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Original Research Article

Morphometric Study of Flexors of Forearm- Cadaveric Study

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ABSTRACT

Introduction: A thorough understanding of the muscles of the forearm serves as the foundation for effective surgical intervention, such as repair of tendon, tendon transfer, and tendon graft.

Aim: To study the morphology and morphometry of the flexors of the forearm.

Materials and Methods: The cadaveric forearms were dissected, and each muscle tendon was identified till the proximal margin of the flexor retinaculum. Any variations and presence of accessory muscles were looked for. Detailed analysis was done, and photographs were taken. The morphometric measurements, such as the total length of the forearm from the medial epicondyle to the proximal margin of the flexor retinaculum (A), and the length of the tendon from the proximal end of the flexor retinaculum (B), were measured. The length of the individual muscle was calculated by the difference between the total length of forearm and the length of the tendon (A-B)

Result: The study was done on 51 specimens of cadavers of the forearm. The mean length of the forearm (A) was 27.33cm, the mean length of the flexor carpi radialis tendon and muscle was 15.79 cm and 11.54 cms, the mean length of the flexor digitorum superficialis tendon and muscle was 10.75 cms and 16.58cms, the mean length of the palmaris longus tendon and muscle was 14.86 cm and 9.45 cm, mean length of the flexor carpi ulnaris tendon and muscle was 8.70 cm and 18.63 cm, the mean length of the flexor profundus tendon and muscle was 14.44 cm and 12.90, and the mean length of the flexor pollicis longus tendon and muscle was 14.05 cm and 13.28 respectively.

Conclusion: The morphometry of muscles of forearm has an important role in tendon graft and reconstructive surgeries. It also helps to outline the muscle belly for botulinum toxin as a therapy in paralysed patients.

KEY WORDS: Flexors of Forearm, Tendon Transfer, Carpal Tunnel Syndrome, Gantzer Muscle.

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INTRODUCTION

The flexor compartment of the forearm is anatomically divided into superficial and deep groups of muscles, each exhibiting significant variations in muscle belly and tendon lengths. These morphometric variations are of immense importance in surgical practices, particularly in tendon transfer procedures [1].

The tendons of key muscles such as the flexor digitorum superficialis, flexor digitorum profundus, and flexor pollicis longus pass through the carpal tunnel to insert into the hand. Compression of the median nerve due anatomical anomalies, including aberrant tendons and hypertrophic muscle bellies, has been implicated in a major contributing factor to carpal tunnel syndrome [2].

Tendon transfer is a transformative surgical technique used to restore lost function following traumatic muscle-tendon unit (MTU) injuries or neurological deficits affecting the upper extremity. This procedure capitalizes on the expendability of certain functional muscles, redirecting them to compensate for the loss of critical motor functions [3].

The process of mobilizing, separating, or dividing a working muscle's tendon of insertion or origin, then reintroducing it into a bone or another tendon to augment or replace the recipient tendon's activity is known as a tendon transfer [4]. Successful tendon transfer depends heavily on selecting a donor muscle with a tendon-to-muscle fiber length ratio comparable to that of the muscle being replaced, ensuring adequate force production and functional motion [5]. When choosing which muscles to use during a tendon transfer treatment, tendon length is a crucial factor [5].

The knowledge of tendon and muscle belly dimensions is of immense importance for optimal donor selection and surgical planning and also help in improving surgical outcomes. Furthermore, anatomical variations in muscle and tendon structures are clinically significant not only for surgical reconstruction but also for understanding the etiology and management of conditions such as carpal tunnel syndrome [6].

Thus, the present study aims to perform a detailed morphometric assessment of the flexormuscles and tendons of the forearm, which will provide a comprehensive data that will support improved surgical planning in tendon transfer procedures and offer understanding into the anatomical factors contributing to carpal tunnel syndrome.

MATERIALS AND METHODS

51 embalmed upper limbs from cadavers were studied in the Department of Anatomy, M.S Ramaiah Medical College.

The cadaveric forearms were dissected and each muscle tendon was identified till the proximal margin of flexor retinaculum. Any variations and presence of accessory muscles were looked for. Detailed analysis was done and photographs were taken. The morphometric measurements such as the total length of forearm from medial epicondyle to the proximal margin of flexor retinaculum (A), length of the tendon from the proximal end of flexor retinaculum were measured (B). The length of the individual muscle was calculated by the difference between the total length of forearm and length of tendon (A-B)

Ratio of muscle to total length was calculated. Detailed analysis was done and photographs were taken. All the morphometric parameters were summarized using descriptive statistic such as mean, SD, range etc.

RESULTS

In the 51 upper limbs studied, the total length of forearm was 27.33±1.82. The mean muscle belly length, mean tendon length (table 1), ratio of muscle belly length to tendon length total length (muscle belly + tendon length) was summarized in table 1 and 2.

Variations: The accessory head of flexor policis longus muscle (AHFPL) was found in 2 of 51 upper extremities (1%). The AHFPL was innervated by the AIN in both the cases. The nervearose from the medial aspect of the median nerve (Fig 1and Fig 2).

Table 1: Mean length of tendon and muscles of forearm with standard deviation.

Name of the Muscle	N	Tendon length in cms Mean±SD	Muscle length in cms Mean±standard deviation
Flexor carpi radialis	51	15.79±1.89	11.54±1.65
Flexor digitorum superficialis	51	10.75±2.25	16.58±2.21
Palmaris longus	50	16.84±1.88	10.71±1.91
Flexor carpi ulnaris	51	8.70±1.92	18.63±2.69
Flexor digitorum profunus	51	14.44±1.75	12.90±1.87

Table 2: Mean length of muscles of forearm and ratio of muscle to total length with standard deviation.

Muscle Name	Number of Specimen	Muscle length in cms	Ratio of muscle to total length of Forearm C/A+B
		Mean +Std. Deviation	Mean+Std.Deviation
Flexor carpi radialis	51	11.54 +1.65	0.42 +0.91
Flexor digitorum superficialis	51	16.58 +2.21	0.61 +1.21
Palmaris longus	50	10.71 +1.91	0.39 +1.05
Flexor carpi ulnaris	51	18.63 +2.69	0.68 +1.48
Flexor digitorum profunus	51	12.90 +1.87	0.47 +1.03
Flexor policis longus	51	13.28 +2.01	0.49 +1.10

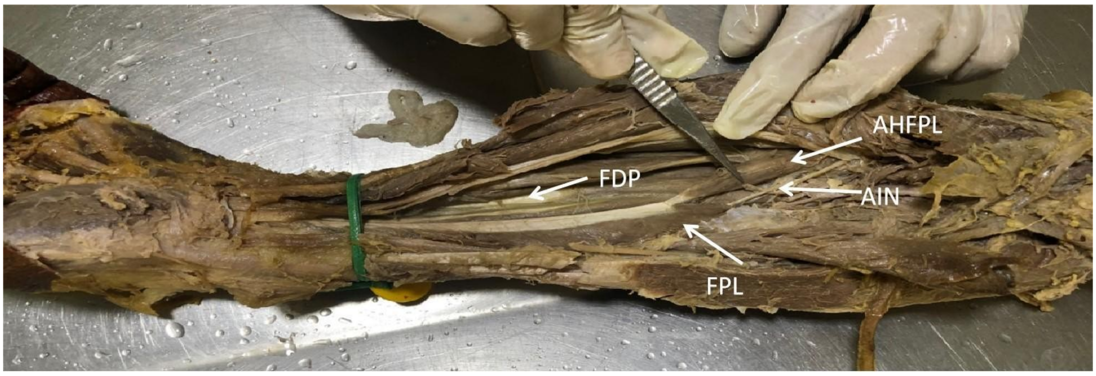

Fig. 1: Right upper limb showing Gantzer's muscle . AHFPL-accessory head of flexor policis longus,FPL-flexor policis longus, FD- Flexor Digitorum, AIN- anterior interosseous nerve

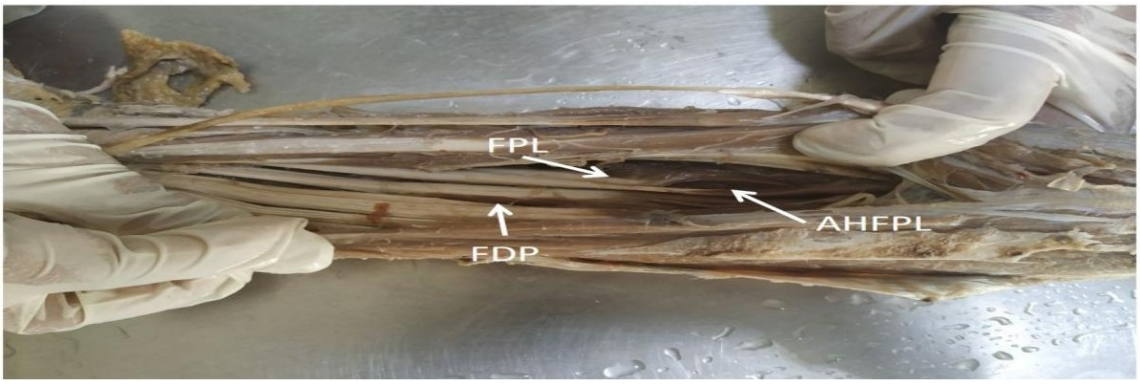

Fig. 2: Left upper limb showing Gantzer's muscle . AHFPL-accessory head of flexor policis longus, FPL-flexor policis longus, FD- Flexor Digitorum.

Fig. 3: Right upper limb showing duplication of Palmaris longus.

In one specimen there was absence of palmaris longus and in one there was duplication of Pamaris longus. Accessory palmaris tendon was present on ulnar side of Palmaris longus tendon (Fig 3).

DISCUSSION

Tendon transfers are frequently employed to restore function following injuries to major nerve trunks, the brachial plexus, or the brain.

They are also indicated in cases where tendon rupture results in a significant defect [5]. The procedure involves Tendon transfers are frequently employed to restore function following injuries to major nerve trunks, the brachial plexus, or the brain. They are also indicated in cases where tendon rupture results in a significant defect [5].

The procedure involves detaching or rerouting the tendon of a donor muscle to replace or augment the function of a damaged, misaligned, or deficient tendon in a recipient muscle. Common examples of tendon transfers include the transfer of the pronator teres (PT) to the extensor carpi radialis brevis (ECRB) to reestablish wrist extension. For thumb extension, either the Palmaris longus (PL) or the flexor digitorum superficialis (FDS) from the ring finger is transferred to the extensor pollicis longus (EPL). Restoration of finger extension is typically achieved by transferring the flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), or FDS to the extensor digitorum (ED), with the FDS being favored for its superior tendon excursion, albeit at the expense of some digital flexion synergy [3].

The functional performance of muscles is influenced by the organization of their contractile and connective tissue elements, as well as the dimensions and morphology of the muscle-tendon unit. Post-mortem tissue shrinkage, especially following embalming, leads to discrepancies between cadaveric measurements and those obtained through imaging modalities such as MRI or ultrasound. Nevertheless, cadaveric studies offer valuable insights into the relative lengths of tendons [6]. Longer initial muscle-tendon lengths contribute to greater peak joint motion and power generation during force production [7]. Tendons play a crucial role in transmitting muscular forces to the skeleton. In an evaluation of muscle and tendon properties, Zajac proposed the concept of the resting tendon-to-fiber length ratio as a key parameter for assessing the static and dynamic force production capabilities of the muscle-tendon unit. He noted that human tendons exhibit limited compliance and tend to rupture when stretched beyond 10% of their resting length. Variations in external tendon length among muscles imply that tendon extension influences the total muscle-tendon length to differing extents. Muscles with a high tendon length-to-fiber length ratio exhibit the greatest functional impact from tendon compliance [4]. Therefore, tendon length is a critical consideration when planning tendon reconstruction procedures.

In the present study the length of muscle and tendon were measured in the forearm and the ratio of length to tendon to the whole length of forearm, ratio of muscle to the whole of the length of forearm and ratio between muscle and tendon were calculated. These measurements will be useful in tendon transfer and tendon lengthening procedures.

In post-stroke patients, chemo denervation of muscles using botulinum toxin (Btx) has been shown to produce a dose-dependent reduction in both muscle spasticity and strength [8]. Previous studies have consistently demonstrated that Btx effectively reduces spasticity after stroke; however, improvements in upper-limb motor function among chronic stroke survivors with moderate to severe impairments were either not reported or lacked statistical significance [8-10]. One potential mechanical cause for suboptimal outcomes is inaccurate localization of target muscles, a limitation that can be addressed through a detailed understanding of the anatomical positioning of muscles and their tendons [11].

Anatomical dissections and surgical procedures frequently reveal accessory muscles within the forearm flexor compartment. Awareness of such anatomical variations is crucial, particularly in plastic and reconstructive surgeries involving tendons. The Gantzer muscle represents an accessory slip of either the flexor pollicis longus (FPL) or the flexor digitorum profundus (FDP) muscles and is located in the forearm. It typically descends alongside the flexor digitorum superficialis (FDS) in the mid-forearm and may originate from the medial epicondyle of the humerus, the coronoid process of the ulna, the fascial sheath of the FDS, or the pronator teres muscle. It inserts into the deep flexors, including the FDP and FPL [12].

Originally described by Albinus in the 18th century and later by Gantzer in 1813[13], the Gantzer muscle exhibits two primary variations: an accessory head of the FPL (ahFPL) and an accessory head of the FDP (ahFDP) [14]. It courses obliquely from the medial to the lateral aspect of the forearm beneath the FDS before merging with the FPL. In some instances, a second tendon originating from the Gantzer muscle contributes to the FDP [15]. Embryologically, this variation can be explained by the incomplete separation of the deep layer of the common flexor muscle mass, which during development differentiates into superficial and deep strata—the latter giving rise to the pronator quadratus, FDP, and FPL. Evolutionarily, the separation of the FPL from the FDP is a unique adaptation in modern humans, facilitating multidimensional thumb movement [15,16].

The prevalence of the Gantzer muscle has been compared across studies (Table 3). The anatomical relationship between the Gantzer muscle, the median nerve, and the anterior interosseous nerve remains a subject of debate. Some reports describe the muscle passing posterior to the median nerve and anterior to the anterior interosseous nerve, while others consistently place it posterior to the median nerve and anterior to the interosseous nerve [17-20]. Additional observations have reported the Gantzer muscle running parallel to the ulnar side of the anterior interosseous nerve [21].

Table 3: Comparison of percentage of Gantzer's muscle with previous studies.

Authors	Gantzer's Muscle	Percentage
Hemmady et al. 1993 [18]	54	66.6%
Oh et al. 2000 [24]	48/72	66.7%
Mahakkanukrauh et al 2004 [25]	149/240	62.10%
Dellon et al 1987 [26]	36/80	45%
Gunnal S.A 2013 [27]	92 /180	51.11%
Sharma et al 2008 [28]	24/60	40
Present study	**2/51**	**4%**

Compression of the anterior interosseous nerve by the accessory head of the FPL may result in paresis or paralysis of the FPL and FDP components supplying the index finger. Clinically, this manifests as difficulty flexing the interphalangeal joint of the thumb and the distal interphalangeal joint of the index finger, impairing the ability to form a precise "O" shape—a sign known as "Spinner's sign." This compression may also cause a weak pinch, described as a "square pinch deformity," due to reduced strength in the thumb and index finger muscles.

Recognition of the Gantzer muscle is important during surgical interventions such as decompression fasciotomy for compartment syndrome or anterior approaches to the proximal radius and elbow. Furthermore, fibrous thickening of the accessory head may occur following elbow fractures or dislocations. Thus, the presence of accessory muscle heads should be carefully considered when evaluating and managing thumb flexion deformities.

When undergoing decompression fasciotomy for compartment syndrome of the forearm or anterior approach surgery of the proximal radius and elbow, it is important to consider the presence of accessory heads of muscles [18]. In certain situations of elbow fracture and dislocation, fibrous stricture of the AHFPL may develop. Therefore, it is important to consider the involvement of accessory heads of muscles while treating a thumb flexion deformity [23].

Palmaris longus: The palmaris longus muscle shows several types of anatomical variations, including: (i) complete absence, (ii) differences in its location or shape, (iii) atypical attachment points, (iv) alterations in the muscle belly such as duplication or triplication, and (v) the presence of additional slips [29]. Despite these variations typically having little functional impact, understanding them is crucial for reconstructive surgery.

In this particular study, one specimen showed unilateral absence of the palmaris longus, while another exhibited a duplicated muscle. Though the absence of this muscle can indicate an abnormal superficial palmar arch [30], no such anomaly was found in the current cases. Interestingly, the presence of the palmaris longus has been linked to a higher risk of Dupuytren's contracture, whereas its absence may lower this risk [31]. Clinical tests can suggest the absence of this muscle, but magnetic resonance imaging (MRI) remains the most accurate method for confirmation, especially when tendon grafting is considered [32].

Agenesis, or congenital absence, of the palmaris longus tendon is the most frequently observed variation worldwide, particularly among Caucasians. It is thought to be influenced by sex-linked dominant traits [33], and it tends to occur more often on one side rather than both, with a higher prevalence in females [34,35]. Importantly, the absence of this muscle does not affect grip strength or wrist flexion.

Duplication of the palmaris longus is sometimes associated with conditions like carpal tunnel syndrome or ulnar neuropathy [36,37]. Recognizing these anatomical differences is vital during surgical procedures to avoid unintended injury to the forearm muscles.

Embryological basis of variation: The flexor mass gives rise to the forearm's flexor muscles, which are further subdivided into superficial and deep layers. The palmaris longus, along with muscles like the pronator teres and flexor carpi radialis, develops from the superficial layer. Variations such as duplication may result from excessive splitting of this layer during development, while failure to divide may explain its absence [29].

Due to its superficial location and presence in around 70–85% of individuals, the palmaris longus is commonly used as a tendon graft in surgeries. Assessing the muscle's size helps in efficient harvesting and reduces complications at the donor site [38]. It plays a valuable role in various surgical repairs, including tendon injuries, ligament reconstruction, procedures involving the thumb and elbow, eye-related surgeries, and or eyelids (e.g., for ptosis)

CONCLUSION

It is essential to consider anatomical variations in the flexor muscles during surgical interventions to prevent any inadvertent complications during the procedure. The morphometric assessment of muscles and tendon length serves as a critical parameter in evaluating the suitability of tendons for transfer procedures, for giving botulin toxin in paralyzed patients.

Author Contributions

Dr Radhika PM: Concept, Design, Literature Search, Data Analysis, Statistical Analysis, Manuscript Preparation, Manuscript Editing, Manuscript Review

Dr Ashwini CA: Concept, Design, Literature Search, Data Analysis, Statistical Analysis, Manuscript Preparation, Manuscript Editing, Manuscript Review

Conflicts of Interests: None

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