**DOI: https://doi.org/10.24297/ijct.v26i.9857**

# A comprehensive, integrated study of the clavicle: Its topographical anatomy, biomechanical architecture and function; pathological anatomy of mid-shaft fractures and the decision-making process for a surgical approach when planning an intramedullary implant: Parts 1-9

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**Abstract:**

The modernization of the clavicle is a continuous evolutionary process. It has been redesigned many times to its current form and function as the key link in the forelimb anatomy and director of the scapula to position the glenoid fossa under the head of the humerus. The clavicle bone is a forerunner to the development of the skeleton from its embryonic days, and it reaches maturity last of all for a special reason. Its intricate biomechanical architecture has evolved in tandem with the emergence of the erect human posture and bipedalism, and the postcranial elongation of the neck to facilitate a forward-facing horizontal gaze, necessitating a significant reorientation of the pectoral girdle musculature.

Modern lifestyles, both at work and during leisure, have led to trauma with varied disruptions in the continuity of the clavicle, resulting in simple and severely comminuted fractures across all age groups, with a bimodal distribution. In very young individuals, with greater potential for linear growth and limited remodelling, conservative treatment is acceptable. However, beyond mid-adolescence, the growth potential and remodelling are minimal. Therefore, to prevent malunion and dysfunction, the clavicle's anatomy and biomechanical architecture must be fully restored to re-establish the patient-specific kinematics, as it plays a crucial role in the normal functioning of the pectoral girdle and the humerus.

This comprehensive nine-part study includes the topographic anatomy of the clavicle, an explanation of its unique biomechanical architecture, and the pathological anatomy of mid-diaphyseal fractures, malunion, and its complications. When and why choose the antegrade or retrograde approach for the insertion of an intramedullary implant? Finally, the newly conceived three intramedullary implant designs for the reduction and biological fixation of the mid-diaphyseal fractures of the clavicle are presented. The study is illustrated with several cadaveric dissections performed by the author, anatomy artwork, and sketches created in PowerPoint.

**Key words:** Clavicle anatomy, Clavicle fracture and malunion, Clavicle morphometry, Biomechanics, Clavicle torsion and version, Hyperbolic paraboloid architecture, Scapular dyskinesis, Intramedullary clavicle implant, Phylogeny and Ontogeny.

**Part 1 Embryology and the Topographical Anatomy of the Nerves, Vessels and Muscles Part**

**2 Functional Anatomy of the Clavicle and Scapula**

**DOI: https://doi.org/10.24297/ijct.v26i.9858**

**Part 3 Articular Anatomy of the Pectoral girdle**

**DOI: https://doi.org/10.24297/ijct.v26i.9859**

**Part 4 The Pathological Anatomy of Mid-diaphyseal Fractures, Controversy and new Paradigms in Radiography**

**DOI: https://doi.org/10.24297/ijct.v26i.9860**

**Part 5 Frustum, a Geometrical Deformity of a Malunited Clavicle Fracture**

**DOI: https://doi.org/10.24297/ijct.v26i.9861**

**Part 6 Scapular Dyskinesis and Acromiohumeral Impingement resulting from Frustum formation**

**DOI: https://doi.org/10.24297/ijct.v26i.9862**

**Part 7 Biomechanical architecture and the Cranking system of the Clavicle**

**DOI: https://doi.org/10.24297/ijct.v26i.9863**

**Part 8 Ideal Approaches for the Insertion of an Intramedullary Implant for Fixation of Diaphyseal Fractures**

**DOI: https://doi.org/10.24297/ijct.v26i.9864**

**Part 9. Newly conceived Intramedullary Implant Designs for the Fixation of Diaphyseal Clavicle Fracture**

**DOI: https://doi.org/10.24297/ijct.v26i.9865**

# A comprehensive, integrated study of the clavicle: Its topographical anatomy, biomechanical architecture and function; pathological anatomy of mid-shaft fractures and the decision-making process for a surgical approach when planning an intramedullary implant: Parts 1-9

## Part 1 Embryology and the Topographical Anatomy of the Nerves, Vessels, and Muscles

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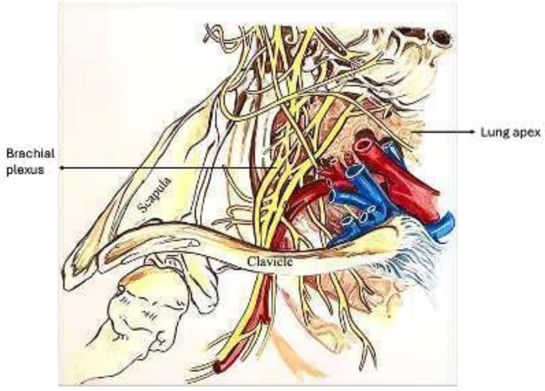
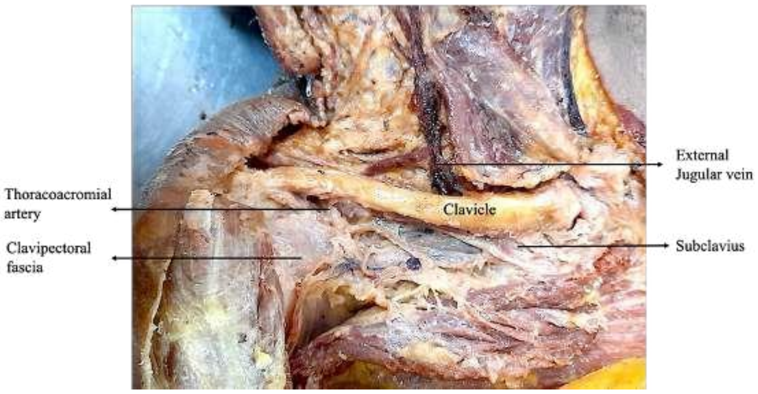
**Highlights:** The post-cranial descent of the pectoral girdle for brachiation and projectile delivery in primates, and the relief of the shoulder joint from weight-bearing in humans, were accompanied by the redesign of the clavicle, which intercalates between the axial and the appendicular skeletons, thereby transforming regional anatomy. Clinically, the glenohumeral articulation serves as a surrogate of the clavicle's kinematics. Between 18 and 30 weeks' gestation, the aborted male and female foetuses do not show right and left-sided directional asymmetry of the clavicle. The clavicle may continue to grow until age of 31, at which point it reaches maturity.

The cutaneous branches of the Supraclavicular nerve are predominantly distributed across the central three-fifths region of the clavicle. The Anterior scalene is key to the neurovascular structures above the clavicle and the Subclavius below it. The large muscles Pectoralis major, Sternocleidomastoid, Deltoid and Trapezius, which act on the clavicle, scapula, and humerus, have been sectioned into their functional units.

**Graphic abstract:**





**Keywords:** Clavicle anatomy, Clavicle embryology, Postnatal development, Subclavian vessels, Supraclavicular nerves, Clavicle fractures

### 1.0 Modernization of the clavicle:

With an erect posture and the repurposing of the shoulder joint, the clavicle was redesigned to support advanced functions of the upper extremities. The primary function of the hand is to grasp, manipulate, and throw an object with maximum velocity at a distance. This is made possible through an arrangement of proximal linkages and joints of the extremity rooted in the axial skeleton at the manubrium of the sternum. From the evolutionary perspective, the forelimbs (upper extremities), apart from weight bearing in the quadrupeds, progressive walking and running in the cursorial, and digging with paws (hands) are essential functions. The phylogeny and ontogeny brought about the necessary changes to redesign and reorient the anatomy of the scapula and clavicle to meet the new demands of the evolving Homo erectus, following primates, by modifying the regional musculoskeletal anatomy as needed by Homo sapiens(Voisin, 2006). The shift from weight-bearing and brachiation in primates to freeing the hands for many other novel activities in humans was a necessary development for bipedal gait.

Unlike in quadrupeds, such as canines and cursorial mammals, the dorsolateral placement of the scapula in Homo sapiens facilitated circumduction for greater reach of the hands within the spherical space around the body(Kapandji, 2005). Along with more lateral and dorsal repositioning of the scapula, the acromial end of the clavicle drifted dorsally with it, shifting the arc of protraction and retraction dorsally. On acquiring the erect posture, with postcranial lengthening of the neck and descent of the pectoral girdle, the earlier cylindrical rib cage reformed into a tapered ellipsoid thorax. The shift came gradually from a greater anterior-posterior diameter in the median sagittal plane to a greater medial-lateral coronal diameter of the thorax. This change accommodated the pectoral girdle linkages and joints, providing congruency and stability to the dorsally placed scapula on the thoracic cage. Along with the postcranial descent, the restructured pectoral girdle and reorientation of the clavicle enabled overhead motion for a high-velocity projectile delivery mechanism and a constant unobstructed panoramic view of the object in hand and the target.

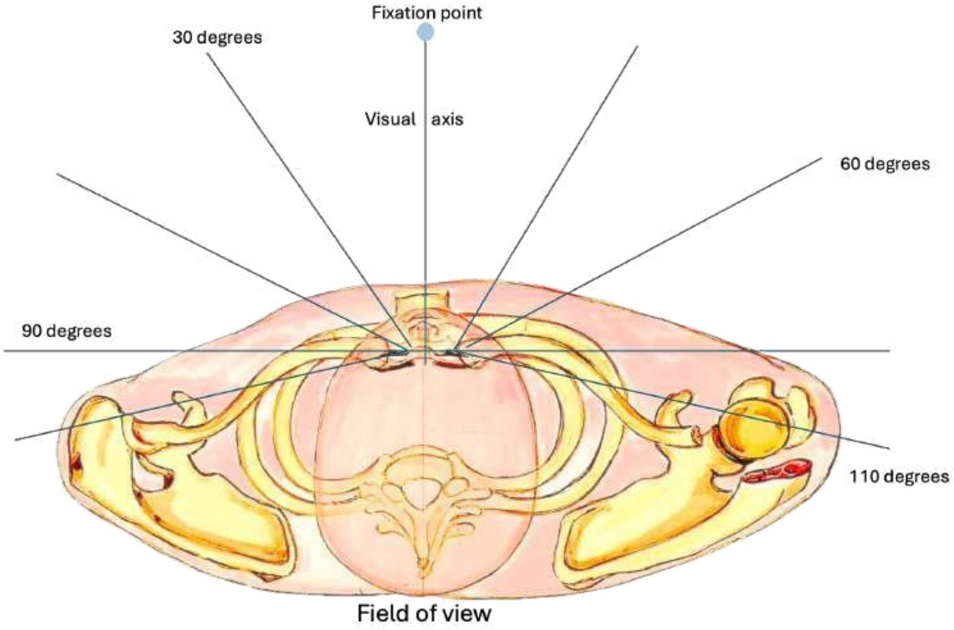


**Figure 1.** Artwork: The illustration depicting the panoramic visual field between the two clavicles.

The anatomical shift of the scapula and the clavicle widened the panoramic arc of the forward-looking field of vision. The oblique cranial and dorsal shift of the clavicle opened the peri-cranial space with maximum side-toside lateral rotation of the cervical spine, ranging between 130 and 160 degrees, and maximum reach of the chin approaching the clavicle in the coronal plane, widening the window of the visual field up to 220-240 degrees (**Fig. 1**). Much of the perimeter traced by the hand falls within the field of vision with the face forward. The visual field extends to 360 degrees with segmental lateral rotation of the spine, from the cervical to the lumbosacral junction, thereby maintaining visual contact with the object held in hand behind the body. Undoubtedly, an evolutionary defensive mechanism for keeping a watch on the field around the body.

The opposing primary double curves of the clavicle in the transverse plane, together with secondary curve(s) in the coronal plane accommodated postcranial modifications of the proximal third of the ellipsoid rib cage, positioning the scapula dorsally and skirting structures at the base of the neck travelling in and out of the thoracic aperture. The belief that the clavicle restructured its anatomy to conform to regional anatomy may be inaccurate. The phylogeny and ontogeny of form and function follow both the topographic anatomical and biomechanical needs of a bone. Forces acting on it in varying proportions, alter its overall biomechanical architecture, without exception. Frequent redesigning of the clavicle is a prime example of repurposing of a bone in the skeletal system. The clavicle, being the first bone to appear in an embryo and last to mature, not only sets the pace for future development of linkages and the joints of the upper extremities but is also very likely the pacesetter of the entire skeleton.

The clavicle is the most important and the most proximal functional segment of the upper extremity rather than merely a link between the axial and the appendicular skeleton. Therefore, in morphometric studies, the length of the upper extremity should be measured from the sternal end of the clavicle to the tip of the radial styloid or tip of the middle finger, with the arm at 90-degree abduction, palm facing forward, instead of the tip of the greater tuberosity of the humerus with the arm on the side of the body.

To attain optimal shoulder breadth and parasagittal positioning of the upper extremities during the development of the erect posture, the bilateral horizontal positioning of the clavicles evolved a sophisticated spatial solution that combines multiple curves and the screw twist to generate swinging force for a progressive propulsive gait, faster running, and projectile delivery. The position and shape of the clavicle fit well into the limited space at the root of the neck, maximizing its biomechanical advantage as a cranking system. To amplify force, the dorsolateral repositioning of the scapula altered the vectors of muscles acting on the clavicle and the scapula, leading to changes in the torsional angular (axial twist) anatomy of the humerus and version of the glenoid(Abbott & Lucas, 1954; Inman & Saunders, 1946). As a result, on average, developed 33 degrees of external rotation of the humeral head on the dominant side and 29 degrees on the non-dominant side, with relative internal rotation of the shaft(Kronberg et al.1990). This added strength and power to the upper extremity to attain maximum throwing distance. The function of the long head of the biceps muscle, which acts as a strong elevator of the forelimb in early claviculate, such as in birds and brachiators, became ineffective during abduction in Homo sapiens until after the humerus is abducted to 90 degrees and rotated externally.

In humans, the rearrangement of the Cranio-Cleidal, Cranio-Spinal, Cranio-Scapular, Thoracoscapular, Thoracohumeral, and Scapulohumeral musculature occurred with the reorientation of all four linkages - the clavicle and scapula translating on the fixed frame formed by the thorax, and the humerus. Thus, creating an effective mechanism for abduction-adduction, flexion-extension, and internal-external axial rotation of the humerus on the glenoid fossa of the scapula with conjunct (*automatic and synergistic*) motion of the clavicle and scapula on the thorax. This arrangement of the musculature was essential for the dynamic stability of the intervening joints and for the harmonious, rapid elevation of the arm, to put the hand in a desired position, not much different from the brachiators, as reflected in architectural changes of the clavicle(Voisin, 2006). The enduring phylogeny and ontogeny over time have led to a characteristic orientation with the strengthening of capsuloligamentous structures and the extracapsular para-articular ligaments, for optimal open and closed packing of the joints, thereby enhancing the strength and stability of linkages and joints during multiplanar and multiaxial movements.

The complex movement of elevating an upper extremity is a compound motion occurring at three true diarthrodial synovial syndesmosis *(two articulating bony linkages held together by a capsule and ligaments having articular cartilage and synovium)* and two junctional synsarcoses *(two bony linkages held together by muscles and tendinous structures with intervening muscles, areolar tissue and a thin film of fluid)*. If the former are anatomical joints, the latter are referred to as physiological joints(Kapandji, 2005). The anatomical synovial joints constructing the pectoral girdle are sternoclavicular, acromioclavicular, and glenohumeral articulations. The two synsarcoses, soft articulations, are between the dorsolateral aspect of the upper rib cage and the scapula and between the humeral head and the acromial arch formed by the acromion and the pretensioned coracoacromial ligament. The structural integrity and stability entrenched in the congruity and concentricity of the opposing articular surfaces, are maintained, directly or indirectly, through a special arrangement of ligaments and cartilaginous labrum or an intraarticular disc, to ensure normal three-dimensional kinematics and prevent the loss of kinetic energy.

### 1.1 The clavicle in anatomical space:

The clavicle, the only horizontal linkage of the appendicular skeleton, is highly specialized in shape and form, making its anatomy and movements difficult to assess clinically and radiologically. Therefore, clinically the kinematics of the remote glenohumeral articulation and scapulothoracic synsarcosis have become the surrogate for the functional outcome of clavicle fractures. It certainly simplifies testing of the injured clavicle against the uninjured contralateral side without paying much attention to the kinematics of the clavicle, the link under examination. But the humerus moves conjunctively through multiple axii and planes with covert axial rotation, that varies depending on the degree of arm elevation and the plane of elevation(Aliaj et al., 2021). The angular orientation of the clavicle and scapula to each other, and the humerus relative to coronal, sagittal and transverse planes of the torso, can be quite ambiguous and confusing when translating their kinematics from experimental studies to clinical practice using Eulerian or Cardan systems of co-ordinates. The clinicians are interested in testing overhead activities by assessing the range of glenohumeral motion in cardinal triplane motion and true axial rotation, either in adduction or abduction, comparing the fractured clavicle, which affects the capsule, ligaments, and musculotendinous structures acting on it, with the intact contralateral side. The functional outcomes of the clavicle, thus derived indirectly from the kinematics of the humerus acting remotely through the scapula, cannot reliably provide otherwise measurable kinematics of the clavicle.

Similarly, in literature, there is confusion in the application of terms anterior-posterior, dorsal-ventral, internal-external, tilting and rotation, particularly when it comes to the movements of the clavicle and scapula at the sternoclavicular, acromioclavicular syndesmoses and scapulothoracic synsarcosis. In engineering, the movement of a linkage around an axis is called rotation, whether it is elevation or depression, abduction or adduction, flexion or extension, protraction or retraction, or oscillation around its longitudinal axis. The terms anterior and posterior especially apply to the quadrupeds, which are forward-looking head-end and tail-end, ventral to the undersurface of the abdomen, and dorsal to the skyward-looking back. The rotation of the clavicle around its longitudinal mechanical axis, only being partial, is referred to as oscillation when rotating towards the scapula in cranial and dorsal direction is craniodorsal, and the opposite is caudal and ventral direction is caudoventral, as well as posterior and anterior, respectively.

The variations in experimental and clinical methodologies are the primary reasons for the variations in the reported range of motions and, therefore, do not apply to patient care. In this regard, the recordings of some older studies are much more appropriate in clinical practice(Abbott & Lucas, 1954; Inman et al., 1944; Inman & Saunders, 1946). The presence of the clavicle at the root of the upper extremity makes it an essential linkage for normal kinematics of the glenohumeral joint and the fulfilment of desirable functions of the hand. It holds the scapula in its dorsal congruent position relative to the thorax, with the glenoid fossa facing laterally and forward. Thereby, at rest, the upper extremity hangs by the side of the trunk in a parasagittal plane to let the hand reach out unobstructed in all directions away from the body while standing in one place under complete visual control relative to the orientation of the pelvis for a balanced bipedal gait.

The knowledge of the clavicle's regional topography and biomechanical anatomy is essential for understanding the normal range of motion between the humerus and the scapula during arm elevation. The movements of the clavicle at the sternoclavicular and acromioclavicular joints help to further the understanding of the kinematics of the scapulothoracic and the acromiohumeral synsarcoses. The study of normal morphology and morphometry of the clavicle, and its biomechanical architecture as a power-generating cranking system, is vital for understanding the pathological anatomy of clavicle fractures and their functional outcomes. Before the age of clavicle maturity, restoring the clavicle to its original anatomy in an individual is essential to reverse its arrested ontogenesis during healing. While the remodelling helps normal progression to its maturity following the principle of 'bone plasticity' - the potential to catch up with growth and remodeling of its architecture. How much axial torsion of the clavicle rectifies during remodelling is unexplored? These are the few reasons why the clavicle must be preserved and restored to its original anatomy following its fracture.

The objectives of this comprehensive, integrated clinically oriented series of biomedical and biomechanical sciences of the clavicle include embryonic and foetal development, and postnatal ossification through to maturity. It deals with the topographical anatomy of the clavicle and associated structures involved in arm elevation, radiological anatomy; and pathological anatomy of its mid-shaft fracture, including malunion leading to shortening and angular deformity, as well as associated acromiohumeral impingement and scapular dyskinesis. The biomechanical architecture is explained by using engineering principles of hyperbolic paraboloid design. When and why an antegrade or retrograde approach is favourable for inserting an intramedullary implant for greater stability of a diaphyseal fracture of the clavicle. The series concludes with the proposals for new intramedullary devices, followed by concluding arguments.

## 2.0 Clavicle embryogenesis and maturation:

### 2.1 Early embryogenesis:

The clavicle is a unique 'long' bone that undergoes significant developmental variation during adolescence until maturity, with distinctive features in males and females. The long-standing perception that it is shaped like an *S* or an *f* is a reasonable notion held by observers. However, neither is a correct representation of the curvatures of different radii at any time from the first eight weeks of the embryonic development through to its final maturity. The postcranial pectoral girdle structures extend bilaterally, from the occipital and cervical regions to the lower end of the thoracic spine, spanning the area covered by the trapezii on the back, inserting on the spine of the scapulae, and the glenohumeral joints laterally. On the front, in the median plane, the manubrium sterni articulates with the clavicles, and the Pectoralis major, arising from the body of the sternum, inserts into the proximal humeral shaft. Together they encircle the upper thorax, which is why it is referred to as the pectoral girdle!

Pectoral girdle parts are derived from both endochondral and dermal elements. The forelimb bud appears in the fourth week post-conception. The clavicle is derived from the transient paraxial mesoderm and somatic-pleuritic mesenchyme, which continues to form the limb bud(Collins & Jawaheer, 2016). In general, the skeletal elements have high cell density in the core of the upper limb bud. The cells in these regions differentiate into chondrocytes, which produce large quantities of extracellular matrix; embedded in it, they form a cartilage model of the bone(Tickle, 2016). In long bones, one centre of chondrogenesis forms in the proximal region, two more distally as the limb bud grows, followed by five centres in the broader distal tip.

The clavicle and the mandible, being subdermal, develop in parallel to each other during the embryonic period, as they are the first two bones to form from the proliferation of mesenchymal cells, which are transformed into connective tissue(Gardener E, 1968). These bones are initially formed in a membrane *(intramembranous ossification)* and later develop in a cartilaginous anlage (*endochondral ossification*). The ossification of the clavicle precedes that of the mandible. The roots of intramembranous beginnings can be traced back to the lateral epidermal fold in the fish, which forms proximal gill elements that were to become the forelimbs or upper extremities(Evans FH & Krahl VE, 1945).

By the sixth week, two distinct primary centres appear within the condensation of the cellular membrane. The medial ossification centre is larger than the lateral one, without an identifiable bony bridge. These primary ossification centres of the primordial clavicle, in the medial and lateral thirds, develop without a cartilaginous anlage. By the middle of the seventh week, neurovascular structures close to the first rib, remote from the clavicle are observed, along with the simultaneous appearance of a narrow bridge between the two primary ossification centres. These centres have a recognizable flat, trabeculated lateral end with a cortical shell and a large oval medial end(Ogata S & Uhthoff HK, 1990). A clavicle of an eight-week-old embryo receives its nutrient vessel on its posterior surface. Between the seventh and ninth weeks, hyaline cartilage develops in the lateral and medial thirds of the embryonic clavicle as a sign of endochondral ossification. However, it is the medial end that contributes more to its length and curved shape(Gardener E, 1968; Ogata S & Uhthoff HK, 1990; O'Rahilly & Gardner, 1972).

By 8.5 weeks, when the crown-rump length of the embryo is 35mm, the 4.2mm clavicle has a flat and shorter acromial end than the cylindrical, longer and bulkier sternal end. However, the acromial end shows greater bone formation, giving it an ice hockey stick appearance. (**Fig. 2**). In the ninth week, at 40mm of crown-rump length, the structure begins to appear claviform due to the anterior convexity of the ossified medial two-thirds(Ogata S & Uhthoff HK, 1990). An eleven-week-old foetus (63mm in length), the 8mm long clavicle begins to show the characteristic shape of a mature clavicle. The direction of growth is notably medial at the medial endochondral ossification centre and the anterolateral end by interstitial growth, adding to the length of the clavicle. The modelling process involves with periosteal bone formation *(intramembranous ossification)* and resorption, adding width to the bone, showing greater activity at the posterior aspect of the acromial end and the anterior aspect of the sternal end curvature(Ogata S & Uhthoff HK, 1990).

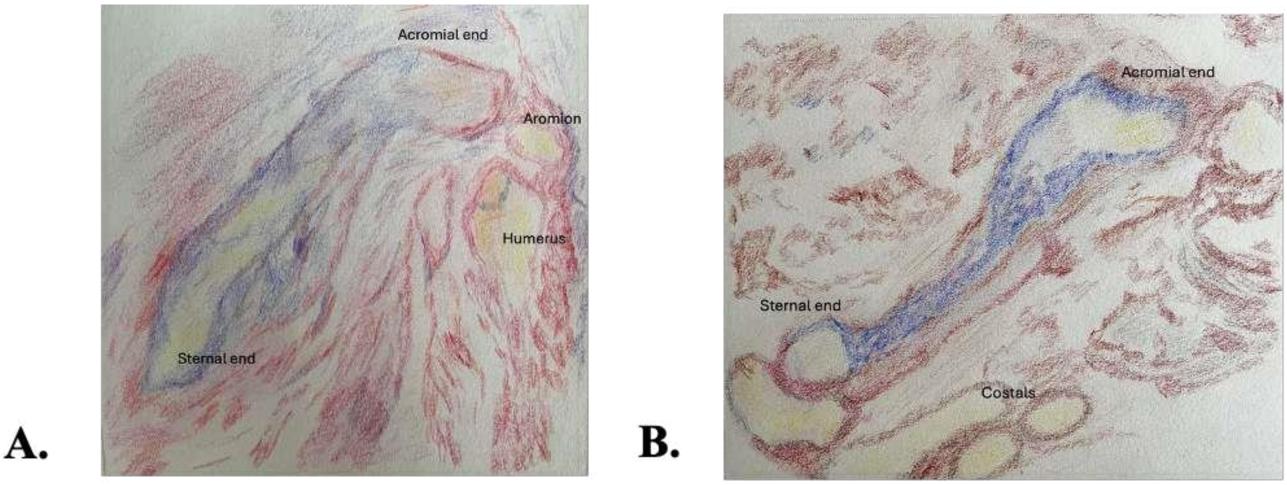


**Figure 2.** By the author: Coloured pencil illustrations **A.** An ice hockey stick appearance of a 4.2mm long clavicle in a foetus with a crown-rump length of 35mm, **B.** Progressive endochondral ossification in a nine-week foetus (Modified from Ogata S. and Uhthoff HK. The early development and ossification of the human clavicle – an embryological study. Acta Othop Scandi, 61:4, 330-334. 1990).

Mechanobiology studies have revealed a complex network of regulatory molecules that direct the embryo's integrated systems through the mechanical influences from the emerging surrounding tissues and biophysical stimuli such as stress, strain, and fluid flow. This is integrated with gene expression, guiding the local cellular events such as differentiation. Consequently, the emerging changes in the primal form and shape of the clavicle are noted through cell proliferation and apoptosis(Henderson & Carter, 2002; Nowlan et al., 2007).

In a study of human foetuses ranging from 14 weeks to 33 weeks of intrauterine life, the direct measurement with vernier calipers to determine bilateral variations in length, biplanar diameters, and circumference at the mid-shaft, sternal and acromial ends found no significant differences in various parameters, except that the right clavicles are distinctly thicker at the mid-shaft than the left during the early period of development and on the left towards the end of gestation (Mohsin et al., 2013). In comparison, a more recent morphometric analysis of digital computed tomographic images of clavicles in aborted foetuses aged between 18 and 30 weeks reported no differences between sexes and directional symmetry in length, width, volume, and projection surface area(Wiśniewski et al., 2017).

## 2.2 Postnatal development:

The medial epiphysis of the clavicle, being the last to ossify, is a well-established parameter for determining the age of legal adulthood maturation. The epiphysis at the medial end of the clavicle appears between the ages of 18 and 20 years and closes between the ages of 23 and 25. A complete closure of the medial epiphysis may not occur until after the age of 31 years(P. A. O. Webb & Suchey, 1985). In a regional study, 39% of male clavicles showed complete fusion at 32 years of age and 29% of female clavicles at 31 years of age(Singh & Chavali, 2011).

The natural history of clavicle development suggests a slow, variable growth pattern during the juvenile, adolescent and early adult years before maturation. According to a cadaveric histological study, from birth to 19 years, the epiphysis behaved as a true physis without the secondary ossification centres at the medial or lateral ends of the clavicle before the age of 18 years(Calixto et al., 2015). A single secondary ossification centre was observed at the sternal end in nineteen years old, while none were at the acromial end of the clavicle. The reduced cellularity of the articular cartilage at the acromial end showed a greater fibrous matrix, suggesting the future formation of fibrocartilage(Calixto et al., 2015).

There is steady growth from birth to 12 years without a significant difference in the length of the right and left clavicles, with a mean difference of 0.036mm(Lazarides & Zafiropoulos, 2006; McGraw et al., 2009).In a radiological study of serial thoracic X-rays in patients with non-neuromuscular scoliosis and kyphosis between the ages of 10 and 25 years old to quantify the yearly longitudinal growth of the clavicle, the terminal age of development of the clavicle in either of biological genders was still progressive at a slower rate in submillimeter numbers every year up to the age of 25 years in most of the cases(Hughes et al., 2020). It indicates significant potential for growth and remodelling in the clavicle in the second and third decades. Also, there are no differences in the ossification and epiphyseal fusion of the medial end between female and male clavicles up to the age of 16. However, in the late teens and early twenties, forensic studies for estimating the legal age reveal a divergence in the maturation rate of the medial epiphysis of the clavicle. This difference in biological age and gender could be due to hormonal influences, such as women's early onset of physeal cartilage mineralisation, leading to its earlier closure(Reder et al., 2024).

Before the age of eighteen, the clavicle grows longitudinally at a variable rate due to reorganization process of chondrogenesis, mostly at medial epiphysis during the early growth spurt between 9 and 14 years of age and afterwards(Calixto et al., 2015). It is not established in the literature if the greater activity of endochondral interstitial tissue growth or ossification alone in the medial epiphysis contributes to the longitudinal increase. Periosteal intramembranous activity adds to the girth at selected places, but there is also a significant role for mechanobiology principles during adolescence and adulthood. It is unclear whether the secondary ossification centre helps achieve remaining longitudinal growth by developing a larger radius of curvature *(flatter curve)* in the medial two-thirds of the clavicle. In the absence of a secondary ossification centre and with relatively little remaining growth in females over the age of nine and boys over twelve, the likelihood of corrective remodelling and lengthening following conservative treatment of mid-shaft clavicle fractures during the growing years is lower(McGraw et al., 2009). The growth of the clavicle is much faster, 80% by the age of 9 in females and 12 in males— compared to the thoracic growth, which is 33% by age 10 and 55% by age 16(Charles et al., 2008; McGraw et al., 2009). The transverse diameter of the thorax is 30%, and the anterior-posterior diameter is 20% of the sitting height(Charles et al., 2008).

In terms of phylogenetics and ontogenesis, the architecture of the clavicle relative to the differential growth of the ellipsoid thorax is no surprise, considering the faster pace of the coronal diameter in comparison to the sagittal diameter. With the changing anatomy of the upper thorax during the growth spurt, along with rapid longitudinal growth of the clavicle, changes in its curvatures are crucial for accommodating the apex of the lung, the subclavian vessels, the brachial plexus and muscles at the base of the neck. The linear growth of the clavicle could also be due to the centrifugal forces acting via all-around parasagittal movements of the upper extremity. However, the thorax reaches adult dimensions much earlier, while the clavicle continues to grow longitudinally until the pelvis also reaches its adult dimensions. The male and female pelvises reach their full width at different times, with the male pelvis completing growth by the early twenties.

In contrast, the female pelvis continues to widen until around 25 to 30 years of age and beyond, which relates well to the age of maturity of the clavicle up to 31 years(Huseynov et al., 2016; Singh & Chavali, 2011; P. A. O. Webb & Suchey, 1985). In both men and women, the proportional growth rate of the clavicle is faster and for a more extended period than the thorax and the pelvis into adulthood. The development of the medial curvature of the clavicle, matching the growth and reorientation of the first rib as one of the dynamic components of the pectoral girdle, is equally crucial. Therefore, restoring clavicle length and its curves is vital in reconstructing the topographic anatomy when treating any clavicle fracture.

### 3.0 Post fracture growth and remodeling of malunion:

Is it for one to believe that even “if the two ends of a fracture of the clavicle are in the same room, in children and adolescents, despite being displaced but in close contact, will always heal?”(Rang M et al., 2005). Does it mean the healed clavicle will always remodel? It is not a well-studied issue of malunion to answer such a conundrum. Recently, in the FACTS study, radiographic findings in a cohort of 98 adolescents of aged 10 to 18 showed that fracture shortening, superior displacement, and angulation significantly improved during a long follow-up period by 61%, 61% and 31% respectively ($p<0.001$). Eighty-five per cent aged under 14 years and 54% older than 14 years at the time of injury had complete or near complete remodeling during 4-year follow-up. Doubtlessly, there is a significant room for remodelling in adolescents with displaced mid-shaft clavicle fractures, and the time elapsed is key to improving function in adolescents as compared to adults, despite malunion(Pennock et al., 2023).

Nonetheless, the outcome numbers from the FACTS study do not encourage continued conservative management of a 100% displacement and more than 10% shortening with angulation deformity that disrupts the normal anatomy and the biomechanical architecture of the clavicle. Despite 100% union a shortened clavicle can leave some 10 to18 years-olds with reduced external rotation and abduction endurance strength of the humerus(Schulz et al., 2013).

Even though, on average, there is continued longitudinal growth of 17.5 mm (10.6%) in males between 16 and 25 and 7.7mm (5.2%) in females between 14 and 25(Hosseinzadeh et al., 2020).

Do such rates of continued growth occur after a malunited fracture of the clavicle, supported by bone tissue plasticity when there is a variable angular deformity and for the most part, the bone is under compression? None of these studies mentions whether the gain in length is in the centreline or end-to-end length of the fractured clavicles. Besides the end-to-end length and girth, restoring the radii of medial and lateral curvatures, torsion, and version angles are essential biomechanical parameters to regain mechanical advantage in a growing clavicle.

There is no explanation as to what biophysical mechanisms are active at the cellular level for remodelling the curved and torsional anatomy of the fractured clavicles when little growth remains. And if the shoulder complex returns to its normal orientation (*bilateral symmetry*) and function in individuals at the age of final follow-up on maturity of the clavicle by age 25 and afterwards. From the perspective of postnatal development, the question arises: why do clavicle fractures in adolescents heal just as well without surgery and enjoy 'satisfactory' shoulder complex functions despite sustained malunion? Does a malunited clavicle truly attain its normal kinematics alongside the reported range of motion and strength endurance measured at the remote glenohumeral articulation without the restoration of the biomechanical architecture of the clavicle? There are many such unexplored questions.

## 4.0 Topographic Anatomy of the clavicle:

Topographic anatomy describes gross anatomical relationships between contiguous structures in a body region. The elements of all areas are either functionally ascribed to the skeleton or intimately related to it. Generally, each region has the same sequential arrangement, from medial to lateral are vein, artery, and nerves. The artery is often closer to a bone. When the finger is pressed against it, the pulsations can be felt and occluded with greater pressure.

The topographic anatomy of the clavicle includes adjacent bones forming interosseous spaces, linkages and joints. The muscles act on them, and in between the fascial layers are vessels and nerves. Each subregion is separated or enclosed within fascial envelopes and/or planes. The regional deep fascia and superficial adipose layer containing cutaneous nerves and vessels are covered in skin. Topographic anatomy helps understand the shared effects arising from the presence of pathological anatomy of the bone and the participating structures, due to their altered biomechanics.

The mandible and the clavicle form superior and inferior neck boundaries since their primary ossification in the sixth week after fertilization. The clavicle extends from the manubrium to the acromion of the scapula, which is a key linkage connecting the upper extremity to the axial skeleton. The clavicle, being subdermal bone, it's form and shape can be easily palpated from one end to the other at the base of the neck, as well as the large muscles attached to it, when made taut. Similarly, all its movements at the sternoclavicular and acromioclavicular joints can be palpated for routine clinical examination from the front, and its relation to the scapula from behind in all three planes during elevation of the arm *(forward flexion and abduction)*. Of course, all geometrical axii, Eulerian and Cardan,

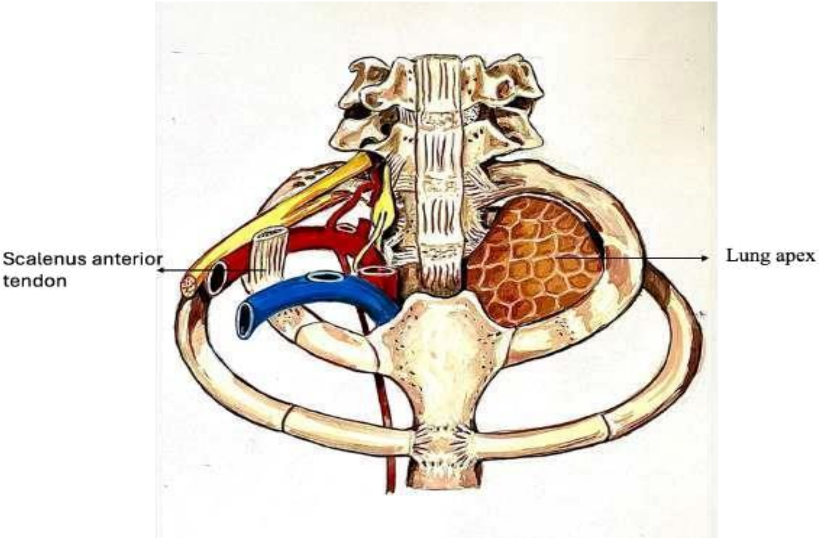


**Figure 3.** Artwork: Schematic artwork of the thoracic aperture showing the relationship of the Subclavian vessels to the first rib and the Scalenus anterior muscle.

are imaginary mobile hinge lines at or external to the anatomy of joints, having little consequence for clinical record keeping(Kapandji, 2005).

The shaft of the first rib is inferior and posterior to the clavicle. It is the shortest, widest, and most sharply curved rib of all true ribs. Its flat sternal end broadens, forming a fibrous sternocostal joint *(synarthrosis)* with the manubrium through intervening costal cartilage(Collin & Cox, 2016). The first costal cartilage joins the manubrium directly inferior to the sternoclavicular articulation. The first rib has a smooth anterior border and a small tubercle on its posterior border for the tendinous insertion of the Scalenus anterior muscle (**Fig. 3**). The cranial surface on either side of the tendon has shallow grooves with a ridge in between. The Subclavian vein occupies the anteromedial groove, and the third part of the Subclavian artery occupies the posterolateral groove. Besides the Subclavian artery, the groove also transmits the lowest trunk of the brachial plexus and fibres of the first thoracic nerve(England, 1961). Further posterior to the posterolateral groove is the attachment of the Scalenus medius.

**Figure 4.** The author's dissection – Subclavius muscle and costoclavicular ligament. The axillary vessels passing under the Subclavius.

Medial to the Subclavian vein is the insertion of the Subclavius tendon (**Fig. 4**). And posterior to the insertion of the Subclavius tendon is the attachment of the Costoclavicular ligament. The first digitation of the Serratus anterior arises from the anterior border of the first rib between the Subclavian artery and the Scalenus medius muscle.

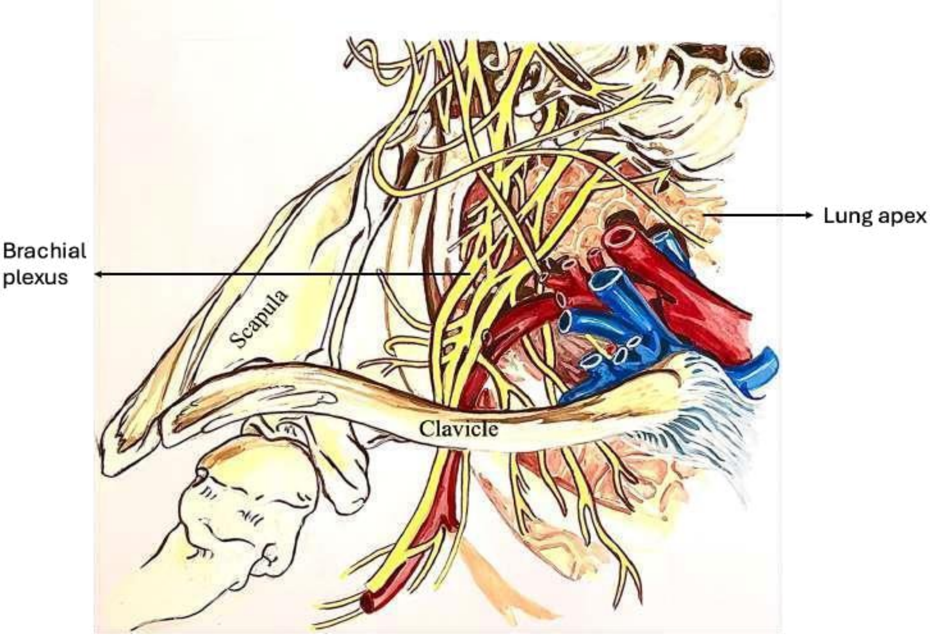


**Figure 5.** A tangential view of the Subclavian vessels and the brachial plexus. (Artwork – modified from Eriksson E. Brachial plexus Block – Supraclavicular Approach. Book Editor Eriksson E and Associates Illustrated Handbook in Local Anaesthesia, Ed second. Llyod-Luke (Medical Books) Ltd. London. 1979 Page 79)

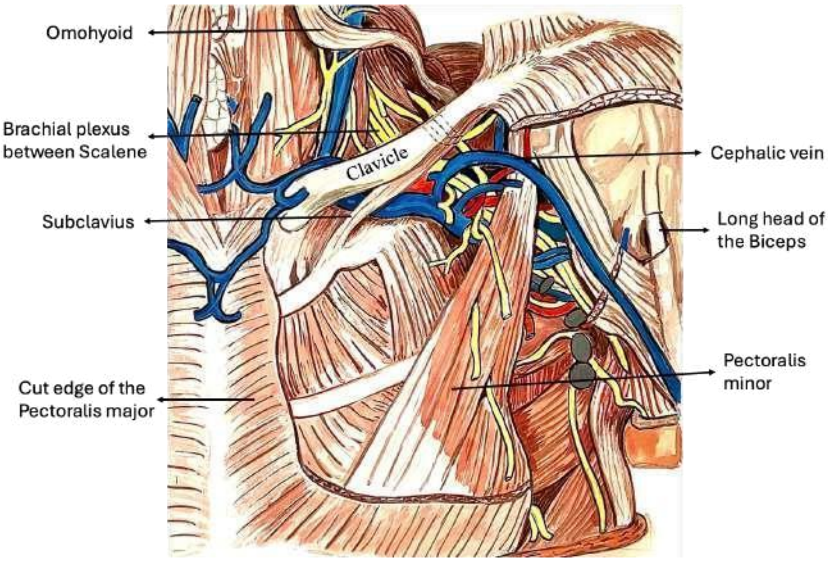


**Figure 6.** Passage of Subclavian vessels from behind the sternoclavicular joint to the lateral edge of the first rib and of the axillary vessels passing beneath the coracoid process and pectoralis minor, entering the axilla. (Artwork – modified from plate 26. The front of the neck and the axilla. Illustration of specimen S. 350 in RCS Museum).

As the clavicle marks the inferior boundary of the neck, it is the meeting zone of three different regions: superiorly, structures of the neck leaving and entering the thorax, inferiorly, the pectoral region, and the ipsilateral upper limb. The clavicle ascends obliquely laterally and dorsally from its articulation at the manubrium, articulating with the acromion of the scapula. It arches above the first rib as its medial curvature borders the structures at the base of the neck. Immediately inferior and posterior to the clavicle, the first rib descends obliquely from its articulation to the body of the first thoracic vertebra to the manubrium, skirting the pulmonary and pleural apices and other structures at the root of the neck(Collin & Cox, 2016) (**Fig. 3**). The oblique plane between the inner border of the first rib and the parasagittal plane medial to its articulations forms the ipsilateral cranial thoracic aperture, often referred to as the thoracic inlet for the veins and their tributaries, and the thoracic outlet for the arteries, and various major nerves that enter and leave the thoracic cavity.

The divergent topographical relationship between the clavicle above and the first rib below creates a definite subclavian space forming a passage for the Subclavian vein, Subclavian artery and cords of the brachial plexus from medial to lateral, over the cranial surface of the first rib (**Fig. 5 and 6**). The Subclavius muscle is oriented obliquely between the clavicle and the first rib, covering two-thirds of its inferior surface, overlying the Subclavian neurovascular structures. The thoracic aperture syndrome symptoms are mimicked whenever there is the altered volume of the wedge-shaped infraclavicular space between the descending first rib and the clavicle ascending laterally, dorsally and cranially, relative to the median plane.

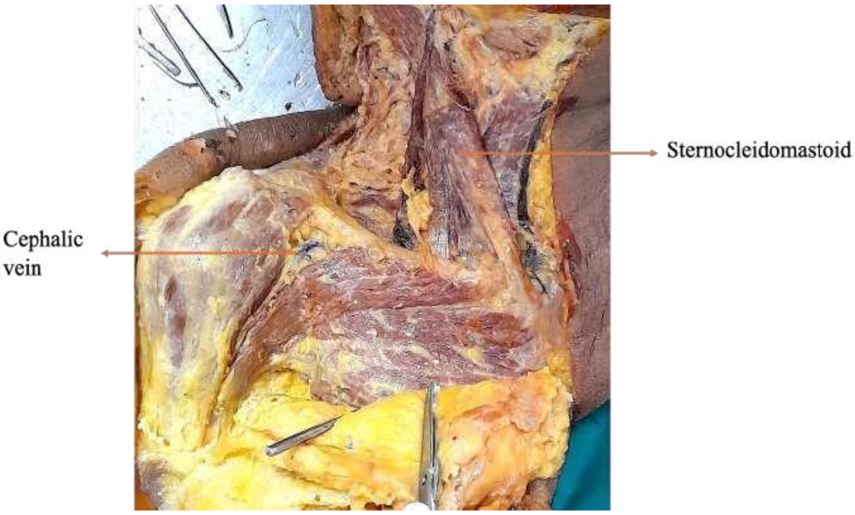


**Figure 7.** The author's dissection – The cephalic vein in the infraclavicular fossa (deltopectoral triangle), piercing the clavipectoral fascia.

The lower part of the posterior triangle of the neck is hollow above the middle two-fifths to two-thirds of the clavicle between the borders of the Sternocleidomastoid and Trapezius muscles (**Fig 7**). The first rib forms solid part of the floor of the supraclavicular fossa along with the Scalenus medius and the first slip of the Serratus anterior muscles. The posterior triangle is covered with skin, superficial fascia, platysma and deep fascia. Most of the branches of the Supraclavicular nerves cross here over the clavicle. The nerve to the Subclavius crosses the area, passing behind the clavicle to supply the named muscle. Beneath the clavicle, the Subclavian artery drapes over the first rib lateral to the Scalenus anterior on the way to the axilla. The Subclavian vein located posterior to the sternal end of the clavicle, deep to the clavicular head of the Sternocleidomastoid, sometimes rises above the level of the clavicle(Birch & Tunstall, 2016a). The brachial plexus trunks lie posterior and superior to the Subclavian artery (**Fig. 6**). When the neck muscles are relaxed, and gentle pressure is applied in the hollow of the supraclavicular fossa, the pulsations of the Subclavian artery can be felt against the first rib.

At the level of the inflection between the medial and the lateral curvatures below the clavicle, the visible depression is called the infraclavicular fossa or deltopectoral triangle (**Fig. 7**). It is bounded by the upper border of the clavicular head (*Cleidobrachialis pectoralis*) of the Pectoralis major and the anterior head (*Cleidobrachialis deltoideus*) of the deltoid muscle. Apart from the deltoid branch of the Thoracoacromial artery in the infraclavicular fossa, the Cephalic vein, upon leaving the deltopectoral groove, pierces the clavipectoral fascia to enter the axillary vein. Under the anterior edge of the *Cleidobrachialis deltoideus* on deep palpation, the coracoid process is felt approximately 25mm below the clavicle. The Axillary vessels run obliquely from the anterior border of the first rib deep to the insertion of the Pectoralis minor, Coracobrachialis and short head of the Biceps muscles at the coracoid process, under the process before entering the axilla (**Fig. 4**).

### 4.1 Cervical fascia:

The cylindrical cervical fascial layer and a complex system of septa in between the neck muscles invest cervical and brachial plexuses, and major vessels(Last RJ, 1980) (**Fig. 8A**). Extending from the midline anteriorly, it splits to enclose Sternocleidomastoid and Trapezius across the posterior cervical triangle(Henry AK, 1957). Below, it is attached to the clavicle. The clavicular part splits into a deep lamina enclosing the inferior belly of the Omohyoid and, like a mesentery, holding it to the back of the clavicle, blends with its periosteum(Last RJ, 1980) (**Fig. 8B**). It continues with the layer covering the deep surface of the Subclavius muscle, descending over the chest to form the clavipectoral fascia to cover the Pectoralis minor. Tracing around the Pectoralis minor, and attaching to the coracoid process, it becomes the suspensory ligament of the axilla, causing the armpit hollow with the elevation of the clavicle(Last RJ, 1980). The prevertebral fascia spreads like a tight sheath over the Scalene group of muscles, binding the brachial plexus, Subclavian artery and the Phrenic nerve over the Scalenus anterior deep to the Sternocleidomastoid (**Fig. 8B and 9**). Descending posterior to the clavicle, it forms the axillary sheath. The axillary vein ascending as Subclavian vein, separated by the Scalenus anterior, diverges from the Subclavian artery and sinks behind sternal end of the clavicle. Even though the vein is far enough during mid-shaft dissection of the clavicle, it is best avoided by staying subperiosteal(Henry AK, 1957).

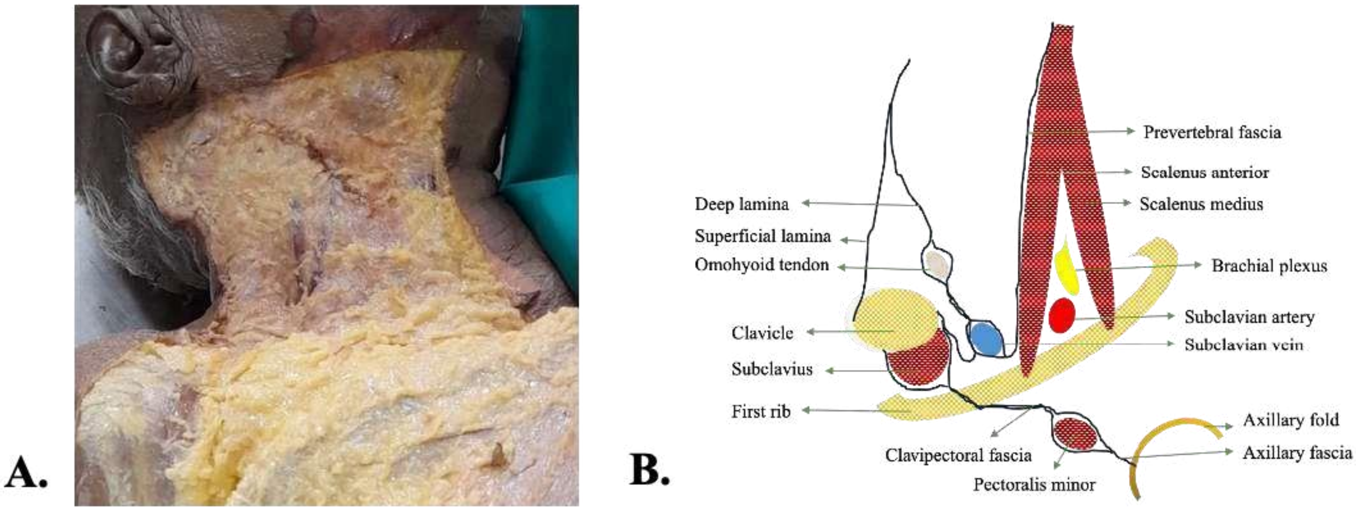


**Figure 8 A.** The author's dissection: Deep cervical fascia. There was no platysma in the adipose layer of the superficial fascia**. B.** A Line drawing created in PowerPoint showing the reflection of the superficial and deep cervical fascial layers.

**Figure 9.** The author's dissection of the deep cervical fascia, prevertebral layer over the Scalenus anterior and brachial plexus, and distally continues to form the clavipectoral fascia over the infraclavicular fossa.

### 4.2 Supraclavicular nerves:

The rami from the third and fourth cervical nerve roots join to form a common trunk. The trunk emerges from behind the Sternocleidomastoid muscle in the posterior triangle of the neck (**Fig. 10**). Descending deep to the platysma and the deep cervical fascia, the trunk divides into medial, intermediate and lateral branches. Just above the clavicle, these branches pierce the deep cervical fascia, and at the posterosuperior border of the clavicle, pierce the platysma. The most medial sternal branches piercing the platysma spread over the clavicular head of the Sternocleidomastoid muscle to supply the skin reaching up to the second rib. According to the Hunter's law, the nerves on the way send branches to the Sternoclavicular joint(Last RJ, 1980). The cutaneous twigs of the second

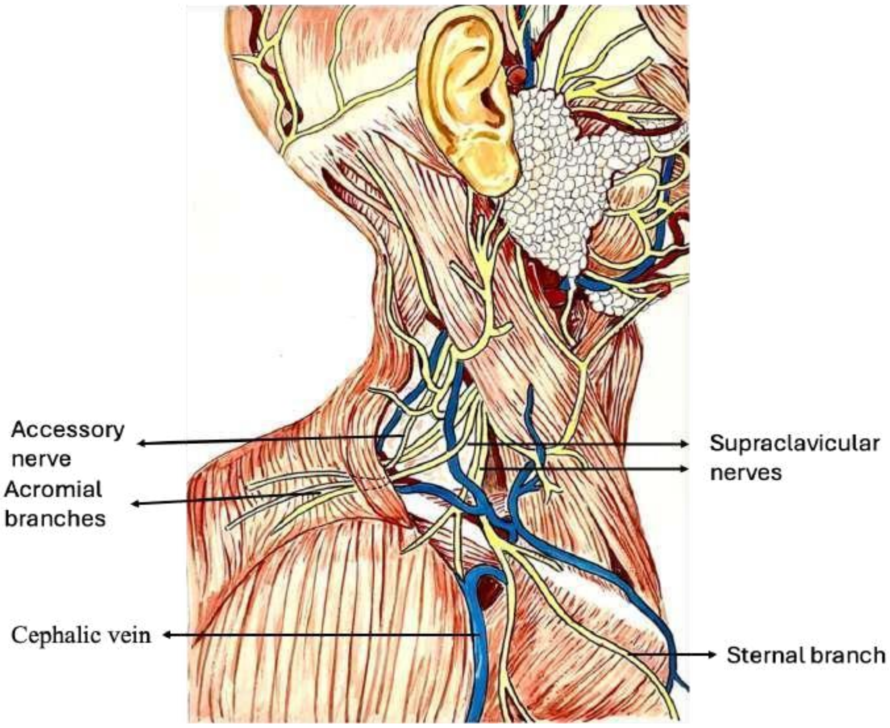


**Figure 10.** Branches of the cervical and brachial plexuses and the branches of the Supraclavicular nerves – Acromial, intermediate and sternal. (Artwork modified from illustration of Specimen S. 350 in RCS Museum).

intercostal nerve are connected to the medial Supraclavicular nerve. The central branches crossing over the diaphysis of the clavicle supply skin over the Cleidobrachialis pectoralis. The lateral acromial branches, distributed over the Cleidobrachialis deltoideus, supply the skin overlying the lateral third of the clavicle and reach the second rib. The distribution of acromial branches sends cutaneous branches over the acromioclavicular joint, acromion, and the upper posterior shoulder. There is minimal overlap of skin supply between the intermediate branches and the distribution of the second intercostal nerve.

The Supraclavicular nerve branches are predominantly distributed in the central three-fifths of the clavicle, with variable distribution from medial to lateral, receiving 41.30%, 30.43% and 19.57%. In contrast, each of the medial and lateral fifths receives merely 4.35% of the total nerve supply(Jeon et al., 2018). No wonder the branches of the intermediate trunk are the most vulnerable to injudicious incisions at open reduction and internal fixation of the mid-diaphyseal fractures. The injury may result in painful neuroma(Lambert, 2016). The entrapment of the Supraclavicular branches in the substance of the fracture callus of the clavicle has been reported as the cause of severe pain during the early and late recovery period(Jupiter & Leibman, 2007). Up to 46% of the patients following plating of the mid-clavicle fractures with a horizontal skin incision may experience paresthesia compared with a vertical incision. The Supraclavicular nerves are spared by performing meticulous dissection of the subcutaneous layer and division of the platysma over the clavicle. Mapping the path of the main branches crossing the clavicle with ultrasound preoperatively can protect them during the approach to the clavicle(Wang et al., 2022).

### 4.3 Subclavian artery:

The right and left Subclavian arteries have different origins. The right Subclavian artery arises from the Brachiocephalic trunk, and the left arises directly from the Aortic arch. Subsequently, both the vessels course anteriorly, intersected by the descending Scalenus anterior muscle, inserting on the Scalene tubercle of the first rib, arbitrarily assigning three parts to the artery. The first part is from the origin of the vessel to the medial border of the Scalenus anterior; the second portion rests posterior to the muscle tendon, and the third portion extends from the lateral border of the Scalenus anterior, curves inferiorly and laterally to the lateral border of the first rib, beyond which it becomes the Axillary artery.

When the insertion of the Sternocleidomastoid muscle extends further laterally on the clavicle, its lateral border aligns with the lateral border of the Scalenus anterior muscle. In the Supraclavicular fossa, from superficial to deep, the skin, superficial fascia, Platysma, Supraclavicular nerves and deep cervical fascia form the anterior relationship to the Subclavian artery. The nerve to the Subclavius muscle, crossing the Suprascapular vessels lying posterior to the clavicle, descends anterior to the Subclavian vessels. The Subclavius muscle separates the Subclavian vessels from the clavicle. The Subclavian vein is medial, anterior and inferior, and the lower trunk of the Brachial plexus is posterior and lateral between the artery and the Scalenus medius in their respective grooves on the cranial surface of the first rib following the medial to lateral VAN rule (**Fig. 6**). The first part of the Subclavian artery, lying in the supraclavicular fossa, is most superficial and vulnerable to severe fractures of the clavicle and is in danger during plating and screw fixation(Clitherow & Bain, 2014).

### 4.4 Subclavian vein:

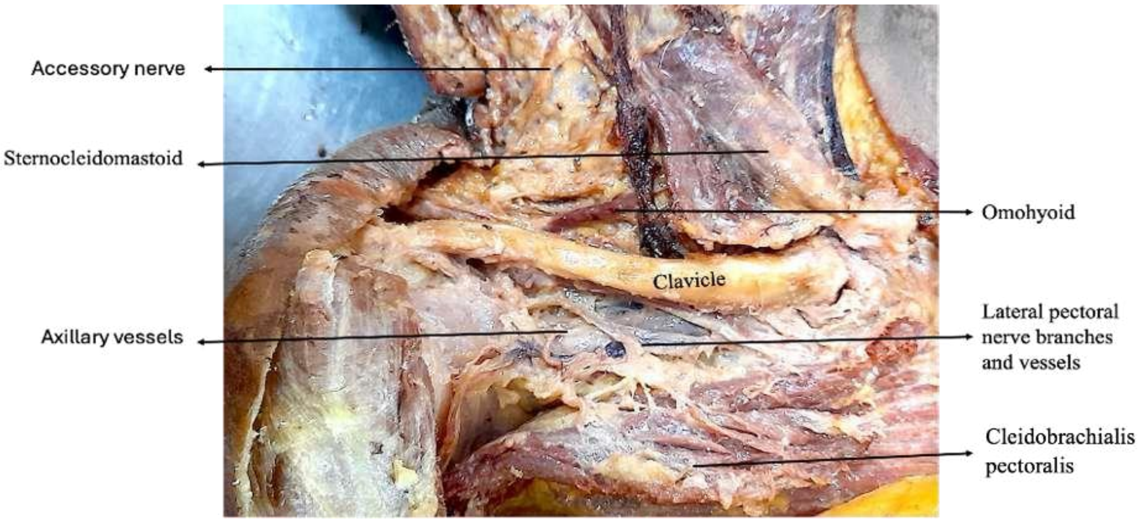


**Figure 11.** The author's dissection showing part of the right Subclavian vessels in the subclavian space and the beginning of the axillary vessels, after lifting the Cleidobrachialis pectoralis muscle, which carries its own independent blood supply and branches of the lateral pectoral nerve.

The axillary vein at the anterior and lateral border of the first rib continues as the Subclavian vein. From there, passing over the first rib to the medial border of the Scalenus anterior, it enters the base of the neck, where it joins the

Internal jugular vein to form the Brachiocephalic vein posterior to the Sternoclavicular joint (**Fig. 5 and 6**). The clavicle and the Subclavius muscle lie anterior and superior to it. From the midline, it is posterior and superior to it in the medial corner of the supraclavicular fossa.

### 5.0 Morphometric topology of the Subclavian vessels relative to the clavicle:

The Scalenus anterior muscle is central to understanding of the relationship between the clavicle and the neurovascular structures that pass obliquely from the medial corner of the supraclavicular fossa to the infraclavicular fossa before disappearing beneath the coracoid process (**Figs. 6 and 11**). In a recent 3D CT angiogram study of skeletally mature non-orthopaedic and non-trauma patients, no significant difference in the relationship between right and left Subclavian vessels was observed in terms of the mean length and girth of the clavicles(Krishna S et al., 2023). The mean clavicle length and thickness in males were154mm and 13.0mm, and in females, 140mm and 10.8mm. The mean distance of the Subclavian artery from the middle of the clavicle on the right side was 14.2mm (12.4-16.6mm), and for the left was 13.9mm (11.9-15.9mm). In the females, the Subclavian arteries were significantly closer to the mid-point of the clavicles than males. In females, the Subclavian veins were significantly closer to the mid-point of the clavicle at a mean distance of 13.3mm (11.5-15.0mm) compared to the males at 17.4mm (13.8-21.1mm). On the right side, in the sagittal plane the artery was at a more acute angle than the Subclavian vein. On the left, both the Subclavian artery and vein were less angled to the clavicle.

In a similar anatomical study using CT angiography, the clavicle was marked into three equal parts to define safe zones during drilling of the clavicle for sites and trajectories of the screws(Sinha et al., 2011). From a mid-central point on the clavicle, the Subclavian vessels were posterior to the medial two-thirds of the clavicle. The artery and vein were at a mean distance of 17.02mm (5.4-26.8mm) and 12.45mm (5.0-26.1mm), respectively. The range of angle between the artery and clavicle was 12 to 80 degrees, and for the vein, 38 to 100 degrees to the transverse plane perpendicular to the sagittal plane.

Although the averages of these two studies are similar, the reported ranges of distances and angles differ significantly. These guidelines should alert surgeons to the danger lurking under and behind the displaced fractured clavicle. The reported numbers for intact clavicles cannot be directly translated to severely displaced fracture fragments, whether for a plating system or for driving an intramedullary implant, regardless of whether using open or closed techniques. Furthermore, these numbers can vary not only with end-to-end lengths and biplanar diameters but also with the radii of medial and lateral curvatures, which can change the centre line length of the fractured fragments. Whether the statistically significant differences surgically relevant with respect to patient specific topographic anatomy, is difficult to determine from such studies. Vascular injuries are uncommon but can be limb-threatening in the form of delayed complications, such as pseudoaneurysm and arteriovenous fistulae(Clitherow & Bain, 2014). Therefore, to prevent iatrogenic injuries, a surgeon should be cognizant of the anatomical variations in topography and remain subperiosteal when approaching the fracture fragments. When there is neurovascular compromise, consider pre-operative CT angiography.

### 6.0 Brachial plexus:

The Brachial plexus crosses from the Supraclavicular fossa to the Infraclavicular fossa at the junction between the medial two-thirds and the lateral third of the clavicle. Passing posterior and inferior to the clavicle and the Subclavius muscle, it crosses superficial to the first digitation of the Serratus anterior at the anterior-lateral border of the first rib. The plexus is formed by the union of the ventral rami of the lower four cervical nerve roots (C5-C8) and the greater part of the first thoracic spinal nerve root. When it receives a significant contribution from the fourth cervical nerve root proximally and from the second thoracic spinal nerve root distally, it is called pre-fixed and post-fixed, respectively. In the Supraclavicular fossa, deep to the Platysma and deep fascia, it lies in the angle between the clavicle and the lower posterior border of the Sternocleidomastoid, crossed by the Supraclavicular nerves and nerve to the Subclavius muscle(Watkinson & Gleeson, 2016). The nerve to the Subclavius often communicates with the phrenic nerve over the Subclavian vein. Aside from the common embryological origin, the communication between the motor supply of the Subclavius muscle and the thoracic diaphragm via the Accessory phrenic nerve is intriguing!

The Brachial plexus emerges into the posterior triangle of the neck between the Scalenus anterior and Scalenus medius muscles. The anatomy of the trunks is relatively consistent, lying in front of each other in the form of a bundle covered by prevertebral fascia, with the Subclavian artery passing anteromedially to it(Birch & Tunstall, 2016) (**Fig. 9 and 10).** The lowest trunk, formed by C8 and T1 of the brachial plexus, is intimately related to the Subclavian artery and sits more anteriorly while crossing the first rib. Immediately inferior to the clavicle, the three cords formed the divisions of the trunks have variable relationships and have historically been given misleading designations of posterior, medial, and lateral to the Axillary vessels(Standring, 2016.

## 7.0 Cervical region myology:

### 7.1 Platysma:

The platysma (panniculus carnosus) is a thin sheet of striated muscle intimately adherent to the adipose tissue, covered on its deeper aspect by a connective tissue layer, forming a myocutaneous covering of the neck(NaldaizGastesi et al., 2018). Although it is widely distributed in the proximal parts of horses, cats and dogs, it is limited to the neck in humans. It is mostly absent in humans; however, when present, it originates from the fascia covering the Cleidobrachialis pectoralis and Cleidobrachialis deltoideus, spreading upwards and medially over the clavicle and neck to insert on the mandible, Orbicularis oris, Risorius and subcutaneous tissue of the face(Kohan & Wirth, 2014). Just above the clavicle, the Platysma, intimately related to the Supraclavicular nerves, is pierced by several of its branches, descending over the clavicle, entering the subcutaneous fascia, and supplying a significant skin area over the pectoralis region. The muscle is innervated by the cervical branches of the cranial facial nerve close to the angle of the mandible(Watkinson & Gleeson, 2016).

Platysma maintains the neck profile, depresses the mandible and moves the lower lip and corner of the mouth as a muscle of expression. When present, it demands meticulous dissection during approach to the clavicle to protect the Supraclavicular nerves. At wound closure, the edges of the myocutaneous layer should be approximated evenly without undue tension to prevent trapping of the Supraclavicular nerve fibres, crushing of the platysma, and corrugating the skin edges.

### 7.2 Scalenus anterior:

The Scalenus anterior lies at the side of the neck, deep to the Sternocleidomastoid muscle. It is attached proximally by musculotendinous bundles to the anterior tubercles of the transverse processes of the third, fourth, fifth and sixth cervical vertebrae. Its fascicles converge, merging to form a tendon that descends almost vertically to insert at the scalene tubercle on the posterior border of the first rib and the ridge on its upper surface (**Fig. 3**). It separates the outgoing Subclavian artery from the incoming Subclavian vein.

At the root of the neck, the Scalenus anterior, covered by the prevertebral fascia, lies posterior to the clavicle and the Subclavius muscle. It is an important landmark, because the phrenic nerve descends on its anterior surface and the second part of the Subclavian artery lies posterior to it. Anteriorly, from medial to lateral, the Scalenus anterior is related to the Subclavian vein, nerve to the Subclavius, Phrenic nerve; posteriorly to the Brachial plexus roots and the Subclavian artery, and laterally the Brachial plexus trunks interposed between it and the Scalenus medius. Coursing horizontally across it are the Transverse Cervical artery, Suprascapular vessels, and inferior belly of the Omohyoid muscle. The proximity of the Subclavian vessels and the Brachial plexus to the Scalenus anterior can give rise to the compression syndrome(Watkinson & Gleeson, 2016).

The Scalenus anterior is innervated by branches from the ventral rami of the fourth, fifth, and sixth cervical spinal nerves(Lambert, 2016). Acting from below, the Scalenus anterior flexes the cervical spine in sagittal and coronal planes. Acting from above, it elevates the first rib.

### 7.3 Subclavius muscle:

This interesting motor entity is described as an asymmetric triangular muscle, that lies inferior to the clavicle past the transition zone, from the medial to the lateral curve (**Fig. 4**). Subclavius originates from the upper surface of the first rib, close to the sternal end and the adjoining costal cartilage anterior to the Costoclavicular ligament, by a thick tendon, stretching along its margin. Its muscular belly passes upwards and laterally gain insertion on the inferior surface of the middle third of the clavicle in the subclavian groove extending up to the conoid tubercle. It may even send a few fibres to the coracoid process(Lambert, 2016).

Posteriorly and inferiorly, it distances the clavicle from the Subclavian vessels and the Brachial plexus traversing over the first rib. Anteriorly, the anterior lamina of the Clavipectoral fascia separates it from the Cleidobrachialis pectoralis. The Suprascapular vessels passing behind the lateral third of the clavicle running between the Subclavius and the inferior belly of the Omohyoid are vulnerable during transition zone fractures of the clavicle.

The Subclavius muscle is innervated by the subclavian branch arising from the upper trunk of the Brachial plexus is often called the nerve to subclavius (C5 and 6). It runs down anterior to the plexus and the Subclavian artery, passing superficial to the Subclavian vein to enter the muscle. The nerve to the subclavius sends fibres to the Sternoclavicular joint following Hunter's law and often gives off the Accessory phrenic nerve.

The action of the Subclavius muscle, having graded lengths of its obliquely oriented muscle fibres, resists elevation and causes depression of the clavicle, stabilizing the Sternoclavicular joint when carrying an overhead load. It decelerates the rapid, forceful elevation and rotation of the clavicle during above-shoulder elevation of the arm(Lambert, 2016). However, there is limited electromyographic information to confirm these actions(Prado Reis et al., 1979). Its role in respiration through the contributing fibres to the accessory phrenic nerve remains unexplored.

### 7.4 Accessory nerve:

The Accessory nerve has both cranial and cervical roots. The cranial part arising from the lower part of the nucleus ambiguus, comes out from the side of the medulla oblongata, passes out of the jugular foramen close to the vagus nerve, and joins its inferior ganglion. The cervical spinal rootlets arise from an elongated nucleus of motor neurons located in the lateral part of the anterior horn of the upper five cervical segments of the spinal cord. These rootlets join to form a trunk that ascends within the dura mater, entering the skull through the foramen magnum. As it ascends, it becomes enclosed in a common sheath with the vagus nerve remaining separate from it by a fold of arachnoid membrane(Watkinson & Gleeson, 2016). It exits through the jugular foramen and travelling with the Internal jugular vein and superior sternocleidomastoid branch of the occipital artery, it enters the deep surface of the Sternocleidomastoid muscle. There, it anastomoses with fibres from C2 or C3 or both, which innervate the muscle. It then emerges at its posterior border, coursing obliquely across the posterior triangle of the neck, 4 to 6cm below the mastoid process, anterior to the prevertebral fascia, and enters deep to the trapezius 3 to 4 cm above the clavicle (**Fig. 7 and 11**). After receiving fibres from C2 to C4 spinal roots, it innervates the Trapezius.

The Accessory nerve provides the sole motor supply to the Sternocleidomastoid, and C2 and C3 cervical nerves are believed to carry proprioceptive fibres. Similarly, the motor supply to all three parts of the Trapezius derived primarily from the Accessory nerve. Additionally, it receives motor and proprioceptive fibres from C3 and C4 in most cases (Tubbs et al., 2011).

### 7.5 Sternocleidomastoid muscle:

The Sternocleidomastoid muscle ascends obliquely on the side of the neck, from its origin at the upper outer corner of the manubrium and the adjoining clavicle to insert into the mastoid process and the superior nuchal line of the occipital bone. Although it has mainly two heads, the literature describes four parts - Sternomastoid, Sterno-occipital, Cleidomastoid and Cleido-occipital(Kennedy et al., 2017). In a study, where dissection, MRI and biomechanical modelling were performed, it was concluded that various components of the muscle could produce variable shear and compression forces at various cervical spine motion segments(Kennedy et al., 2017). The medial or sternal head, Sternomastoid, arises from the upper part of the anterior surface of the manubrium sterni. The lateral or the clavicular head, Cleidomastoid, arises from the superior and posterior surface of the clavicle (**Fig. 12**). The Cleidomastoid attachment can have variable widths up to 7-8 cm. Rarely, the opposing margins of the Cleidomastoid and Cleido-occipital trapezius meet in the middle of the clavicle(Saha et al., 2014; Sarikcioglu et al., 2001).

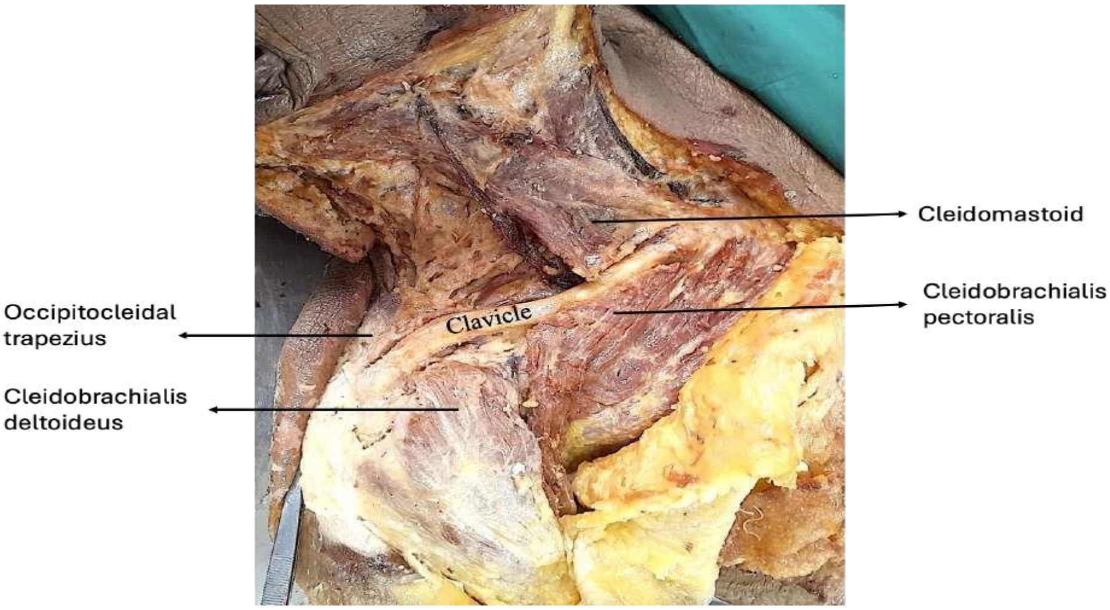


**Figure 12.** The author's dissection - Cleidomastoid, Cleidobrachialis pectoralis, Occipitocleidal part of the Trapezius and the Cleidobrachialis deltoideus raised from their attachments on the clavicle.

As the two heads of the Sternocleidomastoid ascend, they converge about the middle of the neck. The Cleidomastoid, merges on the deep surface of the Sternomastoid, forming a visibly round belly. The superficial oblique fibres of the Sternomastoid are inserted on the lateral half of the superior nuchal line by a thin aponeurosis adjacent to the origin of the Trapezius. The vertical fibre of the Cleidomastoid inserts anteriorly on the entire surface of the mastoid. Accordingly, each muscle head has a notably different vector of action.

As the Sternocleidomastoid crosses the entire length of the neck, covered by skin, Platysma and cervical fascial layers, all its surfaces and borders relate significantly to several neurovascular structures passing proximally and distally. Distally, the deep surface of the muscle near its origin is associated with the Sternoclavicular joint, Sternothyroid, Sternohyoid and Omohyoid muscles, and the Scalenus anterior with the Phrenic nerve coursing over it. The upper part of the Brachial plexus and branches of the Cervical plexus enter the posterior triangle of the neck around the middle, passing underneath its posterior border (**Figure 10**).

The Accessory nerve and branches from the ventral rami of the C2 and C3 nerve roots innervate the Sternocleidomastoid. Occasionally, it receives fibres from the 4th Cervical spinal root. The Accessory nerve fibres originate from the upper part of the brainstem nucleus and receive fibres from both cerebral hemispheres. The Cleidomastoid head and Trapezius muscle share neural branches from the lower portion of the brainstem nucleus, as well as fibres from the contralateral hemispheres(DeToledo & David, 2001). This suggests a combined role of these muscles in maintaining posture and balance of the head and neck(Forbes et al., 2018). In-utero, the Sternocleidomastoid and Trapezius develop from the same set of cell condensation between 33 and 38 days, sharing innervation from the Accessory nerve(Mekonen et al., 2016).

The Sternocleidomastoid muscle acts from its distal end attachment on the clavicle and manubrium sterni. The ipsilateral contraction tilts the head ipsilaterally. It actively turns the face and chin obliquely up towards the opposite direction. More commonly, the right-sided Sternocleidomastoid turns the head towards the left and vice versa without tilt. Bilateral contraction of the Sternocleidomastoid simultaneously bends the head forward and, in conjunction with Trapezius, extends the head in the sagittal plane. The motion of the clavicle during the elevation of the arm, the Sternocleidomastoid, paired with the Trapezius, stabilize the Sternoclavicular joint.

### 7.6 Trapezius muscle:

The Trapezius is a thin flat, triangular muscle that cover the dorsum of the neck and upper thorax. It is divided into three parts: superior, middle and inferior - each part has different vectors of action on various parts of the pectoral girdle.

The superior or Occipitocleidal part originates from the medial third of the superior nuchal line and the external occipital protuberance by fibrous lamina adherent to the skin. It descends to insert on the posterior border of the lateral third of the clavicle (**Fig. 12**). Sometimes, the anterior border of the Trapezius may extend medially to reach the middle of the clavicle, blending with the Cleidomastoid. The middle part originates from the ligamentum nuchae, the apices of the spinous processes and supraspinous ligaments from C6 to T3 and inserts on the medial margin of the acromion and superior lip of the crested scapular spine. The inferior part arises from the spinous processes and the supraspinous ligaments from T4 to T12, passing over the smooth triangular surface at the medial end of the scapular spine, inserts into a tubercle at its apex(Lambert, 2016). The origin of the extensive, triangular aponeurosis of tendinous fibres on either side of the spine appears to have a “diamond” shape.

The entire Trapezius muscle receives its motor supply from the Accessory nerve and sensory supply from the ventral rami of C3 and C4. The Accessory nerve is crucial for thoracoscapular function and essential for the scapulohumeral rhythm(Camp & Birch, 2011).

The Trapezius muscle is an important postural muscle, as its tone maintains the shoulder in its normal, elevated position(Last RJ, 1980). In addition, the Trapezius, in conjunction with other shoulder muscles, stabilizes the scapula during arm elevation. The action of the Occipitocleidal part of the Trapezius is controversial. Its action depends on the head and neck posture and the stability of the scapula at the beginning of shoulder movements, depending on whether it is loaded or unloaded. As load variability accounts for electrical activity in a group of muscle fibres, therefore minimal electrical activity is recorded in the unloaded arm and in the Occipitocleidal part of the Trapezius. The fibres of the Occipitocleidal, acting with Levator scapulae elevate the scapula and point of the shoulder(Lambert, 2016).

In an electromyography study, the Occipitocleidal and the middle part of the Trapezius showed activity during elevation and lowering of the arm from the beginning to the end of the movement. In contrast, the middle and inferior parts are active during retraction but silent during protraction(Filho et al., 1994). The inferior part resists lateral rotation of the scapula under load. It acts with the Serratus anterior, protracting and rotating the scapula upwards *(when seen from behind, the inferior angle turns laterally, clockwise on the left and counterclockwise on the right)* with overhead abduction of the arm. Concurrently, the Rhomboids retract the scapula. With the shoulder fixed, the Trapezius extends the cervical spine directly backwards and laterally(Lambert, 2016).

The Trapezius and Serratus anterior muscles, acting together, form a force couple for regular scapular movements. Depending on the neuromuscular deficit due to injury to the Accessory or Long thoracic nerves or mechanical disturbance, there are distinctive changes in the posture of the scapula at rest and during shoulder movements. In the case of the Accessory nerve injury, there is a failure of the Trapezius, and the glenoid angle of the scapula is tilted laterally and forwards (*protracted*), with sagging of the acromioclavicular joint - the inferior angle of the scapula sags and slides away from the vertebral column. The Levator scapulae, rotating the superior pole of the scapula, turns the inferior angle medially and lifts it away from the chest wall, assisted by the Rhomboids.

In the case of Long thoracic nerve palsy with failure of the Serratus anterior, the entire medial border of the scapula tends to elevate away from the chest wall, classically referred to as "winging of the scapula." The scapula is displaced upwards by the Levator scapulae and towards the spine by the Trapezius and Rhomboids. The altered posture and mechanical misplacement of the scapula create distortion of the cervicoaxillary sheath *(narrowing and elongation)* and its contents, producing the symptoms of reduced venous return, lymphatic obstruction and disturbed neural perfusion, causing pain, paraesthesia, and dysaesthesia(Lambert, 2016). Such a scenario may be encountered in a malunited fracture of the clavicle due to the contractures of the deep cervical fascia and mechanical mispositioning of the scapula.

### 7.7 Pectoralis minor muscle:

The Pectoralis minor muscle, ensheathed in the Clavipectoral fascia below the clavicle, extending to the floor of the axilla, plays a significant role in the movements of the clavicle.

The Pectoralis minor is shaped like an elongated triangle, lying deep to the pectoralis major (**Fig. 6**). It has variable origins from the upper margins and anterior surfaces of the second to the fifth ribs next to the costal cartilages. It inserts into the medial border and upper surface of the coracoid process. On inspection, it visibly appears to continue with the coracoacromial ligament. The upper border of the muscle is separated from the clavicle by a gap covered by the Clavipectoral fascia, which in turn covers axillary vessels passing under the hook of the coracoid process.

Pectoralis minor is innervated by medial and lateral pectoral nerves of the Brachial plexus with an extensive root value of C5, 6, 7, 8, and T1, suggesting its essential role in the movements of the scapula with the coracoid process acting as its handle during scapulothoracic movements. It assists the Serratus anterior in protracting the scapula as part of the couple resisting the Trapezius and depresses the point of the shoulder in conjunction with the Levator scapulae and the Rhomboids.

### 7.8 Serratus anterior muscle:

The segmented anatomy of the Serratus anterior muscle within the scapulothoracic synsarcosis provides a larger and more stable contact area for the scapula and cumulative power generated by its individual digitations. The muscular segments follow the anterolateral contour of the thorax and the deeply curved surface of the scapula. The fleshy digitations of the muscle have variable origin along an oblique curved line from tendinous roots on the ventral surface and superior borders of all the true ribs, as well as from the false ribs, and the fascia covering the intervening intercostal muscles.

This muscle has three parts. The upper part arises from the first and second ribs, the next part from the third to the sixth ribs, and the inferior part from the remaining ribs, interdigitates with the upper five slips of the External obliquus abdominis(Lambert, 2016). All the digitations wrap around the thoracic curve, deep to the costal surface of the Subscapularis muscle, to reach the costal medial border of the scapula. The first digitation, seemingly an independent muscle on reaching the superior angle of the scapula, encloses a triangular area covering both costal and dorsal surfaces for a specific biomechanical function. The digitations of the middle part come together, forming roughly a quadrangle, insert into the costal surface along the entire medial margin, and the inferior part converges, attaching via musculotendinous fibres to the triangular impression on the costal surface and to the dorsal surface enclosing the inferior angle of the scapula(Lambert, 2016).

The mean vector of action of the superior part is 30 degrees with a cross-section of 1.3 $cm^2$, the middle fibres at 90 degrees with a cross-section of 2.2$cm^2$, and the inferior part at 60 degrees having a cross-section of 3.0$cm^2$(A. L. Webb et al., 2018). The physiological cross-section and the vector of action of the digitations suggest the distinct roles of each part in the scapula's motion during elevation of the arm. The first part differs in appearance from the others and shares the insertion with the Levator scapulae, playing an additional role in stabilizing the superior angle during upward motion and providing abduction force to the scapula(Smith et al., 2003).

The Long thoracic nerve, arising from C5, C6, and C7 roots of the Brachial plexus, descends in the subscapular plane to innervate the Serratus anterior deep to its covering fascia.

As the prime mover, the Serratus anterior draws the scapula forward, gliding on the contour of the thoracic cage, protracting the shoulder complex between the coronal and sagittal planes. During arm elevation in the paramedian sagittal plane *(forward flexion)* and the scapular and coronal plane *(abduction)*, the Serratus anterior holds the scapula in a stable position. In conjunction with the Trapezius, the middle and inferior fibres of the Serratus anterior form a force couple to rotate the scapula so that the glenoid faces upwards in the cranial direction, supporting the arm when raised overhead. In the initial stages of abduction, the Serratus anterior fixes the scapula with other scapular muscles, stabilizing the surface of the glenoid fossa, so that the Deltoid muscle can act effectively on the humerus.

Once the arm is abducted to 60 degrees, the Serratus anterior and Trapezius force couple rotate the scapula. As the acromial end of the clavicle elevates, the scapula translates by a few degrees at the acromioclavicular joint to protract in continuation with abduction movement to its vertical posture. At the reversal of the movement, under gravity, the eccentric contraction of the participating muscles smoothly brings the arm to its resting position. In underhand movements, several muscles, including the superior part of the Serratus anterior, Levator scapulae, Rhomboids, Pectoralis minor and the middle part of the Trapezius, contract proportionately to produce precise movement of the arm and hand. There are several combinations of movements in which scapulothoracic synsarcosis helps in completing the required motion to place the hand at a desired point. Unlike overhead high velocity baseball pitching, the underhand shoulder movements in sports such as curling, where a 20Kg stone is delivered, have not received much attention.

When the Long thoracic nerve is injured or suffers from a disease, the Serratus anterior muscle fails to function normally. It leads to the elevation of the inferior angle and medial border of the scapula from the thoracic wall to a variable degree, depending on the involved digitations of the muscle.

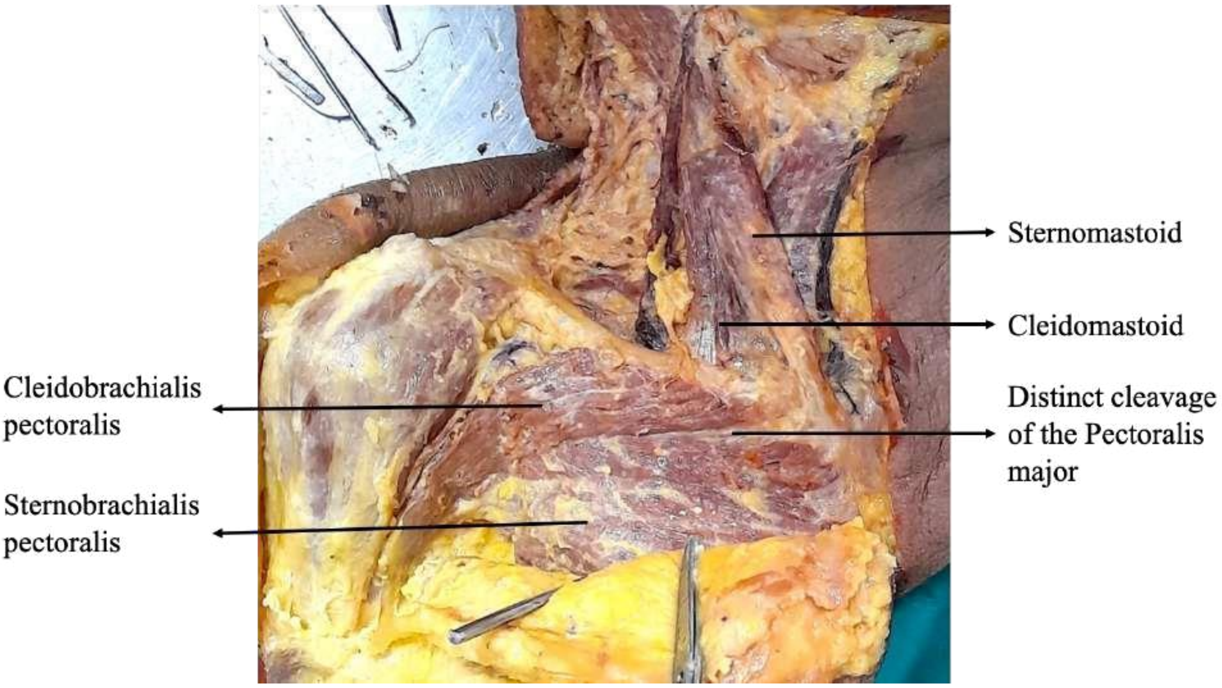


**Figure 13.** The author's dissection - Exposure of the Sternocleidomastoid, Pectoralis major, Trapezius and Deltoid muscles. There is a clear demarcation between the Cleidobrachialis pectoralis and the sternal head of the Pectoralis major.

### 7.9 Pectoralis major muscle:

The Pectoralis major is a large muscle forming a flask-like triangular outline. It is generally divided into three heads: the clavicular, the sternocostal and the abdominal. The clavicular portion, called *Cleidobrachialis pectoralis*, originates from the anterior surface of the clavicle, covering the medial half to two-thirds of it (**Fig. 12 and 13**). The Sternocostal head originates from the anterior surface of half the breadth of the manubrium sterni and the sternal body down to the sixth or seventh costal cartilage. Frequently, the muscle fibres do not arise from the first and sixth costal cartilages(Standring, 2016). The abdominal or the rectus head originates from the aponeurosis of the Rectus abdominis and the External obliquus abdominis.

The absence of attachment to the first costal cartilage creates a gap between the two proximal heads of the Pectoralis major, resulting in a cleavage up to the insertion point (**Fig. 13**). The adipose-filled gap confirms that they are two independent entities. The Thoraco-acromial artery in the infraclavicular fossa gives off two branches: the deltoid and the pectoral. The Cleidobrachialis pectoralis receives its blood supply from the deltoid branch, while the Sternocostal part from the pectoral branch (**Fig. 14**). Similarly, the Cleidobrachialis pectoralis is innervated solely by the lateral pectoral nerve. The independent blood supply and the nerve supply from the rest of the Pectoralis major, establish Cleidobrachialis pectoralis "a true, self-standing anatomical entity"(Barberini, 2014; Haładaj et al., 2019; Larionov A et al., 2018). This suggests a phylogenetic relationship between the clavicle and this muscle. The independent tendon of the Cleidobrachialis pectoralis inserts, alongside the common tendon of the other two heads, on the humerus.

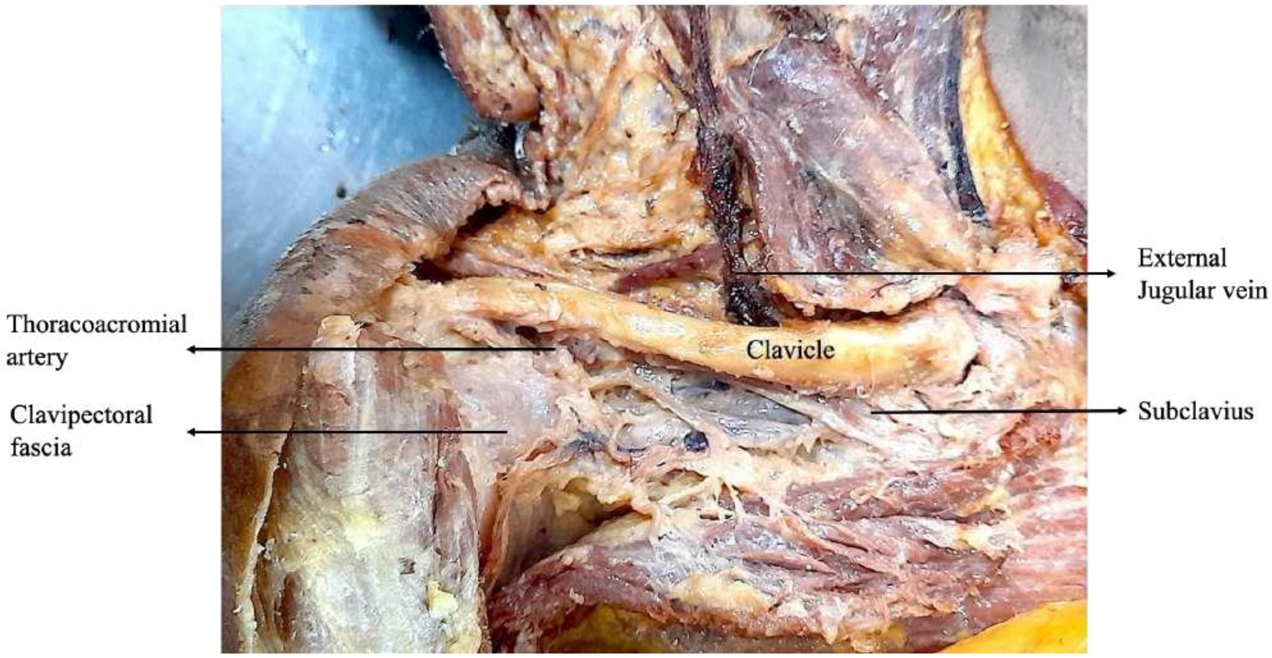


**Figure 14.** The author's dissection – showing the lateral pectoral nerve and the pectoral branches of the thoracoacromial artery piercing the clavipectoral fascia and entering the deep surface of the Cleidobrachialis pectoralis.

The Sternocostal head, the largest and the thickest portion of the Pectoralis major muscle, joins the rectus head, partially winding around each other, creating a rounded caudal edge deep to the Cleidobrachialis pectoralis. The three heads form a broad, flat tendon about 5cm wide, with the Cleidobrachialis pectoralis tendon superficial of the three heads, which inserts into the lateral crest of the bicipital groove, widens extending down from the greater tuberosity(Standring, 2016). There are variations in the way the conjoint tendon of the Pectoralis major is described in the literature(Haładaj et al., 2019; Larionov A et al., 2018). The tendinous lamina formed by the inferior rectus head with the sternocostal fibres deep to the Cleidobrachialis pectoralis tendon climbs to a higher point, giving off a fascial layer covering the intertubercular bicipital groove, blending with capsular ligaments of the shoulder joint, and distally blends with the deep fascia of the upper arm. The superficial Cleidobrachialis pectoralis tendinous fibres may prolong to blend with the tendon of the Deltoid muscle.

Superficially, Pectoralis major is covered by the skin, superficial fascia, platysma, medial and intermediate branches of the Supraclavicular nerves, and breast tissue, and Pectoral fascia. Immediately beneath it, from medial to lateral, are the costal cartilages, ribs and intercostal structures, Clavipectoral fascia, Subclavius muscle, Pectoralis minor, Serratus anterior, and neurovascular structures perforating the Clavipectoral fascia to supply the Pectoralis major.

The nerve supply of the Pectoralis major muscle is through the medial and lateral pectoral nerves. The Cleidobrachialis pectoralis is supplied by roots C5 and C6, while Sternocostal is supplied by roots C7, 8, and T1. The lateral pectoral nerve, which is the sole innervation for the Cleidobrachialis pectoralis, is thicker than the medial pectoral nerve. Its sub-branches are also distributed within the upper portion of the Sternocostal section. The branches of the medial pectoral nerve supply the lower half of the Sternocostal and the Rectus portion, occasionally receiving contributions from the intercostal nerves(Barberini, 2014; Haładaj et al., 2019).

The Cleidobrachialis pectoralis and the Cleidobrachialis deltoideus have a contiguous relationship, and the two structures share the deltopectoral fascia. Rarely, the Deltopectoral triangle or groove may not be present as the Cleidobrachialis pectoralis fuses with the Cleidobrachialis deltoideus(Natsis et al., 2011). It can cause confusion during the Deltopectoral surgical approach to the shoulder joint and proximal humerus.

The size, extent, and position of the Pectoralis major between the infra-clavicular anatomy and the proximal humerus play a significant role in the kinematics of both the clavicle and the glenohumeral articulation. The two or three parts of the Pectoralis major act independently or together, depending on the movement and the stage of arm elevation in different planes. Generally, the Pectoralis major functions as an adductor and medial rotator of the humerus against resistance. The Cleidobrachialis pectoralis is the adductor, medial rotator, and flexor of the arm acting from its clavicular attachment, whereas the Sternocostal part is an adductor. The Cleidobrachialis pectoralis provides additional stability to the glenohumeral joint, synergistic with the Cleidobrachialis deltoideus(Barberini, 2014).

Anatomical fascial plane dissection and electromyographic studies have identified distinct subparts of the Pectoralis major muscle and their segmental myoelectric activity. The agonistic, synergistic and antagonistic activity within the muscle during various stages of abduction in coronal and scapular planes, adduction, and flexion of the arm occur within the same muscle. Depending on the vector of action of the applied force and the moment arm *(the distance between the axis of rotation and the line of action of the force*), these actions occur in conjunction with other shoulder muscles, such as Deltoid and Latissimus dorsi, participating in an intended task(Wickham et al., 2004). However, the roles of various segments within the same muscle vary depending on the type of movement performed by the conjunct and adjunct muscles.

### 7.10 Deltoid muscle:

The Deltoid muscle is a thick, curved triangular cowling over the shoulder joint and the surrounding structures deep to it. It is divided into three portions: anterior, lateral and posterior. Each part, in terms of its origin and point of insertion, is valuable in understanding the segmental function of the muscle during abduction of the arm in coronal, scapular and sagittal planes. The fibres of the anterior clavicular part, *Cleidobrachialis deltoideus*, arise from the anterior border and superior surface of the lateral one-third of the clavicle (**Fig. 12 and 13**). The lateral portion arises from the superior surface of the projecting acromion of the scapula. The fibres of its posterior portion arise from the lower edge of the crested scapular spine, almost matching the insertion of the Trapezius on the superior edge, sharing the rough eminence.

Four intramuscular septa descend from the acromion to interdigitate with three ascending septa from the deltoid tubercle. This arrangement gives the acromial part a powerful traction force during coronal and scapular plane abduction. The feather-like, multipennate arrangement of its acromial segment, along with straight anterior clavicular and posterior fibres, converge distally to form a short, thick tendon. It inserts halfway on the anterolateral surface of the humeral shaft on a variably shaped deltoid eminence, depending on the configuration of the tendon construction. This can be a single broad insertion, with tendon components meeting in a V or W-shape, or diagonally in a stepwise fashion from anterolateral to posterolateral direction. The anterior fibres of the Deltoid are proximal, while the posterior fibres are distal to the middle component(Vohra et al., 2024).

The three portions of the Deltoid muscle are further divided into seven anatomical components that converge into three discrete linear insertions. Four of the seven segments are within the middle portion, arising from the acromion; one anterior clavicular segment; and two posterior segments from the spine of the scapula(Sakoma et al., 2011). PET images taken after Fluoro-Deoxy Glucose intake during arm elevation have shown that the Deltoid muscle functions segmentally, corresponding to the anatomically defined seven segments, with their intramuscular tendons reflecting seven functional muscle units(Sakoma et al., 2011). R. Fick (1911) first described these seven functional segments.

Proximally, the anterior border of the Cleidobrachialis deltoideus is separated from the Cleidobrachialis pectoralis by the infraclavicular fossa, which contains the entry of the cephalic vein into the axillary vein and the exit of the Deltoid branch arising from the Thoraco-acromial artery.

The Axillary nerve innervates the Deltoid muscle with root values of C5 and C6. In more than 85% of the cases, the Cleidobrachialis deltoideus receives a deltoid branch from the lateral pectoral nerve of the same root value (C5 and 6), as the Cleidobrachialis pectoralis(Larionov et al., 2020). The lateral pectoral nerve enters the pectoral region posterior to the clavicle or via the axillary fossa. Such a topographical pattern suggests a conjunct motor function of the Cleidal components of the deltoid and pectoralis muscles during arm elevation.

Each Deltoid muscle component can act independently and together, depending on the type and plane of movement. The Cleidobrachialis deltoideus acts with Cleidobrachialis pectoralis and its other two parts during coronal and scapular planes and in the sagittal plane during arm elevation with medial rotation of the humerus. In conjunction with the Latissimus dorsi, posterior fibres act as lateral rotators, and the Teres major draws the arm into extension. The posterior fibres provide up to 80% of the lateral rotation power during the arm elevation in the scapular plane(Standring, 2016). The middle multipennate acromial component is the primary abductor of the arm, with a synergistic effect from the Supraspinatus. In the scapular plane, the cowl-like architecture of the Deltoid muscle stabilizes the arm, assisting abduction through the synergistic action of its various components(Larionov et al., 2020). The maximum effect of the scapulothoracic motion is available only when overhead abduction occurs in the scapular plane. The Cleidobrachialis deltoideus fibres are the primary flexors.

The fibres arising from the crest of the scapular spine act as extensors to help maintain the course of the arm in the desired plane throughout elevation. At the same time, the rotator cuff group act synergistically to keep the humeral head centralized on the glenoid surface.

### 7.11 Biceps brachii:

The Biceps brachii is a biarticular fusiform muscle with two bellies. Traditionally, it has two named heads, short and long. In 10% of dissections, a third belly originating from the anteromedial aspect of the mid-humeral shaft inserts into the medial side of the common biceps' tendon(Alraddadi, 2024). On average, the short and the long heads are 36 and 38cm long, respectively(Alraddadi, 2024). The parameters of the biceps brachii muscle positively correlate with the length of the humerus. Biological males have higher parameters than females.

The short head and long head originate from two different sites on the scapula. The short head is medial to the long head, with its origin at almost the same level on the transverse plane. It arises from the tip of the coracoid process, conjointly with the Coracobrachialis, lateral to the insertion of the Pectoralis minor muscle. Its origin is muscular with an aponeurotic fascia. The long head of the Biceps brachii has a long, narrow tendon that originates from the supraglenoid tubercle of the scapula at the apex of the glenoid fossa, extending its insertion to the anterior and posterior margins of the glenoid labrum. Rarely, the tendon arises from the undersurface of the Supraspinatus tendon, buttonholing the Supraspinatus tendon, adhering to the capsuloligamentous structures of the joint. Other times, it may be bifurcated at the origin from the supraglenoid tubercle, or it may be bifid.(Andreoli et al., 2016).

The tendon of the long head is extra-synovial but intracapsular, ensheathed in a double synovial tube. It emerges from under the joint capsule and pericapsular ligamentous structures and tendons of the rotator cuff between the lesser and greater tuberosity (**Fig. 15**). It enters the intertubercular groove, which varies in width and depth. When the arm is resting by the side of the body, the exiting tendon makes a sharp angle in its intracapsular course, laterally and distally, under the transverse humeral ligament that spans across the tuberosities. The ligament retains the tendon in the groove during the movements at the shoulder joint. Occasionally, the transverse ligament may be reinforced by the Supraspinatus expansion, extending distally to blend with the tendon of Pectoralis major(Moser et al., 2014).

**Figure 15.** The author's dissection demonstrates the long head of the Biceps brachii in the intertubercular groove with its sleeve laid open vertically (held with the forceps), revealing degenerative changes.

In a medially rotated resting arm, the two elongated muscle bellies come together. Otherwise, the two bellies, on average, meet distally at 84mm from the point where the long head emerges under the intertubercular transverse ligament and 75mm from the tip of the coracoid process, at a variable angle of approximately 14 to 16 degrees(Katsuki et al., 2021). They can function as independent units because of their different action vectors. The two heads can be easily separated within 70mm from the elbow joint line(Lambert, 2016).

At the merger point, the two bellies end into a flattened tendon, which inserts on the rough posterior area of the radial tuberosity. Just before insertion, the tendon spirals on itself so that its anterior surface faces laterally(Standring, 2016). The tendon has a broad medial expansion called bicipital aponeurosis, which takes a curved path descending medially across the Brachial artery in the cubital fossa to fuse with the deep fascia over the long flexors of the forearm. The tendon can be split as far as the tuberosity into anterior and posterior layers from the respective short and long heads. The laminar arrangement may facilitate supination and pronation of the forearm(Benjamin et al., 1992).

The proximal part of the Biceps brachii is deep to the Pectoralis major and Deltoid muscles and distally covered by fasciae and skin. The indirect short head lateral to the Coracobrachialis overlaps the brachial vessels and the Median nerve. The fibres extending from the coracohumeral and superior glenohumeral humeral ligaments retain the direct long head tendon of the Biceps in the bicipital groove in its place as it exits, angulating over the osseous pulley to enter the groove(Clark & Harryman, 1992). As the Biceps muscle is biarticular, depending on the movement of the humerus at the glenohumeral joint and elbow joint, it stabilizes the joints, while the humerus moves relative to the long tendon held in the groove.

The Musculocutaneous nerve, with root values of C5 and C6, innervates the Biceps brachii through separate branches entering the two muscle bellies. The sensory and sympathetic fibres innervating the long head of the biceps, mainly concentrated at its origin, are a source of pain in shoulder pathologies(Alpantaki et al., 2005).

The main action of the Biceps brachii is to supinate the forearm against resistance, when the elbow is at a right angle to the humerus. Secondarily, it acts as a forearm flexor, which is most effective when the forearm is supinated. In a cadaveric study, the long head's moment arm was significantly longer in supination, whereas the short head had a considerably more extended moment arm in neutral and pronation, making it a relatively more efficient supinator(Jarrett et al., 2012). The bicipital aponeurosis, wrapping around the flexors, attaching to the posterior border of the ulna also assist with supination. The role of the long head in stabilizing the glenohumeral articulation and its movements is controversial. It may have a stabilizing role in preventing superior translation of the humeral head in conjunction with the rotator cuff's compressive action with Deltoid contraction during part of the arm elevation arc. However, in a biomechanical study, tenotomy of the long head of the Biceps demonstrated no role during abduction of the arm(Shavana et al., 2022).

From an anatomical and biomechanical evolutionary perspective, the advantages of the biarticular muscles with multiple bellies, featuring distinct origins of the direct and indirect vectors, varying lengths of moment arms, and differential torque generation at either joint due to separate sets of motor neurons in the muscle bellies and conjoint insertions, remain controversial(Watanabe et al., 2021). Strain injuries of biarticular muscles, similar to the Tennis elbow and hamstrings, are common, and rupture of the Biceps brachii tendon due to eccentric contraction, combined with shoulder and elbow extension, often requires surgical reconstruction. How the function and biomechanics of the Biceps brachii alter following the malunion of a clavicle fracture is discussed in greater detail in the part 6 of the series.

### 7.12 Coracobrachialis muscle:

The Coracobrachialis shares the anterior compartment of the upper arm with the Biceps brachii. It has a conjoint muscular origin from the undersurface of the coracoid tip, deep to the aponeurotic origin of the short head of the Biceps brachii. The two muscles are joined for a variable length of 50-100mm. Lying medial to the belly of the short head of the Biceps, the Coracobrachialis has a substantial insertion footprint, 30 to 50mm in length, located halfway along the medial border just above the nutrient foramina on the anteromedial surface of the humeral shaft. It also has accessory insertions via the intermuscular septa that reach the medial epicondyle of the humerus(Standring, 2016). Proximally, it lies deep to the Pectoralis major tendon. Distally, the brachial vessels and median nerve lie deep in the groove between the Coracobrachialis and the shorthead of the Biceps medially, with the Brachialis muscle laterally.

The musculocutaneous nerve innervates the Coracobrachialis with roots from C5, C6 and C7.

The Coracobrachialis act as an adductor of the humerus. At the initiation of abduction and extension of the arm, it antagonizes the Deltoid. As abduction progresses, in conjunction with the anterior fibres of the Deltoid, it acts like a stay wire, preventing the arm and hand from swaying when reaching for a target. It also flexes the arm forward in the sagittal plane.

The other important muscles of the pectoral girdle, including the spinoscapular and scapulohumeral groups, are the Rhomboids and the Subscapularis. These muscles influence the kinematics of the glenohumeral articulation and the scapulothoracic and acromiohumeral synsarcoses.

**Conflict of interest:** The author declares no conflict of interest.

**Acknowledgement:** The author would like to thank Dr. Rajiv Devgan, Director Principal; Dr. Jagdev Singh Kullar, Professor & Head, Department of Anatomy, Government Medical College, Amritsar, Punjab, India, for granting permission to perform anatomy dissection and for providing dry clavicle bone specimens; and S. Jasminder Singh, Anatomy artist, Government Medical College, Amritsar, Punjab, India, for preparing the artwork to compliment the text,

**Funding:** The author received no financial support for the research, travel, authorship and publication of this 9 Part series.

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