diameter of their thorax, the scapula of these animals is almost vertically oriented. In this way the reaction force from the ground meets the glenoid cavity directly, the direction of the reaction force hitting the surface of the cavity almost perpendicularly. The mass of the body is supported on the scapula.

This bone in turn is suspended in the serratus anterior muscle (Grant 1971). This suspensory mechanism, together with the reduction of the clavicle, imply a resilient connection between the forelimb and trunk, and it is in harmony with the lithe and graceful movements of the carnivores and the ability of the ungulates to leap and gallop.

#### *Functional asymmetries*

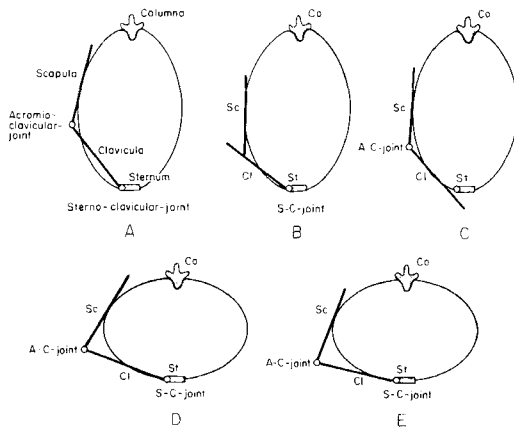
Adequate stimuli for growth in length are intermittent pressure and pull (Pauwels 1957, LeGros Clark 1965). In man the clavicle is the bone first starting to ossify (according to Cunningham (1931) in the fifth foetal week). Considering also that its sternal epiphysis is the last of the epiphyses of the long bones to fuse (according to McKern & Stewart (1957) in the third decade), it seems obvious that functional asymmetries have a long period of time to leave their marks on the bone. The left shoulder girdle to a great extent is used to support body weight. In conformity with the fact that the clavicle is subjected to normal stress in its longitudinal direction in movements and positions where body weight is supported by means of the arms, it is reasonable to find that the left clavicle is often longer than the right one (Martin & Saller 1959, Grant 1971).

#### *Mobility of the shoulder considering the clavicle as a link in the girdle*

Excision of the clavicle is accompanied by increased mobility of the shoulder girdle, especially in the sagittal plane. This characteristic is also a typical clinical sign in cleido-cranial dysostosis. Moreover, experiments with rats (Jenkins 1974) have shown that the shoulder loses its circular path of movement when the clavicle is extirpated. This indicates that the presence of the clavicle allows the upper extremity more degrees of freedom (Hjortsjö 1967). However, one has to consider that since the scapula is gliding on the thorax, the path of movement of the shoulder girdle as well as

that of the arm itself depend upon the thoracic shape (Figure 3). In Figure 3 A, B and C the sagittal diameter of the thorax exceeds the transversal one, and the scapula and the clavicle show about the same medio-lateral length. If the motion of the scapula were equivalent to the shape of the thorax when rotating about craniocaudally directed axes, it might be presumed that one of the joints of the shoulder girdle would be luxated. This is indicated in Figure 3B and C by ventral rotation of the shoulder girdle. In conformity with this, short clavicles are found along with a relatively large sagittal thoracic diameter and a large scapular glenovertebral diameter relative to the scapular craniocaudal diameter (Oxnard 1973). This combination implies a range of motion concentrated to the sagittal plane, exemplified by the ungulates and the carnivores.

On the other hand, long clavicles are found together with a short glenovertebral and a long craniocaudal scapular diameter, and in



*Figure 3. Schematic drawings showing transversal sections of the thorax, the right-side scapula, clavicle and sternum, as well as the joints between them. In A, B, and C the shape of the thorax corresponds to that of most quadruped mammals, whereas the relationship between the mediolateral lengths of the scapula and the clavicle correspond to that of man. D and E are representative of man.*

addition with a relatively large transversal thoracic diameter, implying differentiated movements within a three-dimensional environment. This configuration is typical in arboreal animals (Oxnard 1973). The schematic drawings D and E in Figure 3 are representative of these animals, as well as of man. The clavicle may act as one of the legs in a pair of compasses, its centre being situated close to the sternoclavicular joint. Accordingly, the range of movement of the upper extremity is approximately circular.

It should be noticed that in the new-born the sagittal diameter of the thorax is relatively large, resulting in a more ventrally directed glenoid cavity compared to that in the adult. This also implies that functionally it is more appropriate to crawl before walking.

The clavicle is easily palpated in its whole length, as are its adjacent joints. In spite of this, its kinematics has not been studied as well as that of the scapula. This is connected with the fact that the movements of the latter are more conspicuous, this bone being positioned peripheral to the clavicle. Accordingly, in clinical terms, movements of the shoulder girdle are usually registered as movements of the scapula. This is a simplification, however, indicating an omission of the adaptability of the clavicle. The clavicle, by means of its neighbouring joints and the fascies, constitutes part of a plastic arc (shoulder girdle), mediating the adaptation between the trunk, the neck and the upper extremity. The shoulder girdle of man, with its relatively long clavicles and the synovial joints at both ends of this bone, exemplifies an appropriate compromise between the claims laid upon the skeleto-muscular system concerning stability and mobility.

#### *Rotational axes of the shoulder girdle with a view to the main axes of the body*

Both joint surfaces of the clavicle are relatively plane. Because of the discs and the loose capsules, however, the sternoclavicular joint as well as the acromioclavicular joint,

from a mechanical point of view, are of the spheroidal type; both of them possess three degrees of freedom, i.e., ability of rotation about three axes, perpendicular to each other (Hjortsjö 1967).

Concerning the sternoclavicular joint, it is stated that the point of intersection of the three rotational axes is positioned close to the clavicular attachment of the costoclavicular ligament (Abbott & Lucas 1954, Andreassen 1960, Hjortsjö 1967).

In the transversal plane, however, the sternal joint surface exhibits a convexity directed laterally. According to this the craniocaudal axis of the sternoclavicular joint is situated in the sternum (Kapandji 1970). This means that in protrusion and retraction of the shoulder girdle the sternal and acromial part of the clavicle move in the same direction. True enough, in maximum retraction its sternal end protrudes ventrolaterally. This may be associated with a separation between the surfaces of the sternoclavicular joint, a movement which is not perpendicular to the joint surfaces. Possibly there is a craniocaudally directed rotational axis situated in the dorsal aspect of the joint space. Accordingly, retraction of the shoulder girdle is an example of the way in which axes of rotation shift during movements, impeding kinematical analyses generally.

The anteroposteriorly directed axis of rotation of the sternoclavicular joint obviously is situated on the clavicular side of the joint. Possibly there may even be two axes (Figure 4). Because the clavicle rotates simultaneously about these two axes, and because of the presence of the disc, the sternoclavicular joint functionally corresponds to the accentuated grinding joint principle (Hjortsjö et al. 1977). There is one sliding movement between the sternum and the disc (rotation about axis  $C_y$ ), and one sliding movement between the disc and the clavicle (rotation about axis  $C_x$ ); i.e., the joint may also be classified as a double *sliding* joint. Comparable kinematical problems are met with in the temporomandibular joint (Hjortsjö 1953).

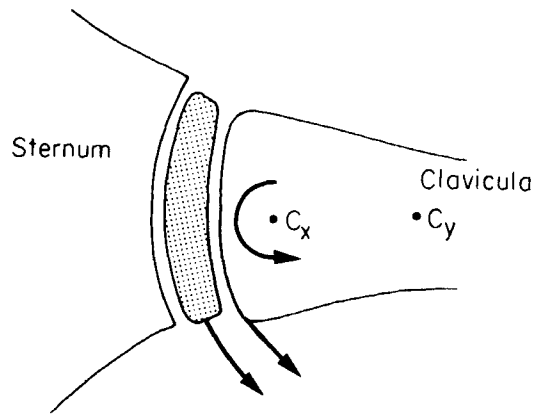
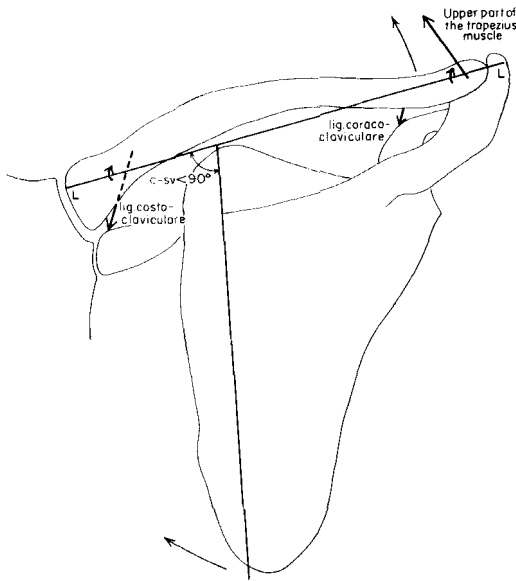


Figure 4. Schematic representation of possible rotation of the clavicle about anteroposteriorly directed axes related to the sternoclavicular joint. Frontal view.  $C_x$  is the centre of the medially directed convexity formed by the sternal joint surface of the clavicle and the disc.  $C_y$  is the centre of the laterally directed concavity formed by the clavicular joint surface of the sternum.

In order to simplify the description of the movements of the shoulder girdle, and to get a more unambiguous reference system, one often regards the axes of rotation of the shoulder girdle as if they were parallel with the three main axes of the body. One exception, however, is the mediolaterally directed axis. This rotational axis, which is equivalent to the long axis of the clavicle (Figures 1 and 5) is common to the two joints of the shoulder girdle. The long axis of the clavicle is shown to form an acute and dorsolaterally directed angle with the transversal plane (Figures 3 and 2). Accordingly, the long axis of the clavicle intersects with the other two main planes as well. Thus, concerning the sternoclavicular joint, the anteroposteriorly directed rotational axis is not parallel with the sagittal axis, the craniocaudally directed rotational axis is not parallel with the frontal (vertical) axis, and, as stated above, the mediolateral axis of the shoulder girdle (the long axis of the clavicle) is not parallel with the transversal axis.

Consequently, the effect on the shoulder girdle of rotational movements about axes



*Figure 5. Simplified representation of rotation about the estimated long axis of the clavicle (L-L) in separate elevation of the right shoulder girdle. Dorsoventral view; the ribs are eliminated. Anteroposteriorly directed axes of rotation are not drawn. The small curved arrows indicate the direction of the rotational moment about the long axis of the clavicle. The two other curved arrows represent the direction of rotation of the two bony components of the shoulder girdle. The C-SV-angle is the frontally projected and medially directed angle between the long axis of the clavicle and the vertebral border of the scapula.*

parallel with the main axes of the body, and of rotation about axes corresponding to the shape of the thorax and the orientation of the bones, will differ.

*Rotation of the clavicle about its long axis in elevation of the shoulder girdle and the arm*

Due to the interposition of the clavicle between the scapula and the sternum, as well as to the connection between the shoulder girdle and the thorax, all movements of the shoulder girdle bring about rotation of the clavicle occurring about more than one of the three axes in the sternoclavicular and the acromioclavicular joints. In the following,

the rotation about the long axis of the clavicle will be dealt with.

In separate elevation of the shoulder girdle (Figure 5) the clavicle and the scapula rotate in opposite directions about anteroposteriorly directed axes in the sternoclavicular and the acromioclavicular joints, respectively. Thus the C-SV-angle, which was introduced by Hjortsjö (1967) decreases. The angle is about 90 degrees in the starting position. A decreased C-SV-angle is supposed to give a relaxation of the coracoclavicular ligament (Bragstad 1974). However, the costoclavicular ligament is stretched during elevation of the shoulder girdle, and in this way the clavicle acquires a ventrally directed rotational moment about its long axis (Figure 5). In addition, because of its direction and insertion on the dorsal convexity of the clavicle the upper part of the trapezius muscle gives the bone a ventrally directed rotational moment (Figure 5). Thus, in separate elevation of the shoulder girdle forces which effect ventrally directed rotational moments to the clavicle dominate. The movement illustrates a ligamento-muscular synergism (Bragstad 1974).

In elevation of the arm, however, the scapula and the clavicle rotate in the same direction about anteroposteriorly directed axes in the two joints of the clavicle. When the inferior angle of the scapula is abducted the C-SV-angle will increase, and the coracoclavicular ligament is stretched. Thus the clavicle obtains a dorsally directed rotational moment, i.e., the opposite of what is shown in Figure 5. When the clavicle rotates dorsally about its longitudinal axis, its acromial joint surface will be more cranially oriented. In this way additional abduction of the inferior angle of the scapula is allowed, resulting in a more cranial orientation of the glenoid cavity, corresponding to the elevation of the arm. The abduction of the inferior angle, taking place about an approximately sagittally directed axis in the acromioclavicular joint, is the result of activity of the trapezius muscle and parts of the serratus anterior muscle.

Dorsally directed rotation of the clavicle

may as well be caused by pull of other muscles attaching to the clavicle. Because of its attachment on the ventral convexity of the bone, the clavicular portion of the pectoralis major muscle rotates the clavicle dorsally when the arm is elevated ventrally above the horizontal plane.

According to DePalma (1957) there is an association between the frequency of degenerative changes in the acromioclavicular joint and the shape of the clavicle. DePalma found that the majority of acromioclavicular joints causing pain and showing degenerative changes exhibited clavicles with relatively little pronounced acromial curvatures. This is interesting, considering the dorsally directed rotational movement of the clavicle when the coracoclavicular ligament is stretched. When the acromial curvature is less conspicuous, the clavicle will have to rotate more and earlier during elevation of the arm, giving increased shearing forces at the acromioclavicular joint.

The findings and theory are in accordance with the conclusions of Inman & Saunders (1946) and Abbott & Lucas (1954). These authors claim that when a clavicular fracture cannot be reduced so that the shape of the bone fits in with the ligamentous pull, it is more to the patient's advantage to extirpate the clavicle. This refers to the acromial as well as the sternal curvature (Inman & Saunders 1946).

#### *The clavicle relative to circulation, ventilation and muscular tone*

Making up the roof in the costoclavicular space the clavicle shelters the great nerves and vessels. On the other hand, caudal and dorsal movements of the lateral end of the bone decrease the space, and in this way the clavicle may cause neurological and circular deficiencies, as in the claviculocostal syndrome.

Elevation of the lateral part of the clavicle results in increased pull on the costoclavicular ligament and the subclavius muscle, especially if the clavicle rotates dorsally, as

it does when the arm is elevated. Due to the articular, ligamentous and muscular connections between the clavicle and the first rib and due to the synchondrosis between the latter and the sternum, elevation of the shoulder girdle, and especially of the arm brings about a cranial motion of the thorax, corresponding to a high costal inspiration. Accordingly, elevation of the shoulder girdle is synergetic to inspiration. This is made use of in indirect breathing exercises and in artificial ventilation.

If the shoulders are habitually elevated, however, the thorax will be fixed in inspiration, causing unsatisfactory utilization of real respiratory capacity, deterioration of circulation and increased muscular tone generally, and it often produces weariness and pain in the arm, neck, throat and head.

Summing up, it should be stated that the clavicle is essential for stability and movements, for circulation, ventilation and tension, and even for the muscles of expression of the throat, shoulder and thorax. In itself the clavicle also contributes greatly to the aesthetic impression of this area.

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