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ORIGINAL ARTICLE

The muscular branching patterns of the ulnar nerve in fetal forearms

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Abstract

Objective We aimed to present our findings systematically by examining the muscular branching patterns of the ulnar nerve (UN) in the forearms of fetuses.

Methods This study was conducted on the 52 forearms of 26 formalin-fixed fetal cadavers with gestational ages varying between 19 and 37 weeks. The anatomical dissection was performed by using stereomicroscope with × 8 magnification. The numbers of muscular branches leaving UN and their order of leaving main nerve were noted down. The findings were classified according to the muscles they reached, and branching typing was done.

Results It was found that a total of 2–6 muscular branches left UN to reach flexor carpi ulnaris (FCU) and flexor digitorum profundus (FDP). UN was classified by separating into five main types according to the number of muscular branches, and these types were classified into 16 different branching patterns according to the order of branches leaving from the main trunk and going to FCU and FDP. The pattern where two branches left UN was classified as Type I ($n = 6$), three branches left was classified as Type II ($n = 18$), four branches left was classified as Type III ($n = 24$), five branches left was classified as Type IV ($n = 3$), and six branches left was classified as Type V ($n = 1$). Martin-Gruber connection occurred in 17 (32.7%) fetal forearms.

Conclusion We believe that the information that UN can demonstrate different branching patterns on the forearm can help the surgeons to prevent complications that may develop in potential nerve injury during the selection and transfer of relevant branch.

Keywords Fetal cadaver · Ulnar nerve · Muscular branches · Flexor carpi ulnaris · Flexor digitorum profundus

Introduction

It is thought that knowing the number of muscular branches of ulnar nerve (UN) in the forearm, their order of leaving main nerve and the variations of their localizations in detail would increase the success of nerve transfers in potential nerve injuries, electrophysiological procedures and botulinum toxin injection done in spasticity treatment [2, 3, 8, 18, 19]. Also, the branching characteristics of UN in the forearm are of vital importance for cubital tunnel syndrome neuropathy and malformations caused by distal end fractures of humerus as well as the decompression and anterior transposition of this nerve [12].

Ulnar nerve, which originates from medial cord (C8-T1) and is one of the terminal branches of brachial plexus, proceeds to distal between the artery medial to axillary artery and the comitans veins in the axilla. It proceeds first in the anterior compartment of the arm towards forearm medial to brachial artery [15]. It demonstrates a posteromedial course here, and moves to posterior compartment by passing through medial intermuscular septum which is 8–10 cm proximal to medial epicondyle [5, 14, 15]. It reaches forearm by passing through cubital tunnel at the elbow. Ulnar nerve usually gives off two motor branches to flexor carpi ulnaris (FCU), the first one often leaves the main trunk after the cubital tunnel and the second one on about upper 1/4 part of the forearm. A few

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Table 1 The distribution of branching patterns of ulnar nerve according to gender, age and side of fetuses

No.	Gender	Gestational age (week)	Side	Type
1	Male	31–33	Right	Type IIb
			Left	Type IIIc
2	Male	27–29	Right	Type IIIc
			Left	Type IIIc
3	Male	29–31	Right	Type IIIa
			Left	Type IIb
4	Female	35–37	Right	Type IIId
			Left	Type Ia
5	Female	21–23	Right	Type IIIa
			Left	Type IIa
6	Female	21–23	Right	Type IIb
			Left	Type IIa
7	Female	25–27	Right	Type Ic
			Left	Type IIa
8	Female	21–23	Right	Type IIa
			Left	Type IVc
9	Male	21–23	Right	Type IIId
			Left	Type IIa
10	Female	23–25	Right	Type IIIa
			Left	Type IIIa
11	Male	25–27	Right	Type IIIb
			Left	Type IIIc
12	Female	19–21	Right	Type IIIf
			Left	Type IIIa
13	Female	27–29	Right	Type IIIc
			Left	Type IIIc
14	Female	29–31	Right	Type IIIc
			Left	Type V
15	Female	25–27	Right	Type IIIc
			Left	Type IIc
16	Female	23–25	Right	Type IIa
			Left	Type IVb
17	Female	19–21	Right	Type Ia
			Left	Type IIc
18	Male	29–31	Right	Type IVa
			Left	Type IIIc
19	Male	21–23	Right	Type IIIc
			Left	Type IIa
20	Male	21–23	Right	Type IIIa
			Left	Type Ib
21	Female	29–31	Right	Type Ia
			Left	Type IIb
22	Female	19–21	Right	Type IIa
			Left	Type IIIa
23	Female	19–21	Right	Type IIb
			Left	Type IIIc
24	Male	23–25	Right	Type IIa
			Left	Type Ia
25	Male	27–29	Right	Type IIa
			Left	Type IIIa
26	Male	21–23	Right	Type IIIe
			Left	Type IIa

branches which leave UN usually at a more distal location reach flexor digitorum profundus (FDP) [15].

There are some studies in the literature which categorize motor branches given to FCU and FDP by UN according to their branching patterns in adult and fetal cadavers [1, 4, 12, 13, 16]. However, there are difference between the results reported by these studies. Therefore, we aimed to present our findings systematically by examining the muscular branching patterns of UN in the forearms of fetal cadavers.

Materials and methods

This study was conducted on the 52 forearms of a total of 26 fetuses, of which 15 were female (57.7%) and 11 were male (42.3%), with gestational ages varying between 19 and 37 weeks that were fixed in 10% formaldehyde and had no visible upper extremity pathology in the Dissection Laboratory of Anatomy Department, Faculty of Medicine, Gaziantep University.

After foot length was measured in all fetuses, the average value of both measurements was used to determine the gestational ages of these fetuses [9–11].

For the anterior dissection of arm and forearm, three transverse incisions were made first between the midline of acromion and anterior axillary fold and then at the level of interepicondylar line and and distal wrist crease. The midpoint of these transverse lines were combined with a longitudinal incision. After the incisions, the skin and subcutaneous fat tissues were removed and FDP and FCU were identified. To track the course of UN in the forearm, the humeral head of FCU was cut with surgical scissors from the point where it is attached to medial epicondyle and reflected medially. Arm and forearm areas of the fetuses included in the study were dissected by using stereomicroscope with × 8 magnification (Leica S4E; Leica Microsystems GmbH, Wetzlar, Germany). On each forearm, the branches leaving UN and reaching the muscles by angulating distally were identified. Of these muscular branches, numbers and their orders of leaving the main body were noted down, and the branching patterns were categorized by classifying the obtained findings according to the muscles they reached. The distribution of these types are given in Table 1 according to gender, age and side. Moreover, Pearson's chi-square test was used to

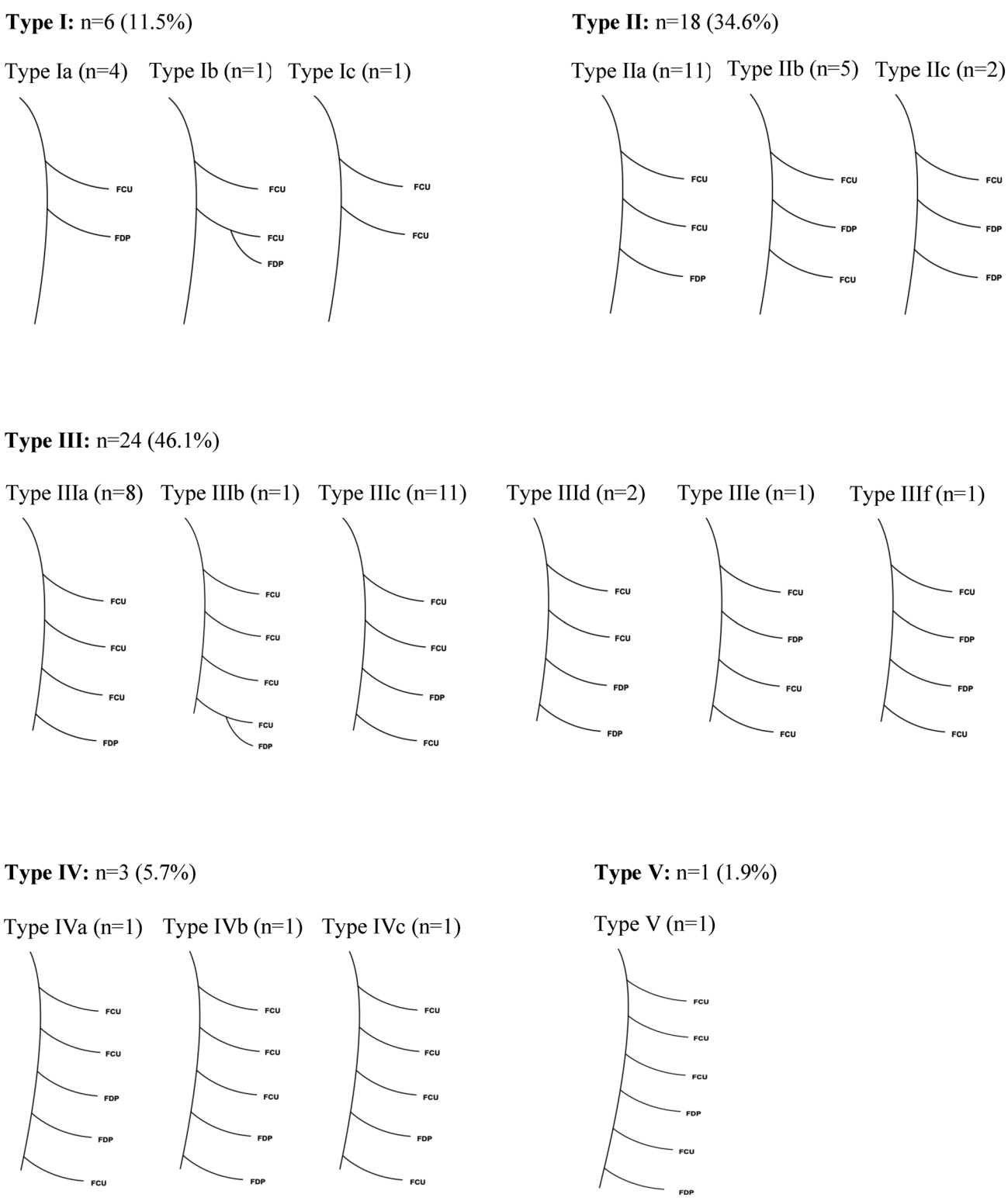

Fig. 1 Muscular branches that leave from UN; number, the row of exit from the main trunk and typing according to the muscles they reached. FCU: Flexor carpi ulnaris, FDP: Flexor digitorum profundus

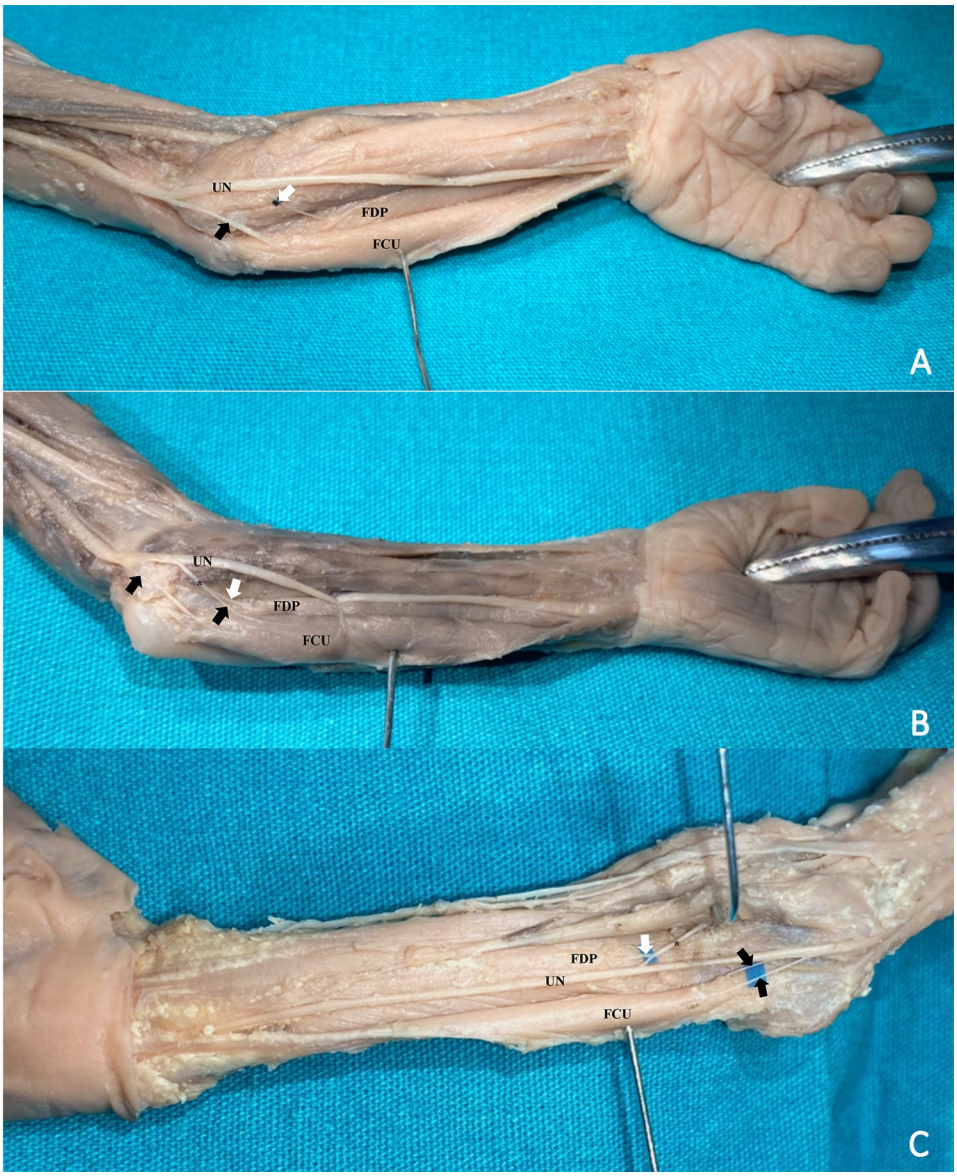

Fig. 2 Type I pattern and view of its subtypes. **A** Type Ia (case 24; left forearm). **B** Type Ib (case 20; left forearm). **C** Type Ic (case 7; right forearm). White arrow: Muscular branch to FDP, Blue arrowhead: MGA, Black arrow: Muscular branch to FCU, *: Muscular branch leaving UN as a common trunk to go FCU and FDP

analysis the correlation between muscular branches leaving UN, types defining branching patterns and gender. The value $p < 0.05$ was considered statistically significant.

Results

We found that a total of 2–6 muscular branches left UN in order to innerve FCU and FDP. UN gave 2–5 branches on the right side for these muscles while a total of 2–6 branches on the left side. In the right forearms we examined, FCU was innerved by 1–4 muscular branches and FDP was innerved by 0–2 muscular branches. On the left forearms, there were 1–4 branches leaving NU to FCU and 1–2 branches to FDP.

Ulnar nerve was classified by separating into 5 main types according to the number of muscular branches, and these types were separated into 16 different branching patterns according to the order of branches leaving main trunk to FCU and FDP (Fig. 1).

The pattern where two muscular branches left UN to innervate FCU and FDP was classified as Type I ($n = 6$) (Fig. 2), three muscular branches left was classified as Type II ($n = 18$) (Fig. 3), four muscular branches left was classified as Type III ($n = 24$) (Fig. 4), five muscular branches left was classified as Type IV ($n = 3$) (Fig. 5), and six muscular branches left was classified as Type V ($n = 1$) (Fig. 6). We found that UN demonstrated bilateral and symmetrical branching in three (2 F, 1 M) fetuses. There was no statistically significant difference between gender and 5 main types that we identified ($p = 0.791$) (Table 2).

In addition, the presence of connecting branches between UN and MN in fetal forearms was examined, and

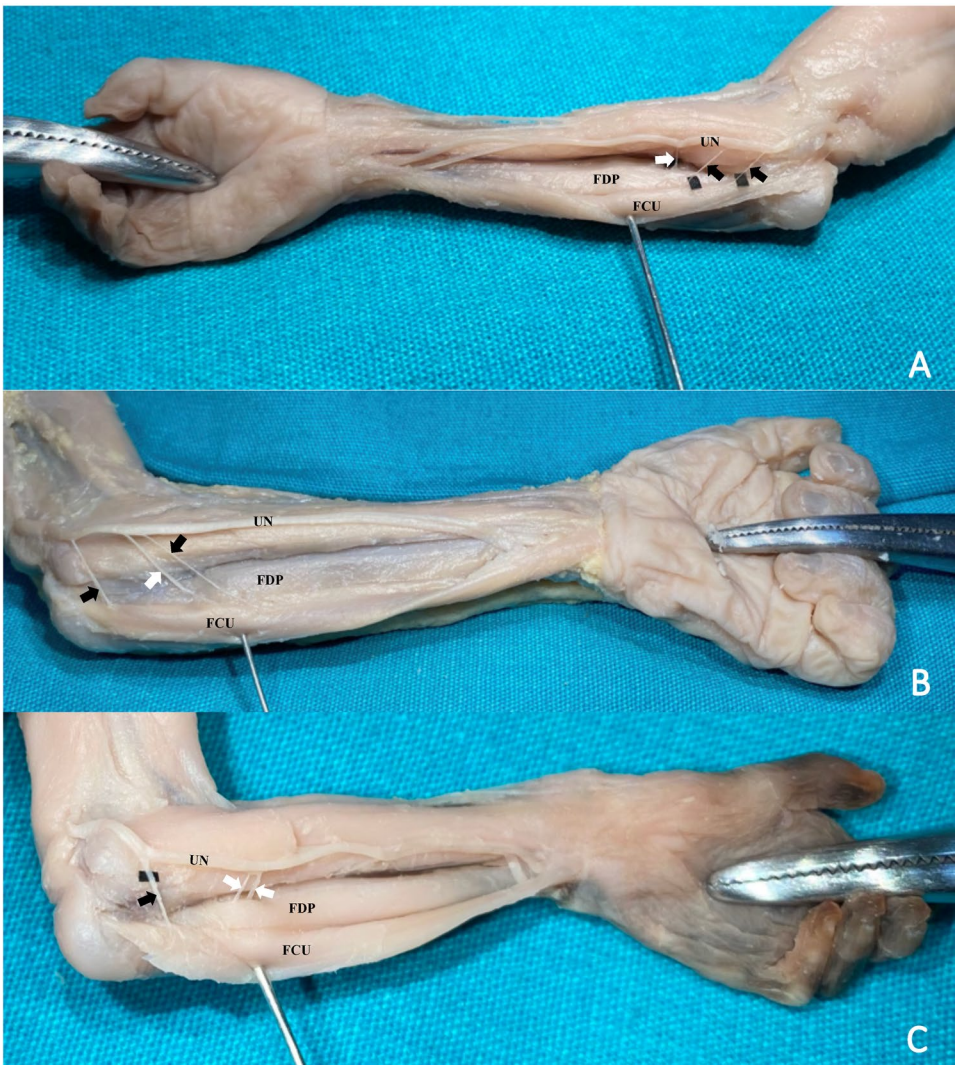

Fig. 3 Type II pattern and view of its subtypes. **A** Type IIa (case 22; right forearm). **B** Type IIb (case 3; left forearm). **C** Type IIc (case 17; left forearm). White arrow: Muscular branch to FDP, Black arrow: Muscular branch to FCU

Martin-Gruber (MG) connection was found in 17 (32.7%) forearms (Fig. 7). In 5 specimens, the communicating branch arose from the median nerve. In 12 forearms, it arose from the anterior interosseous nerve to communicate with the ulnar nerve. In 6 fetuses, MG connection was found bilaterally.

Discussion

Identifying the correlation between the anatomy of UN during fetal period, which is one of the most important neural structures that provide the motor innervation of some forearm and hand muscles, and its course and branching characteristics in adults may contribute to understand its anatomic characteristics in the forearm better. We found 2 fetal and 3 adult cadaver studies which define and classify branching characteristics in the literature [1, 4, 12, 13, 16]. These studies reported that about 2–6 muscular branches leave UN to innerve FCU and FDP. In a recent systematic review, Hwang et al. reported that FDP is innerved by one branch in 95.4% of adult cadaver extremities while 4.6% of them is innerved by two branches [6]. The literature data related with total branch number is consistent with our fetal results.

When we reviewed the results of the studies investigating and classifying the muscular branching patterns of UN in the fetal and adult forearms, we found in the study of Sunderland and Hughes in which they dissected 20 upper extremities of 10 adult cadavers that the muscular branches leaving UN demonstrated different branching characteristics in the forearms. In their study, they presented various branching patterns in 6 forearms without systematizing [16].

Marur et al. conducted a study on 37 upper extremities of 19 adult cadavers, and they classified muscular branches leaving UN in four main groups according to the number of branches leaving this nerve to innerve FCU and FDP. In addition, they categorized these main groups into subgroups according to the distribution of muscular branches to

Fig. 4 Type III pattern and view of its subtypes. **A** Type IIIa (case 3; right forearm). **B** Type IIIb (case 11; right forearm). **C** Type IIIc (case 1; left forearm), **D** Type IIId (case 9; right forearm). **E** Type IIIe (case 26; right forearm). **F** Type IIIf (case 12; right forearm). White arrow: Muscular branch to FDP, Black arrow: Muscular branch to FCU, *: Muscular branch leaving UN as a common trunk to go FCU and FDP

forearm muscles innerved by UN. The authors reported that Group I in which two branches left UN was the most common branching pattern while Group III with four branches leaving NU and Group IV with five branches leaving UN were the least common branching patterns [12].

Unver Dogan et al. dissected 200 forearms of 100 aborted fetuses, and categorized this nerve in two main groups as Type I and Type II according to the number of muscular branches leaving UN. They grouped Type II in 2 sub-groups according to the distribution of muscular branches to the muscles and reported that Type I was the most common pattern while Type II was the least common pattern [4].

In a dissection study examining 116 fetal upper extremities, Albay et al. classified muscular branches leaving UN to innervate FCU and FDP into 8 main groups according to the numbers of these branches and their order of leaving main trunk. They separated main groups into sub-groups according to the distribution of muscular branches medial or lateral to the nerve. They reported that Type III was the most common pattern while Type VI was the least common pattern [1].

In their study in which they dissected 20 upper extremities of 13 fresh adult cadavers, Paulos and Leclercq examined muscular branches leaving UN to innerve FCU and FDP according to the number of branches leaving main trunk in 4 main groups same as the classification of Marur et al. The authors also categorized the branches in 11 subtypes according to their order of leaving UN to innerve FCU and FDP. Compared to the classification of Marur et al., Paulos and Leclercq found that Group II was the most common pattern while Group I was the least common pattern [13].

In the forearms that we dissected, Type III ($n=24$) was the most common pattern while Type ($n=1$) was the least common pattern. While Unver Dogan et al. reported that Type I in which two muscular branches left UN was the most common pattern and Type II in which three muscular branches left UN was the least common pattern, Albay et al. reported that Type III was the most common pattern in which 1st and 3rd branches leaving the main trunk to innerve FCU and 2nd branch leaving to innerve FDP, and Type VI was the least common pattern in which two branches leaving UN and proceeding to FDP and two branches leaving UN and proceeding to FCU [1, 4]. Unlike these studies, we found that Type III in which four muscular branches left UN was the most common pattern and Type V was the least common pattern in which six muscular branches left the main body. We think that the inconsistency of the incidence of these types with each other could be the caused by the fact that the numbers of fetuses examined are different.

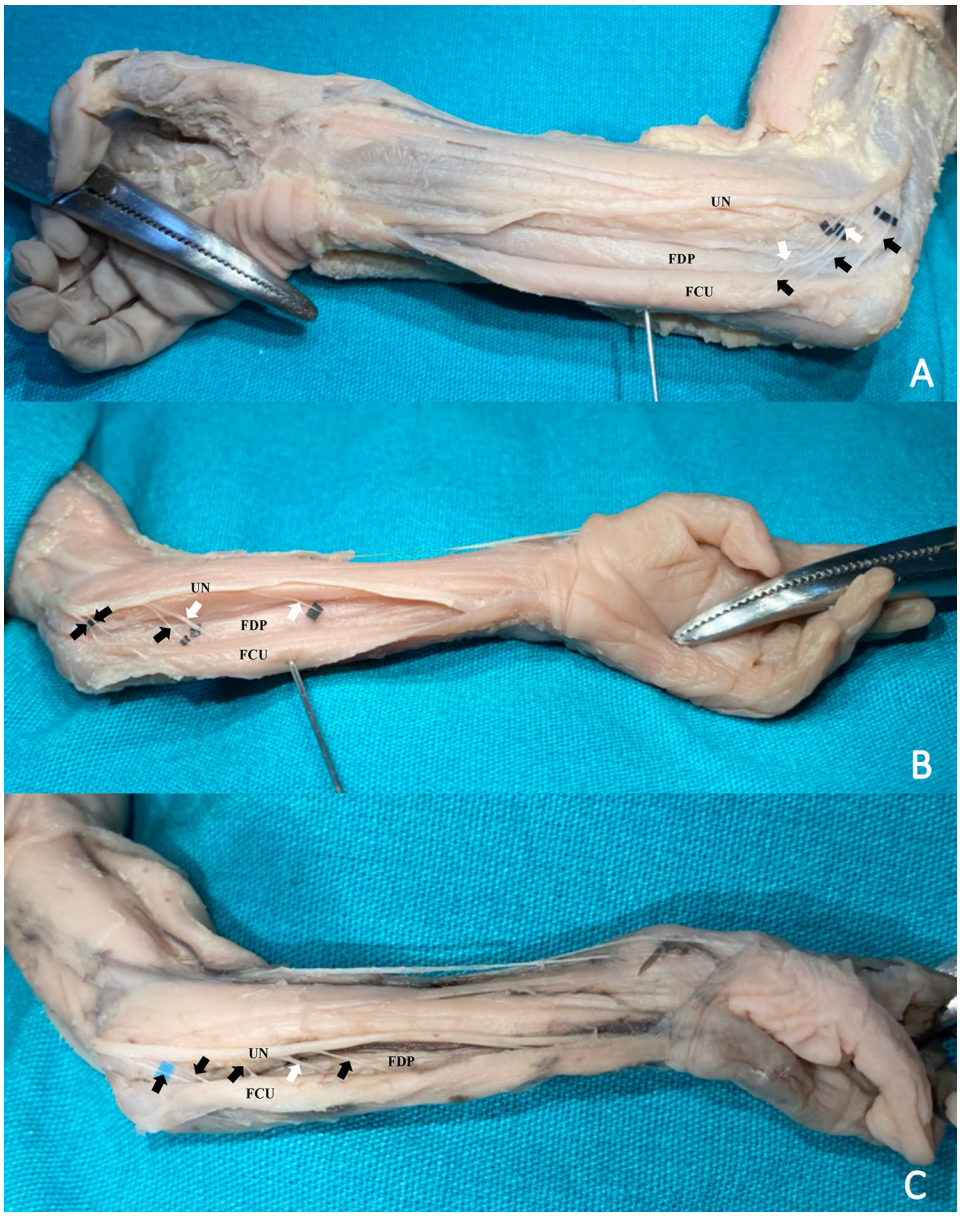

Fig. 5 Type IV pattern and view of its subtypes. **A** Type IVa (case 18; right forearm). **B** Type IVb (case 16; left forearm). **C** Type IVc (case 8; left forearm). White arrow: Muscular branch to FDP, Black arrow: Muscular branch to FCU

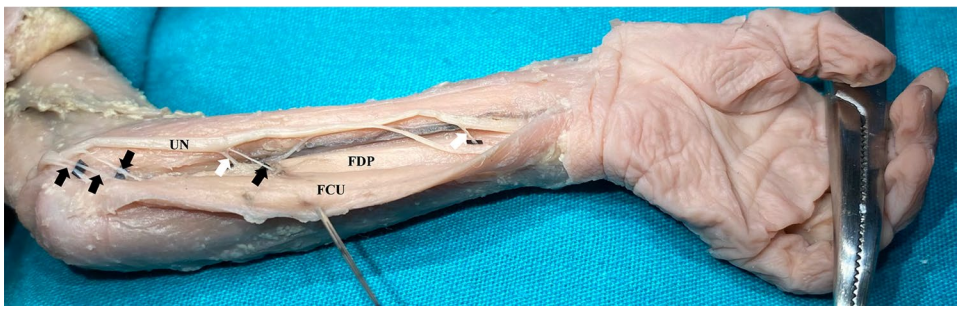

Fig. 6 Type V (case 14; left forearm). White arrow: Muscular branch to FDP, Black arrow: Muscular branch to FCU

Table 2 The comparison of muscular branches leaving ulnar nerve and types defining branching characteristics according to gender

Gender	Type I	Type II	Type III	Type IV	Type V	Total	*p* value
Female, *n* (%)	2 (9.1)	7 (31.8)	12 (54.5)	1 (4.5)	0 (0.0)	22 (100.0)	
Male, *n* (%)	4 (13.3)	11 (36.7)	12 (40.0)	2 (6.7)	1 (3.3)	30 (100.0)	0.791
Total, *n* (%)	6 (11.5)	18 (34.6)	24 (46.2)	3 (5.8)	1 (1.9)	52 (100.0)	

There is statistically significant difference ($p < 0.05$)

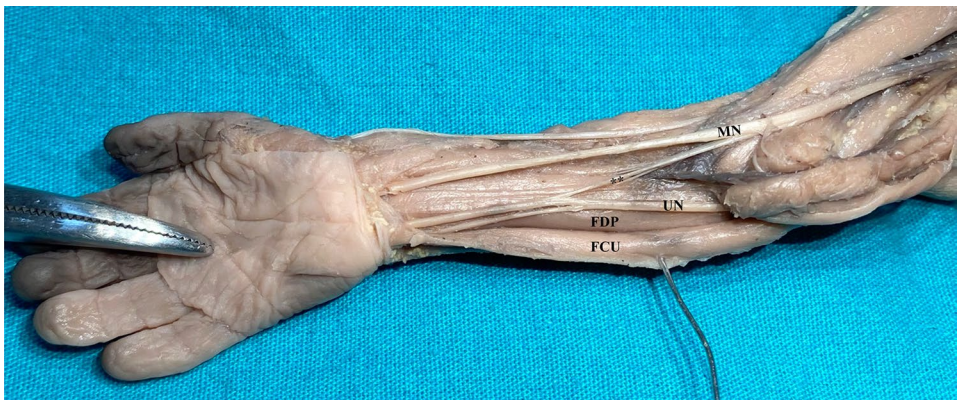

Fig. 7 View of the Martin-Gruber connection from the median nerve to the ulnar nerve (case 26; right forearm). **: Martin-Gruber connection

It has been reported that there may be cases where a branch leaving UN does not participate in the innervation of FDP [5]. It has been stated that Martin-Gruber connection containing the fibers innerving intrinsic hand muscles primarily can also participate in the innervation of FDP [17]. In the present study, we found that UN did not participate in the innervation of FDP and this muscle was innerved by a muscular branch leaving Martin-Gruber connection. Absence of any other study defining this pattern that we referred to as Type Ic shows that we can contribute to the literature with this typing.

The difference of our study from other studies is that Type Ic ($n = 1$), Type IIIb ($n = 1$), Type IIIc ($n = 11$), Type IIIe ($n = 1$), Type IVa ($n = 1$), Type IVb ($n = 1$) and Type V ($n = 1$) patterns have not been found in other studies which examined forearms of fetal and adult cadavers. Therefore, we believe that this is the first study identifying and presenting these patterns. The comparison between the incidence of the types identified in our study and the literature data is presented in Table 3.

In the literature, there are studies reporting that the frequency of MG connection, which is the connecting branch seen in the forearm between UN and MN, is seen at rates ranging from 7.5 to 45%. While the incidence of MG connection was published to range between 8.6 and 45% in studies performed on adult cadavers, it was reported that it ranged between 7.5 and 23% of fetal forearms [4, 7, 8, 13]. We found MGA in 17 (32.7%) of our cases.

Ulnar nerve giving more than one branch to FCU proximal to forearm makes these branches a potential donor. As the branches proceeding to FCU and pronator teres show similarity anatomically and histomorphometrically, it is suggested to transfer one of the branches proceeding to FCU to pronator teres in case of partial median nerve injury in order to provide functional restoration without any significant clinical morbidity [3]. Also, it was reported in cases, in which the function of medial cord was preserved and posterior cord had isolated involvement, that using the motor branches of UN for the reinnervation of triceps brachii successfully restored the elbow extension [2]. We believe that the information that UN can demonstrate different branching patterns on the forearm can help the surgeons to prevent complications that may develop in potential nerve injury during the selection and transfer of relevant branch.

Table 3 The incidence of branching patterns in this study compared to other studies

	Type Ia	Type Ib	Type Ic	Type IIa	Type IIb	Type IIc	Type IIIa	Type IIIb	Type IIIc	Type IIId	Type IIIe	Type IIIf	Type IVa	Type IVb	Type IVc	Type V
Marur et al. [12] ($n=37$)	35%	14%	–	16%	16%	11%	3%	–	–	–	–	–	–	–	–	–
Unver Dogan et al. [4] ($n=200$)	88.5%	–	–	–	8%	3.5%	–	–	–	–	–	–	–	–	–	–
Albay et al. [1] ($n=116$)	19.83%	–	–	12.07%	25.86%	–	–	–	–	–	–	2.59%	–	–	–	–
Paulos and Leclercq [13] ($n=20$)	5%	5%	–	25%	15%	–	15%	–	–	5%	–	–	–	–	10%	–
This study ($n=52$)	7.7%	1.9%	*1.9%*	21.2%	9.6%	3.8%	15.4%	*1.9%*	*21.2%*	3.8%	*1.9%*	1.9%	*1.9%*	*1.9%*	1.9%	*1.9%*

The ones written in italic are the patterns that we have detected different from other studies

Author contributions ATA: project development, dissection of the fetal forearms, data collection, data analysis, article writing. PK: project development, data analysis, article revision. SMA: project development, data analysis, article writing, article revision.

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Declarations

Conflict of interest The authors have no conflict of interest in writing and publishing this article.

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