THE MORPHOLOGY OF A SMARTPHONOPATHIC HAND

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Dedicated to my utmost loving, caring, and supportive mother (Ambareen), father (Hasib), siblings (Zeerak and Jaudat), and my mother-like supervisor Prof. Dr. Ambreen Usmani

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ABSTRACT

Ever since the devise of internet and handheld gadgets, the world has become a global village. Among these handheld devices, smartphones have taken the world by storm and their usage has boomed in the last decade or so. Several studies have reported anatomical changes (such as enlarged median nerve) and reduced grip strength in the wrist and hand of smartphone user. Objectives included measurement and comparison of the grip strength and median nerve cross-sectional area (MN-CSA) between dominant and non-dominant hands of smartphone users, and, to evaluate, measure and compare the anatomical changes in the fifth digit of dominant and non-dominant hands of smartphone users. Hundred and twenty-eight health sciences students were selected aging from 17-25 years. By using the smartphone addiction scale (SAS), the participants were divided into two groups: low-smartphone users and high-smartphone users. Details of the smartphone (weight, screen size) were collected from a reliable smartphone website (GSMArena). Grip strength was measured using a hand dynamometer. Ultrasound of both hands of each individual was done at the distal crease of the wrist to evaluate the median nerve cross-sectional area (MN-CSA). X-Ray (finger PA) was done of both hands. Median value of SAS scores of the 128 participants was 114.5 (>114.5 were classified as high-smartphone users; <114.5 were classified as low-smartphone users). Results demonstrated that the difference between the MN-CSAs of dominant and non-dominant hand of the high-smartphone group was highly significant (*p*=0.007). The difference between the MN-CSAs of dominant and non-dominant hand of the low-smartphone group was significant too (*p*=0.0103). The mean grip strength in the dominant hand of the high-smartphone group was 28.7 kg while in the low-smartphone group it was 29.5 kg. It can be concluded that smartphone over use resulted in an enlarged median nerve, especially in the dominant hand. It can lead to reduced grip strength of the dominant hand in individuals with excessive smartphone use and might also lead to carpal tunnel syndrome.

Key words: Smartphone overuse, Hand function, Median nerve, Hand grip strength, Fifth Digit, Median nerve cross-sectional area (MN-CSA)

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MN-CSA	-	Median Nerve Cross-Sectional Area
CSA	-	Cross-Sectional Area
mm	-	Millimeter
kg	-	Kilograms
SAS	-	Smartphone Addiction Scale
DHI	-	Duroz Hand Index
SP	-	Smartphone
D.H	-	Dominant Hand
BUHSCK	-	Bahria University Health Sciences Campus Karachi
FPL	-	Flexor pollicis longus

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Over the decades there have been numerous inventions which have changed the lives for better or worse. Perhaps, out of all those, the most ingenious one is the devise of handheld devices, particularly smartphones. The term “Smartphone” was originally coined in the year 1997, when Ericsson presented its GS 88 “Penelope” idea/notion as a smartphone (Rockman, 2021). Today’s smartphones resemble mini-computers (Kubal and Dsouza, 2020). A smartphone can be defined, simply, as a hybrid between a computer and a telephone (Wanga, Joseph, and Chuma, 2020). A smartphone, roughly around the size of a person’s palm, lets one have the functionalities of both, a computer and a telephone, with mobility being its biggest advantage. Since the invent of smartphones, the world has never been such a small global village, giving a person access to information about even the most remote areas after just pressing of a few buttons.

Among these handheld devices, smartphones have taken the world by storm and their usage has boomed in the last decade or so. The ongoing COVID-19 pandemic and implied quarantines and lockdowns worldwide have caused the masses to resort to handheld and portable devices such as smartphones, tablets, laptops, etc., to an even greater extent than before, whether that is to work from home or for entertainment purposes. Almost every person owns a smartphone these days. In 2013 it was found that there were nearly as numerous mobile subscriptions as individuals in the world. (Wanga et al., 2020).

Majority comprising the smartphone usage niche is the younger population. The number of smartphone users by the year 2020 had reached to 3.5 billion globally, 9.3% higher than what it was in 2019. (Osailan, 2021)

A smartphone differs from a typical cell phone in the sense that the former can be a cell phone, but the latter cannot be a smartphone. While a cell phone might have limited functions, a smartphone can be summed up as being a brainchild of a telephone and a handheld computer.

Smartphones can receive text messages and voice calls like a telephone while also perform various tasks of a handheld computer such as internet browsing, social networking, snapping pictures and video calling to name a few. Probably the prime factor that differentiates a smartphone from a cell phone is the operating software system it runs which, limited popularly to iOS and Android, offers an ecosystem for the user to inhabit. This enables application developers to make use of this interface and allow smartphone users to carry a cell phone, radio, music player, gaming console, global positioning system (GPS), camera, internet browser all in one handheld gadget (Wanga et al.,, 2020). This makes them a popular device among various age groups but particularly the younger population. In 2016 it was reported that 87% of the teenagers in USA between the ages of 14-18 years and 79% in the UK (12-15 years) possessed a smartphone. (Toh et al., 2017). While majority of the adults (94%) who use smartphones were between the ages of 18-29 years (O'Donnell and Epstein, 2019).

The smartphones have evolved at a blazing pace in the last decade. From being smaller in size and stature and compact to becoming taller; from having physical keypads to having more or an all-screen estate; from having flat displays to having various degrees of curved displays; from being light in weight to some becoming absolute bricks.

All these form factors are worth taking into consideration as they affect how an individual grasps his smartphone, adapts his hand around it, supports and balances the weight of it and perhaps most importantly, how he uses it. The latter refers to using the smartphone either single-handedly or double-handedly and how many times and to what extent one must move his thumb across the screen to avail full functionality of the device. Even though the smartphone design and structure allow making use of both hands, single-handed use is more favored by young people (Osailan, 2021).

What differs human beings from other creatures, apart from their intellect, is the precise movements humans can perform especially with their hands. The hand has distinctive features like various other organs of the human body and any sort of impairment can alter daily life and eventually the quality of life. The hand, in humans, is the only prehensile organ. Prehension is characterized as the act of seizing or clasping, while prehensile defines the adaptation of an organ for clasping or wrapping around an object in hand. Prehension grip allows to grasp the object between the fingertips and thumb (Tidke, Shah, and Kothari, 2019). Commonly, the posture when operating a smartphone involves clutching it single or double handedly below the eye level, looking down at it and using the thumb to glide and tap across the screen of the smartphone (Eitivipart, Viriyarojanakul, and Redhead, 2018). Some users also involve the last digit to support the weight of the phone.

Excessive and prolonged smartphone use has been extensively studied over the past few years and has been proven to correlate to a lot of changes, disabilities, and dysfunction of the human body. Some of the many adverse effects include depression (Alhassan et al., 2018), insomnia and blurred vision (Alkhateeb et al., 2020), alexithymia (Elkholy, Elhabiby, and Ibrahim, 2020), chronic neck and upper back pain (Samaan et al., 2018), thoracic kyphosis and lumbar lordosis (Betsch et al., 2021), and De Quervain’s tenosynovitis (Osailan, 2021).

Perhaps less studied is the effect smartphone overuse has on the wrist and hand. The chief anatomical structures involved in the movements carried out to operate the smartphone in hand comprise of the digits of the hand(s), median nerve, and the flexors and extensors of the thumb. Possibly the two digits that undergo the most strain while using a smartphone are the first-used to navigate through the smartphone-and last-to support the weight of the smartphone-digits which are made up of the metacarpal and phalanx bones. Median nerve provides the sensory and motor innervation to the first three and a half fingers on the palmar surface of the hand.

The wrist and especially the thumb are in constant positional changes when using a smartphone. The thumb of the hand (especially when using single-handedly) in which the smartphone is held must undergo constant flexion and extension to reach different areas of the screen to avail various functions of the smartphone. The degree of this movement depends primarily on the screen estate (screen size), hours spent on the smartphone, and the number of hands being used to operate it.

The limited number of studies that have been conducted have reported that continuous finger movements, unnatural wrist position and forceful exertion might lead to carpal tunnel syndrome (CTS) and deformation of the median nerve after operating a smartphone for 30 minutes (Woo et al., 2016), enlarged median nerve, altered hand function, and decreased pinch and grip strength (Inal et al., 2015; Radwan, Ibrahim, and Mahmoud, 2020).

Indeed, the least studied is the effect of excessive smartphone usage on the morphology of the 5th digit of the hand (Fuentes-Ramírez et al., 2020). To the best of knowledge, no study has thus far investigated the connection between smartphone usage and weight and anatomical changes of the 5th digit of the dominant hand of the user based on radiographic evaluation.

1.2 EMBRYOLOGY OF THE HAND

Development of the fetus comprises of separate and distinct phases; first being from 1^{st}-2^{nd} weeks making up the pre-differentiation phase, second phase being from 3^{rd}-8^{th} weeks making up the embryonic period, and the last being the fetal period from week 9 onward. It is amidst the embryonic period during the 5th week that the differentiation of the upper limb morphology commences with the arising of the upper limb bud.

Three distinct phases of development can be used to describe the morphogenesis of the fetal hand, which takes place between 6^{th}-14^{th} weeks of gestation:

1. Shape – from 6-10 weeks
2. Appearance of creases – from 10-13 weeks
3. Formation of ridges – from week 13 onward

In the first phase, the whole external shape of the hand is achieved in gestation. It is as early as 6 weeks that the initial configuration of the hand takes place along with the asymmetry of the hand primordium and formation of the thumb slots. Rotation of the thumb, orientation of all the fingers in the same spatial plane, and progressive arrangement of the digital and interdigital pads and their prominence occurs through weeks 8 to 10.

The second phase of development, both, digital and interdigital pads, begin to regress during the weeks 10 to 13. The first crease is created around the 10^{th} week due to the opposition of the thumb and the latter also results in the emergence of the thenar pattern area. In the following 2 weeks, proximal and distal palmar creases appear more evident. Interphalangeal flexion crease is the last crease to become evident.

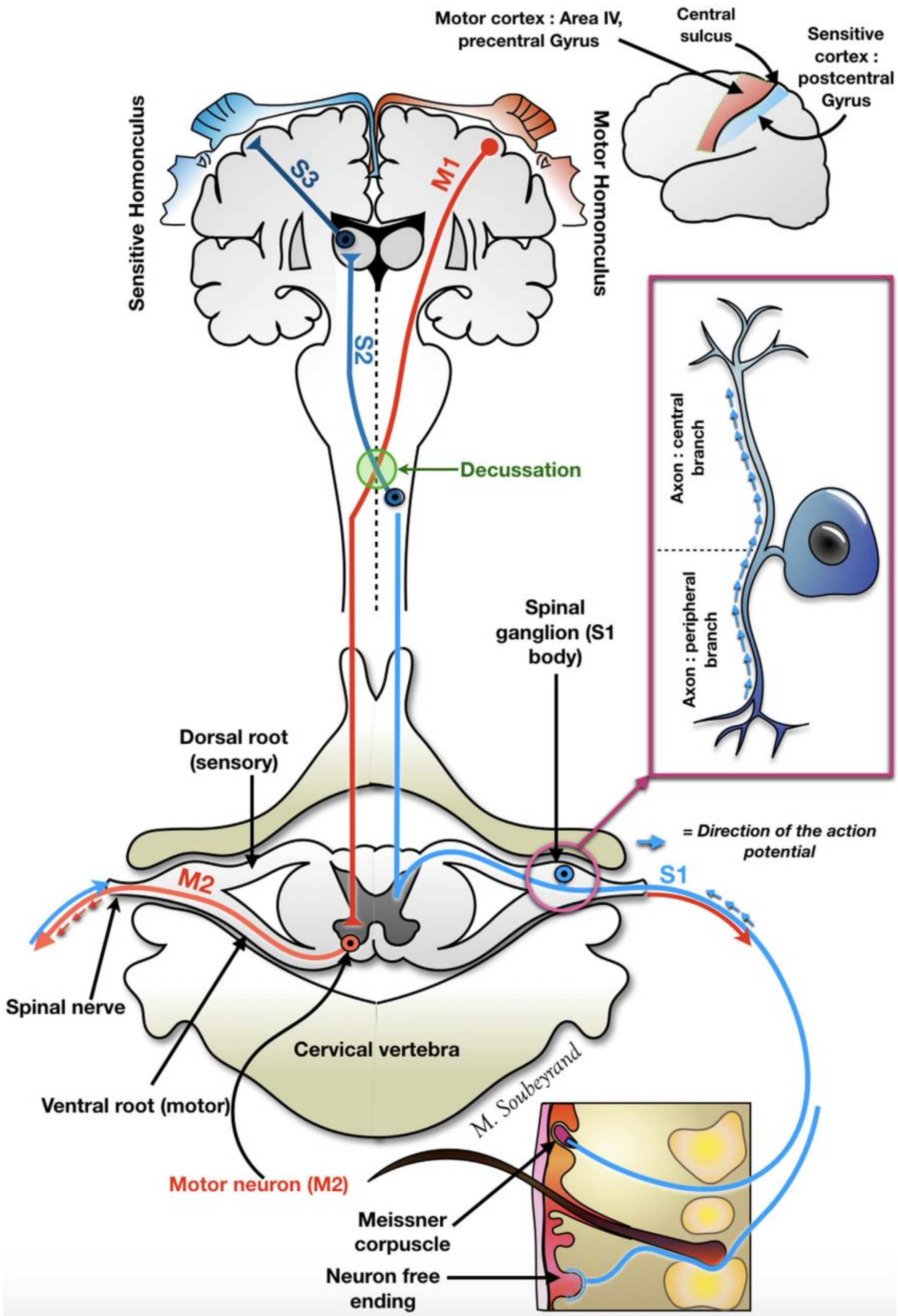
Third phase is characterized by the emergence of ridges, which according to microscopic studies, occur first at the lateral part of the fingertips, then from a lateral to distal position, and then towards the end of the phalanx it proceeds from a more medial to a proximal position (Raszewski and Singh, 2021).

1.3 MEDIAN NERVE ANATOMY

The median nerve is, both, a motor and sensory nerve. Despite receiving efferent commands (motor) from the central nervous system (CNS), it comes under the peripheral nervous system (PNS), it also carries afferent influx (sensory) from the regions it innervates. Motor activity of the hand, like most of the parts of the body, is under the control of both the pyramidal (willful conscious motor activity) and extrapyramidal (unwilful motor activity and muscle tone and postural reflexes) systems. The former comprises of two neurons: A central upper motor (first-order) neuron and a peripheral lower motor (second-order) neuron. The cell bodies of the first-order neurons, also referred to as Betz cells, are present in the fifth layer of primary motor cortex (Brodmann area 4) located in the precentral gyrus. A homunculus, described first by Wilder Penfield (1891-1976), present in the cerebral cortex corresponds specifically to different parts of the body; it is at a specific region here that the first-order neurons are located for the motor activity of the hand. The large area of the cortical surface disproportionally occupied by the hand indicates the fine the intricate motor tuning it requires. All the axons then descend, converging, through the posterior limb of the internal capsule. These axons form the corticospinal tract (pyramidal). The axons then descend further, positioned in the basis of the brainstem, to reach the inferior most part of the pyramids of the medulla oblongata where 90% of the fibers decussate (cross) the midline; this crossing demarcates the level of termination of the medulla oblongata. This decussation is also the reason why a lesion in the right cerebral cortex will result in a motor deficit in the left hand. Axons of these first-order neurons terminate in ventral gray horn of the spinal cord where they synapse with the cell bodies of the second-order (lower order) neuron. It is the axons from these second-order neurons that make up the spinal nerves which eventually give rise to the median nerve.

Multiple types of sensory information are carried back to the CNS via multiple tracts comprising typically of three-order neurons: dorsal column-medial lemniscus (DCML) carrying conscious proprioception, two-point discrimination, vibration, baresthesia; spinothalamic tract carrying crude touch, pain, temperature, pressure, and spinocerebellar tract conveying unconscious proprioception. These first-order neurons have their cell bodies in the dorsal root ganglion situated on the dorsal root of the spinal nerve. These are T-shaped ‘pseudo-unipolar’ neurons with their axon branching into two, a peripheral branch heading towards the periphery and a central branch heading towards the spinal cord. Since these neurons do not have individual dendrites, they are considered unique although the peripheral axon can often be mixed up with one. The second characteristic that makes them rather unique is location of the peripheral axon precisely in the tissue that it innervates. The terminals of this peripheral axon are either free nerve endings receiving the sensory stimulus directly, or endings that are encapsulated (Pacinian & Meissner's corpuscles) by the intercessor of transducers which transform vibratory and crude touch sensation respectively, into an electrical signal.

Residing completely within the CNS are the second-order neurons; their cell bodies are located in the medulla oblongata for the DCML system (nucleus gracilis and cuneatus) and for the spinothalamic and spinocerebellar tracts in the dorsal gray horn of the spinal cord. The axons decussate in the midline and is the reason why the sensations are projected and felt contralaterally to the opposite cerebral cortex. The third-order neurons have their cell bodies in the ventro-posterior nucleus of the thalamus and receive the second-order neurons. The former then projects, forming the corona radiata, on to the somatosensory cortex. Similar to the motor cortex, also present on the somatosensory cortex is a sensory homunculus which corresponds to the specific body part from which the sensation is initiated. This face and hand region of sensory homunculus map disproportionally comprises around 50% of the body projection (Fig. 1.1).



Motor cortex : Area IV, precentral Gyrus
Central sulcus
Sensitive cortex : postcentral Gyrus
Sensitive Homonculus
Motor Homonculus
S3
M1
S2
Decussation
Axon : central branch
Axon : peripheral branch
Spinal ganglion (S1 body)
Dorsal root (sensory)
= Direction of the action potential
M2
S1
Spinal nerve
Cervical vertebra
Ventral root (motor)
Motor neuron (M2)
M. Soubeyrand
Meissner corpuscle
Neuron free ending

Figure 1.1: Sensory (S) and motor (M) pathways for the median nerve. (Soubeyrand et al., 2020)

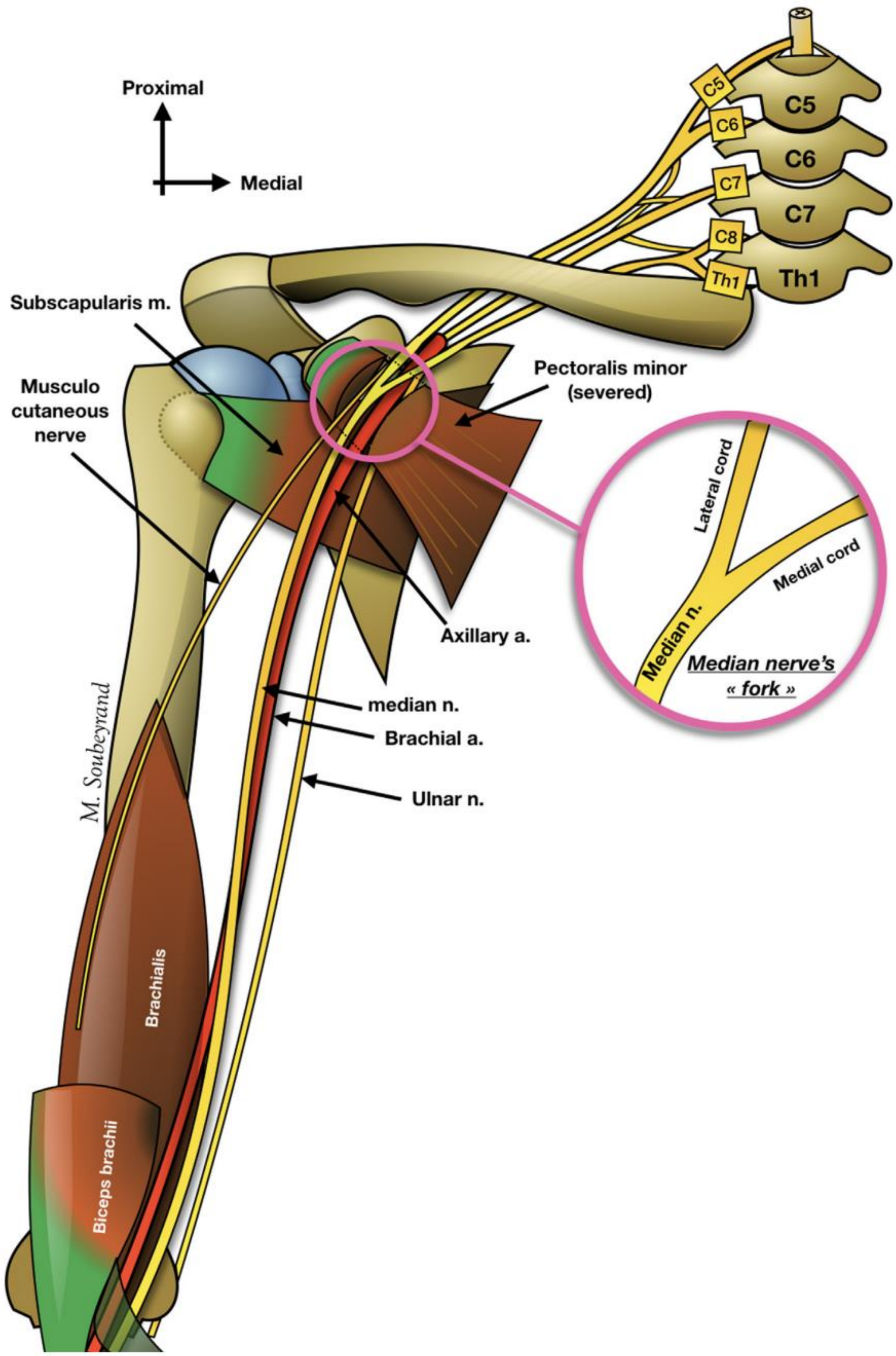
1.3.1 SPINAL SEGMENTS CONTRIBUTING TO THE MEDIAN NERVE

The ventral root of the spinal nerve is made up of axons of the lower motor neurons exiting the spinal cord. As ventral root is concerned with the motor system, the dorsal root is concerned with the sensory system; at every vertebral level both the roots rejoin to form the spinal nerve. The root value of the median nerve is from C6 (at times C5) to T1. The median nerve comes into existence where the lateral branch of the medial cord and medial branch of the lateral cord of the brachial plexus unite. This union is labelled as the median nerve's "fork" (Fig. 1.2). Being the only branch of this union, identification of the median nerve is easy. The axilla region is where the median nerve typically arises but can also occur in the upper arm more distally; regardless, its commencement distal to the origin of the thoracoacromial artery is always inevitable.

1.3.2 NERVE COURSE

During its limited journey in the axillary fossa, the median nerve courses deep to the pectoralis major and minor muscles, and superficial to the subscapularis muscle. It ends its journey in this region by going past the inferior edge of the pectoralis major. The median nerve then enters the upper arm medially via the brachial canal (of Cruveilhier). In this canal it lies anterior to the intermuscular septum, sandwiched between the biceps brachii and brachialis muscles. During this descent, it decussates the brachial artery. After the start of its transit, the median nerve eventually overtakes the artery from the latter's lateral side, to the front, and finally to the medial side near the end of this canal. None of its branches usually arise above the elbow, except for the branch to the pronator teres that might arise in the upper arm (Caetano et al., 2018).

After emerging from the brachial canal, the median nerve enters into the cubital fossa, anterior to the brachialis muscle. In the lower part of this region, it traverses the ulnar artery laterally. It lies superficial in the cubital fossa, separated from the cutaneous layer just by the aponeurosis (lacertus fibrosis) of biceps brachii, hence making it extremely susceptible to piercing wounds on the ventral surface of the elbow. Here, it is found to be sandwiched between the brachialis muscle and lacertus fibrosis (Fig. 1.3). The term “lacertus tunnel” has been coined by certain authors to label the structure in which the entrapment of median nerve can occur. During an ultrasound imaging, this anatomical outlet is easy to visualize in an axial biceps-artery-median (BAM) view. The average anteroposterior and axial diameters of the median nerve at this level are, 7.2mm (±1.5) and 10.7mm (±2.4) correspondingly. However, more work needs to be done on the relationship between median nerve pathology at the elbow and ultrasound findings (Babaei-Ghazani et al., 2018).



Proximal
Medial
C5
C6
C7
C8
Th1
C5
C6
C7
Th1
Subscapularis m.
Musculo cutaneous nerve
Pectoralis minor (severed)
Lateral cord
Medial cord
Median n.
Median nerve's « fork »
Axillary a.
median n.
Brachial a.
Ulnar n.
M. Soubeyrand
Brachialis
Biceps brachii