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)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS/ABBREVIATIONS

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

LIST OF APPENDICES

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 1st-2nd weeks making up the pre-differentiation phase, second phase being from 3rd-8th 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 6th-14th 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).

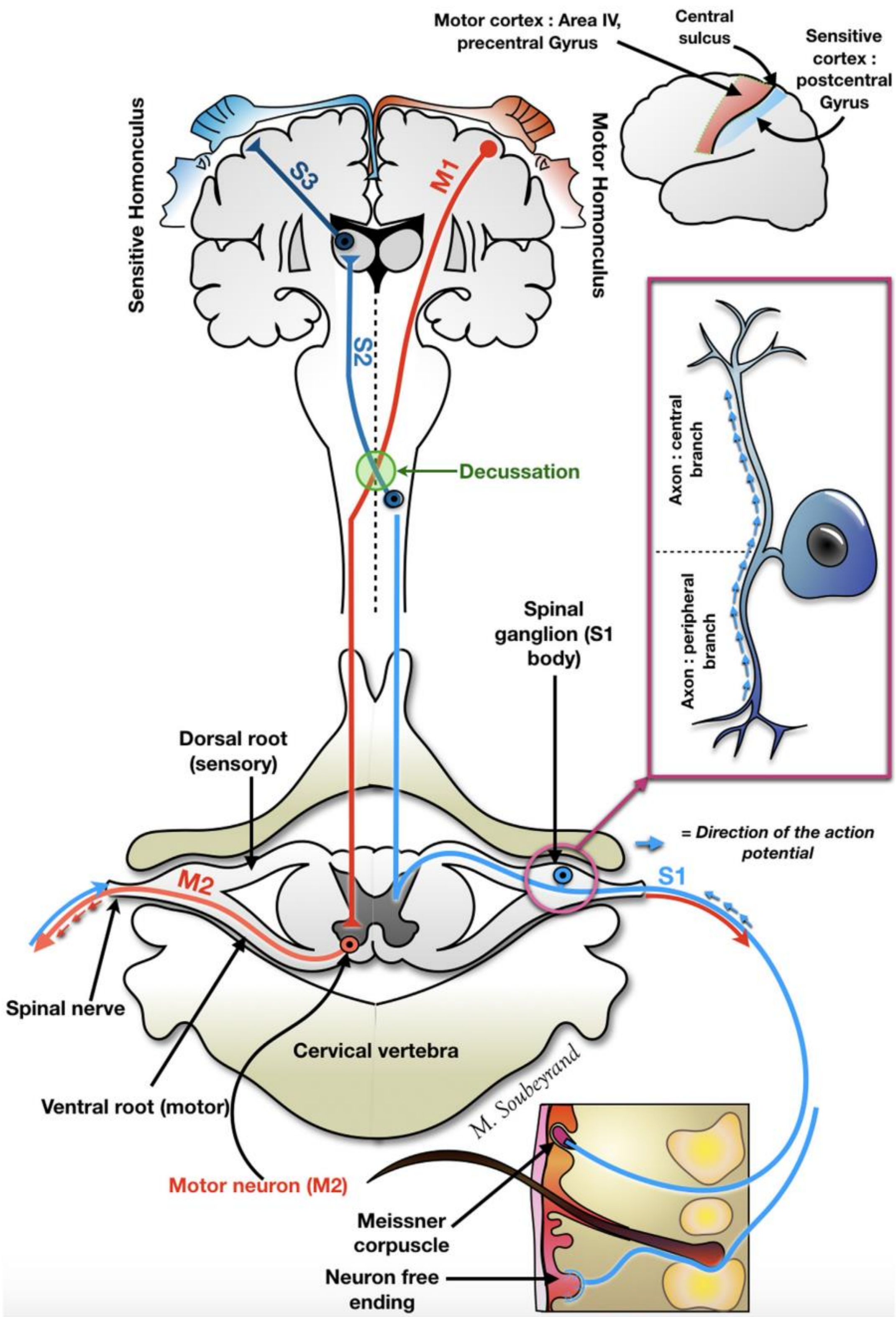

Figure 1.1: Sensory (S) and motor (M) pathways for the median nerve. (Soubeyrand et al., 2020)

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).

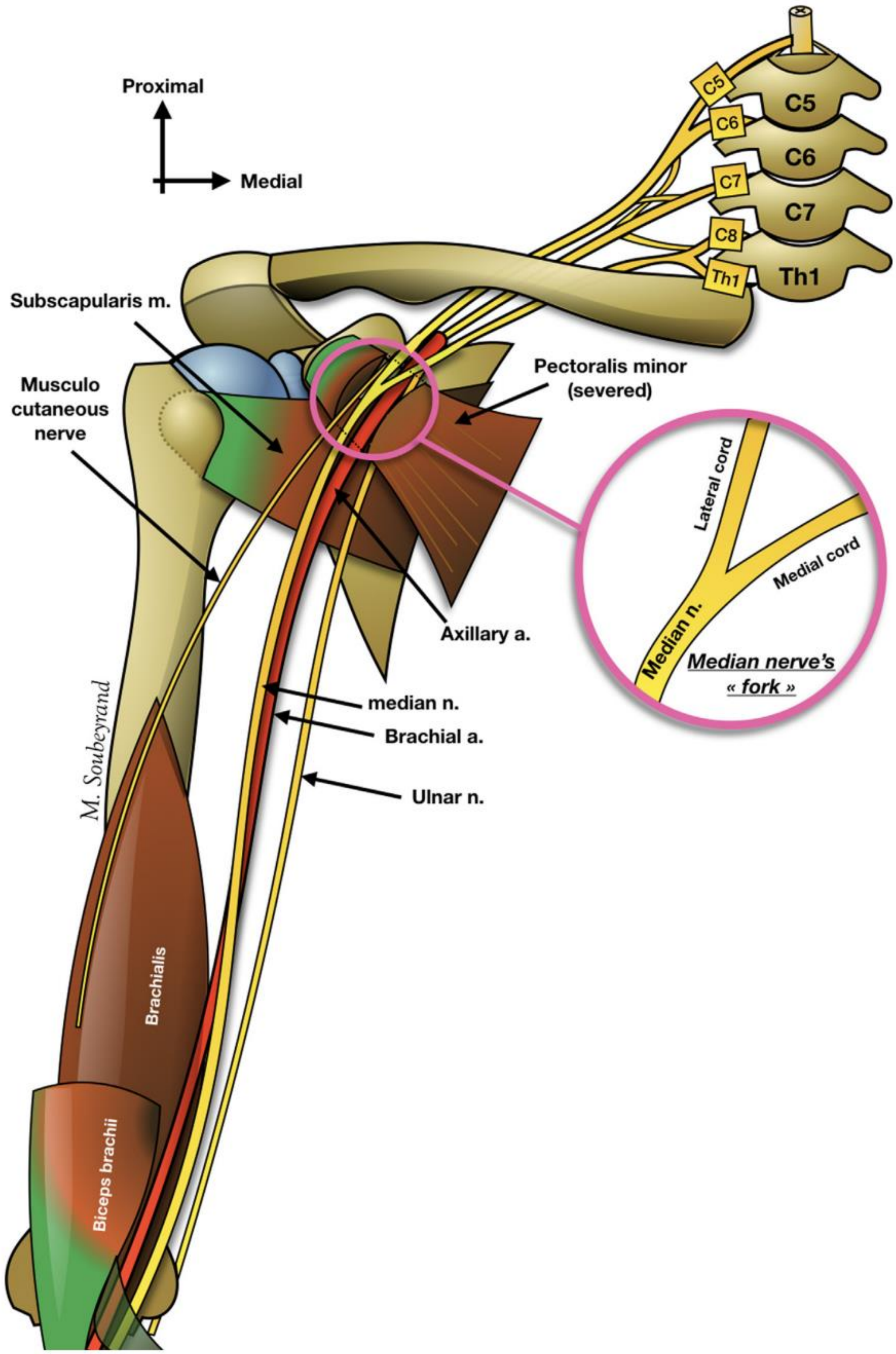

Figure 1.2: Route of median nerve between the axillary fossa and the elbow. (Soubeyrand et al., 2020)

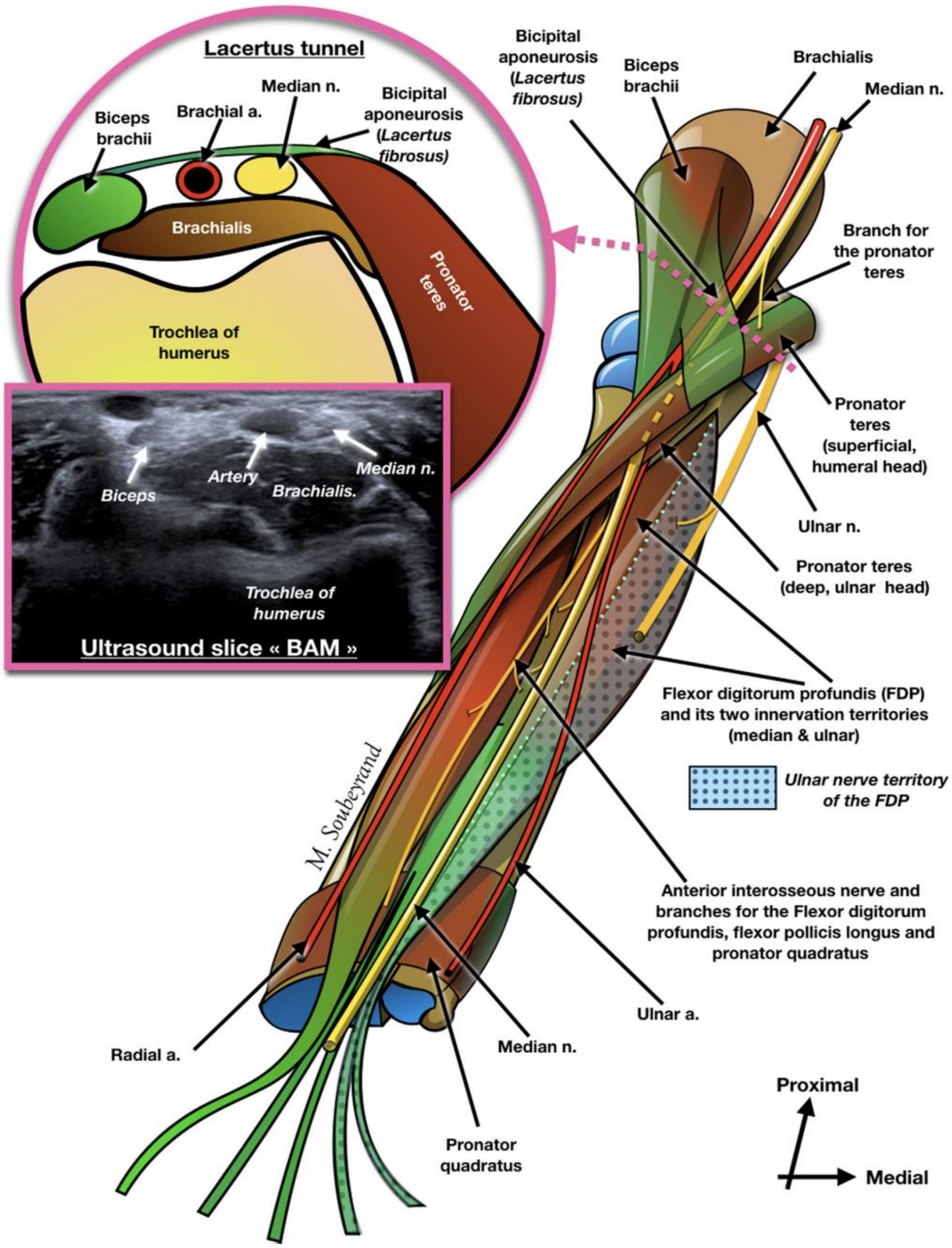

Figure 1.3: Anatomy of the median nerve at the elbow and forearm. The FDP is innervated by both the median and ulnar nerves (territory shown by dotted lines). BAM ultrasonography view: Biceps, Artery, Median nerve (Soubeyrand et al., 2020).

In order to enter into the forearm, the median nerve passes between the two heads (superficial humeral and deep ulnar) of the pronator teres and while doing so innervates its body. It is sandwiched yet again, between the muscle bodies of the flexor digitorum profundus and superficialis after exiting the pronator teres. Positioned centrally, the median nerve then heads for the carpal tunnel, declining vertically (Fig. 1.4).

It enters the carpal tunnel escorted by the nine flexor tendons related with the digits (fingers) and pollicis (thumb), and by their synovial sheaths. Sometimes, a small persistent median artery can be found on the surface of the median nerve serving as an important landmark when repairing a severed nerve. At its posterior aspect, the carpal tunnel is enclosed by the carpal bones which form its carpal groove (sulcus carpi), and anteriorly by a fibrous extension, flexor retinaculum, from the hook of hamate and pisiform on the ulnar side to the trapezium and scaphoid tubercles on the radial side (Fig. 1.5). Despite being communicable on its proximal and distal ends, the carpal tunnel exerts a specific pressure. The median nerve can be damaged if this pressure in the carpal tunnel increases above a physiological threshold. The narrowest diameter of the carpal tunnel, where the nerve morphology is found to be altered in cases of carpal tunnel syndrome, is about 2 cm from its proximal edge.

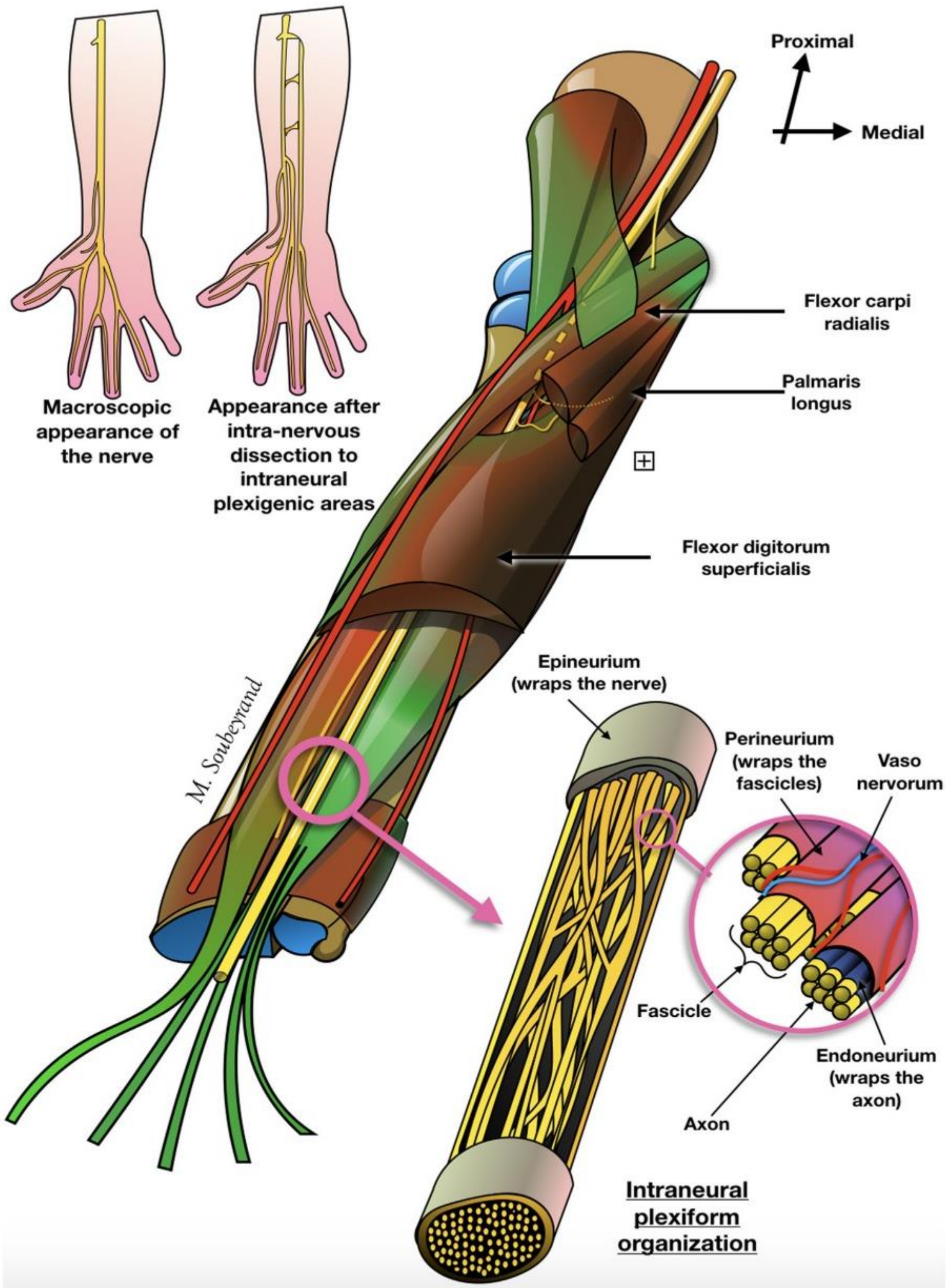

Figure 1.4: Anterior view of the forearm like the one in Fig. 3, but with addition of the flexor digitorum superficialis (FDS), flexor carpi radialis (FCR) and palmaris longus (PL), all of whom are innervated by the median nerve (Soubeyrand et al., 2020).

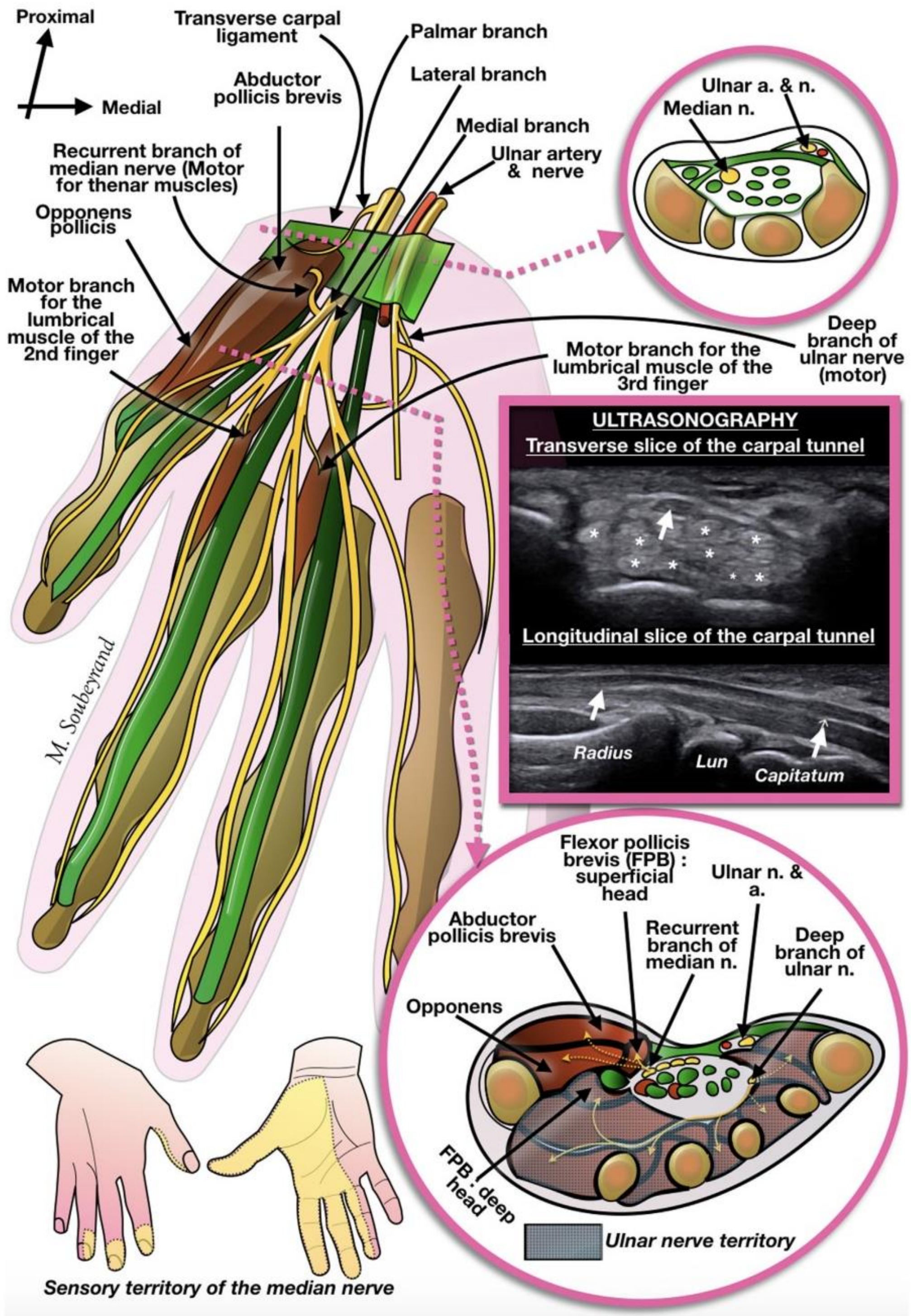

Figure 1.5: Anterior view of the distribution of the median nerve in the hand. Transverse slices at the carpal tunnel and in the palm along with corresponding ultrasonography images (Soubeyrand et al., 2020).

1.3.3 NERVE ENDINGS

The median nerve terminates by dividing into two mixed (sensory and motor) branches – medial and lateral – just distal to the carpal tunnel (Wynter and Dissabandara, 2018)(Fig. 1.5). The common palmar digital nerves (CPDN) come off of the medial branch, which then split into the proper palmar digital nerves (PPDN). The ulnar half of the index finger is innervated by the ulnar PPDN, radial and ulnar halves of the middle finger by the corresponding PPDN, and the radial half of the ring finger by the radial PPDN, along with the nerve to the lumbrical muscle of the same finger; all being branches of the PPDN. The thumb and the radial half of the index finger are innervated by PPDN of the recurrent branch which comes off of the lateral branch of the median nerve. The 2nd lumbrical is generally innervated by a branch of PPDN of the index finger. Living up to its name, the recurrent branch has a recurrent trajectory; with opponens pollicis, abductor pollicis brevis (APB), and superior head of the flexor pollicis brevis (FPB) muscles being its final destination. Ulnar nerve is which innervates the other thenar muscles (adductor pollicis and deep head of FPB). The tendon of the flexor pollicis longus (FPL) separates the deep and superficial heads of the FPB, and in doing so it also serves as a separating line between the motor domains of the ulnar and median nerve at the thenar eminence.

1.3.4 EMBRYOLOGY OF MEDIAN NERVE

Embryogenesis is the reason for the general morphology of the nervous system, and in particular, the median nerve. After differentiation, it’s the embryonic phase in which various anatomical structures appear and position themselves with respect to each other. This phase which comprises of 8 weeks (56 days) starts right after the egg is fertilized, which is then followed by the fetal phase. It is these 8 weeks to which the anatomy of every person’s median nerve and its possible variations can be traced back. Once the neural tube has formed, a few cells, referred to as neural crest cells, bud off of the neural tube and come to be sandwiched between the tube and the skin. These neural crest cells then migrate anterolaterally to give rise to the sensory neurons of the median nerve (and all the other spinal nerves), and posterolaterally to give rise to the skin melanocytes and cells in the sympathetic nervous system. Schwann cells and adrenal glands are formed by the neural crest cells migrating in the ventral direction.

At every somatic level, the advent of the migrating nerve cells matches the primary roots of the spinal nerves. This is the event during which interconnections between myriad branches of spinal nerves ensue. The developing muscles, bones, and joints of the growing limb carry the respective axons with them (De Bakker et al., 2016). The maturing of the brachial plexus and connections between the fibers begin to occur while the on-going growth of the upper limb and the differentiation of its distal structures. Despite the embryo being less than 35 mm long, all the connections are completed.

1.4 HAND GRIP STRENGTH

Perhaps one of the most sophisticated and well differentiated musculoskeletal tools in a human being is the hand. A human hand is made in such a way that complex (grasping ability) and precise (manual dexterity) functions can be performed with it. A unique feature that separates humans from primates is hand grip possessed by the former (Walankar et al., 2016). The complex structure of the hand, anatomically and functionally, is represented by hand gripping (Shaheen, Omar, and Ali, 2021).

Handgrip strength can be defined as the degree of constant force produced by the hand (Bimali, Opsana, and Jeebika, 2020) with all the joints of the fingers flexed along with the thumb, the latter acting as a stabilizer when the object is held between the palm and the fingers (Walankar et al., 2016). Dynamometer has come to widely be accepted as a simple but valid equipment to measure a person’s handgrip strength (Steiber, 2016). One of the instruments that has extensively been used and proven to be viable (Syddall et al., 2018), simple (Granic and Hollenstein, 2015), and reliable (Bohannon, 2017) for the evaluation of strength impairments of the upper-extremity (Gilbert, Thomas, and Pinardo, 2016) is the Jamar-hand/grip dynamometer. In various clinical setting, handgrip strength has proven to be a feasible prognostic tool and in general population and in persons with chronic illnesses, a prognostic factor (Alqahtani et al., 2019). In individuals with major illness, weak handgrip strength has also been linked to high fatality rates (Leong et al., 2016).

1.5 SMARTPHONE ADDICTION

More than half of the global population, having increased over the past decade, owns a smartphone (Olson et al., 2022). Overly preoccupation with the smartphone can have detrimental effects on some individuals coming at the expense of their social relations, academics, work, or other essential life obligations. As a consequence, these people might show problematic smartphone use (PSU), a primary modern-day health concern. Smartphone addiction can be considered a component of PSU. Smartphone addiction can be described as a condition that affects the day-to-day life of users, manifesting clinically as loss of attention, control, and tolerance; mood alterations; and symptoms of withdrawal (Vujić and Szabo, 2022).

Addiction to smartphone as a component of PSU has been reported to have detrimental effects on psychological and physical health. Smartphone addiction has been proven to have a positive relation to depression and anxiety disorders (Kim et al., 2019; Rozgonjuk et al., 2018), decreased sleep quality (Al Battashi et al., 2021), dysfunctional emotional regulation (Ali Yıldız and Ali Yldz, 2017), decreased work productivity, lower academic functioning (Duke and Montag, 2017), and lessened quality of life (Koç and Turan, 2021; Li et al., 2020; Samaha and Hawi, 2017), and increased perceived stress (Elhai et al., 2017; Shen and Wang, 2019).

1.6 RATIONALE

To explore the association between smartphone overuse, holding position and weight of smartphone and the anatomical changes in the middle phalanx of the 5th digit of the dominant hand via radiography Further investigate the relationship between smartphone overuse and the median nerve cross-sectional area at the wrist region and hand grip strength

1.6.1 THEORETICAL GAP

No longitudinal studies have been conducted, as per existing knowledge, which have presented a causal relationship between smartphone addiction and changes in the MN-CSA. No text available on genetic factors, which could possibly play a role in variations in the MN-CSA and also in the thickness or deformity of the 5th digit without any history of trauma from the individual.

1.6.2 CONTEXTUAL GAP

No literature was available on the normal measurements (especially thickness) of the fifth digit of the hands to compare the values of the parent study with. Limited material was available on the relationship between smartphone usage and thickness/deformity of the fifth digit. Insufficient studies available which tested the relationship between smartphone addiction and the MN-CSA and/or grip strength. No text available regarding the MN-CSA being affected by smartphone usage in the respective country. Scarce literature available regarding values of the hand-grip strength, especially related to smartphone addiction.

1.6.3 METHODOLOGY GAP

Lack of longitudinal studies on the respective topic. Previously, according to the review of literature, separating or controlling confounding factors (such as hobbies, exercise, usage of other electronic devices) was difficult, not enough studies on the correlation between the topic and the confounding factors. The present study aims to provide material on the latter.

1.7 PROBLEM STATEMENT

Smartphone usage is increasing at an alarming rate. It has come to a point where smartphone addiction has become an entity. Smartphone overuse has been linked with several musculoskeletal problems according to numerous studies; lesser of which have been carried out on its effect on the hand and wrist region. Smartphone use, especially for a prolonged period, can lead to wrist pain, thumb pain and altered hand function and daily life.

1.8 RESEARCH QUESTIONS

1. Does smartphone overuse lead to reduced hand-grip strength on a hand dynamometer of the medical students of BUHSCK?
2. Does smartphone overuse lead to increased median nerve cross-sectional area (MN-CSA) on ultrasound in the wrist region of the medical students of BUHSCK?
3. Does single-handed smartphone overuse and weight of smartphone lead to radiographically measured reduced thickness of the middle phalanx of the fifth digit in the dominant hand of medical students of BUHSCK?

1.9 OBJECTIVES

- To measure and compare the hand-grip strength between dominant and non-dominant hands of smartphone users
- To measure and compare the cross-sectional area of median nerve at the wrist region between the dominant and non-dominant hands of smartphone users
- To identify, measure and compare the morphological changes in the fifth digit of dominant and non-dominant hands of smartphone users

1.10 SIGNIFICANCE OF THE STUDY

To best of knowledge, this would be the first study worldwide to investigate the correlation between smartphone use and possibly its weight and the anatomical changes of the fifth digit by using a radiograph, hence making it a pioneer study and one of its kind. Limited studies have been conducted to explore and establish a relation between smartphone overuse and its effect on the median nerve cross-section and grip strength; the current study would be the first of its type in the respective country and the first to involve a number of subjects that thus far would be the most to be featured in this type of study, thereby possibly establishing a stronger relation between them. These investigations can add to, and cement, the long list of adverse effects that can be caused by excessive smartphone usage and hence warrant its reduced usage or in a healthier manner keeping the findings of this study into consideration. This study could also possibly be among the very few studies to become the ground for the term “smartphonopathy” or/and “smartphone pinky” to be coined.

CHAPTER 2

LITERATURE REVIEW

Inal et al. (2015) assessed smartphone users' median nerve and flexor pollicis longus (FPL) tendon for the first time by ultrasonography to evaluate the impact of smartphone obsession on the clinical and operational status of the hands. One hundred and two participants were divided into 3 groups: non-users, low and high smartphone-users. Smartphone Addiction Scale (SAS) scores were recorded, and grip-pinch strengths measured. Pain in thumb at rest and movement was investigated on a visual analog scale (VAS) and the Duruöz Hand Index (DHI). The median nerve and FPL tendon cross sectional areas (CSA) were bilaterally assessed and calculated via ultrasonography.

Handgrip strength and fatigue was assessed in female college students who overused smartphones (Abelkader, 2021). One hundred and eighty-eight female college students were recruited and divided into two groups: smartphone users and non-smartphone users. Their handgrip strength was evaluated by a handheld dynamometer.

Another study engaged 12 healthy volunteers who were instructed to play a popular smartphone game called Subway Surfers constantly for 30 minutes (Wang et al., 2019). This was done to assess the effect of continuous movements of the thumb while playing the game. The function of two pollicis brevis muscles (abductor and extensor) was evaluated using surface electromyography. Muscle fatigue was assessed by using the median frequency (MDF) as an indicator. Participants' subjective discomfort was evaluated by visual analogue scale (VAS). The study reported significantly reduced MDF of the two pollicis brevis muscles (abductor and extensor) over the study period. Conversely, after half an hour of constant gaming the VAS scores increased considerably. This study concluded that continuous gaming on a smartphone may cause chronic muscle damage.

A study examined the effect of smartphone overuse on the wrist, specifically the carpal tunnel and median nerve (Lee et al., 2012). The measures carried out on the subjects included ultrasound of the median nerve, reverse Phalen's tests. This study concluded that prolonged one-time usage rather than total usage duration of smartphone may lead to compression of median nerve and carpal tunnel.

A recent study intended to highlight the effect of smartphone usage on hand performance of young adults, which included evaluation of grip strength and upper limb disability (Din and Hafeez, 2021). The former was done with the help of a hand dynamometer and the latter via a quick DASH questionnaire. Smartphone addiction was assessed by a SAS questionnaire.

Hand comfort while using handheld devices with touchscreen single-handedly and its relationship with screen curvature and hand anthropometry was investigated in 26 adults (Ahn et al., 2016). Three mock-up devices were used; one flat and the other two with curvatures of 400R and 100R to measure the comfort level by electromyography and subjective ratings methods. The subjects were grouped according to sizes and shapes of their dominant hand. The results of study indicated that handheld devices with curved touchscreen affected perceived comfort but failed to affect muscle activity. Conversely, the factor which affected muscle activities was size and shape of the hand. The interaction effects between size and shape of hand were found as well. Overall, this study was suggestive of anthropometric and curvature of hand being the common factor in assessing level of comfort for the design of handheld devices.

Yi et al. (2017) examined the effects of hand span and display curvature on the ability to use smartphone. This was evaluated in terms of grip ease, sense of immersion, typing performance, and general satisfaction. Twenty participants were recruited and divided into three groups according to hand size. Two smartphones were used of similar screen size – one with a plane display and the second with a curved (side-edge) display. Smartphone usability was assessed by performing three tasks: watching video, texting, and calling. For the first task the smartphone was held in a landscape mode and in portrait mode for the other two. The p-values indicated more grip ease for the plane display while doing all three tasks as well as higher general satisfaction as compared to the curved (side-edge) display. Hence, according to this study consideration should be given to the display curvature when applying touchscreen to handheld device for grip ease.

The cross sectional area of the median nerve was also assessed and compared between single handed and double handed smartphone users (Mousa et al., 2019) . Fifty-six students of ages 18-25 were recruited and were asked to type a specific phrase on a smartphone for one minute while undergoing ultrasonography at the level of carpal tunnel. Ultrasound was performed both, while typing single handedly and then double handedly and the participants were instructed to only use their thumb while keeping the rest of the hand stationary. Cross-sectional area (CSA) of the median nerve was determined by tracing the boundary along its borders.

Xiong and Muraki (2016) assessed thumb length and age of 48 individuals, and the screen size on a smartphone as possible factors affecting the movement coverage while operating a smartphone. By using a right-hand phone holding posture and moving the thumb in an adduction-abduction orientation, the thumb-coverage area that signifies how far the thumb can reach was assessed. The center of gravity during the thumb coverage was also determined. The study concentrated on comparing these indicants between thumb lengths, ages, and smartphone screen sizes. The results depicted that the bottom right side of touchscreens was the space most likely to be left unreached by users with longer thumbs and the elderly. Additionally, an increase in thumb coverage area was observed with the increase in touchscreen size; however, the increase in smartphone touchscreen's size was not directly proportional to the distance covered by the thumb.

In an observational study, conducted on 60 children between the ages of 9-15, investigated the interrelation between the degree of smartphone use and hand preference on functional hand operation, pinch strengths, and handgrip (Radwan et al., 2020). By using the smartphone addiction scale-short version, the children were designated into two groups: High-frequency smartphone users (group A) and low-frequency smartphone users (group B). Pinch strength and handgrip were assessed by a hand dynamometer and pinch gauge correspondingly. A questionnaire (Quick Disabilities of the Shoulder, Arm and Hand) was used to score the upper extremity and hand functions.

Reduced pinch strength was also observed in another study carried on participants using smartphones for a prolonged period of time (Iqbal, Akib, and Hossain, 2019).

One study on the ergonomics of mobile phones and its relationship with physiological thumb discomfort was conducted on undergraduate students at a Philippines college (Bendero et al., 2017). It was directed to find out about the major factors linked with mobile phone usage and its consequence on thumb pain. The main tools used to determine the major factors included a correlation-prediction analysis and multiple linear regression. These tools were also used as prototypes of predictive models on thumb associated pain. The result signified 2 major factors on thumb-associated pain, one being the proportion of time while texting in a portrait orientation per day, and the second being the total time spent playing games with one hand per day.

In a study examining the contribution of the last two digits (ulnar) of the hand in total grip strength, 50 individuals were selected and only their dominant hands included and assessed (Methot, Chinchalkar, and Richards, 2010). The instrument used for grip strength assessment was the Jamar hand dynamometer and the excluded digits were secured in place by generic splints. The study concluded a 33% decrease in overall grip strength by eliminating the little finger (fifth digit). While another recent similar study reported the contribution of the ring and little finger to the overall grip strength to be 30%, the second most important contribution after the middle finger (Cha et al., 2014).

Hand-grip and key-pinch strengths were assessed and compared in the dominant and non-dominant hands of healthy individuals at three different arm positions (El-gohary et al., 2019). Only right hand-dominant male college students aged 19-23 years were selected. The number of students was 61. Jamar hand-grip dynamometer was used with the handle set to the second position to assess the grip-strength of the participants in the 3 different positions. The positions included the participants' elbow flexed at 90°, shoulder flexed at 90°, and arm in a dangling position. For all these positions the participants were instructed to squeeze the handle of the dynamometer. In order to assess the key-pinch strength, the participants were instructed to proximate the thumb pad and the lateral aspect of index finger (middle phalanx) and squeeze them. Same positions were considered for the key-pinch strength as with the hand-grip strength.

In one study smartphone addiction scale-short version (SAS-SV) was used to assess the degree of addiction to smartphone and its effect on the musculoskeletal system of medical students (Alsalameh et al., 2019). In order to assess musculoskeletal pain, Nordic musculoskeletal questionnaire (NMQ) was used. Two hundred and forty two medical students were incorporated and a three-part self-administered questionnaire was distributed with the first part related to the demographic details, the second being the SAS-SV, and the third part being the NMQ.

Kubal and Dsouza (2020) conducted an observational study in a tertiary care hospital of Mumbai, India selected a total of 75 asymptomatic young adults, by convenience sampling, using smartphone to find the effect of frequency and intensity of smartphone usage on the cervical core muscle endurance and neural tissue mobility of the median nerve. Problematic Use of Mobile Phone (PUMP) Scale was used to evaluate the intensity and frequency of smartphone usage. In order to assess the cervical core muscle endurance, a folded pressure biofeedback unit inflated to 20 mmHg baseline pressure was positioned under the upper cervical spine. This pressure was increased incrementally by 2 mm up to 30 mmHg. At every increment the participant was instructed to nod and maintain the pressure steadily for 10 seconds. Final pressure being the one at which the participant failed to hold steady for 10 seconds. Documentation of the objective measure was done by a performance index. Different movement sequences were performed on the upper extremity being tested of the participant by the examiner in order to evaluate the neural tissue mobility of the median nerve.

One study assessed the association, prevalence and risk factors for carpal tunnel syndrome symptoms among the general population, above 18 years of age, of Riyadh, Saudi Arabia who used electronic devices (Al Shahrani et al., 2019). Eight hundred Arabic self-administered questionnaires were distributed which included patterns of electronic devices use, socio-demographic, and a standardized questionnaire “Boston Carpal Tunnel Questionnaire (BCTQ)”. The latter is used to assess the symptoms severity scale (SSS) and functional status scale (FSS) in CTS and is considered a reliable and valid method to do so. The SSS investigated about the most common symptoms of CTS such as numbness, tingling sensation, wrist pain, weakness and problems in grasping objects. The FSS was evaluated based on difficulties in executing eight daily hand activities such as, buttoning, writing, bathing and dressing, grasping a telephone handle, holding a book while reading, household chores, opening jars, and carrying grocery bags. Details collected also included sociodemographic data and patterns of using electronic devices.

An observational cross-sectional study on hand dexterity affected by the usage of smartphone was also conducted (Shetty et al., 2019). Two hundred and twenty medical students were recruited and were each administered the smartphone addiction scale (SAS). Purdue Pegboard Hand Dexterity Test was administered to assess finger dexterity. The scores along with the demographics of students such as age, gender, numbers of hours of active smartphone usage (texting and scrolling) were documented on a predesigned case record form.

One study conducted in the same country provided gender and age-specific normative standard reference values for hand grip strength among the adolescents of South Punjab, Pakistan by using the LMS technique, and compared with international reference values (Hamdani et al., 2021). Two thousand nine hundred and seventy students aged 12-16 from 60 public high schools were recruited.

Ko, Hwang, and Liang (2016) recruited 27 subjects aged between 20-39 years and gave typing tasks to be completed in 2-minutes making use of 4 different typing styles. The aim was to find if biomechanical exposure and typing performance were influenced by different smartphone use styles. The participants were administered a questionnaire that documented their age, gender, dominant hand, occupation, time spent using a smartphone or daily computer, and past medical history. The typing trials were conducted with the participants seated in a five-point adjustable chair without armrests and soles of the participants' feet were ensured to completely rest on the floor. The 4 typing styles included double-handed typing at 3 heights (B-high: typing with both thumbs while holding the smartphone at eye level with both hands, B-mid: typing with both thumbs while holding the smartphone at chest level with both hands, and B-low: typing with both thumbs while holding the smartphone with both hands, elbows resting on the thighs, and trunk inclined) and single right-handed typing with the right thumb (S-thumb). The orientation adapted by the devices was portrait in order to eliminate the change in orientation as a confounding factor. The same phone was used for all the participants, which was the Sony Xperia P smartphone and the typing trials conducted lasted for 2 minutes. This was recorded with the 10fastfingers app and computed as the average characters typed each minute. The muscle activities of the right upper limb were quantified by using surface electromyography (sEMG). The muscles included the upper trapezius, biceps brachii, extensor digitorum communis (EDC), flexor digitorum superficialis (FDS), and flexor pollicis brevis (FPB). Measurements of joint motion was also carried out with flexible electrogoniometers (SG 110 and SG 65) during the trials. This required the recording of the flexion/extension angles of the neck, right elbow and right wrist.

Singh, Rathod, and Sorani (2022) randomly selected 140 (70 females and 70 males) young adults aged between 17-23 years to evaluate the wrist and hand muscle strength among smartphone users. This was done using a hand-held dynamometer. The inclusion criteria consisted of using a smartphone for 2 hours minimum each day, being able to understand the procedure of the study, and who voluntarily participated. A Saehan hand dynamometer was used to measure the strength and power (cylindrical) grip of the wrist flexors and extensors. Spearman's correlation analysis was applied on wrist muscles and grip strength in order to find a correlation between them.

Motimath, Luis, and Chivate, (2017) aimed to determine if the addiction to smartphone had an influence on grip and pinch strength. Hundred collegiate students of the ages between 18-24 years were selected randomly for this study. SAS-SV was used to evaluate smartphone addiction and DHI to assess hand function. A dynamometer was used to measure the grip strength and a pinch gauge to measure the pinch strength.

Effect of extended smartphone use on the cervical spine and hand grip strength was also investigated (Samaan et al., 2018). Sixty asymptomatic healthy individuals were selected with the ages of 14-18 years and divided equally in two groups (Group A, group B). Those who used their smartphone for less than four hours per day were Group A, the control group. Those using the smartphone for more than four hours per day were put in Group B, the study group. In order to assess the nerve conduction velocity of the ulnar and median nerves, an electromyography machine was used. A hand dynamometer was used to measure the grip strength in both the groups.

One study aimed to assess the median nerve and flexor pollicis longus for changes in high and low addiction smartphone user using diagnostic ultrasound (Samuel et al., 2021). This was a cross-sectional study which incorporated 54 healthy male university students which were divided, based on SAS, into two groups: high and low users. Cross-sectional area of the flexor pollicis longus tendon (mm^2) and median nerve (mm^2) of the dominant and non-dominant hand was determined with diagnostic ultrasound examination.

Fatigue of hand muscles due to the size of smartphone was also investigated in 40 people who were assigned to the experimental group and were asked to use the smartphone at least 6 hours while supporting it on their digiti minimi (Lee, 2017). The control group used the smartphone for at least 3 hours but did not use their digiti minimi to support it. Demographic details along with the method of grasping the smartphone and its usage was obtained via questionnaires. Deformity of the interphalangeal joint angle of the digiti minimi was also assessed via X-rays.

To the best of knowledge, only one study has been conducted on smartphone usage and its effect on the fifth digit of the hand (Fuentes-Ramírez et al., 2020). The study intended to find out any anatomical changes in the fifth digit of the hand due to smartphone usage. The study invited 143 university students, with a mean age of 20, to participate. A millimeter paper was used as a background to place the dorsal surfaces of both hands and photograph them. Pairs of photographs were analyzed in the ImageJ software after calibration and areas of irregularity were obtained. Hand technique and position while using a smartphone and sociodemographic information was acquired through a survey.

Very few similar studies stem from the country of origin of this parent study. Only one study was found to originate from the same city, that is, Karachi, which was by Mirza et al. (2020) who assessed the grip strength in 412 participants in relation to increased cortisol levels. The ages of the participants ranged from 20-69 years. Electronic hand dynamometer (EH101) was used to measure the grip strength and to measure the cortisol levels quantitively immunoassay method was used. Multiple linear regression analysis was used to assess the correlation of hand grip strength. Overall population's mean grip strength was found to be 30.75 kg. Grip strength and obesity were found to have a significant correlation between them as was the case between obesity and cortisol. The study concluded weakened grip strength to be an indicator of increase in cortisol and resultant biological ageing. Hamdani et al. (2021) conducted a cross-sectional study in South Punjab, Pakistan with the aim to provide normative hand grip strength reference values according to age and gender. Two thousand nine hundred and seventy students of ages between 12-16 were recruited and a GRIPX digital hand dynamometer was used to measure their grip strength. To calculate the reference norms, LMS method was used. Another study by Tahir et al. (2020) aimed to investigate the relationship of hand grip strength and peak expiratory flow rate (PEFR) with bone mineral density (site-specific) T scores. Study was conducted in Lahore, Pakistan on 102 subjects. Hand grip strength was measured using the BIOPAC hand dynamometer and Wright's Peak Flow Meter was used to record the PEFR. The study concluded that site-specific calcaneal bone mineral density was found to be high in healthy adolescence who had better respiratory function and hand grip strength.

2.1 OPERATIONAL DEFINITIONS

1. **SMARTPHONE:** A handheld device having features of both, a cellular phone, and a portable computer (Baabdullah et al., 2020)**.**
2. **MEDIAN NERVE:** One of the nerves that provides motor and sensory innervation to part of the upper limb. It is a moveable structure that extends, condenses, and translates in reaction to upper extremity motion (Yao et al., 2019).
3. **GRIP STRENGTH:** The force with which an object is held with all the fingers (Yoosefinejad et al., 2019).
4. **CARPAL TUNNEL SYNDROME:** A pressure neuropathy that is described by numbness, pain and tingling over the first-three and a half digits and radial portion of the palmar surface (Woo et al., 2016).
5. **FIFTH PHALANGES/DIGIT:** Bones in the fifth digit of the hand (Fuentes-Ramírez et al., 2020)
6. **LINEAR ARRAY PROBE:** A type of probe used in ultrasonography (Inal et al., 2015).
7. **SMARTPHONE ADDICTION:** Smartphone addiction can be described as a condition that affects the day-to-day life of users, manifesting clinically as loss of attention, control, and tolerance; mood alterations; and symptoms of withdrawal (Vujić and Szabo, 2022).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 STUDY DESIGN

This was a descriptive cross-sectional study based on human subjects. The time period of this study was from January-June 2022. It was conducted at the Ultrasound and X-Ray departments of PNS Shifa Hospital, Karachi. The ethical approval was granted by the Ethical Review Committee (ERC) of Bahria University of Health Sciences Campus Karachi (BUHSCK).

Questionnaires were distributed to as many students as possible. Distribution of questionnaires was to students of different medical disciplines. The self-filling questionnaire comprised of open-ended questions specifying demographics and questions related to their hobbies, smartphone usage, medical history, etc. Smartphone usage was of particular importance. The questionnaire included questions for the latter such as asking the students whether they used their smartphones single-handedly or double-handedly, the position of holding their smartphone, the duration of their smartphone ownership, model of their smartphone and most importantly, whether they had noticed any deformity of their fifth digit. The latter being the first and primary filtering criteria of the subjects to then be clinically and radiologically assessed after their consent.

3.2 SUBJECTS

Students at Bahria University Health Sciences Campus Karachi (BUHSCK)

3.3 SETTING

Bahria University Health Sciences Campus Karachi (BUHSCK) and the Ultrasound and X-Ray Departments PNS Shifa, Karachi.

3.4 INCLUSION CRITERIA

- Students of every gender at BUHSCK between the ages of 17-25
- Visible deformity of the fifth digit noticed and documented by the student
- Single handed smartphone users
- Double-handed smartphone users considered only in the individuals who noticed and documented deformity of the fifth digit

3.5 EXCLUSION CRITERIA

- Individuals with a history of trauma or fracture of the upper limbs
- Individuals with any sort of neuropathy

3.6 DURATION OF STUDY

- Individual study period: 2-3 hours per case
- Total period of study: 6 months

3.7 SAMPLE SIZE ESTIMATION

The sample size for the current study 'The Morphology of a Smartphonopathic Hand' was calculated using method of sample size for frequency in a population www.openepi.com which is an open-source calculator, version 3-SSPropor using the following equation:

Sample size $n = [DEFF*Np(1-p)]/[(d^2/Z^2_{1-\alpha/2}*(N-1)+p*(1-P)]$

3.8 SAMPLING TECHNIQUE

The sampling technique implemented in this research was of the purposive type. The subjects were selected non-randomly. The samples were collected for specific purpose with predetermined basis of selection which was based on inclusion and exclusion criteria of the study.

3.9 HUMAN SUBJECTS AND CONSENT

The consent forms for subjects were designed in both English and Urdu which included information about the research work. Written informed consent was obtained from all subjects.

3.10 MATERIALS USED (DRUGS/ CHEMICAL/ PROFORMA/ QUESTIONNAIRE AND ANY OTHER)

The materials used to conduct this study included questionnaires, smartphone addiction scale (SAS), Duroz Hand Index (DHI), consent forms in English and Urdu, Lafayette Digital Hand Dynamometer (fig. 3.1, 3.2), a pillow, diagnostic ultrasound system (Toshiba Aplio 500 model TUS-A500) (fig. 3.3), ultrasound gel (fig. 3.4), x-ray system, x-ray reporting room.

The instruments used for the clinical evaluation consisted of the 5030D1-Lafayette Digital Hand Dynamometer (DHD) by which the subjects' grip strength was assessed; for radiological evaluation a linear array probe was used of the diagnostic ultrasound system (Toshiba Aplio 500 model TUS-A500) with the frequency set to 13 MHz to perform the ultrasound and visualize the median nerve and measure its cross-sectional area (mm^2), and x-ray system (Fujifilm Profect CS Plus; Toshiba Rotanode 150kVs; Model # DRX 3124HD) (fig.3.5) was used to conduct PA-view X-rays of the dominant and non-dominant hands of each participant.

Figure 3.1: Jamar Hand Dynamometer (in box)

Figure 3.2: Jamar Hand Dynamometer

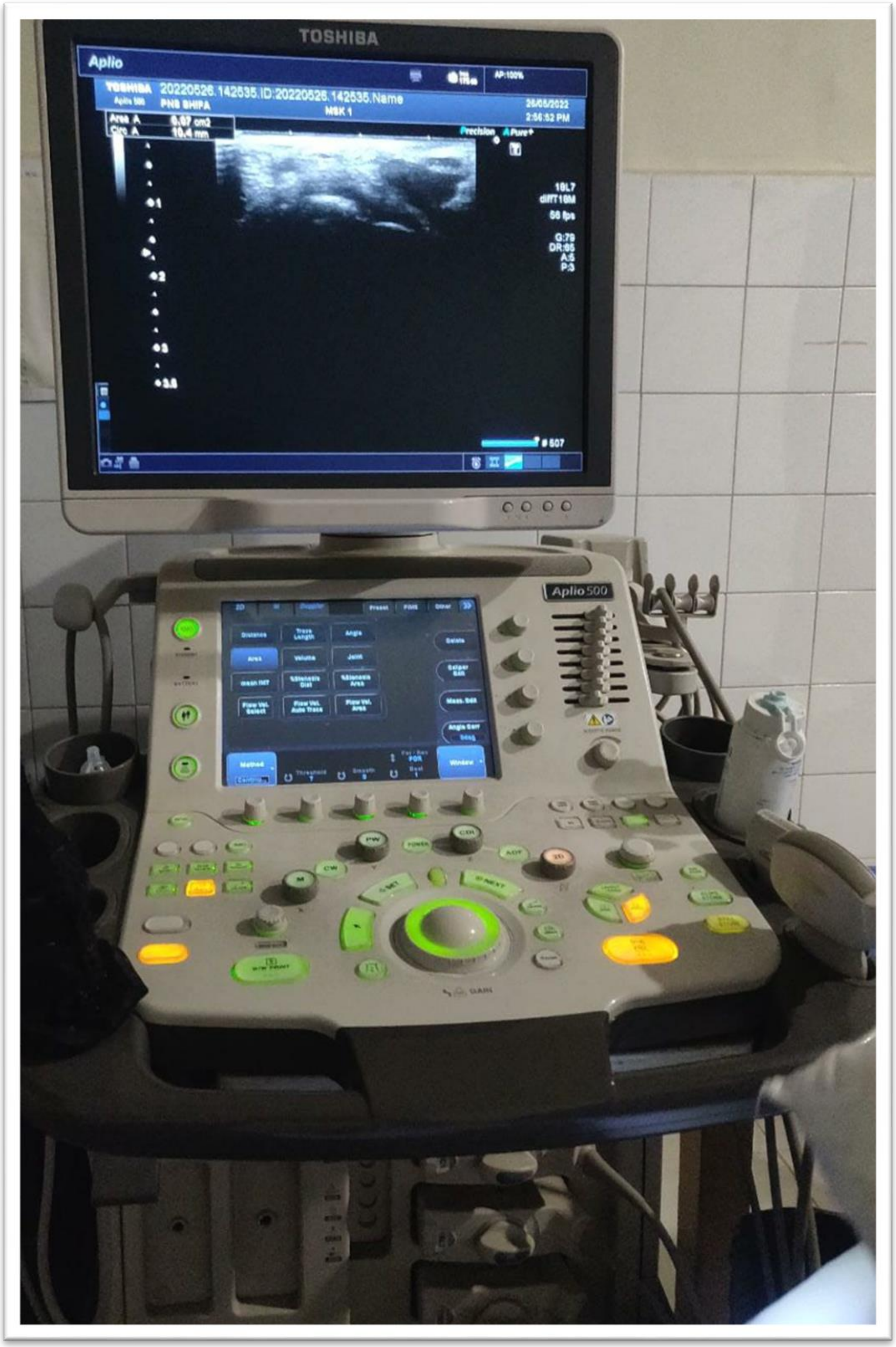

Figure 3.3: Diagnostic ultrasound system (Toshiba Aplio 500 model TUS-A500)

Figure 3.4: Sky Gel Ultrasound Gel which was applied on the wrists of the subjects prior to placing the transducer.

Figure 3.5: X-ray system (Fujifilm Profect CS Plus; Toshiba Rotanode 150kVs; Model # DRX 3124HD) with which the PA-view was carried out of dominant and non-dominant hands of the participants

3.11 PARAMETERS OF THE STUDY

- Gender
- Age
- Weight (kg)
- Ethnicity
- Use of laptop
- Status of exercising
- Hobbies
- Dominant hand
- Smartphone use (single-handed or double-handed)
- Number of years operating a smartphone
- Smartphone addiction score (assessed by the SAS)
- Dimensions of the smartphone currently being used (weight, screen size, model)
- Dimensions of the 5th finger (thickness/width (mm) of the middle phalange of the 5th digit at its narrowest portion visible to the naked eye on an x-ray picture)
- Median nerve cross-sectional area (CSA) (mm^2)
- Grip Strength (kg)

3.12 PROTOCOL OF STUDY

The current study collected data through a self-administered questionnaire. The questionnaire comprised of three parts. First part collected the demographic details, medical history, smartphone related details (model, weight, handedness, number of years using smartphone), questions related to hobbies, laptop usage and exercise, position by which single-handed users used their smartphone, and a question (Q27) asking whether they had noticed deformity in the fifth digit of their dominant hand as compared to their non-dominant hand. Second part consisted of the smartphone addiction scale (SAS), and the third part consisted of the Duroz Hand Index (DHI). Initially only those were selected and called who had marked in agreement to one of the questions (Q27) asking whether deformity in the fifth digit of their dominant hand as compared to their non-dominant hand was acknowledged by them, and who had no history of trauma to the upper limb. Since the initial inclusion criteria considered was the noticing deformity of the fifth digit for the x-ray evaluation, single-handed or double-handed usage of smartphone was not considered. However, all other subjects who did not qualify for the x-ray were selected solely on the inclusion criteria of using their smartphone single-handedly without any history of trauma to the upper limb. The three-parts questionnaire was then followed by the consent forms which also briefed them about the research and the following clinical and radiological evaluation. The measurements of the MN-CSA, grip strength, and thickness of the fifth digit was done on a separate sheet of paper (Annexes)

3.12.1 CLINICAL EVALUATION

The subjects' grip strength was then assessed, by the researcher, using a 5030D1-Lafayette Digital Hand Dynamometer with the handle set at level II (fig. 3.6, 3.7), which is the standard. The instrument was calibrated to measure the grip strength in kilograms.

The individuals placed their arms based on American Society of Hand Therapists' suggestions, with the shoulder neutrally rotated and adducted, the elbow flexed at 90°, and the wrist and forearm in a natural position. All of these were performed with the individual in a seated position. (fig. 3.6, 3.7)

Individuals, as instructed, pressed the handle (set to level II) of the dynamometer as forcefully as possible and sustained maximum grip contraction until the digital reading on the gauge became stationary. This action was duplicated 3 times (with 30 second rest periods) between each attempt. The average score of the 3 attempts was then calculated, and lesser scores suggested decreased grip strength.

Figure 3.6: A female subject performing the hand-grip strength test according to the American Society of Hand Therapists' suggestions

Figure 3.7: A male subject performing the hand-grip strength test according to the American Society of Hand Therapists' suggestions

3.12.2 RADIOGRAPHIC EVALUATION

3.12.2.1 ULTRASOUND

After the clinical evaluation, the students were called to the ultrasound and radiology department PNS Shifa. Ultrasounds of the both the wrists were done by a clinician blinded to the SAS scores and grip strength values. A diagnostic ultrasound system (Toshiba Aplio 500 model TUS-A500) was used, and ultrasound was carried out with a linear array probe (13 MHz). Individuals were seated with a pillow over their legs, their arms (semi-flexed) resting on the pillow, and the hands completely supinated. The transducer was placed axially at the carpal tunnel inlet denoted by the distal wrist crease on the anterior surface of the upper limb (fig. 3.8). Minimal pressure was applied by the transducer on the wrist. The median nerve was identified and confirmed by its superficial position just beneath the flexor retinaculum, its honeycomb appearance, and its stationary diameter upon moving the digits and pollicis (thumb) which identified the flexors of the hand as well and aided in differentiating them from the median nerve (fig. 3.9). The image was then frozen, and the cross-sectional area (CSA) was then measured with axial imaging and the manual tracing method (fig. 3.10). The dominant hand was assessed first followed by the non-dominant hand.

Figure 3.8: A subject undergoing ultrasound of his right wrist at the distal wrist crease level (carpal tunnel inlet)

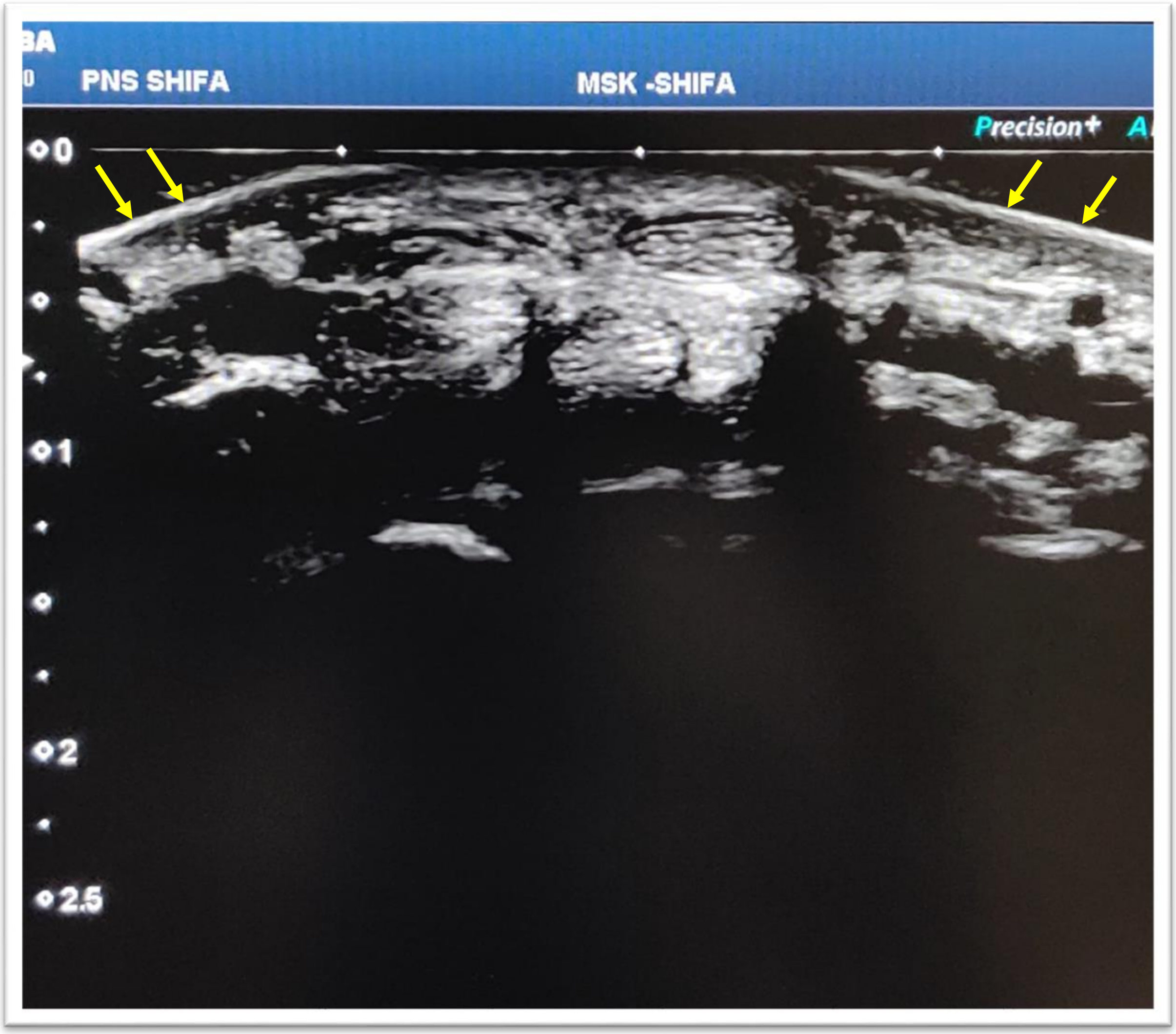

Figure 3.9: Ultrasound image of the wrist at the level distal wrist crease (carpal tunnel inlet). Notice the flexor retinaculum (yellow arrows)

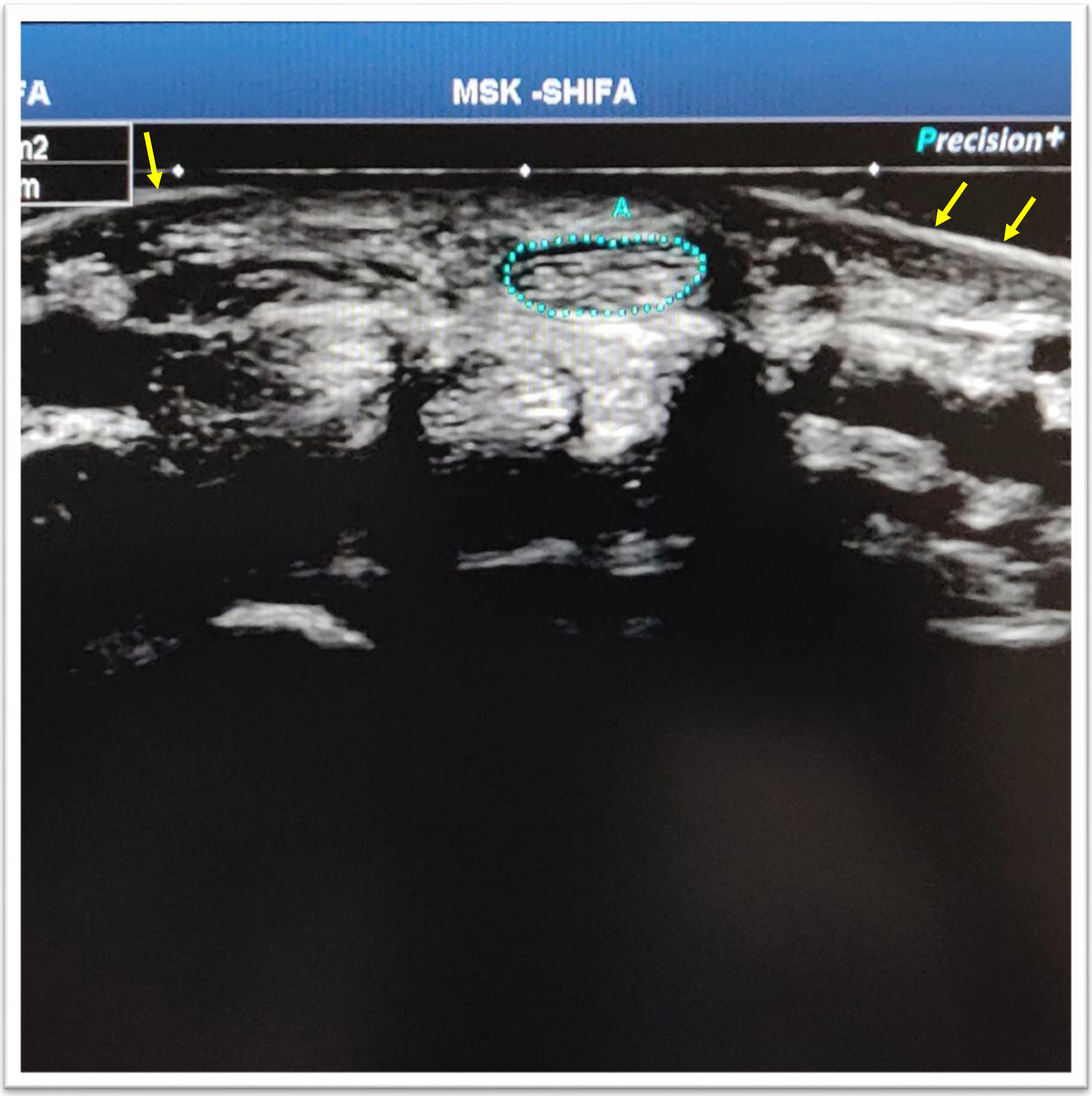

Figure 3.10: Ultrasound image of the wrist at the level distal wrist crease (carpal tunnel inlet). Notice the flexor retinaculum (yellow arrows). The median nerve has been outlined/manually traced (blue dotted line)

3.12.2.2 X-RAY

After assessing the median nerve cross-sectional area, only the subjects who documented noticing deformity of their fifth digit were taken to the x-ray room. Posterior-anterior view of both the hands was carried out by a radiologist blinded to the ultrasound results and the SAS and grip strength values. Individuals were asked to sit on a stool set at the flatbed height and place both of their hands, palms down on the image receptor (fig. 3.11). The centering point was set in between the thumbs of both the hands. Collimation was such that both the hands were completely covered (fig. 3.12). Fujifilm Profect CS Plus system was used with the exposure set to 50kVp and 5mAs. The students were then dismissed. The thickness of the middle phalange of fifth digits of both the hands was measured using the EFilm 3.4.0 Workstation software (fig. 3.13). Narrowest portion of the middle phalange was visibly detected and its thickness measured (fig. 3.14, 3.15)(DeSilva, Flavel, and Franklin 2014).

Figure 3.11: A subject positioned to undergo PA-view X-ray of both his hands.

Figure 3.12: A subject with his hands rested on the X-ray tray while the collimation area was being adjusted.

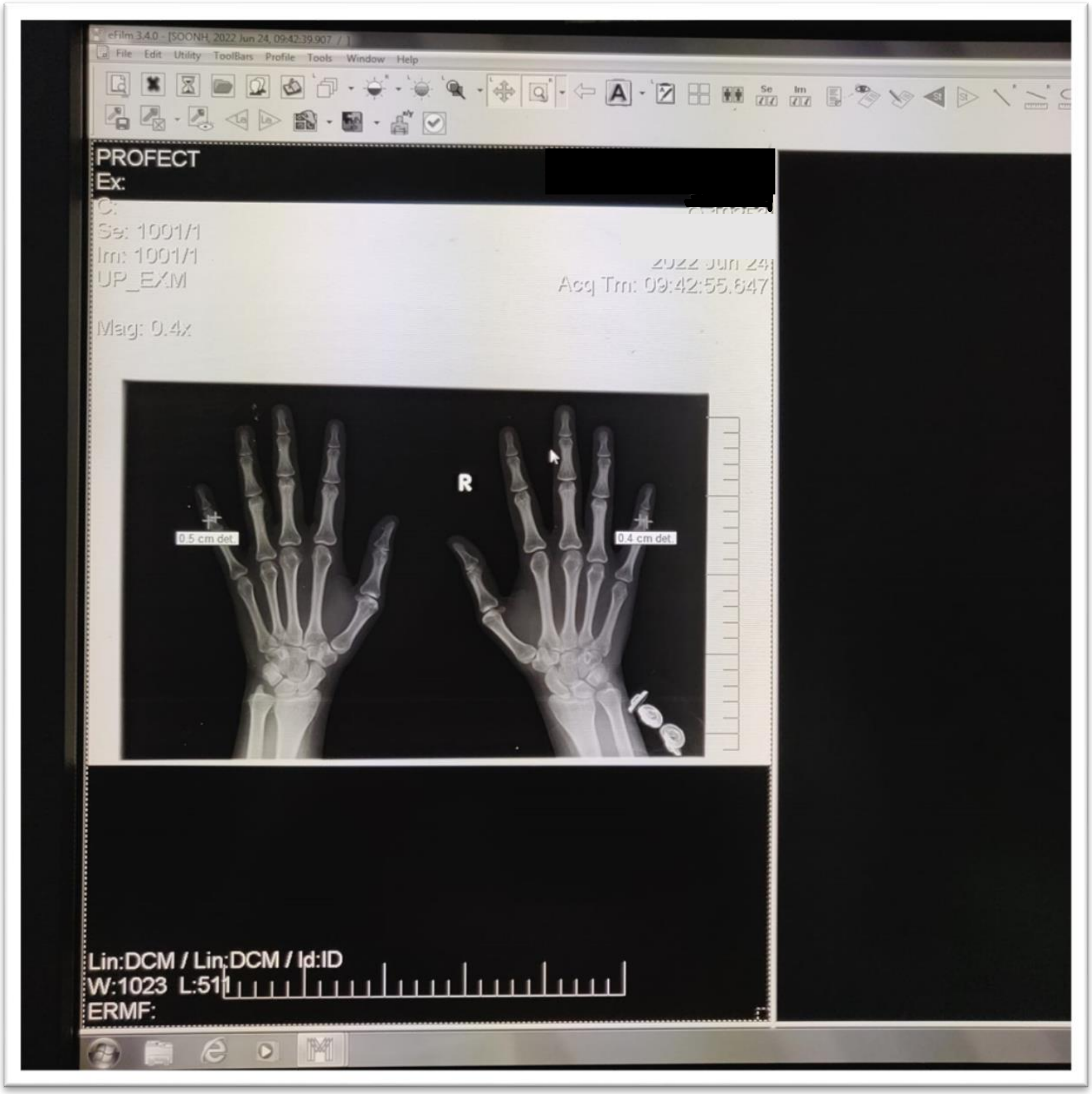

Figure 3.13: X-ray image of both the hands of the subject. The thickness of the middle phalanges of 5th digits have been marked and measured at their visible narrowest thickness.

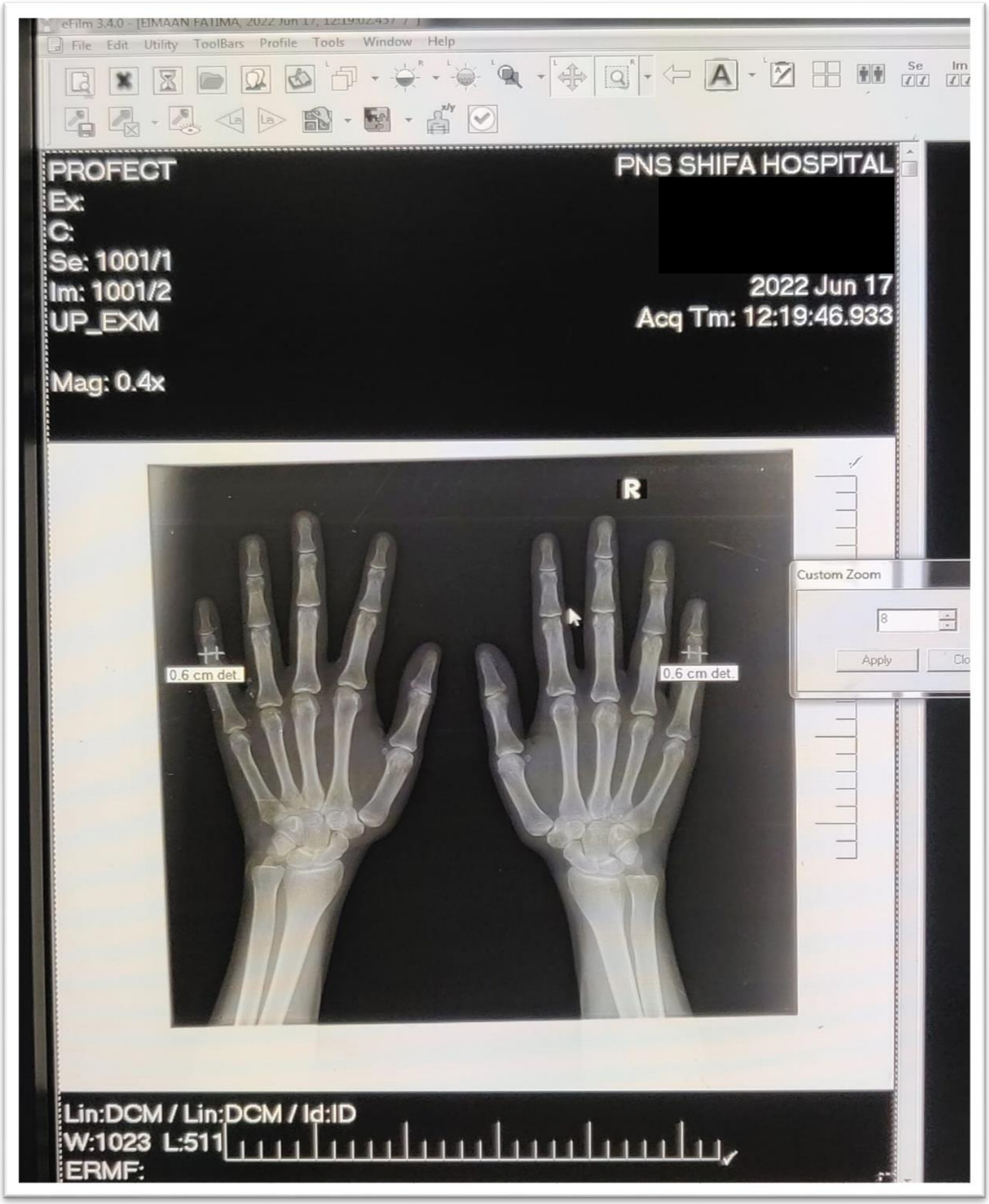

Figure 3.14: X-ray image of both the hands of another subject. The thickness of the middle phalanges of 5th digits have been marked and measured at their visible narrowest thickness.

Figure 3.15: Magnified image of the right fifth digit showing how the thickness was measured (white line) of the middle phalange of the 5th digit. Same was done on the opposite hand

3.13 STATISTICS

Statistical analysis was done using the IBMM SPSS 22.0. The data was checked for normality by Shapiro-Wilk test and was proven not normal. Hence, the data was considered non-parametric. Difference between two variables was statistically assessed and compared using the Wilcoxon signed rank test. Association between variables was assessed using biserial correlation test. The *p* value was set to ≤ 0.05.

CHAPTER 4

RESULTS

The present study was conducted on 128 subjects from Bahria University Health Sciences Karachi Campus. The subjects were of different medical disciplines which included MBBS, BDS, DPT, and Dental House Officers. The participants aged from 17-25 years of age with the mean age being 20.55 ± 1.787 (Table 4.1). Of the 128 participants, 43 (33.6%) were males and 85 were females (66.4%) (Table 4.2). Majority of the students were of the Punjabi ethnicity (41.4%), followed by Urdu Speaking (33.6%) (Table 4.3). Only 4 (3.1%) participants were left-dominant handed and the remaining 124 (96.9%) were right-dominant handed. One hundred and eight (84.4%) were single handed smartphone users and 20 (15.6%) were double-handed smartphone users (Table 4.4).

Out of the 128 subjects, 83 had a hobby which required the use of the hand or digits, 100 owned a laptop, and 40 students actively exercised at the time of the study (Table 4.5).

4.1 SMARTPHONE ADDICTION SCALE (SAS) RESULTS

The median score of SAS of the 128 participants was 114.5, lowest score being 53 and the highest being 185 (Table 4.6). Subjects having a score higher than 114.5 were considered as high-smartphone users and those having a lower score than 114.5 were considered as low-smartphone users (Table 4.2). Equal number of participants scored higher and lower than 114.5, resulting in 64 people in both the groups. In the high-smartphone user group, 45 (70.3%) were females and 19 (29.7%) were males. In the low-smartphone user group, 40 (62.5%) were females and 24 (37.5) were males.

The SAS did not show any significance with the age, gender, ethnicity, hand-dominance, use of smartphone (single-handed or double-handed), hobbies, laptop usage, or exercise.

4.2 GRIP STRENGTH RESULTS

The overall mean hand-grip strength in the dominant hand was recorded as 29.1 kg and 28 kg in the non-dominant hand. Mean hand-grip strength in the dominant hand of the 43 male participants was 40.7 kg (Table 4.10) while in the 85 females it was 23.2 kg (Table 4.11). In the non-dominant hand of male participants, the mean hand-grip strength recorded was 40.3 kg whereas it was 21.7 kg in the females. The differences in the grip strengths compared between both the genders was highly significant (*p*=0.000).

The mean grip strength in the dominant hand of the high-smartphone user group was 28.7 kg while in the non-dominant hand it was 28.2 kg. The difference between the two was not statistically significant (*p*=0.056). In the low-smartphone user group, the mean grip strength in the dominant hand was 29.5 (higher than the high-smartphone user) and 27.7 in the non-dominant hand, this difference between the two was statistically significant (*p*=0.000) (Table 4.7).

However, the difference between the two groups in dominant hand grip-strengths did not prove statistically significant (*p*=0.647) and neither did it in the non-dominant hand grip strengths (*p*=0.986) (Table 4.8).

The range of grip strength in the dominant of both the genders was represented in the form of bar graphs (Table 4.12, 4.13).

4.3 ULTRASOUND RESULTS

Of the 256 ultrasounds done (128 x 2), the lowest median nerve cross-sectional area recorded in the dominant hand was 3 mm² and highest was 14 mm². In the non-dominant hand, the lowest median nerve-cross sectional area recorded was 3 mm² and the highest was 12 mm². The mean MN-CSA in the dominant hand of high-smartphone user group was 7.95 mm² while in the non-dominant hand of this group it was 7.34 mm². The difference between the two was highly significant (*P*=0.007) (Table 4.7). In the low-smartphone user group, the mean MN-CSA in the dominant hand was 7.16 mm² (lower than the high-smartphone group) and 6.64 mm² (lower than the high-smartphone group) in the non-dominant hand, the difference between the two was also significant (*p*=0.0103) (Table 4.7).

The comparison was then done between the MN-CSAs of the dominant hands in both the groups, which yielded highly significant (*p*=0.013) (Table 4.8). Comparison between the MN-CSAs of the non-dominant hands was also statistically significant (*p*=0.025) (Table 4.8), less significant than the dominant hand which is worth noting.

The MN-CSA of dominant hand did not show any statistically significant correlation to hobbies, exercise, and laptop use (Table 4.14).

4.4 X-RAY RESULTS

Out of the 128 participants 45 were short-listed for the X-ray of their hands as they marked the question 27 (Have you ever noticed any deformation of your dominant hand's little (pinky) finger as compared to the other one?) on the questionnaire as 'yes'. Among these 45 short-listed participants, 25 were single-handed and 20 were double-handed smartphone users. The lowest thickness recorded of the middle phalanx of the 5^{th} digit of the both the hands (dominant and non-dominant) was 4mm and the highest 7mm. The mean thickness of the 5^{th} digit of the dominant hand was 5.42 mm whereas of the non-dominant hand it was 5.47 mm (Table 4.15). Despite the 5^{th} digit of the dominant hand being lesser in thickness compared to the non-dominant hand, the difference between the two was not significant (p=0.564) (Table 4.16).

Table 4.1: Range of ages of the participants and their mean age

AGE		
N	Valid	128
	Missing	0
Mean		20.55
Median		20.00
Std. Deviation		1.787
Range		8
Minimum		17
Maximum		25

Table 4.2: Shows the number of male and female participants which have been divided according to the Median value (114.5) of SAS scores in to high-smartphone and low-smartphone users

		SAS		**Total**
		< 114.5 (Low Smartphone User)	>114.5 (High Smartphone User)	
Gender	F	40 (62.5%)	45 (70.3%)	85 (66.4%)
	M	24 (37.5%)	19 (29.7 %)	43 (33.6%)
Total		64 (100%)	64 (100%)	128 (100%)

Table 4.3: Participants according to their ethnicity

		Frequency	**Percent (%)**
Ethnicity	Balochi	2	1.6
	Gilgiti	1	0.8
	Mixed	2	1.6
	Other	11	8.6
	Pathan	10	7.8
	Punjabi	53	41.4
	Sindhi	6	4.7
	Urdu	43	33.6
	Total	128	100.0

Table 4.4: Number of single-handed users and double handed smartphone users

		Frequency	**Percent (%)**
Use of Smartphone	Double-handed	20	15.6
	Single-handed	108	84.4
	Total	128	100.0

Table 4.5: Number of participants having a hobby, laptop, or/and actively exercising during the time of the study

	Yes	**No**	**Total**
Hobby	84 (65.5%)	44 (34.4%)	128
Laptop user	100 (78.1%)	28 (21.9%)	128
Exercise	88 (68.8%)	40 (31.3%)	128

Table 4.6: Details of the SAS showing the Median value, as well as the maximum and minimum score

N	Valid	128
	Missing	0
Mean		112.02
Median		114.50
Std. Deviation		26.091
Range		132
Minimum		53
Maximum		185

Table 4.7: MN-CSA and grip strength of dominant hand and non-dominant hand compared

	Dominant Hand	**Non-dominant Hand**	***p***
High Smartphone Users			
MN-CSA (mm^2)	7.95±1.855	7.34±1.896	0.007**
Grip strength (kg)	28.703±10.235	28.236±11.529	0.056
Low Smartphone Users			
MN-CSA (mm^2)	7.16±1.921	6.64±1.495	0.0103*
Grip strength (kg)	29.567±11.093	27.741±10.998	0.000**

p-value < 0.05 = statistically significant (*); <0.01 = highly statistically significant (**)

Test applied = Wilcoxon matched-pairs signed-ranks test

Table 4.8: MN-CSA and grip strength of high-smartphone and low-smartphone users compared

	High-Smartphone Users	**Low-Smartphone Users**	***p***
MN-CSA (mm^2) Dominant Hand	7.95±1.855	7.16±1.921	0.013*
MN-CSA (mm^2) Non-Dominant Hand	7.341±1.896	6.64±1.495	0.025*
Grip Strength (kg) Dominant Hand	28.703±10.235	29.567±11.093	0.647
Grip Strength (kg) Non-Dominant Hand	28.236±11.529	27.741±10.998	0.986

p-value < 0.05 = statistically significant (*); <0.01 = highly statistically significant (**)

Test applied = Wilcoxon matched-pairs signed-ranks test

Table 4.9 MN-CSA in dominant hands of single-handed and double-handed smartphone users compared between the two groups (high smartphone and low smartphone users)

	High Smartphone Users	**Low Smartphone Users**	***p***
MN-CSA in Dominant Hand			
Single-Handed Smartphone Users (mm^2)	7.94±1.937	7.22±1.939	0.033*
Double-Handed Smartphone Users (mm^2)	8.00±1.414	5.80±1.874	0.119

p-value < 0.05 = statistically significant (*); <0.01 = highly statistically significant (**)

Test applied = Wilcoxon matched-pairs signed-ranks test

Table 4.10: Descriptive statistics of dominant hand grip strength in males

DOMINANT HAND GRIP STRENGTH (KG) IN MALES	
Mean	40.71
Standard Error	1.36
Median	40.00
Mode	26.10
Standard Deviation	8.93
Range	36.40
Minimum	23.00
Maximum	59.40
Count	43.00

Table 4.11: Descriptive statistics of dominant hand grip strength in females

DOMINANT HAND GRIP STRENGTH (KG) IN FEMALES	
Mean	23.28
Standard Error	0.57
Median	22.80
Mode	25.40
Standard Deviation	5.29
Range	31.50
Minimum	13.30
Maximum	44.80
Count	85.00

Table 4.12: Bar graph representing range of ages and dominant hand grip strength in males

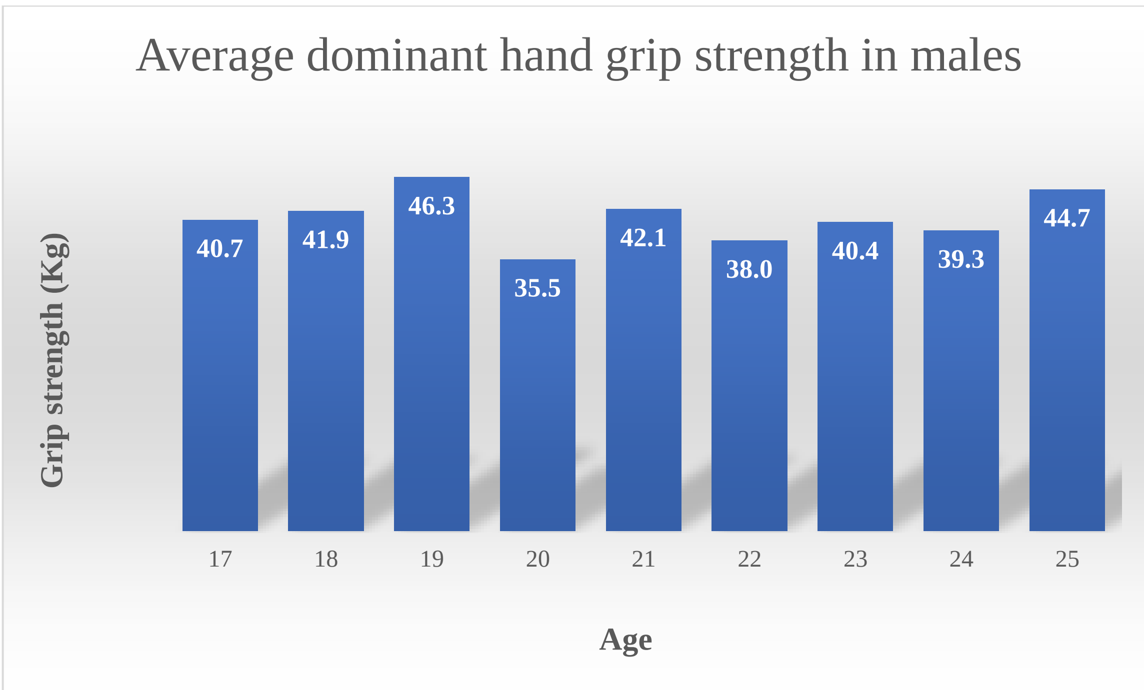

Table 4.13: Bar graph representing range of ages and dominant hand grip strength in females

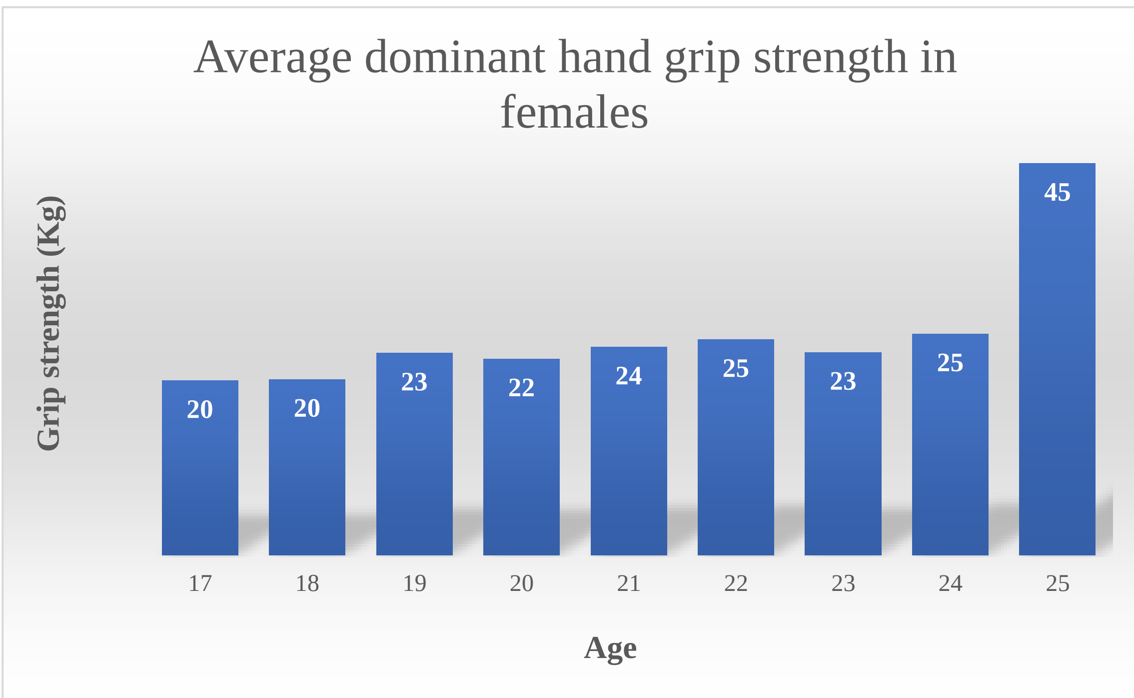

Table 4.14: Correlation between MN-CSA in dominant hand and hobbies, laptop use, and exercise

	MN-CSA in dominant hand of all subjects (n = 128)	
	r_{pb}	*p*
Hobbies	-0.051	0.568
Laptop Users	0.010	0.909
Exercise	-0.148	0.096

p-value < 0.05 = statistically significant (*); <0.01 = highly statistically significant (**)

Test applied = Point biserial correlation

Table 4.15: Descriptive statistics of the 5th digit of dominant and non-dominant hands

	N	**Mean**
Thickness of 5th digit of the dominant hand (mm)	45	5.42±0.657
Thickness of 5th digit of the non-dominant hand (mm)	45	5.47±0.661

Table 4.16: Difference between the thickness of 5th digit in both the hands

Thickness of 5th digit of dominant hand	**Thickness of 5th digit of non-dominant hand**	***p***
5.42±0.657	5.47±0.661	0.564

CHAPTER 5

DISCUSSION

5.1 SEQUENCE OF DISCUSSION EXPERIMENT/HYPOTHESIS WISE

The current study found that young people are becoming more and more addicted to handheld devices, especially smartphones. The highest score recorded on the SAS in the current study was 185, mean score was 112.02 ± 26.091and median score was 114.5.

This was different from what Inal et al. (2015) found in their study on overuse of smartphone and its effect on the median nerve, hand function, and pinch strength conducted on 102 participants, which had the highest SAS score of 122. Another study aimed towards investigating the severity of smartphone use and its relation to sleep quality, depression, and anxiety in 319 university students with a mean age of 20.5 ± 2.45 (Demirci, Akgonul, and Akpinar, 2015), similar to the current study. To assess the addiction to smartphone use, SAS was used, and the median score was reported to be 72 which was significantly lower than 114.5 in the current study. In a recent study which was conducted to find out a relationship between bruxism and smartphone overuse in 167 young adults aged from 21-29 years, the median SAS was reported to be 84 (Tinastepe and Iscan, 2021). Smartphone addiction was also assessed with the help of SAS in 420 Jordanian ungraduated dental students with a mean age 20.9 (Sanusi et al., 2022). The mean SAS score was reported to be 109.9. In an observational study conducted in India on 220 medical students to evaluate the effect of smartphone use on hand dexterity reported 96.94 as the mean SAS score. In another recent cross-sectional study in Oman, 404 university students were recruited in order to investigate anxiety and insomnia in them as a result of smartphone use (Al Battashi et al., 2021). The average age of the participants was 21.5 years and SAS was used to assess smartphone addiction. The mean SAS score was reported to be 83.9. One recent study evaluated the effect of internet and smartphone addiction on sleep quality among 910 adolescents between the ages of 13-18 years (Acikgoz, Acikgoz, and Acikgoz, 2022). They evaluated smartphone addiction with the help of SAS for which the mean score was reported to be 77.9. The high addiction to smartphone observed in our study was also supported by Alsalameh et al. (2019) and Javaid, Yasir, and Ahmed (2019) which also reported high smartphone addiction in medical students

Thus, the young adults of Pakistan may be addicted to smartphones more, possibly because of the country being a developing country with inaccessibility to proper education but easier accessibility to smartphones which might be used more in educational institutions to gather more information and knowledge.

Out of the 128 participants, 108 were single-handed users. This is supported by one of the studies which reported participants using the smartphone single-handedly (Inal et al., 2015) and also with Woo, White, and Lai (2019) who reported majority of their participants using the smartphone single-handedly. This is in contradiction with the study done by Sampath et al. (2022) which reported 62% of its participants using their smartphone double-handedly.

Our study reported no significant difference between the grip strengths of dominant hand and non-dominant hand in the high-smartphone users. However, our study did report significant difference between the grip strengths of the two hands in the low-smartphone user group. The difference between the two groups in dominant hand grip-strengths did not prove statistically significant, despite being closer to be so, and neither did it in the non-dominant hand grip strengths. It is worth noting that the mean value of the grip strength in the dominant hand of high-smartphone users was indeed lesser than the mean value of the grip strength in the dominant hand of low-smartphone users and was closer to the non-dominant hand mean value in the former group. Normally, the hand-grip strength of dominant hand is noticeably higher than the non-dominant hand (as in the low-smartphone user group) because of hand dominance and development and hypertrophy of the respective muscles (Nakandala et al., 2019). This suggests that high-smartphone usage does decrease the grip strength in the dominant hand despite it not being significant, similar to that suggested by Inal et al. (2015).

Normative values were also obtained for the grip strength of dominant hand in males and females. In females our study reported the mean grip strength to be 23.28 kg which was less than the mean values observed in studies conducted in other countries such as Saudi Arabia (Shaheen, Omar, and Ali, 2021), South Korea (Kim et al., 2018), Germany (Steiber, 2016), Nepal (Bimali et al., 2020), and India (Walankar et al., 2016). In males our study reported the mean grip strength of their dominant hand to be 40.71 kg for the respective age range which compares to those from other countries as the following: 47.41 kg from Nepal (Bimali et al., 2020), 40.1 kg from South Korea (Kim et al., 2018), 44.6-47.0 kg from Germany (Steiber, 2016), and 32.08 kg from India (Walankar et al., 2016). Only a few studies were found in literature to evaluate hand-grip strength in the same respective country, Pakistan. One was conducted by Hamdani et al. (2021) in the province of Punjab. However, the age range was different to ours, 12-16 years, but since the material in literature to come from the same country is so scarce, it is worth comparing. The mean hand grip strength in the dominant hand of males was found to be 31.81 kg which was lesser compared to our findings; and of females it was reported to be 17.06 kg which, too, was lesser than our findings. Another study from the same country but, different province, was by Tahir et al. (2020) who assessed hand grip strength in the similar age range and reported the median value in males to be 29.85 kg and 13.85 kg in females. Both of these were less than the median values observed in our study, 40 kg in males and 22.8 kg in females. Mirza et al. (2020) reported the overall mean hand grip strengths of both, males, and females in the ages of 20-29 years to be 31.26 kg. More studies are suggested to be done on this with a preferably larger sample size to establish a firmer relation.

Non-significant reduction of the grip strength in the dominant hand of high-smartphone users compared to low-smartphone users is contradicted by numerous studies done on the matter; Din and Hafeez (2021) concluded that there was a significantly high prevalence of smartphone addiction in young adults and it led to reduced hand grip strength, Radwan et al. (2020) reported weakened hand and pinch-grip strengths in the dominant hands of high-smartphone users. However, dominant hands of both low-smartphone users and high-smartphone users had altered hand functions. Grip strength findings of our study are supported by Abelkader (2021) who reported no significant difference was found between the right and left hand's handgrip strength, along with the fatigue values; Shetty et al. (2019) reported no significant negative impact on the hand dexterity of dominant hand by excessive smartphone usage. Singh et al. (2022) also reported results similar to our study, that is, no adverse effect of smartphone usage on power grip was observed despite the wrist muscles found to be weak. Our results were also supported by those of Samaan et al. (2018) which concluded that while extended smartphone use did decrease the conduction velocity of ulnar nerve and neck pain, it did not affect the handgrip strength. On the extreme end, one study (Motimath et al., 2017) reported higher grip strength in high-smartphone users.

The results of our study showed significantly increased MN-CSA in the dominant hands of both, the high-smartphone and low-smartphone user, groups when compared with their non-dominant hands. The mean value of MN-CSA in dominant hand, however, was higher in the high-smartphone users than in the low-smartphone users despite both being significantly high when compared to the non-dominant hands of each group. Increase in MN-CSA, due to smartphone use as observed, can also lead to carpal tunnel syndrome (CTS). MN-CSA > 9 mm^2 proximal to the carpal tunnel, >10.03 mm^2 in the proximal carpal tunnel, or >10.5 mm^2 at pisiform bone level, is considered to be abnormal (Yao et al., 2019). This increase in MN-CSA due to high smartphone usage in the dominant hand, or smartphone usage in general, possibly leading to CTS, is supported by the few studies done on this matter. Possibly the mainstay of ultrasonography of the median nerve in relation to smartphone usage is the study done by Inal et al. (2015) which reported considerably increased MN-CSAs in the predominant hands of the high smartphone users than non-dominant hands, thereby supporting the results of the current study; Samuel et al. (2021) also reported significantly high MN-CSA in the high-smartphone users as compared to the low-smartphone users; Mousa et al. (2019) observed that the CSA of median nerve was higher in the participants typing on their phone single handedly than the ones typing with two hands, hinting that rapid movement of digit and extensive thumb-tapping activity resulted in swelling of the median nerve; İlik et al. (2017) results showed that using smartphone at an increasing rate adversely influenced the median nerve; Woo et al. (2017) similarly reported that intensive electronic device users also had significantly enlarged MN-CSA, flattening ratios, and perimeters.

One significant study which was theoretically similar to ours was by Lee (2017). However, the results observed were contradictory to ours. They measured the angle deformity in distal interphalangeal joint of the fifth digit radiographically in relation to the size of the smartphone. They observed significant difference between the angle deformity in the experimental group and the control group in relation to the large size of the smartphone, the former group was the one which used digiti minimi for support of the smartphone.

Our study showed no significant differences in the thickness of 5^{th} digit of both the hands when compared with each other. This result was supported by one study very similar to ours which assessed the changes in the area of irregularity and minifret of the fifth digits due to smartphone usage (Fuentes-Ramírez et al., 2020). The comparative study also reported no significant irregularities between the fifth digits of both hands of young adults in relation to the type of smartphone holding method or the number of years having used a smartphone.

5.2 IMPLICATIONS OF THE STUDY

5.2.1 THEORITACIAL IMPLICATIONS

The past studies failed to exclude many other factors such as hobbies, status of exercise and other device usage (for e.g., laptops) which played a role of confounding factors on the results when assessing the impact of smartphone usage on the median nerve cross-sectional area and grip strength. Our study was successful in extracting that and observed that even though many of the subjects had some hobby, it did not prove to significantly affect the results of the study (i.e., MN-CSA and grip strength) and found no relation between them. Hence, theoretically there was no impact of hobbies, exercise, and laptop usage on MN-CSA and grip strength, but this needs to be further investigated in a larger sample size. Medical students at the respective university and region of the country in the current study presented the highest addiction to smartphone documented thus far, the possible reason could be the respective country being a third world (developing) country and smartphones being easily available and a cheap price. Despite no such difference found in the middle phalanx of fifth digit of the dominant hand as compared to the non-dominant hand of smartphone users, it should be noted that out of 128 people 45 agreed to having noticed deformity in the fifth digit without having had any history of trauma or illness. This aspect needs to be explored more as it is still a theory and possibility that prolonged usage of smartphone in a particular position and its weight might lead to deformity of the fifth digit.

5.2.2 PRACTICAL IMPLICATIONS

Our study provided more material to the scarce existing literature on the relationship between smartphone usage and its effect on the median nerve cross-sectional area (MN-CSA) and grip strength. Our study showed that MN-CSA indeed increased in smartphone users, more so in the high-smartphone group than the low-smartphone group. It also suggested reduced grip strength in dominant hands of high-smartphone users. This increase in the MN-CSA could lead to carpal tunnel syndrome over a prolonged period as suggested by a few other past studies. Hence, clinicians should take notice of these findings and investigate thoroughly the pattern and extent of smartphone usage in patients presenting with complaint of altered hand function, tingling sensation, atrophied thenar eminence, etc and impaired hand-grip strength without any significant medical history.

5.2.3 POLICY IMPLICATIONS

As it was observed that smartphone addiction was significantly high in the medical students of BUHSCK there should be a policy which aims to reduce that, perhaps an automated box or storage in which the smartphones of students are stored at the start of the college/university and are given at the end of it. This would possibly reduce smartphone usage thus reducing addictive behavior while increasing social interaction amongst students. The study also showed that difference between the MN-CSA in dominant hand of single-handed high-smartphone users and low-smartphone users was more and significant than compared to the MN-CSA in dominant hand of double-handed high-smartphone users and low-smartphone users. This warrants a policy encouraging using of smartphones double-handed rather than using them single-handedly.

5.3 LIMITATIONS

- The COVID pandemic has taken everyone in to a spiral and this study was not spared from its clutches. The on-and-off lockdowns provided a difficult obstacle in conducting this study the way and in the timespan it was intended to.
- As is with every cross-sectional design of study, a causal relationship could not be established.
- The sample size was less and that was the reason why the data was non-parametric.
- Pinch strength and flexor pollicis longus (FPL) tendon CSA were also intended to be assessed but due to the limited time, funds, and resources, that was not done.
- Whether the individuals were single-handed smartphone users or double-handed, although documented, was not taken in to consideration for analysis and results.
- The nature of the gender population in medical universities in the respective country made it almost impossible to take the genders in equal numbers.
- The median score of the SAS was high, highest we could find when searched in literature, which made dividing individuals in to two groups, high-smartphone, and low-smartphone users, cumbersome as the low-smartphone user group still had individuals with a relatively high SAS score, this did not provide the exact results we had anticipated.

5.4 STRENGTHS

Despite the sample size being low, it is by far the most in which MN-CSA has been assessed at the carpal tunnel level by ultrasonography to evaluate a relationship with smartphone use. It is, so far, the first study in the respective country to do so. Equal number of individuals were grouped in to high-smartphone users and low-smartphone users which helped provide a stronger and unbiased relation.

5.5 RECOMMENDATIONS

- Our study has laid down the foundation conceptually and theoretically for the effect of smartphone usage and deformity of the fifth digit of the hand. That along with the effect of smartphone use on the median nerve CSA and grip strength should further be evaluated on a larger sample size in hopes of possibly cementing the term 'smartphonopathic hand' in the future, which was first coined in our study. Muscles and tendons specifically related to the fifth digit should also be specially assessed as the soft tissues (Fuentes-Ramírez et al., 2020) and bones have already been tried to be
- More similar studies should be conducted in the respective country to compare the parameters that were assessed in this study such as the smartphone addiction, MN-CSA, and grip strength for better implications and outcomes, especially clinical and policy wise, as this was the first study conducted in the respective country
- In the future, if SAS in any study is observed to be higher, as in our study, the subjects should be divided in to three groups, instead of the two as in our study, preferably low-smartphone users, moderate-smartphone users, and high-smartphone users for a better comparison and correlation
- Numerous subjects agreed and reported noticing deformity or difference in their fifth digit of the dominant hand compared to the non-dominant hand without any history of trauma or illness which should raise concern and should be assessed in the future for its reason
- Single-handed smartphone usage should further be assessed and compared with double-handed smartphone usage which our study failed to do so to the extent we had preferred
- Apart from the median nerve, muscles and tendons of the hand should also be assessed in relation to the usage of smartphone, especially those that are used to hold or navigate through the smartphone
- Similar study and parameters should be assessed in different age groups and the results compared

5.6 CONCLUSION

Smartphone addiction is on the rise at an alarming rate. Smartphone overuse leads to enlarged median nerve cross-sectional area in the dominant hand and possibly to reduced grip strength in the dominant hand. Over usage of smartphone for a prolonged period might lead to altered hand function and even to developing carpal tunnel syndrome over a prolonged period of time.

CHAPTER 6

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CHAPTER 7

APPENDIX A: FRC

Bahria University
Discovering Knowledge
Medical and Dental College, Karachi

Ref no: FRC/BUMDC -14/2021-Ana-102 MS-11

Approval of Research Proposal

Mr/Miss/Ms/Mrs/ **Dr. Syed Wajahat Hasib**

Registration No:

Dear MS/MPhil Student,

I am pleased to inform you that your research proposal on **"The Morphology of a Smartphonopathic Hand"** has been approved. You may, therefore, continue your research on this theme and produce a quality thesis, as per the HEC requirements.

I take this opportunity to remind you that you must complete your thesis, and defend it successfully, by **SPRING 2023**; this is the date which marks the end of the Extended Duration of your programme. However, to remain eligible for honours and awards, you must complete the thesis, and successfully defend it, by the end of 10 week of final semester.

I wish you every success.

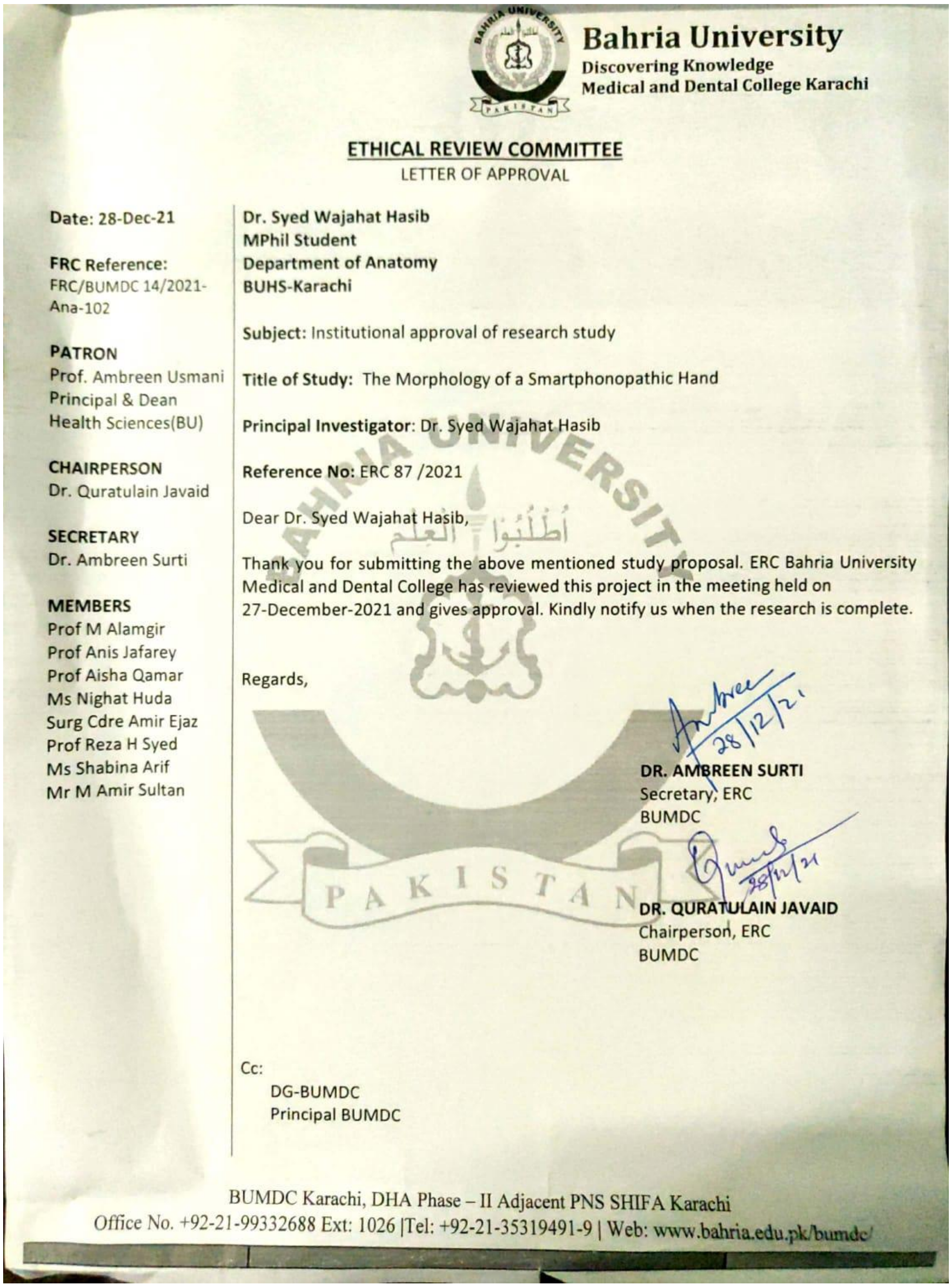
Dated: 17/9/2021

CHAIRPERSON FRC, BUMDC

Distribution:

- DG
- Principal
- Student's File (with the HOD/PGP Coordinator)
- Student

APPENDIX B: ERC



Bahria University
Discovering Knowledge
Medical and Dental College Karachi

ETHICAL REVIEW COMMITTEE
LETTER OF APPROVAL

Date: 28-Dec-21

FRC Reference:
FRC/BUMDC 14/2021-Ana-102

PATRON
Prof. Ambreen Usmani
Principal & Dean
Health Sciences(BU)

CHAIRPERSON
Dr. Quratulain Javaid

SECRETARY
Dr. Ambreen Surti

MEMBERS
Prof M Alamgir
Prof Anis Jafarey
Prof Aisha Qamar
Ms Nighat Huda
Surg Cdre Amir Ejaz
Prof Reza H Syed
Ms Shabina Arif
Mr M Amir Sultan

Dr. Syed Wajahat Hasib
MPhil Student
Department of Anatomy
BUHS-Karachi

Subject: Institutional approval of research study

Title of Study: The Morphology of a Smartphonopathic Hand

Principal Investigator: Dr. Syed Wajahat Hasib

Reference No: ERC 87 /2021

Dear Dr. Syed Wajahat Hasib,

Thank you for submitting the above mentioned study proposal. ERC Bahria University Medical and Dental College has reviewed this project in the meeting held on 27-December-2021 and gives approval. Kindly notify us when the research is complete.

Regards,

28/12/21

DR. AMBREEN SURTI
Secretary, ERC
BUMDC

28/12/21

DR. QURATULAIN JAVAID
Chairperson, ERC
BUMDC

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APPENDIX C: SUBJECT CONSENT FORM - ENGLISH

You are giving your consent to participate voluntarily and at your own will in the research project that aims for the investigation of the dimensions and usage of smartphone and their effect on the median nerve, flexor pollicis longus, hand grip and pinch strength and the fifth digit of the hand. The project will evaluate the changes that will help prevent any anatomical variations in the future that could possibly result in altered hand function and daily life.

You have been explained in detail the nature and significance of participating in the project, and that the radiographic and clinical analysis of your hand and wrist will help notify you about any possible abnormalities and to prevent or correct them.

You have been told that all the findings and your personal data will be kept strictly confidential and will be used only for the benefit of orthopedics to consider smartphone usage as a major cause for altered anatomy and function of the hand, and hence to advise precautions and preventive measures in the future. The study will be strictly used only for the betterment of the community, in publications and paper presentations.

You have been explained that radiological investigations will be conducted to evaluate your health status. You have been notified about the amount and time of exposure to x-rays. Youhave been explained about any possible harm related to the study and the measures that would be taken to compensate if any harm was to occur.

I agree to give all the relevant information needed to the researcher in full and to the best of my knowledge. It is clarified to me that no incentive, financial assistance, or reimbursement will be provided to me for participating in the study whereas I do have the right to withdraw from the study at any time. Keeping all the above in mind, I agree to give my full consent for this purpose.

You are advised to contact **Dr. Syed Wajahat Hasib** on

Mobile number: **0333-3832715** or visit **PNS Shifa** hospital in case of any query.

Name of Participant: ______________________

S/o, D/o, W/o__________________

Signature of Participant: _________________

Name of Researcher: _______________________________________

Signature of Researcher: ______________

Date: _______________

APPENDIX D: SUBJECT CONSENT FORM - URDU

میں رضاکارانہ طور پر اور اپنی مرضی سے اس تحقیقی منصوبے میں حصہ لینے کے لئے اپنی رضامندی دے رہا ہوں۔ جس کا مقصد اسمارٹ فون کے مختلف پہلوؤں اور استعمال کی تفتیش ہے۔ اور اس کا اثر میڈین اعصاب ،ہاتھ کے انگوٹھے کو ہتھیلی کی طرف موڑنے والے پٹھا ، ہاتھ کی گرفت، انگلیوں سے پکڑنے کی طاقت اور چھنگلی پر اس کا اثر جیسے عنوانات کے تحت تبدیلیوں کا جائزہ لیا جائے گا جو مستقبل میں ہاتھ کے افعال اور روزمرہ زندگی میں تبدیلیوں کو روکنے میں مددگار ثابت ہوں گے۔

مجھے منصوبے میں حصہ لینے کی نوعیت اور اس کی اہمیت کے بارے میں تفصیل سے بتایا گیا ہے۔ نیز ، یہ کہ میرے ہاتھ اور کلائی کا ریڈیوگرافک اور کلینیکل تجزیہ مجھے کسی بھی ممکنہ بگاڑ کے بارے میں مطلع کرنے اور ان کی روک تھام یا اصلاح کرنے میں مدد کرے گا۔

مجھے بتایا گیا ہے کہ تمام نتائج اور میرے ذاتی اعداد و شمار کو سختی سے راز میں رکھا جائے گا اور اسے صرف آرتھوپیڈکس کے فائدہ کے لئے استعمال کیا جائے گا تاکہ اسمارٹ فون کے استعمال کو ہاتھوں کی بدلی ہوئی اناٹومی اور افعال کی ایک بڑی وجہ سمجھا جائے اور اسی وجہ سے مستقبل میں احتیاطی تدابیر اختیار کی جائیں۔ اس مطالعے کو سختی سے صرف اشاعت اور کاغذی پیشکش میں معاشرے کی بہتری کے لئے استعمال کیا جائے گا۔

مجھے بتایا گیا ہے کہ میری صحت کی حالت کا اندازہ کرنے کے لئے ریڈیولوجیکل تحقیقات کی جائیں گی۔ مجھے ایکس رے کی شعاعوں کی مقدار اور دورانیے کے بارے میں مطلع کیا گیا ہے۔ مجھے اس مطالعے سے متعلق کسی بھی ممکنہ نقصان اور ان اقدامات کے بارے میں بتایا گیا ہے جو نقصان ہونے کی صورت میں اسے پورا کرنے کے لیے اٹھائے جائیں گے ۔

میں پوری طرح سے اور اپنے علم میں بہترین طور پر محقق کو درکار تمام متعلقہ معلومات دینے پر راضی ہوں۔ یہ بات مجھے واضح کردی گئی ہے کہ مطالعے میں حصہ لینے کے لئے مجھے کوئی ترغیبی ، مالی امداد ، یا

معاوضہ فراہم نہیں کیا جائے گا جب کہ مجھے کسی بھی وقت مطالعے سے دستبرداری کا حق حاصل ہے۔
مذکورہ بالا تمام نکات کو مدنظر رکھتے ہوئے ، میں اس مقصد کے لئے اپنی مکمل رضامندی دینے پر راضی ہوں۔

مجھے ڈاکٹر سید وجاہت حسیب سے رابطہ کرنے کا مشورہ دیا گیا ہے
موبائل نمبر: 0333-3832715 یا کسی بھی سوال کی صورت میں پی این ایس شیفا اسپتال دیکھیں۔

شریک کا نام:______________

ولدیت/زوجیت:______________

شریک کے دستخط:____________

محقق کا نام:______________

محقق کے دستخط:____________

تاریخ:___________

APPENDIX E: QUESTIONNAIRE

You give your consent to participate in filling the following questionnaire as a part of an ongoing research on smartphone overuse and its adverse effects on the human anatomy. Further participation would depend on your answers to the questions below. Your information would remain confidential.

Signature: ___________________

DEMOGRAPHICS			
1.	Name:	**2.**	Gender:
3.	Age:	**4.**	Height:
5.	Weight:	**6.**	Phone no.:
7.	Father’s name:	**8.**	Father’s occupation:
9.	Education (mention discipline and year, e.g. 1st year MBBS):	**10.**	Roll no. (if assigned):

Please answer the following questions by placing a single (✓) on the boxes:

11.	Ethnicity:	□ Urdu speaking □ Sindhi □ Punjabi □ Pathan □ Balochi □ Other
12.	Marital status:	□ Single □ Married
13.	Job description:	□ Student □ Employed (give a short description):
14.	Do you use a laptop?	□ Yes □ No
15.	Do you actively exercise?	□ Yes □ No
16.	If you answered above as ‘yes’, which of the below describes the type of exercise?	□ Weight lifting □ Cross-fit □ Cardio □ Yoga □ Other (please specify):

17.	Which game console do you own?	□ Playstation □ Xbox □ Nintendo □ None □ Other (please specify):
18.	How many hours (approx.) do you play the game console per day?	□ ≤1 hour □ 1-2 hours □ 2-3 hours □ 3-4 hours □ >4 hours □ None
19.	Pick from the following any habits/hobbies that you might have:	□ clicking the top of a ballpen □ guitar playing □ violin playing □ keyboard playing □ none □ other (please specify):
20.	Dominant hand:	□ Right □ Left
21.	Do you own a smartphone?	□ Yes □ No

Attempt the following questions only if you answered the previous question, ‘Yes’.

22.	You use your smartphone:	□ Single-handedly □ Double-handedly
23.	(Only answer if you answered the above, ‘single-handedly’) Encircle/tick the image below that best describes the position you use your smartphone with (whether left or right): 	
24.	Please specify the model of your smartphone:	
25.	How many years have you been using a smartphone for?	
26.	What year did you get your first phone in?	
27.	Have you ever noticed any deformation of your dominant hand’s little (pinky) finger as compared to the other one?	□ Yes □ No

ANY CURRENT ILLNESSES:

FAMILY MEDICAL HISTORY:

MEDICAL HISTORY: (HOSPITALIZATION, SURGERIES, TRANSFUSIONS)

COMORBIDITIES: (HYPERTENSION, DIABETES, ALLERGIES, ETC)

MEDICATIONS: (NAME & DOSE)

APPENDIX F: SMARTPHONE ADDICTION SCALE (SAS)

SMARTPHONE ADDICTION SCALE

Instructions: Indicate the degree to which you agree with the following using this scale: 1 = strongly disagree, 2 = disagree, 3 = weakly disagree, 4 = weakly agree, 5 = agree, 6 = strongly agree.

1. Missing planned work due to smartphone use
2. Having a hard time concentrating in class, while doing assignments, or while working due to smartphone use
3. Experiencing lightheadedness or blurred vision due to excessive smartphone use
4. Feeling pain in the wrists or at the back of the neck while using a smartphone
5. Feeling tired and lacking adequate sleep due to excessive smartphone use
6. Feeling calm or cozy while using a smartphone
7. Feeling pleasant or excited while using a smartphone
8. Feeling confident while using a smartphone
9. Being able to get rid of stress with a smartphone
10. There is nothing more fun to do than using my smartphone.
11. My life would be empty without my smartphone.
12. Feeling most liberal while using a smartphone
13. Using a smartphone is the most fun thing to do.
14. Won't be able to stand not having a smartphone
15. Feeling impatient and fretful when I am not holding my smartphone
16. Having my smartphone in my mind even when I'm not using it
17. I will never give up using my smartphone even when my daily life is already greatly affected by it.
18. Getting irritated when bothered while using my smartphone
19. Bringing my smartphone to the toilet even when I am in a hurry to get there
20. Feeling great meeting more people via smartphone use

21. Feeling that my relationships with my smartphone buddies are more intimate than my relationships with my real-life friends
22. Not being able to use my smartphone would be as painful as losing a friend.
23. Feeling that my smartphone buddies understand me better than my real-life friends
24. Constantly checking my smartphone so as not to miss conversations between other people on Twitter or Facebook
25. Checking SNS (Social Networking Service) sites like Twitter or Facebook right after waking up
26. Preferring to talk with my smartphone buddies to hanging out with my real-life friends or with the other members of my family
27. Preferring searching from my smartphone to asking other people
28. My fully charged battery does not last for one whole day.
29. Using my smartphone longer than I had intended
30. Feeling the urge to use my smartphone again right after I stopped using it
31. Having tried time and again to shorten my smartphone use time but failing all the time
32. Always thinking that I should shorten my smartphone use time
33. The people around me tell me that I use my smartphone too much.

APPENDIX G: DUROZ HAND INDEX (DHI)

Duruöz Hand Index (DHI)

Answers to the questions:	Score
C1 - In the kitchen	
1 Can you hold a bowl?	
2 Can you seize a full bottle and raise it?	
3 Can you hold a plate full of food?	
4 Can you pour liquid from a bottle into a glass? **5** Can you unscrew the lid from a jar opened before?	
6 Can you cut meat with a knife?	
7 Can you prick things well with a fork?	
8 Can you peel fruit?	
C2 - Dressing	
9 Can you button your shirt?	
10 Can you open and close a zipper?	
C3 - Hygiene	
11 Can you squeeze a new tube of toothpaste?	
12 Can you hold a toothbrush efficiently?	
C4 - In The Office	
13 Can you write a short sentence with a pencil or ordinary pen?	
14 Can you write a letter with a pencil or ordinary pen?	
C5 - Other	
15 Can you turn around door knob?	
16 Can you cut a piece of paper with scissors?	
17 Can you pick up coins from a table top?	
18 Can you turn a key in a lock	
Total	

0 : Yes, without difficulty
1 : Yes, with a little difficulty
2 : Yes, with some difficulty
3 : Yes, with much difficulty
4 : Nearly impossible to do
5 : Impossible

APPENDIX H: EVALUATION FORM

PHYSICAL EVALUATION (GRIP STRENGTH IN KG)

	1^{ST} ATTEMPT	2^{ND} ATTEMPT	3^{RD} ATTEMPT	AVERAGE
DOMINANT HAND				
NON-DOMINANT HAND				

RADIOLOGICAL (ULTRASOUND) EVALUATION

	MEDIAN NERVE CSA (mm^2)
DOMINANT HAND	
NON-DOMINANT HAND	

RADIOLOGICAL (X-RAY) EVALUATION

	THICKNESS OF MIDDLE PHALANGE OF 5^{TH} DIGIT (mm)
DOMINANT HAND	
NON-DOMINANT HAND	

APPENDIX I: TURNITIN PLAGIARISM CHECK REPORT

The Morphology of a Smartphonopathic Hand (Thesis)

ORIGINALITY REPORT

14%	6%	13%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES