“ A STUDY OF THE FORMATION AND BRANCHING PATTERN OF BRACHIAL PLEXUS AND ITS VARIATIONS IN ADULT HUMAN CADAVERS OF NORTH KARNATAKA ”

by

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Dissertation

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MASTERS DEGREE

in

ANATOMY

Under the guidance of

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LIST OF ABBREVIATIONS USED

C -	Cervical
T -	Thoracic
CNS -	Central Nervous System
MT -	Middle Trunk
MN -	Median Nerve
AA -	Axillary Artery
MCN -	Musculocutaneous Nerve
RN -	Radial Nerve
LT -	Lower Trunk
UN -	Ulnar Nerve
LPN -	Lateral Pectoral Nerve
MPN -	Medial Pectoral Nerve
UT -	Upper Trunk
AN -	Axillary Nerve

ABSTRACT

Background and objectives -

The brachial plexus is highly variable in its formation and branching pattern and the knowledge of its basic anatomical pattern may be insufficient for the surgeon operating on or around these nerves and for the anaesthesiologist while working in this area. Commonly the brachial plexus can get injured in infants during the process of parturition and during adult life due to fall on an outstretched hand. Thus, the present study was an effort to know further, about variations of brachial plexus encountered during routine dissection classes, thus tracing the plexus in its entire course right from its formation in the cervical region to its branching pattern confined to the axilla and arm region of the upper extremity.

Methods -

The present descriptive study was carried out by dissection of 60 upper limbs of 30 cadavers, in the age group of 18 to 85 years, obtained during a study period of 2 years from the Department of Anatomy. The plexus was studied in its entire course commencing from the formation in cervical region, course through root of the neck and axilla, till the main terminal branches of the upper extremity. During the dissection, variations of brachial plexus pertaining to its formation from the roots, trunks, divisions and cords and the branching pattern were observed and data was collected.

Results -

Out of the 60 cadaveric upper limbs studied for the anatomical variations of the brachial plexus, 2 limbs (3.33%) were pre-fixed plexuses. Fusion of adjacent trunks was detected in 2 limbs (3.33%), where middle and lower trunks were fused. Variations in branches of lateral cord was detected in 8 limbs (13.33%), in which extra lateral root of median nerve was detected in 7 limbs (11.67%) and 4 limbs (6.67%) had absence of musculocutaneous nerve. Among Posterior cord variations 2-thoracodorsal nerves were detected in 2 limbs (3.33%). In one limb (1.67%) the posterior cord divided into two branches/roots, which later fused to form the radial nerve. In two limbs (3.33%) the posterior cord was formed from joining of the posterior division of upper trunk to the common posterior division from fused middle and lower trunks. The median nerve was formed from 3 roots in 7 limbs (11.67%). In 7 limbs (11.67%) communicating branch was encountered between musculocutaneous nerve and median nerve. In one limb (1.67%) there was a communicating branch from radial nerve to ulnar nerve. In another case (1.67%) radial nerve was formed from two roots, formed by splitting of the posterior cord, which subsequently united to form radial nerve. In one case (1.67%) there was high division of radial nerve in the arm. In one case (1.67%) axillary nerve, upper subscapular nerve and lower subscapular nerve originated from posterior division of upper trunk and only the radial nerve and thoracodorsal nerve originated from posterior cord. All the other branches from brachial plexus had been found to have no anatomical variations.

Conclusion and Interpretation -

In the present study, an attempt has been made to know the possible variations of the brachial plexus. Though the variations mentioned may not alter the normal

functioning of the limb of the individual, but knowledge of the variations is of prime importance to be kept in mind, during anaesthetic and surgical procedures. The restricted sample size was a limitation in our study. Yet an earnest effort in the study has opened new avenues for further research.

Key words - brachial plexus; variations; median nerve; ulnar nerve; radial nerve; musculocutaneous nerve; axillary nerve; thoracodosal nerve; posterior cord; cadavers; upper trunk; middle trunk; lower trunk.

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INTRODUCTION

The brachial plexus is a complex network of nerves, which extends from the neck to the axilla and supplies motor, sensory, and sympathetic fibers to the upper extremity. In the brachial plexus, the intricate manner in which anastomotic connections are formed, give rise to the nerves as the cutaneous and motor supply with successions of separations and conjunctions, accounts for the numerous variations, which in some instances may be salient. The fibers certainly find their final destination but the reason for the deviation producing such neuronal complexity, is beyond comprehension, in spite of the fact that many theories have been propagated to account for it.

The brachial plexus literally means arm braid and has been a topic of discussion in medical literature through the centuries, right from the first anatomical dissections in the ancient period. The brachial plexus is situated in the posterior triangle of the cervical region and in the axilla. This plexus is a union of the lower four cervical (C5, C6, C7, and C8) ventral rami and the first thoracic (T1) ventral ramus. At the lateral border of the anterior scalene muscle, the five roots unite to form the upper, middle and lower trunks, each of which splits into anterior and posterior divisions in the floor of the posterior triangle of the neck. At the upper border of the first rib, the divisions join to form lateral, medial and posterior cords. Just distal to the inferior border of the pectoralis minor muscle, near the third part of the axillary artery, the cords give off their terminal branches, including the axillary, musculocutaneous, radial, median and ulnar nerves.[1-4]

The frequency of variations found in the arrangement and distribution of the branches in the brachial plexus, make this anatomical region extremely complicated. The medical interventions involved with these variations include anaesthetic blocks, surgical approaches, interpreting nervous compressions caused by tumor or trauma, having unexplained clinical symptoms and the possibility of these structures being sometimes irreversibly damaged.

As the embryonic somites migrate to form the extremities, they bring their own nerve supply, so that each dermatome and myotome retains its original segmental innervation. Throughout somite migration, some of the nerves come into close proximity and fuse in a particular pattern, forming a plexus early in fetal life. However, the neurovascular bundle changes with growth, with respect to relative elongation of the neck and alterations of the ribs.[5-7] Its location and osseous relations make the plexus vulnerable to damage by traction[8], especially during routine neck dissection[9], penetrating wounds, compression from cervical ribs or damage to related vertebrae.[10, 11]

Injuries to upper trunk of brachial plexus of the infant may occur during the process of parturition requiring interventional obstetric procedures, as a result of application of forceps, which can cause a condition called Erb's palsy.

During adult life, fall on an outstretched hand may cause wide separation of head and shoulder, injuring the lower trunk of brachial plexus, which can give rise to Klumpke's palsy.[12]

The present study was an effort to know more about variations of brachial plexus encountered during routine dissection classes, thus tracing the plexus in its entire course right from its formation to its branching pattern into main nerves of the upper extremity.

OBJECTIVES

To study the neuroanatomical variations of brachial plexus pertaining to its formation and branching pattern, in its supraclavicular course, as well as, in its infraclavicular course limiting the study to its five main terminal branches confined to the arm region in upper limbs of human cadavers.

REVIEW OF LITERATURE

The brachial plexus is a union of the ventral rami of the lower four cervical nerves and the greater part of the first thoracic ventral ramus. The fourth ramus usually gives a branch to the fifth and the first thoracic frequently receives one from the second. These ventral rami are the roots of the plexus and are almost equal in size but variable in their mode of junction. Contributions to the plexus by C4 and T2 vary. When the branch from C4 is large, that from T2 is frequently absent and the branch from T1 is reduced, forming a 'prefixed' type of plexus. If the branch from C4 is small or absent, the contribution from C5 is reduced but that from T1 is larger and there is always a contribution from T2; this arrangement constitutes a 'postfixed' type of plexus.[13]

Close to their exit from the intervertebral foramina, the fifth and sixth cervical ventral rami receive grey rami communicantes from the middle cervical sympathetic ganglion, and the seventh and eighth receive grey rami from the cervicothoracic ganglion. The first thoracic ventral ramus receives a grey ramus from, and contributes a white ramus to, the cervicothoracic ganglion.[13] The most common arrangement of the brachial plexus is as follows: the fifth and sixth rami unite at the lateral border of scalenus medius as the upper trunk; the eighth cervical and first thoracic rami join behind scalenus anterior as the lower trunk; the seventh cervical ramus becomes the middle trunk. The three trunks incline laterally, and either just above or behind the clavicle each bifurcates into anterior and posterior divisions. The anterior divisions of the upper and middle trunks form a lateral cord that lies lateral to the axillary artery. The anterior division of the lower trunk descends at first behind and then medial to the axillary artery and forms the medial cord, which often receives a branch from the seventh cervical ramus. Posterior divisions of all three trunks unite to form the posterior cord, which is at first above and then behind the axillary artery. The posterior division of the lower trunk is much smaller than the others and contains only a few, if at all any, fibres from the first thoracic ramus. It is frequently derived from the eighth cervical ramus before the trunk is formed.[13]

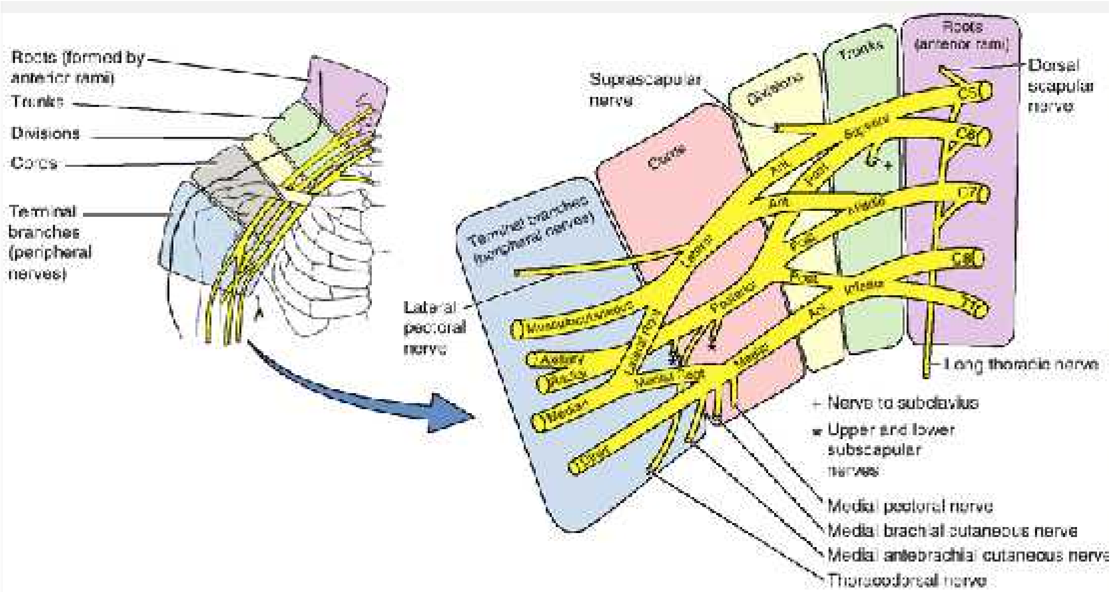


Diagram showing anatomy of normal brachial plexus[14]

Nerve	Origin	Course	Structures Innervated
Supraclavicular branches			
Dorsal scapular	Posterior aspect of anterior ramus of C5 with a frequent contribution from C4	Pierces middle scalene; descends deep to levator scapulae and rhomboids	Rhomboids; occasionally supplies levator scapulae

Long thoracic	Posterior aspect of anterior rami of C5, C6, C7	Passes through cervicoaxillary canal, descending posterior to C8 and T1 roots of plexus (anterior rami); runs inferiorly on superficial surface of serratus anterior	Serratus anterior
Suprascapular	Superior trunk, receiving fibers from C5, C6 and often C4	Passes laterally across lateral cervical region (posterior triangle of neck), superior to brachial plexus; then through scapular notch inferior to superior transverse cervical ligament	Supraspinatus and infraspinatus muscles; glenohumeral (shoulder) joint
Subclavian nerve (nerve to subclavius)	Superior trunk, receiving fibers from C5, C6 and often C4	Descends posterior to clavicle and anterior to brachial plexus and subclavian artery; often giving an accessory root to phrenic nerve	Subclavius and sternoclavicular joint (accessory phrenic root innervates diaphragm)
Infraclavicular branches			
Lateral pectoral	Side branch of lateral cord, receiving fibers	Pierces costocoracoid membrane to reach deep surface of pectoral	Primarily pectoralis major; but some lateral pectoral nerve fibers

	from C5, C6, C7	muscles; a communicating branch to the medial pectoral nerve passes anterior to axillary artery and vein	pass to pectoralis minor via branch to medial pectoral nerve
Musculo-cutaneous	Terminal branch of lateral cord, receiving fibers from C5-C7	Exits axilla by piercing coracobrachialis; descends between biceps brachii and brachialis, supplying both; continues as lateral cutaneous nerve of forearm	Muscles of anterior compartment of arm (coracobrachialis, biceps brachii and brachialis); skin of lateral aspect of forearm
Median	Lateral root of median nerve is a terminal branch of lateral cord (C6, C7); medial root of median nerve is a terminal branch of medial cord (C8, T1)	Lateral and medial roots merge to form median nerve lateral to axillary artery; descends through arm adjacent to brachial artery, with nerve gradually crossing anterior to artery to lie medial to artery in cubital fossa	Muscles of anterior forearm compartment (except for flexor carpi ulnaris and ulnar half of flexor digito-rum profundus), five intrinsic muscles in thenar half of palm and palmar skin

Medial pectoral		Passes between axillary artery and vein; then pierces pectoralis minor and enters deep surface of pectoralis major; although it is called medial for its origin from medial cord, it lies lateral to lateral pectoral nerve	Pectoralis minor and sternocostal part of pectoralis major
Medial cutaneous nerve of arm	Side branches of medial cord, receiving fibers from C8, T1	Smallest nerve of plexus; runs along medial side of axillary and brachial veins; communicates with intercostobrachial nerve	Skin of medial side of arm, as far distal as medial epicondyle of humerus and olecranon of ulna
Median cutaneous nerve of forearm		Initially runs with ulnar nerve (with which it may be confused) but pierces deep fascia with basilic vein and enters subcutaneous tissue, dividing into anterior and posterior branches	Skin of medial side of forearm, as far distal as wrist
Ulnar	Larger terminal branch of medial cord, receiving	Descends medially in arm; passes posterior to medial epicondyle of humerus;	Flexor carpi ulnaris and ulnar half of flexor digitorum profundus

	fibers from C8, T1 and often C7	then descends ulnar aspect of forearm to hand	(forearm); most intrinsic muscles of hand; skin of hand medial to axial line of digit 4
Upper subscapular	Side branch of posterior cord, receiving fibers from C5	Passes posteriorly, entering subscapularis directly	Superior portion of subscapularis
Lower subscapular	Side branch of posterior cord, receiving fibers from C6	Passes inferolaterally, deep to subscapular artery and vein	Inferior portion of subscapularis and teres major
Thoracodorsal	Side branch of posterior cord, receiving fibers from C6, C7, C8	Arises between upper and lower subscapular nerves and runs inferolaterally along posterior axillary wall to apical part of latissimus dorsi	Latissimus dorsi
Axillary	Terminal branch of posterior cord, receiving fibers from C5, C6	Exits axillary fossa posteriorly, passing through quadrangular space with posterior circumflex humeral artery; gives rise to superior lateral brachial	Glenohumeral (shoulder) joint; teres minor and deltoid muscles; skin of superolateral arm (over inferior part of deltoid)

		cutaneous nerve; then winds around surgical neck of humerus deep to deltoid	
Radial	Larger terminal branch of posterior cord (largest branch of plexus), receiving fibers from C5-T1	Exits axillary fossa posterior to axillary artery; passes posterior to humerus in radial groove with profunda brachii artery, between lateral and medial heads of triceps; perforates lateral intermuscular septum; enters cubital fossa, dividing into superficial (cutaneous) and deep (motor) radial nerves	All muscles of posterior compartments of arm and forearm; skin of posterior and inferolateral arm, posterior forearm, and dorsum of hand lateral to axial line of digit 4
Table explaining anatomy of normal brachial plexus[14]			

Embryological basis

During development, the sensory and motor neurons of the brain become interconnected in functional patterns and the axons grow out of the CNS and ganglia to innervate appropriate target organs. Axons travel to their target structures through the active locomotion of an apical structure called a growth cone. The growth cone moves by means of filopodia and guides the axon to its destination by sensing molecular markers that designate the correct route. This activity of the growth cone is called pathfinding. Once the growth cone reaches its target, it halts and forms a synapse. Somatic motor and sensory fibres synapse directly with their end organs.[15]

A number of mechanisms have been proposed to explain the ability of the neurons to establish correct connections with each other and with end organs. It has been suggested, that at the appropriate time during development the end organs secrete either a trophic substance [netrin-1 and netrin-2] that attracts the correct growth cones or a trophic substance [brain-derived neural growth factor (BDNF) and insulin-like growth factor (IGF)] that supports the viability of growth cones that happen to take the right path. It is also likely that the first or pioneer growth cones traverse a route and establish a pathway that is used by later growing axons. This mechanism would account for the formation of nerves, in which many axons travel together.[15]

The base of the early limb bud is relatively broad in comparison with the length of the body and lies at the level of a greater number of somites than it does after further growth occurs. Since the segmentation of spinal nerves is dependent upon that of the somites, the limb bud develops at the level of a number of spinal nerves, typically those from C5 to T1. The ventral branches of these spinal nerves join each other to form a plexus and the plexus divides into dorsal and ventral parts, corresponding to the division of premuscle mass into extensor and flexor parts. The nerves from these divisions grow out with the developing limb, the dorsal or extensor portion of the plexus (largely the posterior cord and its branches) supplying the corresponding part of the premuscle mass, ventral or flexor portion (medial and lateral cords) supplying the developing anterior or flexor muscles.[16]

History

Hippocrates provided one the first known references that stressed the importance of nerves, warning physicians to avoid injuring the nerves within the dislocated shoulders of soldiers during repair. Sushruta, through the observation of different injuries and their results, was able to describe the function of many components of the peripheral nervous system. Galen differentiated nerves from tendons and reported the successful repair of nerves by other physicians, although no record exists that he attempted any repairs (130-200 AD). In the seventh century, Paulus Aegineta was the first to report the use of suture and agglutination to repair nerves. Other physicians who performed early work with nerves and their repair include Rhazes and Avicenna in the ninth century, Ali Abu Ibn Sina in Persia during the 10th century, and Ferrara in Italy in the 17th century.[17]

Clinical applications

Injuries to the brachial plexus usually affect movements and cutaneous sensations in the upper limb. Disease, stretching, and wounds in the lateral cervical region i.e. the posterior triangle of the neck or in the axilla may produce brachial plexus injuries. Signs and symptoms depend on the part of the plexus involved. Injuries to the brachial plexus result in paralysis and varying degrees of anesthesia. Testing the person's ability to perform movements assesses the degree of paralysis. In complete paralysis, no movement is detectable. In incomplete paralysis, not all muscles are paralyzed; that means, the person can still move, but the movements are weak comparatively than those on the normal side. Determining the ability of the person to feel pain (e.g., from a pinprick of the skin) tests the degree of anesthesia.[14]

Injuries to superior parts of the brachial plexus (C5 and C6) usually result from an excessive increase in the angle between the neck and the shoulder. These injuries can occur in a person who is thrown from a motorcycle or a horse and lands on the shoulder in a way that widely separates the neck and shoulder. When thrown, the person's shoulder often hits something (e.g., a tree or the ground) and stops, but the head and trunk continue to move due to inertia which in turn stretches or ruptures superior parts of the brachial plexus or avulses the roots of the plexus from the spinal cord. Injury to the superior trunk of the plexus is apparent by the characteristic position of the limb described as the waiter's tip position, in which the limb hangs by the side in medial rotation. Upper brachial plexus injuries can also occur in a newborn when excessive stretching of the neck occurs during a difficult labor or interventional obstetric procedure like the application of obstetric forceps.[14]

As a result of injuries to the superior parts of the brachial plexus classically described as the Erb-Duchenne palsy, muscles of the shoulder and arm supplied by the C5 and C6 spinal nerves for e.g. the deltoid, biceps, brachialis, and brachioradialis are paralyzed. The usual clinical appearance is an upper limb with an adducted shoulder, medially rotated arm, and extended elbow. The lateral aspect of the upper limb also experiences loss of sensation. Chronic microtrauma to the superior trunk of the brachial plexus from carrying a heavy backpack for e.g. during mountaineering, can produce motor and sensory deficits in the distribution of the musculocutaneous and radial nerves. A superior brachial plexus injury may produce muscle spasms and a severe disability in hikers described as backpacker's palsy who carry heavy backpacks for long periods.[14]

Acute brachial plexus neuritis or in other words brachial plexus neuropathy is a neurologic disorder of unknown cause that is characterized by the sudden onset of severe pain, usually around the shoulder. The pain characteristically begins at night and is followed by muscle weakness and sometimes, muscular atrophy called the neurologic amyotrophy. Inflammation of the brachial plexus or brachial neuritis is often preceded by some event for e.g., upper respiratory infection, vaccination, or non-specific trauma. The nerve fibers thus involved are usually derived from the superior trunk of the brachial plexus.[18]

Compression of cords of the brachial plexus may result from prolonged overhead abduction or hyperabduction of the arm usually encountered in painters during painting a ceiling. The cords are impinged or compressed between the coracoid process of the scapula and the pectoralis minor tendon. Common neurologic symptoms are pain radiating down the arm, numbness, paresthesia or tingling sensation, erythema or redness of the skin caused by capillary dilation, and weakness affecting the hands. Compression of the axillary artery and vein causes ischemia of the upper limb and subsequent distension of the superficial veins. These signs and symptoms of hyperabduction syndrome result from compression of the axillary vessels and nerves.[14]

Injury to inferior parts of the brachial plexus characteristically described as Klumpke paralysis is much less common. Inferior brachial plexus injuries may occur when the upper limb is suddenly pulled superiorly, for example, when a person grasps something to prevent a fall or a baby's upper limb being pulled excessively during delivery. These events injure the inferior trunk of the brachial plexus (C8 and T1), which may avulse the roots of the spinal nerves from the spinal cord. The short muscles of the hand are thus affected and a claw hand results.[14]

Injecting an anesthetic solution into or immediately surrounding the axillary sheath interrupts nerve impulses and produces anesthesia of the structures supplied by the branches of the cords of the plexus. Sensations are blocked in all deep structures of the upper limb and the skin distal to the middle of the arm. This procedure combined with an occlusive tourniquet technique to retain the anesthetic agent, enables surgeons to operate on the upper limb without using a general anesthetic. The brachial plexus can be anesthetized using a number of approaches like an interscalene, supraclavicular and axillary approach or block.[19]

Previous studies related to brachial plexus

Pandey SK and Shukla VK (2002) studied the variations in formation, location and courses of the cords of brachial plexus and the median nerve in both axillae of 172 cadavers. The total prevalence of variation was 12.8% and it was found in 13.2% of male and in 10.7% of female cadavers. These variations were divided into three groups. In the first group there was abnormal location of the cords, which was either posterolateral or anteromedial in relation to the axillary artery in 2.3% cadavers. The lateral cord and the medial root of the median nerve had received communicating branches from the posterior cord in most of the cases of this group. In the second group there was absence of the posterior cord in 3.5% of cadavers. The lateral and medial cords of this group were connected with the communicating branches, which had a course in front of the axillary artery. In the third group there was abnormal formation and course of the median nerve in 7% of cadavers. In all cases of this group the medial root received communicating branch/branches either from the lateral or posterior cord. In eight (4.7%) cadavers, both roots of the median nerve were joined on medial side of the axillary artery to form a median nerve, which traveled medial to the artery. In four (2.3%) cadavers the roots of the median nerve did not join and both traveled separately anteromedial to the axillary and brachial arteries. This study indicates that all three cords and median nerve vary considerably in levels of origin, location and course in relation to the axillary artery and in addition to these there were communicating branch/branches accounting for increased number of variations encountered.[20]

Oluyemi et al (2007) observed a unilateral variation in the pattern of formation of brachial plexus in the left arm of an adult cadaver. This Brachial plexus had only two cords (medial & lateral) with three abnormal communications. A branch was observed to originate from the posterior aspect of medial cord, which ran for about 2cm before it divided into the axillary and radial nerves, both of which had normal courses. The lateral cord sent an abnormal communication to the medial cord as the latter gave off the medial root of median nerve. This abnormal branch fused with the branch from medial cord to form the medial root of median nerve. The lateral cord also gave the lateral root of median nerve. An abnormal communication was observed between the musculocutaneous and median nerves. The abnormal branch of the musculocutaneous nerve was found originating at the junction of the superior and middle thirds of the left brachium. It coursed inferiorly between the accessory head of biceps brachii and brachialis muscles for about 9.2 cm and joined the median nerve 15.5 cm below its origin and 5.5cm above the base of the cubital fossa. Giving its accessory branch and the nerve to the biceps brachii and brachialis muscle, the

Musculocutaneous nerve coursed normally as lateral cutaneous nerve of forearm. In this case of a brachial plexus with only two cords (medial & lateral) axillary and radial nerves originated from what seems like posterior cord from the posterior aspect of medial cord. This states that the three posterior divisions of upper, middle and lower trunks that were supposed to form the posterior cord were fused with the medial cord. The communication between the medial and lateral cords is unusual. An abnormal branch from the medial to lateral cord running laterally has been reported but not vice versa as seen in this case. This branch fused with the medial root of median nerve. This is probably due to some fibres of medial cord running in lateral cord leaving it later to join the medial cord. Because each peripheral nerve is a collection of nerve fibres bound together by connective tissue, it is understandable that the median nerve, for instance, may have two medial roots instead of one, which means the nerve fibres are simply grouped differently. This results from the fibres of the medial cord of the brachial plexus dividing into three branches, two forming the median nerve and the third forming the ulnar nerve. In the present study though the median nerve has two medial roots, one of them came from the lateral cord and fused with the medial root from the medial cord.[21]

During the routine dissection of the left upper limb of a 60-year-old Caucasian male cadaver, Saeed M et al (2003) observed median nerve formation by three roots, two from lateral cord and one from medial cord of brachial plexus. The lateral root of median nerve crossed anterior to distal part of axillary artery. In the distal half of the arm median nerve contributed a communicating branch to musculocutaneous nerve.[22]

A variation of the brachial plexus, characterized by the absence of the musculocutaneous nerve on the left arm, was found during the dissection of a 28-year old male cadaver in which the whole lateral cord was joined to the median nerve, which met it in two points. One was a typical junction of both roots of the median nerve at the level of the coracoid process. The other was a junction of the remaining lateral cord and the median nerve 9.2 cm away from the typical junction. As the nerves are named due to their course or innervation, and not from their origin, it is reasonable to assume that the combined nerve was actually the median nerve, and that the musculocutaneous nerve did not exist.[23] During the dissection done on 24 upper limbs, two cases of absence of musculocutaneous nerve (8%) were seen. Median nerve took over the area of supply of musculocutaneous nerve. [24]

The anatomical knowledge of variations of the innervations of the coracobrachialis muscle is important for the surgeons performing coracoid transfers.[25] Coracobrachialis is a flexor muscle of arm, which is vulnerable to injury from retractors placed under the coracoid muscle during shoulder reconstructive surgery. The operative management by coracoid graft transfers in recurrent dislocation of shoulder and arthroscopic procedures on the shoulder could be the potential source of lesions to structures piercing the muscle.[26] The muscle has also been suggested for possible use as flap for coverage in infra clavicular defects of exposed axillary vessels, especially in post mastectomy reconstructive surgery.[27]

Absence of musculocutaneous nerve was noted by Sud and Sharma (2000), in which the lateral cord gave a lateral pectoral nerve just below the outer border of the first rib to the pectoralis major muscle. Instead of giving musculocutaneous nerve, there were two lateral roots joining the median nerve. The first root and the second root given to the median nerve were 5 and 10 cm from the outer border of the first rib respectively. Both these roots were observed to join the median nerve in front of the axillary artery. From the lateral side of the median nerve, 6 cm from the outer border of the first rib, a branch was given to the coracobrachialis. Another branch was given to biceps brachii from its lateral side at a distance of 16.5 cm from the outer border of first rib. The lateral cutaneous nerve of the forearm was also given from the lateral side of the median nerve about 17 cm from outer border of the first rib. The lateral cutaneous nerve of the forearm gave a branch 20 cm from the outer border of the first rib to the brachialis muscle. This branch after supplying the brachialis, pierced its substance and emerged to supply the biceps brachii.[28]

Hye Y L et al (1992) studied the variations in the ventral rami of 152 brachial plexuses in 77 Korean adults. Brachial plexus were composed mostly of the fifth, sixth, seventh and eighth cervical nerves and the first thoracic nerve (77.0%). In 21.7% of the cases examined, the fourth, fifth, sixth, seventh and eighth cervical and the first thoracic nerves contributed to the plexus. A plexus composed of the fourth, fifth, sixth, seventh and eighth cervical and the first and second thoracic nerves, and a plexus composed of the fifth, sixth, seventh eighth cervical nerves were also observed. The plexuses were classified into three groups according to cephalic limitation, and the plexus of group 2 in which the whole fifth cervical nerve enters the plexus, were observed the most frequent. The average diameter of the sixth and the seventh cervical ventral rami of the plexus were greatest and that of the fifth cervical was smallest. The largest nerve entering the plexus was the sixth or the seventh cervical nerve in about 79% of cases. The dorsal scapular nerve originated from the fifth cervical ventral ramus in 110 cases (75.8%). The long thoracic nerve was formed by, joining of roots from the fifth, sixth, and seventh cervical nerves in 76.0% of cases. Also, a branch to the phrenic nerve, the suprascapular nerve, a nerve to the pectoralis major muscle and a nerve to the subscapular muscle arising from the ventral rami of the plexus were observed. A brachial plexus composed of the fourth to eighth cervical and the first and second thoracic nerves was present in one case. And in another case, a plexus composed of only cervical nerves (fifth to eighth) was observed. In females, the incidence of the fourth cervical nerve joining the brachial plexus was higher than in males.[29]

Anterior scalene muscle is separated from middle scalene muscle by the subclavian artery and the anterior rami of the C8 and T1 nerves. The second part of the subclavian artery lies behind anterior scalene muscle. The trunks of the brachial plexus and the third part of the subclavian artery emerge from the lateral border of the anterior scalene muscle. When present a cervical rib or fibrous band, it may result in pressure to the subclavian artery or T1 root when they cross over them. The subclavian artery and T1 nerve become displaced upwards over such a rib or band, and pressure upon the neurovascular structures from below may cause severe symptoms.[30]

Until the 1920s, thoracic outlet syndrome (TOS) was believed to be a vascular condition caused by compression of the subclavian artery by a congenital anomaly, either a cervical rib or tight anterior scalene muscle. Today it is regarded primarily as a neurologic condition caused by neck trauma injuring and scarring the scalene muscles.[31, 32] The subclavian artery may be affected either by a hypertrophic muscle, a strain, or accompanying soft tissue problems like fibrosis or congenital bands.[31]

Kocabiyik N (2007) reported a case where, suprascapular nerve did not arise from the superior trunk. It arose from the root of C5; while the other branch of C5 joined C6. Superior subscapular, thoracodorsal and inferior subscapular nerves arose from the posterior division of the upper trunk, instead of the posterior cord. Then, the posterior cord continued as axillary and radial nerves. The musculocutaneous and ulnar nerves had their normal course.[33]

Uysal I et al (2003) studied the brachial plexus variations in human fetuses. There were no variations in 93 plexuses, and 107 plexuses were observed to have different variations. Morphological variations were observed more frequently among female fetuses and right sides. The brachial plexuses were composed mostly of the C5, C6, C7, and C8 nerves and the T1 nerve (71.5%). A prefixed plexus was observed in 25.5% of cases, and a postfixed plexus was observed in 2.5% of cases. In one case (0.5%), the C4 and T2 nerves joined the formation. The inferior trunk was not formed in 9% of cases. The superior trunk was not formed in 1% of cases. In one plexus, the superior trunk was formed by the ventral rami of the C4 and C5 nerves. In one case, the inferior trunk was formed by the ventral rami of the T1 and T2 nerves. Division variations were observed most frequently. There were also variations in the terminal branches, such as the roots of the median nerve joining in the distal part of the arm (8.5%), the axillary nerve being separate from the posterior division of the superior trunk (2.5%), and a connection existing between the median and musculocutaneous nerves (1%). [34]

Although Hollinshead (1982) [6] & Williams et al. (1995) [35] have mentioned that if the lateral root of median nerve is small then a communication is formed between musculocutaneous and median nerve. This results from the fact that majority of median nerve fibers from the lateral cord pass into musculocutaneous nerve and then rejoining the median nerve at lower level. Joshi S D et al (2008) reported an interesting finding in their series where the formation of median nerve was in two stages in 20% limbs In their series of two-stage formation of median nerve, in the majority (70%), in place of one there were two roots derived from the lateral cord. The lower of the two roots joined the main trunk at a variable distance in the arm. They have found a communication between musculocutaneous and median nerves in approximately 14% limbs which may be i) thick - where after the origin of branches of musculocutaneous the whole nerve joins the median nerve; ii) thin - where the fibres could cross from one nerve trunk to other in either direction and iii) where there were two communications observed between these nerves.[36]

Chitra R (2007) observed during dissection that the two roots of the median nerve joined behind the axillary artery to form the median nerve, which coursed behind the brachial artery and then crossed to the medial part of cubital fossa. The lateral root passed between the axillary artery and anterior circumflex humeral artery to course posteriorly to join the medial root of median nerve. This variation may be clinically important because symptoms of median nerve compression arising from similar variations are often confused with more common causes such as radiculopathy and carpal tunnel syndrome.[37]

Intercommunications between musculocutaneous nerve and median nerve deserve important interest in view of their clinical significance. In the study done by Chitra R (2007) on 50 upper limb specimens, the various communications between the musculocutaneous and median nerve in the arm were observed carefully. The communications between the two nerves were found in 13 arms. Variations involving the median nerve and musculocutaneous nerve are important in repairs for trauma to the shoulder and the understanding of the median nerve and the musculocutaneous nerve dysfunction.[38]

Ibrahim et al (2005) have reported an unusual unilateral variation between median and musculocutaneous nerves in the arm of a 48 years old male cadaver. The median nerve originated normally from brachial plexus but received a branch from musculocutaneous nerve on its way to the cubital fossa. The abnormal branch from the musculocutaneous nerve coursed an oblique pathway to join the median nerve. These types of variations of the nerves of the arm should be considered prior to traumatic evaluations and reconstructive interventions. In their observation, the lateral root of median nerve from the lateral cord was significantly normal and the abnormal communicating branch was significantly thick. It is not unusual to find a nerve trunk of considerable size leaving the musculocutaneous and passing distally and medially to join the median nerve. This is a result of median nerve fibers from the lateral cord passing into the musculocutaneous rather than into the lateral root of the median and then rejoining the median nerve at a lower level. When this occurs, the lateral root of the median nerve is typically abnormally small. After a trauma to the arm, signs of median nerve injury could be observed in a patient with an intact median nerve if such a variation is present and the fibers coursing in the musculocutaneous nerve are damaged. Result of an exploratory intervention of the arm for peripheral nerve repair in a patient with these variations can be successful only if the surgeon is aware of such variations of peripheral nerves and specifically looks for their presence. Additionally, during flap dissections, unexpected nerve damages could arise especially by surgeons who are familiar with routine course of peripheral nerves and their relationship with neighboring structures but inexperienced in variations. Any injury to musculocutaneous nerve in a patient with this kind of variation presents as double nerve injury, which makes the diagnosis more problematic.[39]

Venieratos and Anagnostopoulou (1998) described three different types of communication between Musculocutaneous and Median nerve in relation to Coracobrachialis. In 16 out of 79 cadavers 22 communications were found between the musculocutaneous and median nerves. In six subjects they were present bilaterally. There were three types, based on the sites of communication. Type I: The communication was proximal to the entrance of the musculocutaneous nerve into coracobrachialis; Type II: The communication was distal to the muscle; Type III: The nerve as well as the communicating branch did not pierce the muscle. Bilateral communications were not necessarily of the same type.[40]

Choi D et al (2002) performed a study in 138 cadavers to know variations in connections between the musculocutaneous and median nerves in the arm. These variations were seen in 64 cadavers (46.4%), 9 bilaterally and 55 unilaterally (26 right and 29 left); in total, therefore, variations were observed in 73 out of 276 arms (26.4%). They classified the variations into three main patterns: Pattern 1, fusion of both nerves (14 arms, 19.2%); Pattern 2, presence of one supplementary branch between both nerves (53 arms, 72.6%); and Pattern 3, two branches (5 arms, 6.8%). Pattern 2 was further subdivided into a sub-group 2a when a single root from the musculocutaneous nerve contributed to the connection (51 arms, 69.9%), and 2b when there were two roots from the musculocutaneous nerve (2 arms, 2.7%). A combination of Patterns 1 and 2a was observed in one case (1.4%). [41]

Beheiry E (2004) studied the variations of the median nerve in the arm with respect to its branching pattern and distribution as well as its possible communication with the musculocutaneous and/or ulnar nerves. Author studied sixty arms pertaining to 30 preserved human cadavers, ranging in age from 30 to 67 years. In one limb out of 60 (1.7%) the median nerve gave off muscular branches to the brachialis muscle as well as a branch from its lateral root to supply both heads of the biceps brachii muscle. Concomitantly the musculocutaneous nerve was absent. The same limb demonstrated a branch from the lateral cord of the brachial plexus supplying the coracobrachialis muscle. Three limbs (5%) showed a communicating branch between the median and the musculocutaneous nerves. These observations should be considered when a high median nerve paralysis is shown to originate in the axilla or proximal arm in a patient presenting with weakness of forearm flexion and supination, as per author's opinion. Similarly, it can explain weakness of the arm flexor muscles in thoracic outlet syndrome with median nerve affection.[42]

Fazan et al (2003) in their study gave a classical description of the thoracodorsal nerve origins, involving two different origins including an axillary origin and a radial nerve origin in 13% and 5.5% of cases, respectively.[43] Tubbs et al (2007) in their study found 1.5% of thoracodorsal nerves coming from the radial nerve.[44] In a similar study by Ballesteros (2007) has reported about thoracodorsal nerve variations. The thoracodorsal nerve was originated from the usual posterior cord in 44 (78.6%) cadavers in the study. Remaining 12 (21.4%) cadavers had variations in thoracodorsal nerve origin, among them from radial nerve 5 (8.9%), from MT 2 (3.6%) and from axillary 5 (8.9%) cadavers. Trauma of the posterior wall of the axillary region could harm latisimus dorsis muscle function (humeral movement extension, adduction and medial rotation), depending on lesion level and the involvement of its several origins. For instance, an axillary nerve lesion engaging the thoracodorsal nerve origin may produce a more extensive functional lesion including latisimus dorsi, deltoid and teres minor muscles.[45]

Bhat KMR (2008) has reported variation in the branching pattern of the posterior cord of brachial plexus. Normally, a single posterior cord is formed by the union of posterior divisions of the trunks of the brachial plexus. All the branches of the posterior cord arise from this single cord. In the case report, after formation of posterior cord, the cord had divided again into two roots and enclosed the subscapular artery. Then, these two roots fused to continue as radial nerve.[46]

These are few of the studies available in the literature on brachial plexus and its variations.

METHODOLOGY

Materials

The present descriptive study was carried out by dissection of 60 (30 Right and 30 Left) upper limbs of 30 human cadavers, in the age group of 18 to 85 years, obtained during a study period of 2 years from the Department of Anatomy, J. N. Medical College, KLE University, Belgaum.

Study design

This is a cross-sectional type of study.

Inclusion criteria

All upper limbs, of cadavers in the age group of 18 to 85 years.

Exclusion criteria

Cadavers with deformed or traumatized cervical, axillary and arm regions of upper limbs.

Method of collection of data

Permission was obtained from the Head of Department of Anatomy and the Principal, J. N. Medical College, Belgaum to conduct the study. The project was submitted to Independent Ethics Committee of J. N. Medical College, Belgaum. After getting the approval letter from Independent Ethics Committee, the study commenced.

Dissection was done of the upper arm, axilla and posterior triangle of the neck on same side successively as per Cunningham's manual of practical Anatomy. The skin, superficial fascia and deep fascia were dissected and the pectoralis major and pectoralis minor muscles muscles were cut and reflected and the arm was abducted to 45 degrees. Incision was put over the skin of axillary region and the fascia was reflected to uncover the axillary sheath, which surrounds axillary vessels and brachial plexus. The axillary vein and its tributaries were identified and separated from the underlying axillary artery and brachial plexus by dissecting with a probe. Then the axillary vein was cut at the lateral border of the teres major muscle and removed along with the associated lymph nodes.

The infraclavicular part of the brachial plexus was dissected at this time. The three cords of brachial plexus (lateral, medial and posterior) were identified and named according to their relationship to the second part of the axillary artery posterior to the pectoralis minor muscle. The various branches were also studied.

To study the supraclavicular part of brachial plexus, the posterior triangle and muscles of its floor were dissected as per the manual, then the clavicle was cut at the middle thirds of its shaft and the tendon of omohyoid was cut and its bellies were retracted. The deep fascia and fatty tissue were excised. Further deep dissection of the structures at the root of the neck was performed. Blunt dissection was used to define the borders of anterior scalene and middle scalene muscles. The subclavian artery and roots of the brachial plexus, which passed in the inter-scalene triangle i.e., between the posterior scalene muscle and anterior scalene muscle, were carefully observed. The trunks and divisions of the brachial plexus and their branches were identified.

The prevertebral muscle longus colli was separated to trace the roots of the plexus to their origin, to study whether the plexus was normal, prefixed or post-fixed type.

Thus the plexus was studied in its entire course from the formation in cervical region, course through root of the neck, axilla and up to the terminal branches into the major nerves of the upper extremity. During the dissection, variations of brachial plexus pertaining to its formation from the roots, trunks, divisions and cords and the branching pattern were observed and data was collected. Photographs were taken under good lighting, using zoom digital camera. Rough schematic diagrams were drawn and photographs were labelled. The data collected in the present study was recorded, tabulated, analyzed and compared with previous studies.

The following parameters were looked for in the present study of formation and branching patterns of brachial plexus,

1. Roots
    a. Type of plexus depending upon number of roots
    b. Number of branches from the roots
2. Trunks
    a. Branches from upper trunk
3. Divisions
    a. Number of divisions from each trunk
4. Cords
    a. Number of branches from the lateral cord
    b. Number of branches from the medial cord
    c. Number of branches from the posterior cord

5. Formation of median nerve
    a. Number of roots contributing to median nerve formation
    b. Relationship with axillary artery
    c. Relationship with brachial artery
6. Other main terminal branches
    a. Musculocutaneous nerve
    b. Axillary nerve
    c. Radial nerve
    d. Ulnar nerve
7. Communicating branches encountered between the nerves

RESULTS

The data obtained on different parameters were tabulated and recorded as follows.

<u>Table No. 1:</u> Roots (ventral rami of spinal nerves) contributing to formation of Brachial Plexus

TYPE	INCIDENCE	PERCENTAGE
Pre-fixed ($C_4 – T_1$)	2 out of 60	3.33%
Normal ($C_5 – T_1$)	58 out of 60	96.67%
Post-fixed ($C_5 – T_2$)	Nil out of 60	-

<u>Graph No. 1:</u> Roots (ventral rami of spinal nerves) contributing to formation of Brachial Plexus

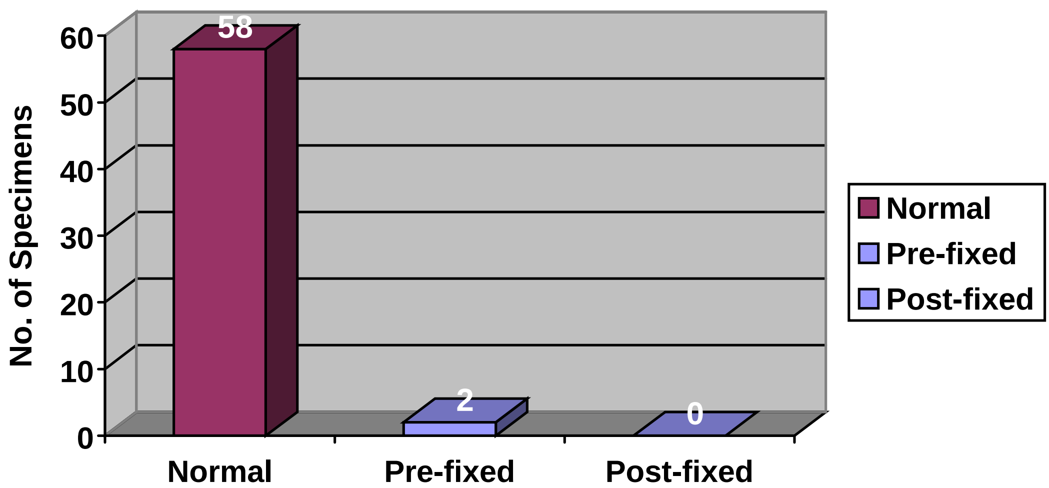
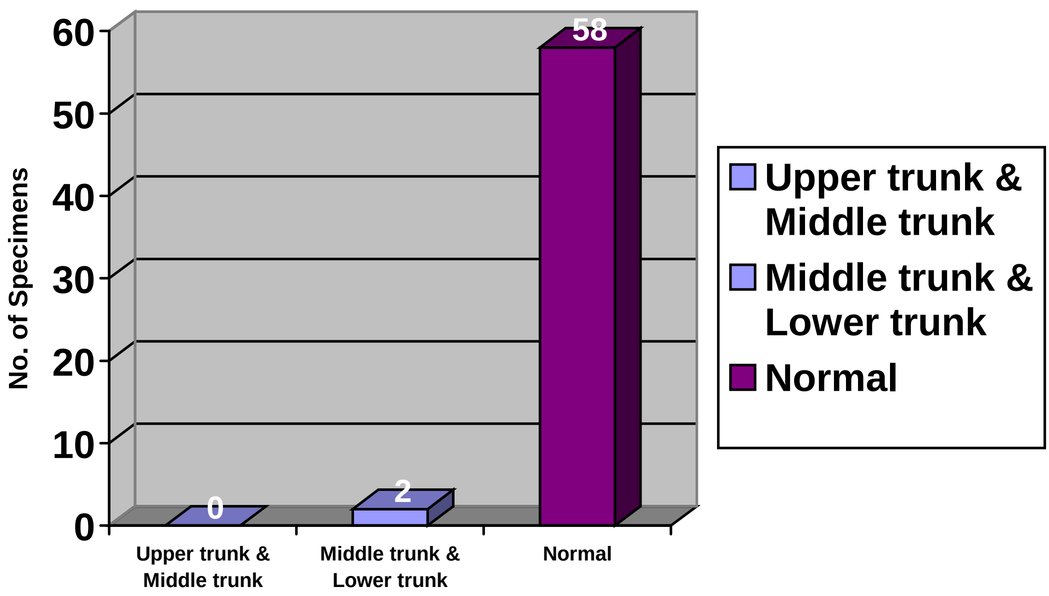


Table No. 2: Fusion of adjacent trunks

FUSION OF ADJACENT TRUNKS	INCIDENCE	PERCENTAGE
Upper trunk & Middle trunk	Nil	-
Middle trunk & Lower trunk	2 out of 60	3.33%

Graph No. 2: Fusion of adjacent trunks



<u>Table No. 3:</u> Variations in branches from Cords

CORDS	VARIATION	INCIDENCE	PERCENTAGE
LATERAL	Extra lateral root of MN	7 out of 60	11.67%
	Absence of MCN	4 out of 60	6.67%
MEDIAL	Medial root of MN not given from medial cord	2out of 60	3.33%
POSTERIOR	Two Thoracodorsal nerves	2 out of 60	3.33%
	Division into 2 roots & union to form RN	1out of 60	1.67%

**** 3 of the cases in which absence of MCN was detected, also had extra lateral root of median nerve. So the total number of variations detected in branches from lateral cord was in 8 out of 60.**

<u>Graph No. 3:</u> Variations in branches from Cords

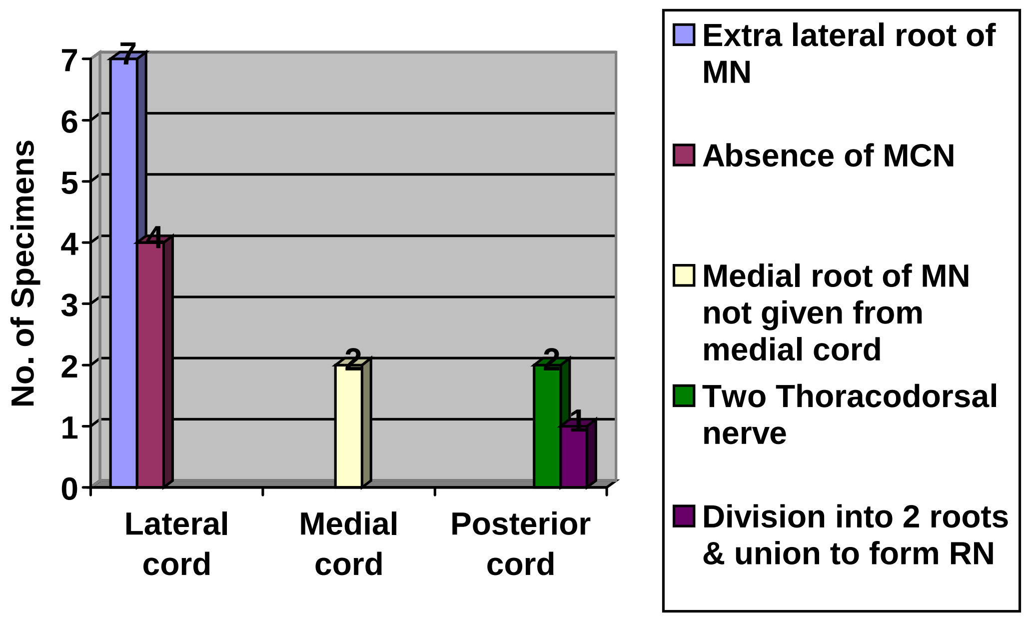


Table No. 4: Musculocutaneous Nerve

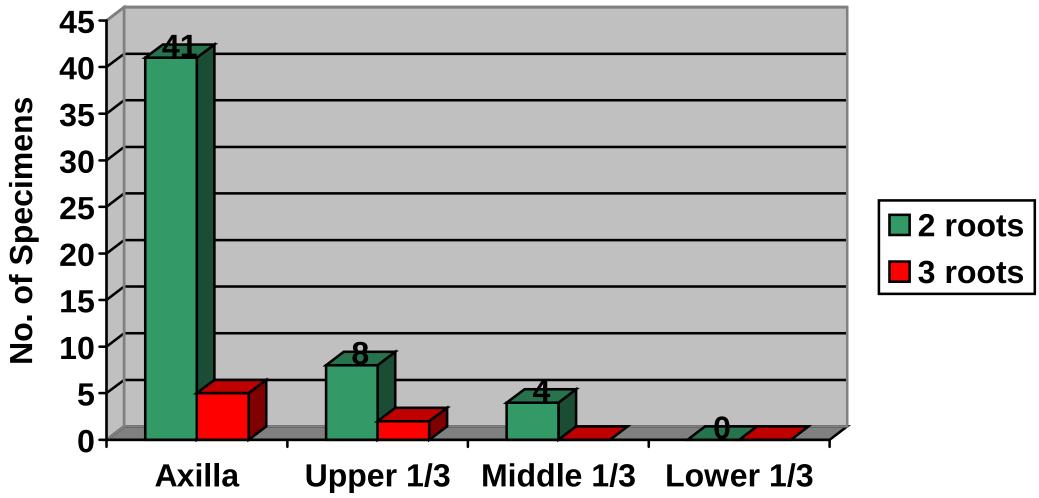
SL NO	PARAMETERS	NORMAL		VARIATION	
		INCIDENCE	PERCENTAGE	INCIDENCE	PERCENTAGE
1	Existence (60)	56	93.33%	4	6.67%
2	Origin (56)	56	100%	Nil	-
3	Relation to 3rd part of AA (56)	56	100%	Nil	-
4	Piercing of coracobrachialis (56)	56	100%	Nil	-
5	Communication with MN in arm			7/56	12.5%
	- Before Piercing coracobrachialis			3/56	5.36%
	- After Piercing coracobrachialis			4/56	7.14%

Table No. 5: Number of roots and level of formation of median nerve out of 60

LEVEL OF FORMATION OF MEDIAN NERVE	NUMBER OF SPECIMENS	
	WITH 2 ROOTS	WITH 3 ROOTS
Axilla	41 (68.33%)	5 (8.33%)
Upper third of arm	8 (13.33%)	2 (3.33%)
Middle third of arm	4 (6.67%)	-
Lower third of arm	-	-

**** Branch encountered as connection between MCN & MN in axilla or upper 1/3 was considered as second lateral root and in the middle 1/3 or lower 1/3 of arm as a communication.**

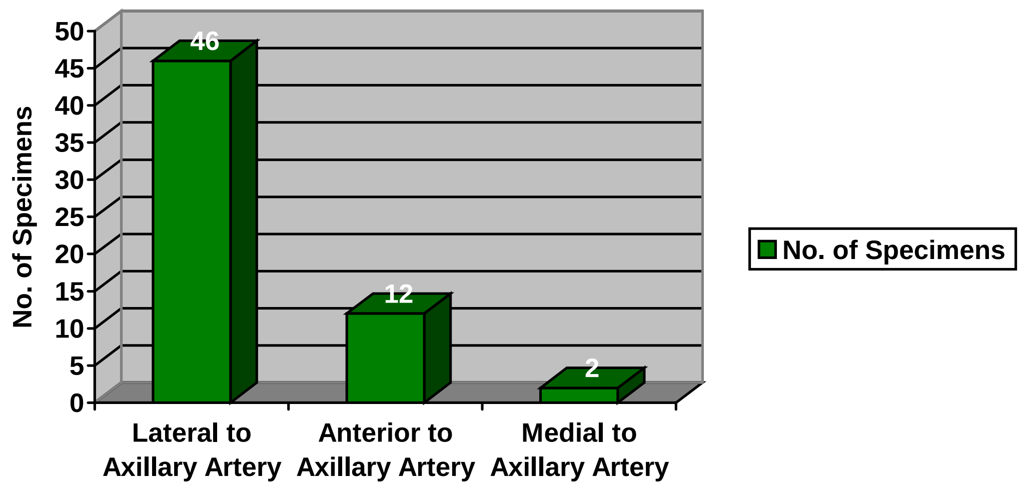
<u>Graph No. 4:</u> Number of roots and level of formation of median nerve



<u>Table No. 6:</u> Formation of Median Nerve in relation to Axillary Artery

FORMATION OF MEDIAN NERVE	NUMBER OF SPECIMENS	PERCENTAGE
Lateral to Axillary Artery	46	76.67%
Anterior to Axillary Artery	12	20%
Medial to Axillary Artery	2	3.33%

<u>Graph No. 5:</u> Formation of Median Nerve in relation to Axillary Artery



<u>Table No. 7:</u> Course of Median Nerve in relation to Brachial Artery

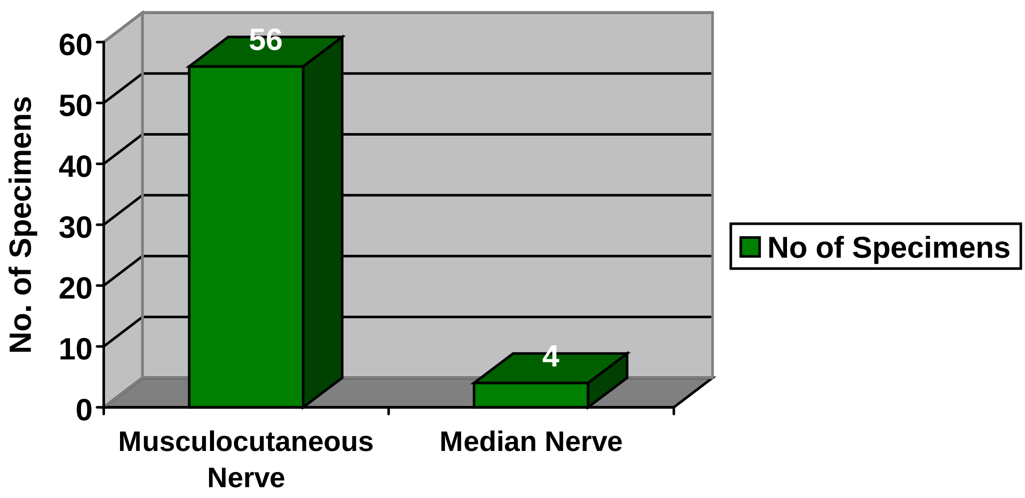
COURSE	NUMBER OF SPECIMENS	PERCENTAGE
Lateral	58	96.67%
Medial	2	3.33%

<u>Table No. 8:</u> Innervation of muscles of anterior compartment of arm

NERVE OF ANTERIOR COMPARTMENT OF ARM	NUMBER OF SPECIMENS	
	INCIDENCE	PERCENTAGE
Musculocutaneous	56	93.33%
Median	4	6.67%

**** In absence of MCN, Median nerve supplied the muscles of anterior compartment of forearm in 4 specimens.**

<u>Graph No. 6:</u> Innervation of muscles of anterior compartment of arm



<u>Table No. 9:</u> Communication between MN & MCN (out of 60)

LEVEL OF COMMUNICATION	NUMBER OF SPECIMENS	PERCENTAGE
Upper third of arm	3	5%
Middle third of arm	4	6.67%
Lower third of arm	-	-

<u>Table No. 10:</u> Ulnar nerve

SL NO	PARTICULARS	NORMAL	VARIATIONS
1	Existence	Present 60 (100%)	-
2	Origin	Medial cord 58 (96.67%)	2nd part of anterior division of fused MT & LT 2 (3.33%)
3	Relation to 3rd part of AA	Medial 60 (100%)	-
4	Communication with any nerve	Absent 59 (98.3%)	Present 1 (1.67%) -With Radial nerve

<u>Table No. 11:</u> Radial nerve

SL NO	PARTICULARS	NORMAL	VARIATIONS
1	Existence	Present 60 (100%)	-
2	Origin	Posterior cord 60 (100%)	-
3	Relation to 3rd part of AA	Posterior 60 (100%)	-
4	Communication with any nerve	Absent 59 (98.3%)	Present 1 (1.67%) -With Ulnar nerve
5	High division of Radial Nerve & subsequent fusion to form Radial nerve	Absent 59 (98.3%)	Present 1 (1.67%)

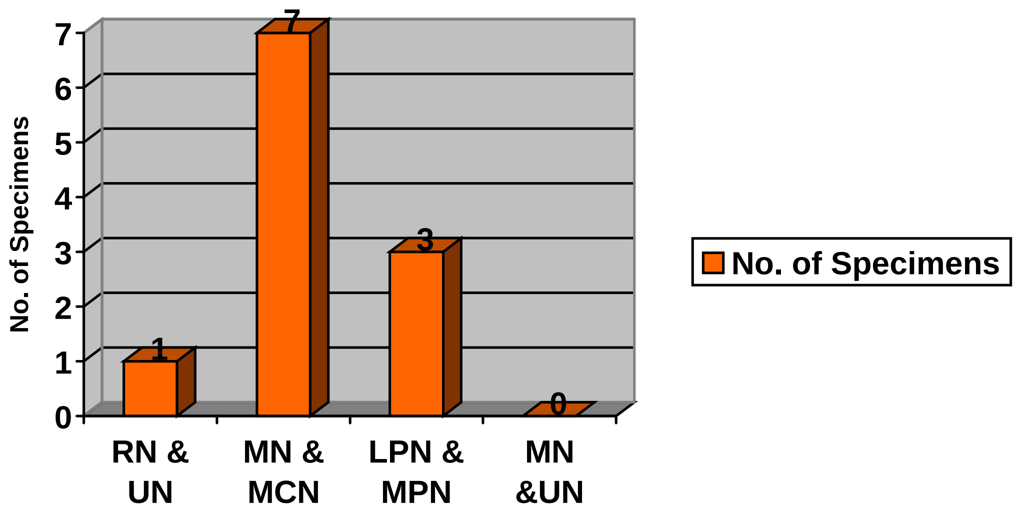
<u>Table No. 12:</u> Axillary nerve

SL NO	PARTICULARS	NORMAL	VARIATIONS
1	Existence	Present 60 (100%)	-
2	Origin	Posterior cord 59 (98.3%)	Posterior division of upper trunk 1 (1.67%)
3	Relation to 3rd part of AA	Posterior 60 (100%)	-
4	Communication with any nerve	Nil 60 (100%)	-

Table No. 13: **Communicating branches between nerves**

SL NO	PARTICULARS	INCIDENCE	PERCENTAGE
1	RN & UN	1	1.67%
2	MN & MCN	7	11.67%
3	LPN & MPN	3	5%
4	MN & UN	Nil	-

Graph No. 7: **Communicating branches between nerves**



DISCUSSION

The brachial plexus begins with the anterior rami of C5, C6, C7, C8 and T1. It terminates with the formation of musculocutaneous, median, ulnar, axillary and radial nerves. The intermediate portions are described in sets of threes: three trunks are formed, followed by three divisions, then three cords. Each trunk gives rise to two divisions and each cord gives rise to two branches. The lateral cord divides into the musculocutaneous nerve and lateral root of the median nerve. The medial cord divides into medial root of median nerve and ulnar nerve. The posterior cord divides into axillary nerve and radial nerve. The anatomy of brachial plexus can be confusing, especially because of frequent variations in length and caliber of each of its components.[55]

The knowledge of variations in brachial plexus anatomy, is important particularly to anatomists, radiologists, anesthesiologists and surgeons and has gained much importance due to the wide use and reliance on computer imaging in diagnostic medicine.[47] Also, the presence of anatomic variations of the peripheral nervous system is often used to explain unexpected clinical signs and symptoms. Descriptions of nerve variations are useful in clinical/surgical practice since an anatomical variation can be the cause of a nerve palsy syndrome due to different relation of a nerve and a related muscle. In most of these cases, surgery can lead to a rapid recovery of nerve function.[48] Although a brachial plexus injury during neck surgery is a rare condition, especially due to its protection by a dense layer of deep cervical fascia surrounding the scalenus muscles and also the protection of its roots between the scalenus anterior and scalenus medius muscle, anatomical variations of the brachial plexus may render it vulnerable to injury during routine surgical neck dissection.[9]

Roots (ventral rami of spinal nerves) contributing to formation of Brachial Plexus:

Hye YL et al. (1992) reported that a brachial plexus composed of the fourth to eighth cervical nerves and the first and second thoracic nerves was present in one case and in another case, a plexus composed of only cervical nerves (fifth to eighth) was observed. In their study, the incidence of the fourth cervical nerve joining the brachial plexus was higher in females than in males.[29]

In the present study out of the 60 cadaveric upper limbs studied for the anatomical variations of the brachial plexus, 2 limbs (3.33%) were pre-fixed plexuses (Figure No. 8), 58 limbs (96.67%) were normal and no post-fixed plexus was detected In a similar study by Uysal I et al. (2003), the brachial plexuses were composed mostly of the C5, C6, C7, and C8 nerves and the T1 nerve (71.5%). A prefixed plexus was observed in 25.5% of cases, and a postfixed plexus was observed in 2.5% of cases. In one case (0.5%), the C4 and T2 nerves joined the formation.[34]

Fusion of adjacent trunks:

In a case reported by Nayak S et al. (2005), the union of ventral rami of C5, C6 and C7 nerves formed the upper trunk. The middle trunk was absent and the union of ventral rami of C8 and T1 spinal nerves formed lower trunk. The abnormal upper trunk passed laterally between the scalenus anterior and medius muscles. After giving the two branches, suprascapular nerve and nerve to subclavius, the trunk divided into two divisions. These two divisions divided again into anterior and posterior divisions, which further coursed like the divisions of normal upper and middle trunks.[49]

Villamere J et al. (2009) observed during routine dissection of a 55-year-old female cadaver, a variation of the brachial plexus characterized by the absence of the superior trunk on the left side. The ventral rami of the C5 and C6 nerve roots, without joining to form the superior trunk, independently divided into anterior and posterior divisions, which joined the lateral and posterior cords, respectively. Additionally, the suprascapular nerve that commonly originates from the superior trunk, initiated exclusively from the C5 nerve root in this variation. Similar variations in the brachial plexus were not observed on the contra lateral side.[50]

Kocabiyik N et al. (2007) reported that the anterior divisions of upper and middle trunks united to form the lateral cord lateral to the axillary artery. The anterior division of the lower trunk ran as the medial cord, medial to the axillary artery. Suprascapular nerve did not arise from the superior trunk instead; it arose from the C5 nerve root. Superior subscapular, thoracodorsal and inferior subscapular nerves arose from the posterior division of the upper trunk. Afterwards, the posterior cord continued as axillary and radial nerves.[33]

In our study fusion of adjacent trunks was detected in 2 limbs (3.33%), where middle and lower trunks were fused which gave common anterior and posterior division and this anterior division split into 2 parts. The smaller contribution from the first part, joined with anterior division of upper trunk to form lateral cord and larger contribution acted as the medial root of median nerve. Branch to coracobrachialis was also given from first part of common anterior division of fused middle and lower trunks. The second part of anterior division acted as medial cord and gave the ulnar nerve and medial cutaneous nerve of arm and forearm (Figure No. 4 & 7). The posterior division of upper trunk united with the common posterior division of the fused middle and lower trunks to form posterior cord. In one of these cases the axillary nerve, upper subscapular nerve and lower subscapular nerve were formed from posterior division of upper trunk and radial nerve and thoracodorsal nerve originated from the posterior cord.

Variations in branches from Cords:

Uzun A et al. (1999) reported the variations in the formation of brachial plexuses and classified them into three groups. Group 1 had a variation in the formation of the median nerve (10.77%), with fusion of three branches; one each coming from the lateral and medial cords and one coming directly from a branch of the anterior division of the middle trunk. Group 2 had three anterior division cords: a) the lateral cord formed from anterior division of the upper trunk b) an "intermediate" cord formed from the anterior division of the middle trunk and c) the medial cord formed from the anterior division of the lower trunk (3.07%). In-group 3, there was a rare variation of the medial cord (1.54%), which receives an anastomotic branch from the posterior division of the middle trunk.[51]

Oluyemi KA et al.[21] (2007) and Pandey & Shukla[20] (2007) reported similar cases of brachial plexus with two cords (Medial and Lateral). Axillary and radial nerves originated from what seemed like posterior cord from the posterior aspect of medial cord thus stating that the three posterior divisions of upper, middle and lower trunks that were supposed to form the posterior cord were fused with the medial cord.

Singhal S et al. (2007) reported in their case, that the lower trunk divided into one anterior and two posterior divisions. The first fused with the posterior divisions of middle trunk and the upper trunk. The second joined the radial nerve. The anterior division, which was the medial cord, gave rise to the medial root of the median nerve, medial cutaneous nerve of the arm, the medial cutaneous nerve of forearm and continued as the ulnar nerve. The medial cord was medial to the axillary artery.[52]

Bhat K et al. (2008) reported that, after formation of posterior cord, the cord had divided again into two roots and enclosed the subscapular artery. Then, these two roots fused to continue as radial nerve.[46]

Fazan et al. (2003) in their study gave a classical description of the thoracodorsal nerve origins, involving two different origins including an axillary nerve origin and a radial nerve origin in 13% and 5.5% of cases, respectively.[43] Tubbs et al. (2007) in their study found 1.5% of thoracodorsal nerves coming from the radial nerve.[44] In a similar study by Ballesteros (2007) has reported about thoracodorsal nerve variations. The thoracodorsal nerve originated from the usual posterior cord in 44 (78.6%) cadavers in the study. Remaining 12 (21.4%) cadavers had variations in thoracodorsal nerve origin, among which the origin from radial nerve was reported in 5 (8.9%), from middle trunk in 2 (3.6%) and from axillary in 5 (8.9%) cadavers.[45]

Das S et al. (2005) reported anomalous branches of lateral cord crossing the artery anteriorly, which are liable to cause compression symptoms producing ischemia. Such variations are likely to confuse the operating surgeons who usually operate in this region with the standard anatomical knowledge.[53]

Gupta M et al. (2005) observed in his study that anterior division of middle trunk also gave rise to the nerve to coracobrachialis and an additional lateral root of median nerve.[54]

In present study variations in branches of lateral cord were detected in 8 limbs, in which extra lateral root of median nerve (Figure No.5, 6 & 12) was detected in 7 limbs (11.67%) and 4 limbs (6.67%) had absence of musculocutaneous nerve (Figure No.13). Medial cord variation was seen in 2 limbs (3.33%) both of which did not give the medial root of median nerve but other branches were given normally (Figure No.4& 7). The medial root of median nerve was given from the first part of anterior division of fused middle and lower trunks and the second part of the anterior division acted as the medial cord and gave rest of its branches normally. Among Posterior cord variations, 2-thoracodorsal nerves were detected in 2 limbs (3.33%). Both of these nerves arose as direct branches of posterior cord supplying latissimus dorsi (Figure 3 & 9). In one limb (1.67%) the posterior cord divided into two branches/roots, which subsequently united to form the radial nerve.

Musculocutaneous Nerve:

Prasad Rao PV and Chaudhary SC observed two cases of absent musculocutaneous nerve in 24 upper limbs. Median nerve took over the area of supply of the musculocutaneous nerve by giving both muscular and sensory branches.[56]

Hollinshed (1982) [12] has stated that rarely the musculocutaneous nerve is not found and its various branches arise from median nerve.[57] The absence of musculocutaneous nerve was noted by Sud M and Sharma A (2000), [28] Le Minor (1990), [58] Nakata et.al (1997) [59]and Gumusburn (2000). [60]

Hollinshed (1982) [12] quoting Rao et al. has described that 9.3% musculocutaneous nerves did not pierce coracobrachialis muscle.

The musculocutaneous nerve ordinarily enters coracobrachialis muscle from its medial aspect approximately 5cm distal to tip of coracoid process. It may run behind the coracobrachialis muscle or adhere for some distance to the median nerve or pass behind the biceps or may be accompanied by fibres from the median nerve as it transits coracobrachialis, less frequently the reverse occurs.[61]

Anastomosis between musculocutaneous nerve and median nerve is by far the most common and frequent of the variations that are observed among the branches of brachial plexus.

Le Minor (1992) [58] classified communications between musculocutaneous nerve and median nerve into 5 types.

Type I - No communication between musculocutaneous nerve and median nerve

Type II - Fibres of medial root of median nerve pass through musculocutaneous nerve and join the median nerve in the middle of the arm.

Type III - The lateral root fibres of median nerve pass along the musculocutaneous nerve and after some distance, leave it to form lateral root of median nerve.

Type IV - The musculocutaneous nerve fibres join lateral root of median nerve and after some distance the musculocutaneous nerve arises from median nerve.

Type V- The musculocutaneous nerve is absent and all the fibres of musculocutaneous nerve pass through the lateral root and fibres to the muscles supplied by musculocutaneous nerve branch out directly from median nerve.

Choi et al. (2002) generally classified the communications between musculocutaneous nerve and median nerve into three patterns[41].

Pattern I: Both the nerves are fused.

Pattern II: One communicating branch between musculocutaneous nerve and median nerve.

Pattern III: Two communicating branches between musculocutaneous nerve and median nerve.

Venieratos and Anagnostopoulou (1998) [40] classified the communication between two nerves into 3 types.

Type I - Communication between musculocutaneous nerve and median nerve is proximal to the entrance of musculocutaneous nerve into the coracobrachialis

Type II - Communication is distal to the muscle.

Type III - The nerve or communicating branch did not pierce the muscle.

A study done by Atkan ZA et al (2001) showed connections between musculocutaneous nerve and median nerve were found in five arms. The connections were not bilateral in any cadaver.[62]

Communication between the musculocutaneous and median nerves in the arm is considered as remnant from the phylogenetic or comparative point of view. Kosugi[63] reported that there was one trunk equivalent to the median nerve in the thoracic limb of lower vertebrates (amphibians, reptiles, birds).

In man, the forelimb muscles develop from the mesenchyme of the paraxial mesoderm during the fifth week of intrauterine life.[17] The axons of spinal nerves grow distally to reach the mesenchyme. The peripheral processes of the sensory and motor neurons grow in the mesenchyme, in different directions.[64] The guidance of developing axons is regulated by the expression of chemo-attractants and chemo-repulsants in a highly co-ordinated site specific fashion, significant variations in the nerve patterns may be a result of altered signaling between mesenchymal cells and neuronal growth cones or circulatory factors at the time of fusion of brachial plexus.[65]

In the present study of 60 upper limbs musculocutaneous nerve was present in 56 (93.33%) and all of which originated from lateral cord and were lateral to 3rd part of axillary artery. After the formation of musculocutaneous nerve, it descended down to pierce coracobrachialis in all the cases where it was present. Out of 56 limbs where it was present, in 7 limbs (12.5%) there was a communication with the median nerve. In 3 (5.36%) the communication was before musculocutaneous nerve pierced coracobrachialis and in 4 (7.14%) after piercing coracobrachilis. Absence of musculocutaneous nerve was detected in 4(6.67%). These variations have already been reported by several workers.

The variation in our study in comparison to Venieratos and Anagnostopoulou classification includes out of 56,

Type I – 3 (5.36%), **Type II –** 4 (7.14%) and **Type III –** nil.

After supplying muscles of front of the arm, it continued below as lateral cutaneous nerve of forearm.

Median nerve:

- **Number of roots and level of formation of median nerve**

Eglseder and Goldman[66] also found that the median nerve was formed from two lateral roots in 14% of their specimens. Uzun A et al. (1999) reported the variation in the formation of the median nerve (10.77%), with fusion of three branches, one each coming from the lateral and medial cords and one coming directly from a branch of the anterior division of the middle trunk.[51] Uzun et al. (2001) found that, the median nerve was formed by three branches coming from lateral cord of the brachial plexus and one branch coming from the medial cord of the brachial plexus.[67]

Mohammed HM Badawoud (2003) found four anomalies of the median nerve formation in his study. In one anomaly (2.1%), two interconnecting branches were present between the two roots of the median nerve. These two branches had a very close relation to the axillary artery. One interconnecting branch was found between the roots of the median nerve in three upper limbs (6.3%). [68]

Fazan et al. (2003) reported in their study the median nerve was formed by 2 lateral roots and 1 medial root (from the medial cord) in 28 (52%) limbs. Four (7%) median nerves were formed distally, in the arm [43]. Gupta M et al. (2005) observed in his study that anterior division of middle trunk also gave rise to an additional lateral root of median nerve.[54]

In a case reported by Nayak S et al. (2006), The median nerve was formed below the midpoint of the arm and passed through a tunnel in the third head of the biceps along with brachial artery.[69]

Pandey & Shukla[20] (2007) reported in their study of 344 specimens median nerve formation at lower level in 6 (1.7%) limbs. The exact level of formation however has not mentioned.

In the present study, the median nerve (MN) was formed from two roots in 53 (88.33%) specimens, of which, level of formation was also recorded. In 41 (68.33%) MN was formed in axilla, in 8 (13.33%) MN was formed in upper third of arm, in 4 (6.67%) MN was formed in middle third of arm. The formation of MN by 3 roots (Figure No.5, 6 & 12) was detected in 7 (11.66%) out of which, in 5 (8.33%) MN was formed in axilla and in 2 (3.33%) MN was formed in upper third of arm.

- **Formation of Median Nerve in relation to Axillary Artery**

Standring S, Ellis H, Johnson D et al. (2005) mentions that the formation of median nerve is either anterior or lateral to third part of axillary artery.[13] Chitra R

(2007) reported that the two roots of the median nerve joined behind the axillary artery to form the median nerve[37] and in another case she reported formation of median nerve medial to axillary artery bilaterally.[70] Pandey & Shukla[20] (2007) reported in their study of 344 axillae have reported formation of median nerve medial to axillary artery in 8 (2.3%) cases.

In our study median nerve was formed lateral to axillary artery (AA) in 46 (76.67%), anterior to AA in12 (20%) and medial to AA in 2 (3.33%). None of the limbs showed formation of median nerve to be posterior to AA.

- **Course of Median Nerve in relation to Brachial Artery**

Nayak S et al. (2006) have reported the median nerve to descend medial to brachial artery.[69] Chitra R (2007) reported that the median nerve to descend posterior to brachial artery [37] and in another case she reported formation of median nerve medial to axillary artery bilaterally.[70]

In our study the median nerve coursed lateral to brachial artery in 58 (96.67%) and medial to brachial artery in 2 (3.33%). The course of MN posterior to brachial artery in was detected in none of the specimens.

- **Innervation of muscles of anterior compartment of arm**

Le Minor (1990) has reported absence of musculocutaneous nerve where in the lateral cord of brachial plexus gave muscular branches to coracobrachialis and biceps brachi.[58]

Gumusburn (2000) have noted bilateral absence of musculocutaneus nerve. Two branches from the lateral cord innervated the coracobrachialis muscle. The median nerve innervated the biceps brachi and brachialis muscle. [60]

Sud M and Sharma (2000) have also reported absence of musculocutaneus nerve.[28]

Beheiry EE (2004) has noted absence of musculocutaneus nerve in one limb (1.7%) out of 60 upper limbs studied.[42]

Guttenberg et al. (2009) in their study of 56 upper limbs have noticed absence of musculocutaneus nerve in 2 (3.6%) upper limbs.[71]

In our study musculocutaneous nerve (MCN) was present in 56 (93.33%) and supplied muscles of anterior compartment and in 4 (6.67%) MCN was found to be absent (Figure No 13) and in 3 out of the 4 specimens where absence of MCN was detected, median nerve was formed by 3 roots the extra lateral root joined the main nerve at different levels. In one of the cadavers absence of MCN was bilateral and on one of the sides median nerve was formed from 3 roots. The branches either from lateral roots of median nerve or directly from MN itself innervated biceps brachii, coracobrachialis and brachilis.

- **Communication between MN & MCN**

Chitra R (2007) Ibrahim CH et al. (2005) and Oluyemi KA et al. (2007) have reported median nerve communications with musculocutaneous nerve.[38, 39,21]

Venieratos and Anagnostopoulou (1998), in their study of 158 upper limbs found median nerve communications with musculocutaneous nerve in 22 (13.9%) limbs. In 6 cadavers these were bilateral.[40]

Eglseder and Goldman in their study of 54 cadavers found that interconnections between median nerve and musculocutaneous nerve in 36% cases.[66]

Choi D et al (2002) reported in their study on 138 cadavers, connections between the musculocutaneous and median nerves in the arm were seen in 64 cadavers (46.4%), 9 bilaterally and 55 unilaterally; in total, interconnections were observed in 73 out of 276 arms (26.4%). [41] Beheiry EE (2004) has noted interconnections between median nerve and musculocutaneous nerve in 3 (5%) upper limbs studied.[42] Guttenberg et al. (2009) in their study of 56 upper limbs have noticed median nerve communications with musculocutaneous nerve in 30(53.6%) limbs. [71]

In the present study communicating branches between MN and MCN were in 7 cases (11.67%) out of which communication was in the upper third of arm in 3 (5%) and in middle third of arm in 4 (6.67%). Our study was confined to the arm region only.

Ulnar nerve:

In our study ulnar nerve arose from medial cord of brachial plexus. Many workers described variation in the origin of this nerve. In our study in 58 (96.67%) limbs the nerve arose from medial cord of brachial plexus.

The ulnar nerve was lying medial to third part of axillary artery in all the 60 upper limbs. No variation was observed in this regard. It ran distally through the axilla between axillary artery and vein and was lying medial to brachial artery as far as midarm in all the limbs.

In our study fusion of adjacent trunks was detected in 2 limbs (3.33%), where middle and lower trunks were fused which gave common anterior and posterior division and this anterior division split into 2 parts. The first part smaller contribution joined with anterior division of upper trunk to form lateral cord and larger one acted as the medial root of median nerve. The second part of anterior division acted as medial cord and gave the ulnar nerve and medial cutaneous nerve of arm and forearm. The medial pectoral nerve was cut and could not be traced to its origin

In one of the limb (1.67%) where middle trunk and lower trunk was fused, the ulnar nerve received an abnormal communicating branch from radial nerve. This variation is not well documented from previous investigators. In the middle of the arm the nerve pierced the medial intermuscular septa. It descended to the forearm by passing posterior to medial epicondyle of humerus.

Gupta M et al. (2005) [54] found a communicating branch (C7) arose from ulnar nerve 0.9cm distal to its origin and run downwards and laterally for 3cm to join the radial nerve. In their study communications were also seen in the branches of the medial and posterior cords, as the medial root of median nerve gave a communicating twig to the ulnar nerve which could be the fibers that median root of median received from the lateral root as described by Hollinshead (1958). [16] He stated that ulnar nerve usually receives fibers from seventh cervical nerve by receiving a contribution from the LC. Iyer and Fenichel (1976) [73], Gutmann (1977) [74], Crutchfield and Gutmann (1980) [75] and Snock et al. (1991) [76] reported the communication between median and ulnar nerve in forearm and hand. The communication between ulnar and radial nerve is not well documented.

Radial nerve:

Atkan et al.[62] reported a case in which radial nerve arose from the union of posterior divisions of inferior trunk and middle trunk in the left upper extremity.

Bhat KMR et al. (2008) has reported variation in the branching pattern of the posterior cord of brachial plexus. In the case report, after formation of posterior cord, the cord had divided again into two roots and enclosed the subscapular artery. Then, these two roots fused to continue as radial nerve.[46] Gupta M et al. (2004) reported that the branches of radial nerve, which normally arise in the radial groove, arose in the axilla on both the sides in their study. So in cases of trauma or injury of arm some of these branches may be spared.[77]

In our study radial nerve was present in all 60 limbs (100%) originated from posterior cord and was posterior to 3rd part of axillary artery. Only in one limb (1.67%) thoracodorsal and radial nerve originated from posterior cord, where as axillary, upper subscapular and lower subscapular originated from posterior division of upper trunk. Posterior division of upper trunk joined common posterior division of fused middle trunk and lower trunk to form posterior cord. The communication between radial and ulnar nerve is not well documented.

In one case (1.67%), there was high division of radial nerve in the arm before passing through the lower triangular space, to enter the spiral groove. In only one limb (1.67%) communication was formed between radial to ulnar. In another case (1.67%) radial nerve was formed from two roots, formed by splitting of the posterior cord, which subsequently united to form radial nerve.

The nerve then descended behind the brachial artery and entered the spiral groove by passing through lower triangular space. On reaching the lateral side of humerus it pierced the lateral intermuscular septum and came to lie in front of lateral epicondyle of humerus.

Axillary nerve:

The axillary nerve divided into two branches – anterior and posterior. The anterior branch supplied anterior part of deltoid and posterior branch supplied posterior part of deltoid and teres minor in all the limbs of our study.

Bergman et al (2000) [72] described origin of nerve to teres major muscle from axillary nerve instead of lower subscapular nerve. Kocabiyik N (2007) reported a case where, suprascapular nerve did not arise from the superior trunk. It arose from the root of C5; while the other branch of C5 joined C6. Superior subscapular, thoracodorsal and inferior subscapular nerves arose from the posterior division of the upper trunk, instead of the posterior cord. Then, the posterior cord continued as axillary and radial nerves. The musculocutaneous and ulnar nerves had their normal course.[33]

In our study, axillary nerve existed in all 60 limbs (100%), which originated in 59 (98.3%) from posterior cord and in one case (1.67%) from posterior division of upper trunk. In all the cases axillary nerve was formed postero-lateral to 3rd part of axillary artery and there was no communication with any other nerves. The nerve along with posterior circumflex humeral artery traveled in quadrangular space.

Communicating branches between nerves:

In our study, 7 limbs (11.67%) had communicating branch was encountered between musculocutaneous and median nerve out of which 3 (5%) were in upper third of arm and 4 (6.67%) in middle third of arm. In one limb (1.67%) there was a communicating branch from radial nerve to ulnar nerve. In 3 (5%) limbs there was communicating branch between MPN and LPN. There was no communicating branch between UN and MN.

Choi D et al (2002) reported variations in connections between the musculocutaneous and median nerves in the arm. These variations were seen in 64 cadavers (46.4%). [41] Iwamoto S et al. (1990) reported a case in which a communicating branch was observed from the median nerve to the musculocutaneous, the fibers from C7 join to the median nerve via the medial cord. Thus the median nerve involved all elements of the spinal nerve from C5 to T1. The elements of the median and the musculocutaneous nerves, therefore, are not affected by appearance of the communicating branch. The communicating branch between the median and the musculocutaneous nerves, consists of the fibers arose from C5 and C6, in all examined cases.[78]

CONCLUSION

A thorough knowledge of variations of brachial plexus is mandatory in cases like, surgical exploration of axilla and arm, during cervical rib correction, which is one of the causes for thoracic outlet syndrome, anesthetic block either through, cervical or axillary approach, internal fixation of humeral fracture from common anterior approach and even during orthopedic and neurosurgical procedures on cervical spine and prosthetic implant placements.

The brachial plexus lesions may follow trauma, compression of nerves, shoulder dislocation, iatrogenic damage, and traumatic delivery in infants or malpositioning of patient during anaesthesia.

The neurovascular relations of the Brachial plexus and axillary artery and its branches are intricate and intimate. It is a known fact that the normal and anomalous positions of arteries and veins may be determined pre-operatively by angiographic studies, but in case of nerves it is not possible to detect such an anomaly. It is only at the time of surgery that the surgeon is exposed to such variations. Therefore, as anatomists, we believe, that prior anatomical knowledge of such anomalies may provide great help to neurologists, traumatologists and surgeons.

Injuries could be due to avulsion of the nerve roots from spinal cord, rupture of the nerve (neurotmesis), neuroma by a scar tissue during regeneration of an injured nerve or just compression or stretching (neuropraxia). All of these cause varying degrees of paresthesias, paresis or paralysis which in addition to compromising muscle function and movements hampering activities of the affected limb and can also affect physical appearance as in Erb-Duchenne’s and Klumpke’s palsy, etc. The importance of having experienced medical experts to treat brachial plexus injuries is thus rightfully emphasized.

In the present study, an attempt has been made to know the possible variations of the brachial plexus. Though the variations mentioned may not alter the normal functioning of the limb of the individual, but knowledge of the variations is of prime importance to be kept in mind, during anaesthetic and surgical procedures. The restricted sample size was a limitation in our study. Yet an earnest effort in the study has opened new avenues for further research. Thus, we would have better guidelines for successful surgical interventions.

SUMMARY

The present study was conducted to know the variations of brachial plexus pertaining to its formation and branching pattern in its supraclavicular course and infraclavicular course limiting to the axillary and arm region, in a total of 60 upper limbs of 30 human cadavers.

Out of the 60 cadaveric upper limbs studied for the anatomical variations of the brachial plexus, 2 limbs (3.33%) were pre-fixed plexuses, 58 limbs (96.67%) were normal and no post-fixed plexus was detected. Variations in branches of lateral cord was detected in 8 limbs, in which extra lateral root of median nerve was detected in 7 limbs (11.67%) and 4 limbs (6.67%) had absence of musculocutaneous nerve. Among Posterior cord variations 2-thoracodorsal nerves were detected in 2 limbs (3.33%). In one limb (1.67%) the posterior cord divided into two branches/roots, which later fused to form the radial nerve. In two limbs (3.33%) the posterior cord was formed from joining of the posterior division of upper trunk to the common posterior division from fused middle and lower trunks and in one of these two limbs (1.67%) the axillary nerve, upper and lower subscapular nerves were formed from posterior division of upper trunk and then posterior division of upper trunk joined the common posterior division of fused middle and lower trunks to give radial nerve and thoracodorsal nerve. This radial nerve communicated with the ulnar nerve. The musculocutaneous nerve was found to be absent in 4 limbs (6.67%) and present in 56 limbs (93.33%), all of which originated from lateral cord and were lateral to 3rd part of axillary artery and all of them pierced coracobrachialis. In 7 limbs out of 56 limbs (12.5%) there was communication of musculocutaneous nerve with median nerve out of which 3 limbs

(5.36%) communication was before musculocutaneous nerve pierced coracobrachialis and in 4 limbs (7.14%) after piercing coracobrachialis. Among the limbs where median nerve was formed by 2 roots, 41 (68.33%) were formed in axilla, 8 (13.33%) were formed in upper third of arm and 4 (6.67%) in middle third of arm. Among the limbs where median nerve was formed by 3 roots in 5 limbs (8.33%) median nerves were formed in axilla and 2 (3.33%) median nerves were formed in upper third of arm. In 46 limbs (76.67%), median nerve was formed lateral to axillary artery, 12 limbs (20%) anterior to axillary artery and in 2 limbs (3.33%) medial to axillary artery. In 58 limbs (96.67%) median nerve coursed lateral to brachial artery in arm and in 2 limbs (3.33%) median nerve coursed medial to brachial artery in arm. In 56 limbs (93.33%) musculocutaneous nerve supplied muscles of anterior compartment of arm and in 4 limbs (6.67%) where musculocutaneous nerve was absent, median nerve took over the function of supplying muscles of the anterior compartment of arm.

In 7 limbs (11.67%) communicating branch was encountered between musculocutaneous and median nerve out of which 3 (5%) were in upper third of arm and 4 (6.67%) in middle third of arm. Ulnar nerve was present in all 60 limbs (100%) and originated from medial cord and was formed medial to 3^{rd} part of axillary artery and in one limb (1.67%) there was a communicating branch from radial nerve to ulnar nerve. Radial nerve was present in all 60 limbs (100%) originated from posterior cord and was posterior to 3^{rd} part of axillary artery. Only in one limb (1.67%) thoracodorsal nerve and radial nerve originated from posterior cord, where as axillary nerve, upper subscapular nerve and lower subscapular nerve originated from posterior division of upper trunk. Posterior division of upper trunk joined common posterior division of fused middle trunk and lower trunk to form posterior cord.

In only one limb (1.67%) communication was formed between radial nerve to ulnar nerve. In another case (1.67%) radial nerve was formed from two roots, formed by splitting of the posterior cord, which subsequently united to form radial nerve. In one case there was high division of radial nerve in the arm.

Axillary nerve existed in all 60 limbs (100%), which originated in 59 (98.3%) from posterior cord and in one case (1.67%) from posterior division of upper trunk. In all the cases axillary nerve was formed postero-lateral to 3^{rd} part of axillary artery and there was no communication with any other nerves. All the other branches from brachial plexus had been found to have no anatomical variations.

It is reasonable to believe that a thorough knowledge of variations of brachial plexus is binding during surgical exploration of axilla and arm during cervical rib correction, anesthetic block, humeral fracture surgery and even during orthopaedic and neurosurgical procedures on cervical spine and prosthetic implant placements. Thus, we would have better guiding principles for successful surgical interventions.

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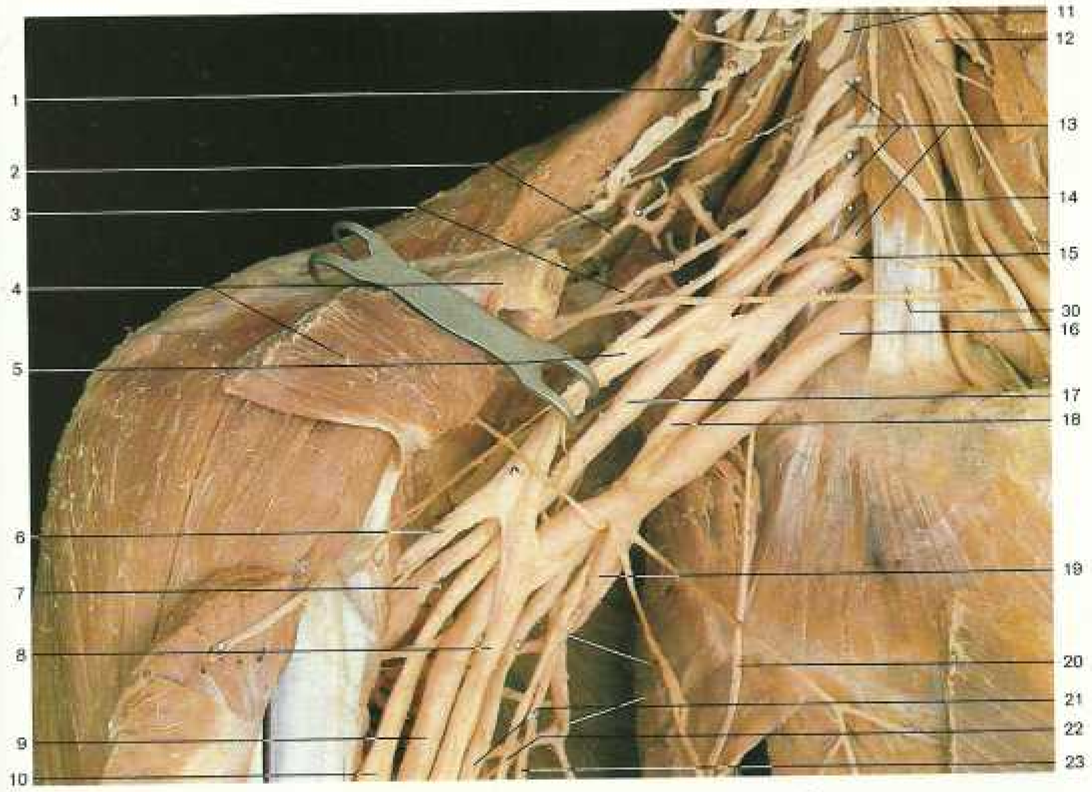
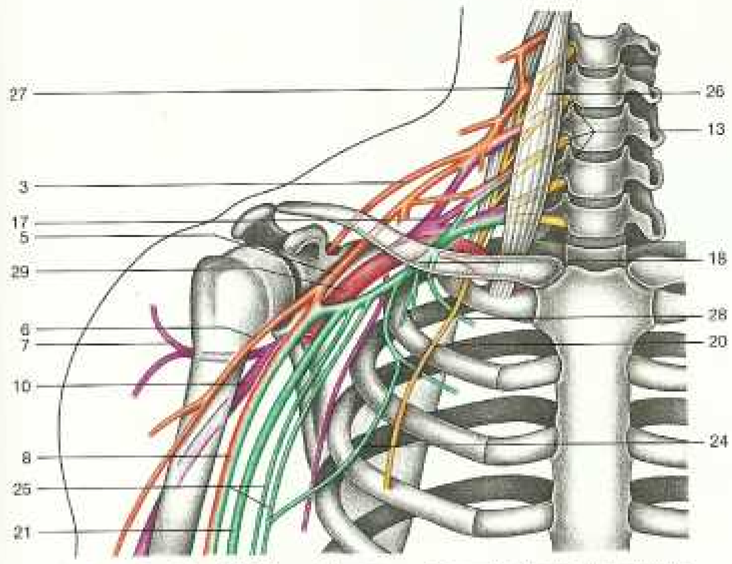


Brachial plexus (anterior aspect). Clavicle and the two pectoralis muscles have been partly removed.



Main branches of brachial plexus. Posterior cord in purple, lateral cord in orange, and medial cord in green (schematic drawing).

1 Accessory nerve
2 Dorsal scapular artery
3 Suprascapular nerve
4 Clavicle and pectoralis minor muscle
5 Lateral cord of brachial plexus
6 Musculocutaneous nerve
7 Axillary nerve
8 Median nerve
9 Brachial artery
10 Radial nerve
11 Cervical plexus
12 Common carotid artery
13 Roots of brachial plexus (C_5–T_1)
14 Phrenic nerve
15 Transverse cervical artery
16 Subclavian artery
17 Posterior cord of brachial plexus
18 Medial cord of brachial plexus
19 Subscapular artery
20 Long thoracic nerve
21 Ulnar nerve
22 Medial cutaneous nerve of forearm
23 Thoracodorsal nerve
24 Intercostobrachial nerve
25 Medial cutaneous nerves of arm and forearm
26 Scalenus anterior muscle
27 Scalenus medius muscle
28 Intercostal nerve (T_1)
29 Axillary artery
30 Suprascapular artery

Figure No. 1 – Normal Brachial plexus Anatomy

Figure No. 2 – Instruments used in the study

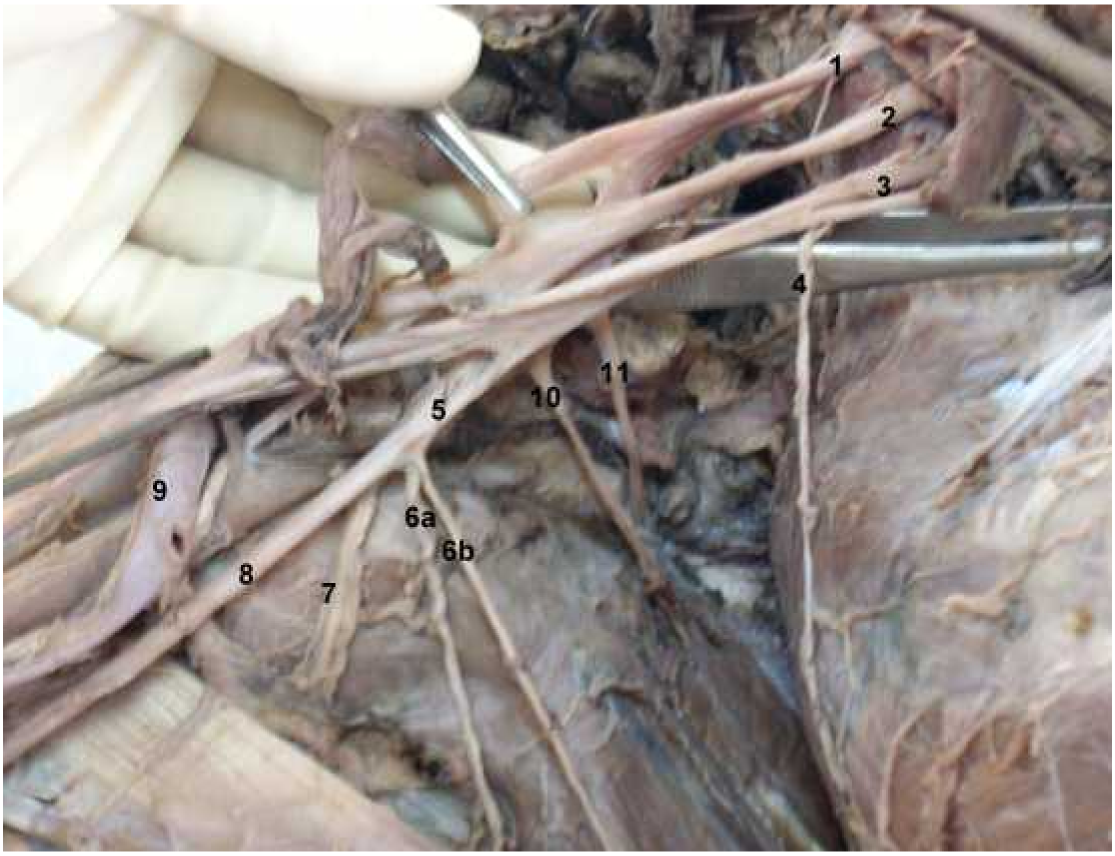


Figure No. 3 – Right- sided Brachial plexus showing two Thoracodorsal nerves
1) Upper trunk **2)** Middle trunk **3)** Lower trunk **4)** Long thoracic nerve **5)** Posterior cord **6a) & 6b)** Thoracodorsal nerves **7)** Lower subscapular nerve **8)** Radial nerve **9)** Brachial artery **10)** Upper subscapular nerve **11)** Suprascapular nerve

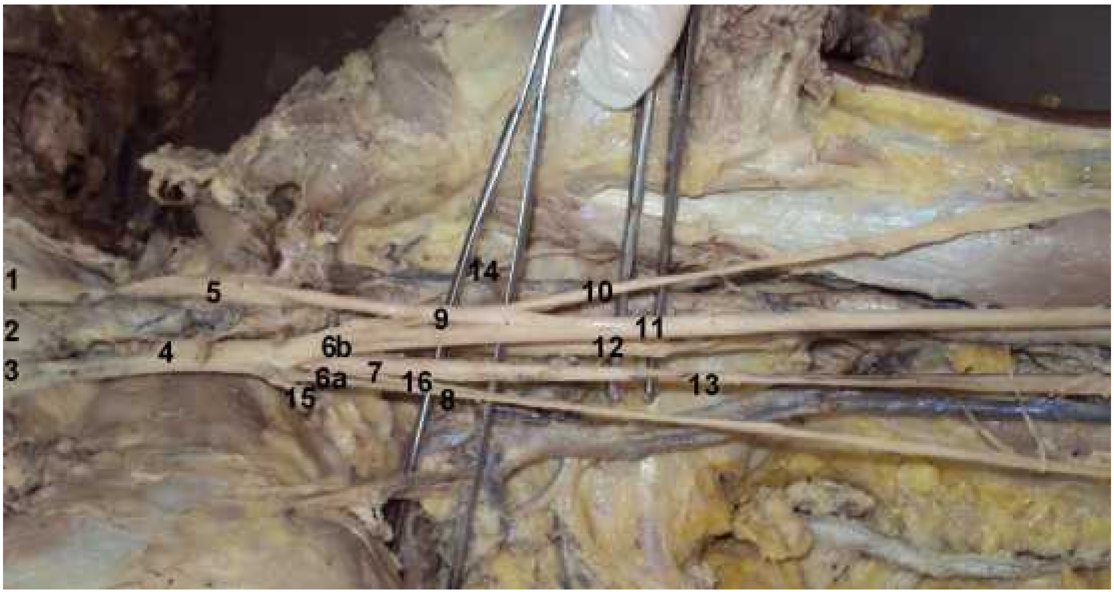


Figure No. 4 –Left-sided brachial plexus showing Fusion of middle and lower trunks giving common anterior and posterior divisions

1) Upper trunk **2)** Middle trunk **3)** Lower trunk **4)** Fused middle and lower trunks **5)** Anterior division of upper trunk **6a) & 6b)** 1st and 2^{nd} parts of common anterior division of middle and lower trunks **7)** Posterior cord **8)** Ulnar nerve **9)** Lateral cord **10)** Musculocutaneous nerve **11)** Median nerve **12)** Axillary nerve **13)** Radial nerve **14)** Branch to Coraobrachialis from the anterior division i.e. 6b **15)** Medial cutaneous nerve of forearm **16)** communicating branch between RN & UN

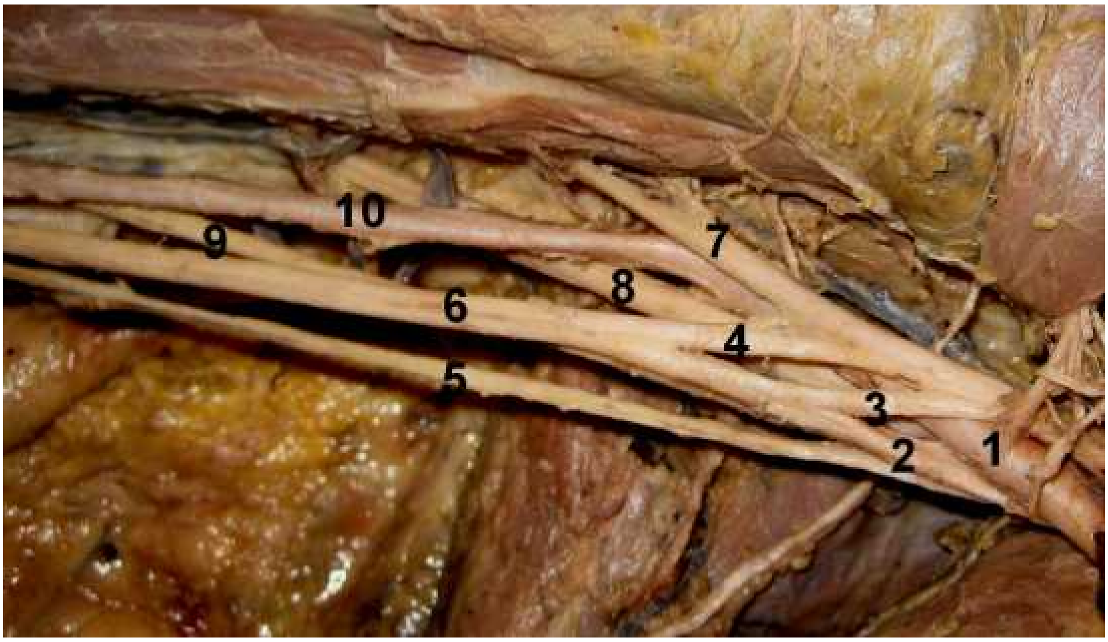


Figure No. 5 – Right-sided Median Nerve formation by 3 roots

1) Axillary artery **2)** Medial root of Median nerve **3)** 1^{st} Lateral root of Median nerve **4)** 2^{nd} Lateral root of Median nerve **5)** Ulnar nerve **6)** Median nerve **7)** Musculocutaneous nerve **8)** Axillary nerve **9)** Radial nerve **10)** Brachial artery

Figure No. 6 – Left-sided Median formation by 3 roots
1) Musculocutaneous nerve **2)** 2nd lateral root of Median nerve **3)** 1st lateral root of Median nerve **4)** Lateral cord **5)** Medial root of Median nerve **6)** Medial cord **7)** Ulnar nerve **8)** Medial cutaneous nerve of forearm **9)** Axillary artery

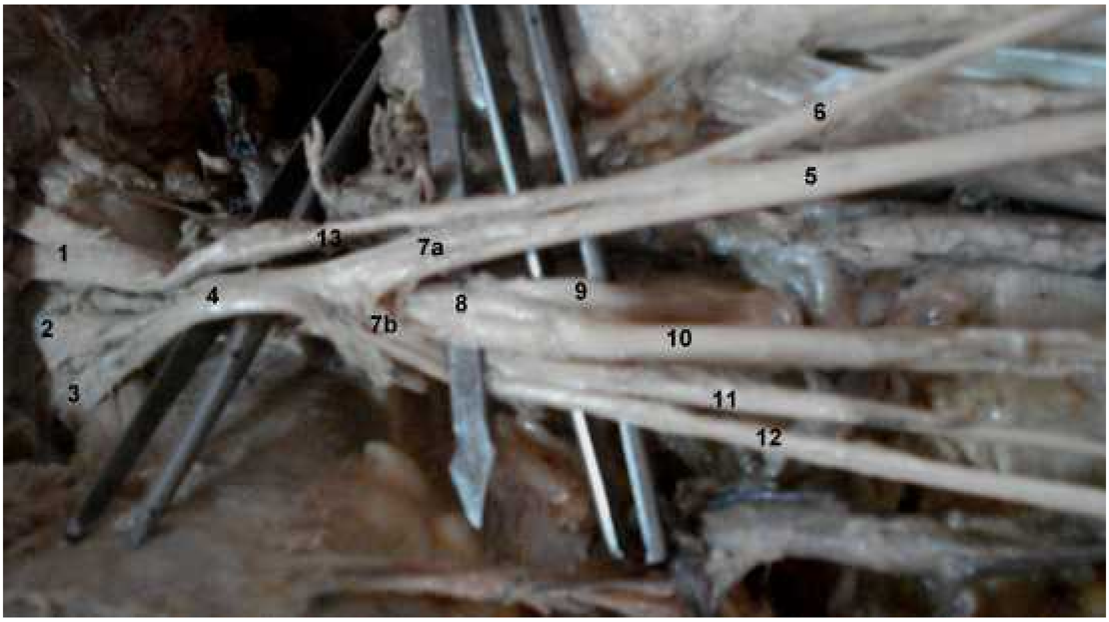


Figure No. 7 – Left-side Brachial plexus: Fusion of Middle and Lower trunks
1) Upper trunk **2)** Middle Trunk **3)** Lower trunk **4)** Fused Middle and Lower trunk **5)** Median nerve **6)** Musculocutanneous nerve **7a) & 7b)** 1st Anterior division and 2nd Anterior division from fused middle and lower trunks **8)** Posterior cord **9)** Axillary nerve **10)** Radial nerve **11)** Ulnar nerve **12)** Medial cutaneous nerve of forearm **13)** Anterior division of upper trunk receiving fibres from 7a to form Lateral cord

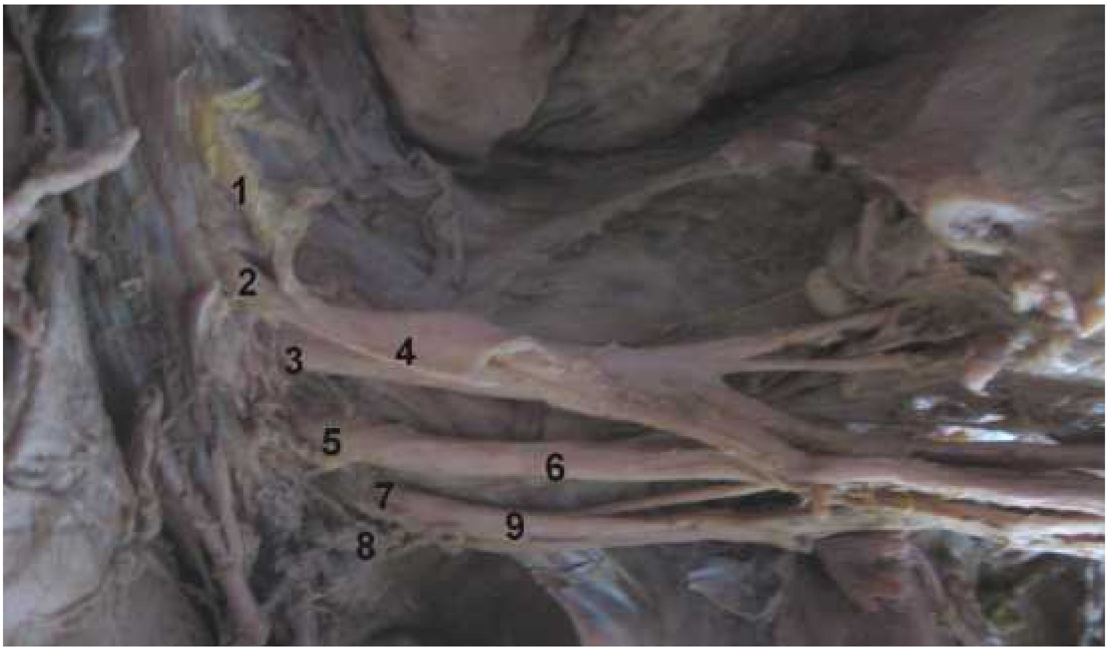


Figure No. 8– Left-sided Pre- fixed Brachial plexus
1) Ventral ramus of C4. **2)** Ventral ramus of C5. **3)** Ventral ramus of C6. **4)** Upper trunk **5)** Ventral ramus of C7. **6)** Middle trunk **7)** Ventral ramus of C8. **8)** Ventral ramus of T1 **9)** Lower trunk

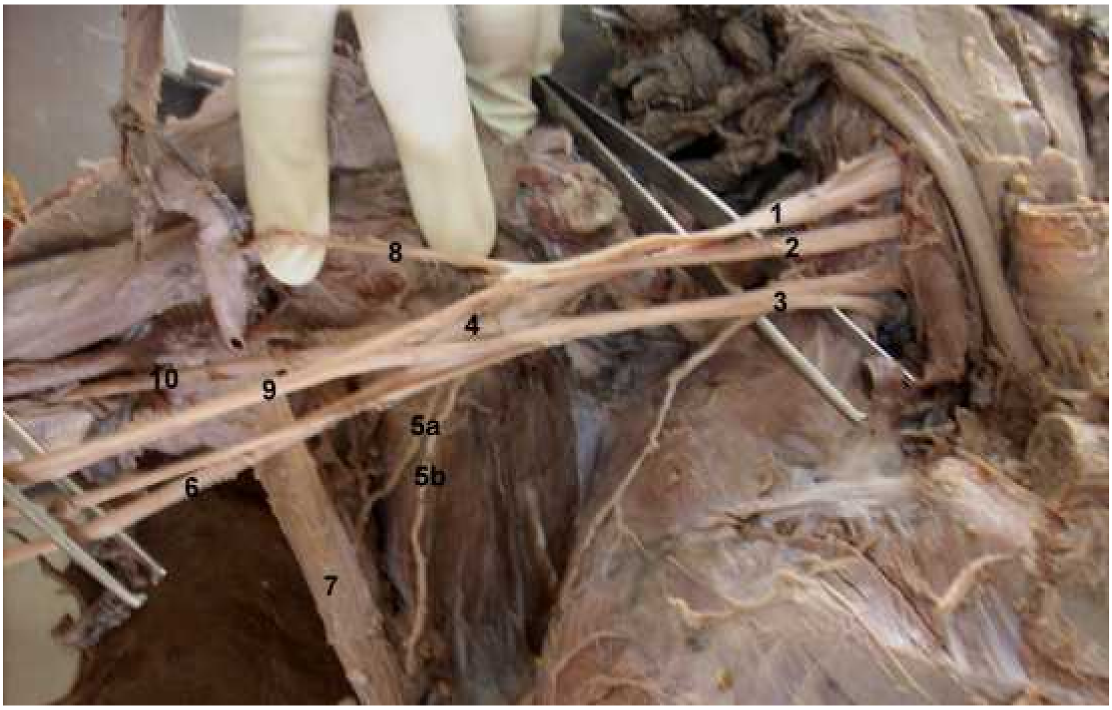


Figure No. 9 – Right- sided Brachial plexus showing Two Thoracodorsal nerves supplying Latissimus dorsi
1) Upper trunk **2)** Middle trunk **3)** Lower trunk **4)** Posterior cord **5a) & 5b)** Thoracodorsal nerves (two nerves supplying Lattisimus dorsi) **6)** Ulnar nerve **7)** Lattisimus dorsi **8)** Musculocutaneous nerve **9)** Median nerve **10)** Radial nerve

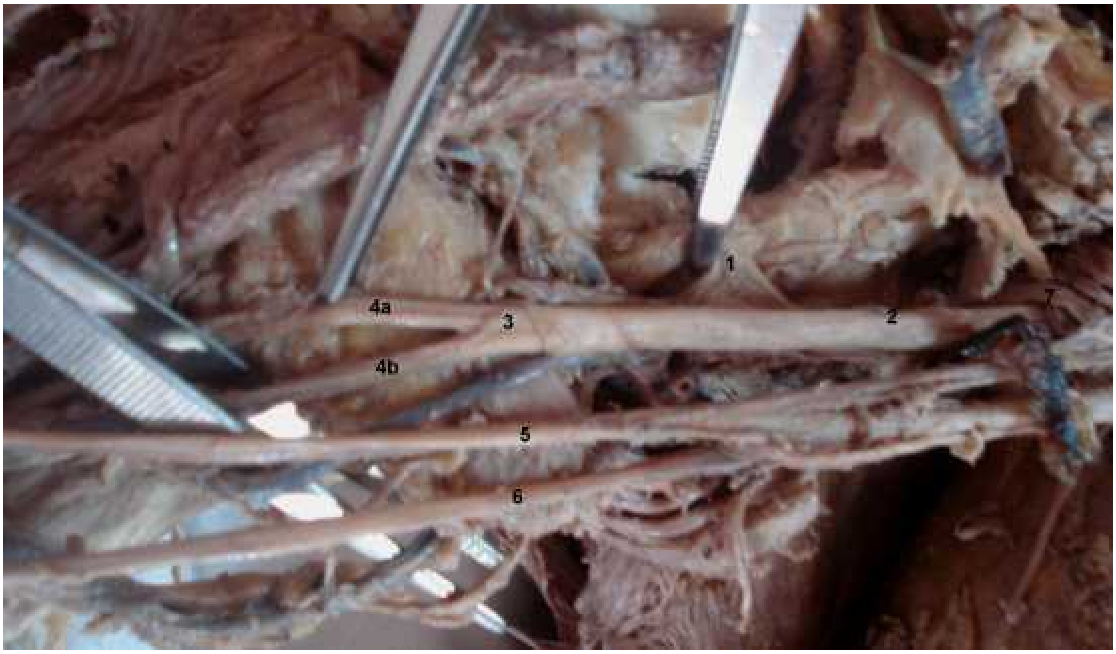


Figure No. 10 – High division of Radial nerve
1) Axillary nerve **2)** Posterior cord **3)** Radial nerve **4a) & 4b)** two divisions of Radial nerve **5)** Median nerve **6)** Ulnar Nerve **7)** Musculocutaneous nerve

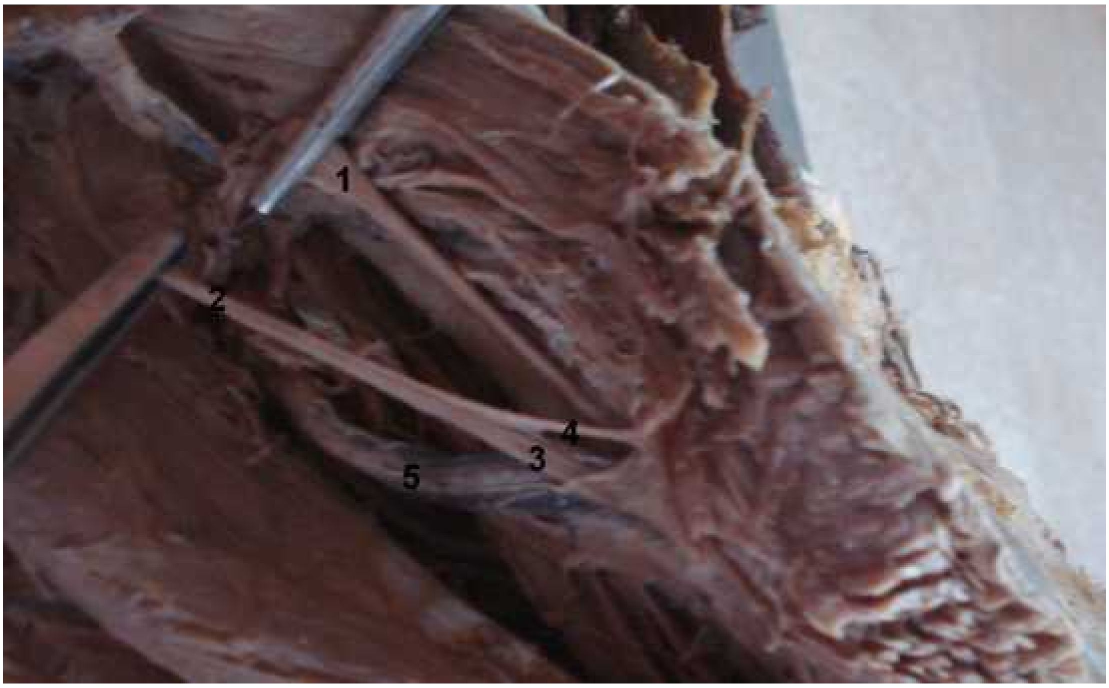


Figure No. 11 - High division of radial nerve (from figure 10 continued …) two divisions of radial nerve in spiral groove
1) Posterior interosseous nerve or deep terminal branch of radial nerve (1^{st} division of radial nerve) **2)** 2^{nd} division of radial nerve **3)** Superficial terminal branch of radial nerve **4)** Posterior muscular branches supplying triceps **5)** Profunda brachii artery

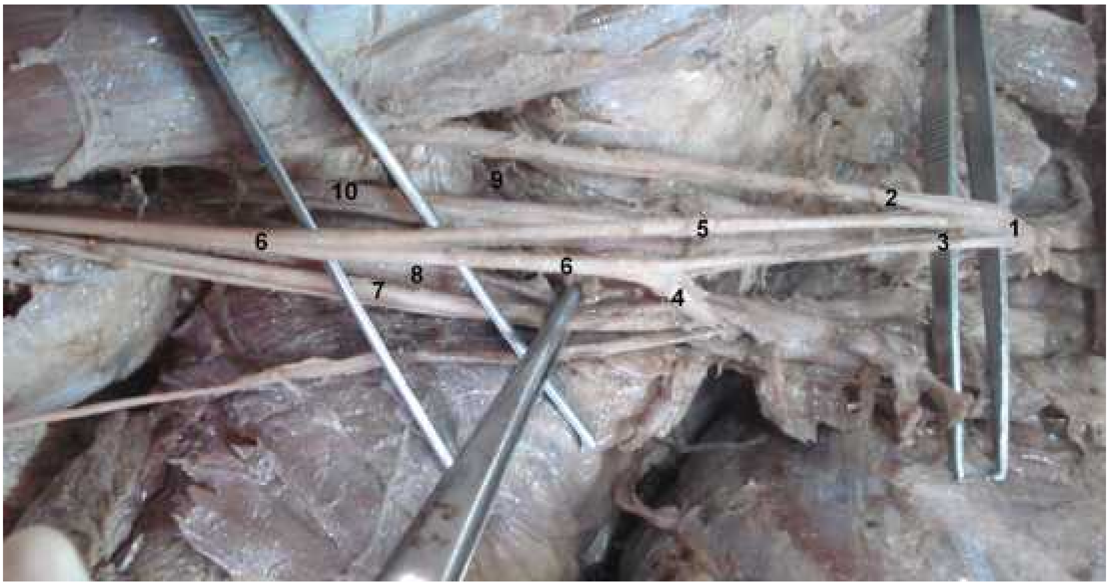


Figure No.12 – Right-sided Brachial plexus showing Median nerve formation by 3 roots

1) Lateral cord **2)** Musculocutaneous nerve **3)** 1st Lateral root of Median nerve **4)** Medial root of Median nerve **5)** 2nd Lateral root of Median nerve **6)** Median nerve **7)** Ulnar nerve **8)** Brachial artery **9)** Axillary nerve **10)** Radial nerve

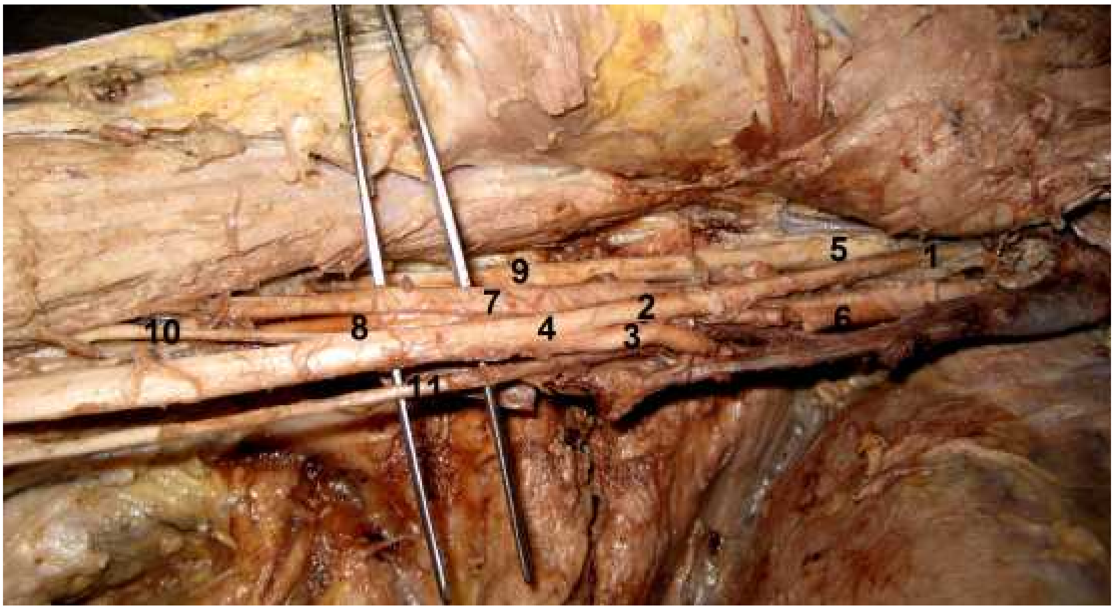


Figure 13- Absence of Musculocutaneous nerve

1) Lateral cord **2)** Lateral root of Median nerve **3)** Medial root of median nerve **4)** Median nerve **5)** Posterior cord **6)** Axillary artery **7)** Profunda brachii **8)** Radial nerve **9)** Axillary nerve **10)** branch from Median nerve supplying muscles of anterior compartment of arm

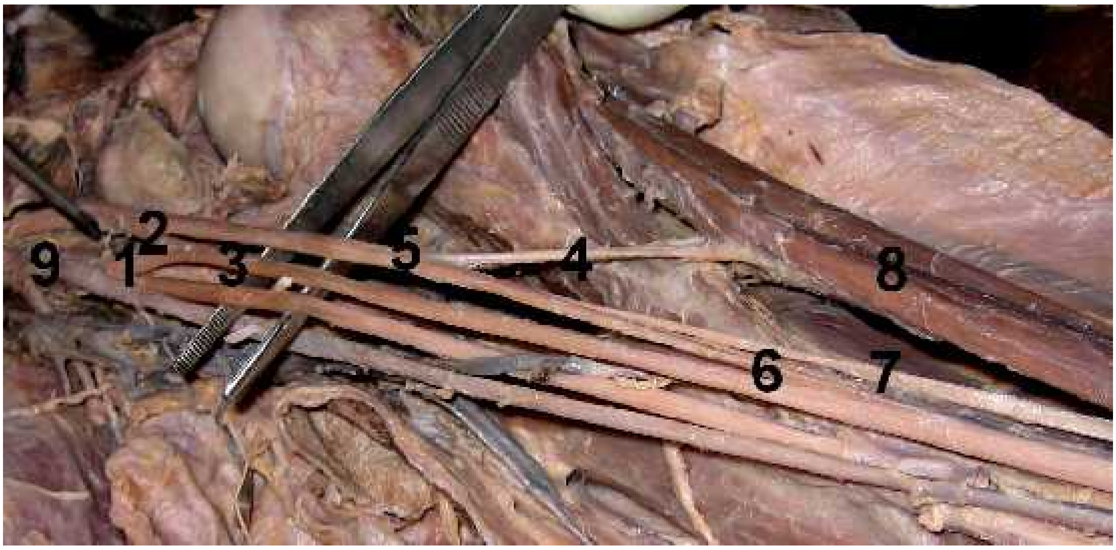


Figure No. 14 – Left-sided Musculocutaneous nerve communicating with Median nerve

1) Medial root of Median nerve **2)** Lateral root of median nerve **3)** Median nerve **4)** Branch to Biceps brachii from Musculocutaneous nerve **5)** Musculocutaneous nerve **6)** communication between Musculocutaneous nerve and Median nerve **7)** Continuation of Musculocutaneous nerve **8)** Biceps brachii **9)** Axillary artery

MASTER CHART SHOWING THE IMPORTANT PARAMETERS STUDIED																								
			ROOTS				TRUNKS							CORDS			MAIN TERMINAL BRANCHES							COMMUNICATING BRANCHES
S.No	Sex	Side	Type			Branches	UT			MT		LT		Formations & Branches			MCN	MN Formation			Other			
			N	Pre	Post		Branches	Division		Division		Division		Lat	Med	Pst		No of Roots	Relation to AA	Level	RN	AN	UN	
								A	P	A	P	A	P											
1	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
2	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Anterior	U 1/3	√	√	√	
3	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
4	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
5	F	R	√			Normal	Normal	√	√	√	√	√	√	**$**	N	N	√	**3**	Anterior	U 1/3	√	√	√	
6	F	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Anterior	Ax	√	√	√	MN with MCN
7	M	R		√		Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
8	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
9	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	LPN with MPN
10	M	L	√			Normal	Normal	√	√	√	√	√	√	**$**	N	N	√	**3**	Anterior	U 1/3	√	√	√	
11	F	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
12	F	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	U 1/3	√	√	√	
13	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
14	M	L	√			Normal	Normal	√	√	√	√	√	√	**$**	N	N	√	**3**	Medial	Ax	√	√	√	
15	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Anterior	M 1/3	√	√	√	
16	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Anterior	Ax	√	√	√	
17	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	MN with MCN
18	M	L		√		Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
19	F	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	M 1/3	√	√	√	
20	F	L	√			Normal	Normal	√	√	√	√	√	√	**$**	N	N	**Ab #**	**3**	Lateral	Ax	√	√	√	
21	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
22	M	L	√			Normal	Normal	√	√	*	*	*	*	*	*	*	√	2	Lateral	Ax	√	√	√	
23	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	U 1/3	√	√	√	
24	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
25	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	MN with MCN
26	M	L	√			Normal	Normal	√	√	√	√	√	√	**$**	N	N	√	**3**	Lateral	Ax	√	√	√	
27	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Anterior	Ax	√	√	√	
28	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	U 1/3	√	√	√	LPN with MPN
29	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
30	M	L	√			Normal	Normal	√	√	√	√	√	√	**$**	N	N	**Ab #**	**3**	Anterior	Ax	√	√	√	

MASTER CHART SHOWING THE IMPORTANT PARAMETERS STUDIED

S.No	Sex	Side	ROOTS				TRUNKS							CORDS			MAIN TERMINAL BRANCHES							COMMUNICATING BRANCHES
			Type			Branches	UT			MT		LT		Formations & Branches			MCN	MN Formation			Other			
			N	Pre	Post		Branches	Division		Division		Division		Lat	Med	Pst		No of Roots	Relation to AA	Level	RN	AN	UN	
								A	P	A	P	A	P											
31	F	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
32	F	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
33	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	LPN with MPN
34	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
35	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	**2 TD**	√	2	Lateral	Ax	√	√	√	
36	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Anterior	U 1/3	√	√	√	
37	F	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
38	F	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
39	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	MN with MCN
40	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
41	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
42	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	U 1/3	√	√	√	
43	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
44	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Anterior	U 1/3	√	√	√	
45	M	R	√			Normal	Normal	√	√	√	√	√	√	**$**	N	N	**Ab #**	**3**	Lateral	Ax	√	√	√	
46	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	**Ab #**	2	Lateral	Ax	√	√	√	
47	F	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Medial	Ax	√	√	√	MN with MCN
48	F	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	M 1/3	√	√	√	
49	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	**2 TD**	√	2	Lateral	Ax	√	√	√	
50	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	U 1/3	√	√	√	
51	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
52	M	L	√			Normal	Normal	√	√	*****	*****	*****	*****	*****	*****	**¥**	√	2	Lateral	Ax	√	**§**	√	RN with UN
53	F	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Anterior	Ax	√	√	√	
54	F	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	
55	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	**@**	√	√	
56	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	**£**	√	2	Anterior	Ax	√	√	√	
57	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	MN with MCN
58	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	M 1/3	√	√	√	
59	M	R	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Lateral	Ax	√	√	√	MN with MCN
60	M	L	√			Normal	Normal	√	√	√	√	√	√	N	N	N	√	2	Anterior	Ax	√	√	√	

Abbreviations used in Master Chart

S.No	Serial number
M	Male
F	Female
R	Right
L	Light
N	Normal
√	Present/normal
Pre	Pre-fixed
Post	Post-fixed
A	Anterior
P	Posterior
*	Fused MT and LT which gives common anterior and posterior divisions. The common anterior division split into 2 parts. First anterior division also split into 2 parts : 1st part smaller contribution joined with anterior division of UT to form lateral cord. 2nd larger contribution was medial root of median nerve. Second anterior division acted as medial cord and gave ulnar nerve, medial cutaneous nerve of arm, medial cutaneous nerve of forearm. MPN was cut and could not be traced to its origin. The posterior division of UT joined with common posterior division of fused MT and LT to form posterior cord.
Lat	Lateral
Med	Medial
Pst	Posterior
TD	Thoracodorsal nerve
$	Extra lateral root of MN
£	Posterior cord split into 2 roots which united to form RN
Ab #	Absence of MCN & muscles of anterior compartment supplied by MN
Ax	Axilla
U 1/3	Upper third
M 1/3	Middle third
@	High division of RN
¥	The posterior division of UT gave the AN and upper subscapular nerve and lower subscapular nerve and then joined common posterior division of fused MT and LT to form posterior cord to give RN & TD nerve.
§	AN origin from posterior division of UT.
LPN	Lateral pectoral nerve
MPN	Medial pectoral nerve
MN	Median nerve
MCN	Musculocutaneous nerve
AN	Axillary nerve
RN	Radial nerve
UN	Ulnar nerve