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ORIGINAL ARTICLE

Motor branches of the ulnar nerve to the forearm: an anatomical study and guidelines for selective neurectomy

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Abstract
Purpose Precise knowledge of motor nerve branches is critical to plan selective neurectomies for the treatment of spastic limbs. Our objective is to describe the muscular branching pattern of the ulnar nerve in the forearm and suggest an ideal surgical approach for selective neurectomy of the flexor carpi ulnaris.
Methods The ulnar nerve was dissected under loop magnification in 20 upper limbs of fresh frozen cadavers and its branches to the flexor carpi ulnaris muscle (FCU) and to the flexor digitorum profundus muscle (FDP) were quantified. We measured their diameter, length and distance between their origin and the medial epicondyle. The point where the ulnar artery joined the nerve was observed. The position in which the ulnar nerve gave off each branch was noted (ulnar, posterior or radial) and the Martin-Gruber connection, when present, had its origin observed and its diameter measured.
Results The ulnar nerve gave off two to five muscular branches, among which, one to four to the FCU and one or two to the FDP. In all cases, the first branch was to the FCU. It arose on average 1.4 cm distal to the epicondyle, but in four specimens it arose above or at the level of the medial epicondyle (2.0 cm above in one case, 1.5 cm above in two cases, and at the level of the medial epicondyle in one). The first branch to the FDP arose on average 5.0 cm distal to the medial epicondyle. All the branches to FDP but one arose from the radial aspect of the ulnar nerve. A Martin-Gruber connection was present in nine cases. All motor branches arose in the proximal half of the forearm and the ulnar nerve did not give off branches distal to the point where it was joined by the ulnar artery.
Conclusions The number of motor branches of the ulnar nerve to the FCU varies from 2 to 4. An ideal approach for selective neurectomy of the FCU should start 4 cm above the medial epicondyle, and extend distally to 50 % of the length of the forearm or just to the point where the ulnar artery joins the nerve.

Keywords Selective neurectomy · Branching patterns · Ulnar nerve · Spastic limb · Motor branches

Introduction

Muscle hypertonia due to spasticity may occur as a result of stroke, traumatic brain injury, cerebral palsy, and cervical spine injury, among others. When it involves the upper limb, function, hygiene and cosmetics may be greatly impaired. In selected cases, it is amenable to a surgical treatment [7, 29].

The use of selective neurectomy has been widely studied for the treatment of the spastic foot [9], but very few studies have analyzed its use in the upper limb [6, 14, 21], especially in the forearm. It is Stoffel [25] who introduced this treatment for the upper limb, but it was not widely spread until the extensive studies by Brunelli [5].

In the spastic upper extremity, the typical posture pattern includes shoulder internal rotation, elbow flexion, forearm pronation, wrist flexion and ulnar deviation, thumb-in-palm, and clenched fist deformities [10, 15]. The

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ulnar nerve is involved in the deforming process of the wrist and fingers, as it gives off motor branches to the flexor carpi ulnaris (FCU) and the medial part of the flexor digitorum profundus (FDP).

The flexor carpi ulnaris is a strong wrist flexor, and it is the main deforming factor into wrist flexion and ulnar deviation in cases of spasticity. Selective neurectomy of its motor branches can be beneficial for some patients, but a precise knowledge of the extra-muscular nerve supply is required [17].

The aim of this study was to describe the motor branches of the ulnar nerve in the forearm for planning selective neurectomies and determinate the optimal surgical approach.

Materials and methods

Twenty upper limbs from 13 fresh frozen human cadavers were dissected for this study. All dissections were performed at the anatomy laboratory of the Ecole de Chirurgie (Assistance Publique—Hopitaux de Paris, France). In seven subjects, the dissection was done bilaterally and in six, on one side only (because the contralateral forearms had been previously used for other studies). In total, 12 left and 8 right upper limbs were dissected. There was no selection based on sex, age, or side. Thirteen limbs were from female cadavers, and seven from male cadavers.

The elbows were brought to full extension before performing the dissections. The landmarks used for measurements were the tip of the medial epicondyle and the tip of the ulnar styloid. The ulnar nerve was dissected out through a longitudinal incision, from approximately 6 cm proximal to the medial epicondyle until the level of the wrist joint. An epineural dissection was performed under loop magnification (4.3×).

The nerve was identified anterior to the medial head of the triceps muscle, the cubital tunnel was opened and the humeral head of the flexor carpi ulnaris muscle was detached from the medial epicondyle. The ulnar nerve was followed and the branches to the FCU and FDP were identified. Measurements from their origins at the ulnar nerve to the medial epicondyle, their length (from their origin until the point where they enter into the muscle) and diameter were obtained using a line gauge. If a branch originated above the medial epicondyle, the distance was recorded as a negative value. The aspect of the ulnar nerve where each individual branch came off was noted (ulnar, posterior or radial). The length of the forearm from the medial epicondyle to the ulnar styloid process, the diameter of the ulnar nerve before giving the first motor branch and the distance from the medial epicondyle to the point where the ulnar artery joined the ulnar nerve were also measured and recorded. When a Martin-Gruber connection was present, it was dissected until its origin (median nerve or anterior interosseous nerve) and its diameter measured.

Results

The average length of the forearm was 24.9 cm (min: 21.0, max: to 28.0 cm) and the mean distance between the medial epicondyle and the point where the ulnar nerve was joined by the ulnar artery was 12.3 cm (min: 10.0, max: 17.0 cm). The ulnar nerve had an average diameter of 0.5 cm (min: 0.4, max: 0.7 cm).

The cases were divided in four groups according to the number of muscular branches: Group I (two branches) = 2 cases, Group II (three branches) = 10, Group III (four branches) = 5, and Group IV (five branches) = 3 cases. Within each group, there were differences regarding the distribution of the branches to the FCU and the FDP (Table 1).

There were 11 different types of branching patterns (Table 2). In the most frequent pattern (5 cases—25 %), there were 3 branches, the first two innervating the FCU and the last one innervating the FDP.

The first muscular branch was always for the FCU and the mean distance from its origin to the medial epicondyle was 1.4 cm (min: −2.0, max: 3.8 cm). In three cases, the ulnar nerve gave off its first motor branch above the medial epicondyle, and in one case at the level of this landmark. The FCU received 1 to 4 branches (mean of 2.6). The average diameter of all the branches received by the FCU was 0.14 cm (min: 0.05, max: 0.3 cm) and their mean length was 3.4 cm (min: 1.0, max: 9.0 cm). Sometimes, transverse communications were found between the branches to FCU, but they were not quantified in this study (Fig. 1).

The FDP received one single branch in 18 cases and two branches in two cases. The average distance from the medial epicondyle to the origin of its first (or single) branch was 5.0 cm (min: 2.8, max: 8.7 cm). The mean diameter of all branches received by the FDP was 0.2 cm (min: 0.1, max: 0.3 cm) and their mean length was 3.3 cm (min: 1.7, max: 9.0 cm). The branch for the FDP had its origin on the radial aspect of the ulnar nerve in all but one specimen.

In three cases, an articular branch which went directly to the joint connective tissue was found between 0 and 0.5 cm from the medial epicondyle. When present, after careful dissection to make sure it did not innervate any muscle, this branch was sacrificed.

In one case, a small branch to the flexor digitorum superficialis (FDS) was found arising from a common trunk which also gave branches to FCU and FDP. This small

Table 1 Branching pattern: distances from the medial epicondyle to the origin of the first and last branches (cm), and location of the point where the ulnar artery joins the ulnar nerve

Group	Branching pattern	Nb of cases	First branch	Last branch	A+N
1	FCU; FDP	1	2.0	3.5	69 %
	FCU; FCU + FDP	1	1.0	5.0	53 %
2	FCU; FCU; FDP	5	−1.5 to 3.8	2.8–8.7	40–74 %
	FCU; FDP; FCU	3	−1.5 to 3.2	5.8–10	40–53 %
	FCU; FCU; FCU + FDP	1	2.0	4.5	48 %
	FCU; FCU; FCU + FDP + FDS	1	3.0	5.0	54 %
3	FCU; FCU; FCU; FDP	3	−2 to 2.5	3.3–6.5	45–62 %
	FCU; FCU; FDP; FDP	1	1.0	5.8	46 %
	FCU; FCU; FDP; FCU + FDP	1	3.0	10.5	43 %
4	FCU; FCU; FCU; FCU; FDP	1	1.0	5.5	61 %
	FCU; FCU; FCU; FDP; FCU	2	0.5 to 2.5	7.5–11.6	32–46 %

Group according to Marur's classification

FCU flexor carpi ulnaris, *FDP* flexor digitorum profundus, *FDS* flexor digitorum superficialis, *A+N* point where the ulnar artery joins the ulnar nerve as percentage of the length of forearm

Table 2 Different types of branching patterns

Type	Branching pattern	%
I	FCU; FCU; FDP	25
II	FCU; FPD; FCU	15
III	FCU; FCU; FCU; FPD	15
IV	FCU; FCU; FCU; FDP; FCU	10
V	FCU; FCU; FDP; FDP	5
VI	FCU; FCU; FCU + FDP + FDS	5
VII	FCU; FCU; FDP; FCU + FDP	5
VIII	FCU; FCU; FCU; FCU; FDP	5
IX	FCU; FCU; FCU + FDP	5
X	FCU, FCU + FDP	5
XI	FCU, FDP	5

FCU flexor carpi ulnaris, *FDP* flexor digitorum profundus, *FDS* flexor digitorum superficialis

branch passed behind the ulnar artery before reaching the FDS.

A Martin-Gruber connection (MGC) existed in nine cases (45 %) and its average diameter was 0.09 cm (min: 0.05, max: 0.2 cm). It originated from the median nerve in five forearms, and the anterior interosseous nerve (AIN) in four. In five specimens, there were some variations in the anatomy of the MGC, in the form of either a communicating branch between MGC and the branch from the ulnar nerve to FDP, or a direct branch from the MGC to the FDP (ulnar half) or even a communicating branch between the MGC and the branch from the AIN to the FDP (Table 3). In all cases, the MGC passed behind the artery and, sometimes, it could easily be mistaken for a vascular branch (Fig. 2).

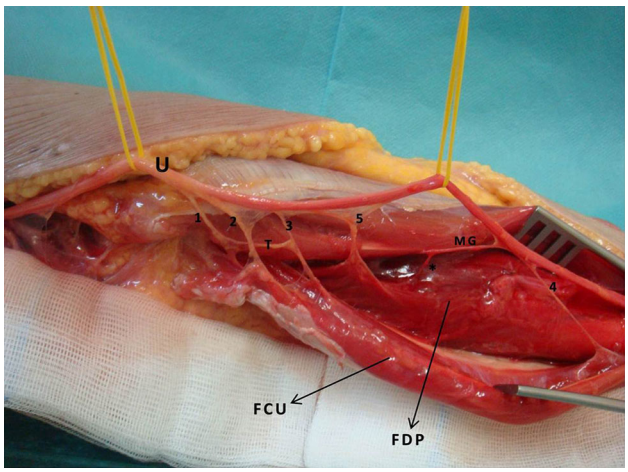

Fig. 1 Branches of the ulnar nerve, case number 19, left forearm. *U* ulnar nerve, *1* first branch to FCU, *2* second branch to FCU, *3* third branch to FCU, *4* forth branch to FCU, *5* branch to FDP, *MG* Martin-Gruber connection, *asterisks* branch from the Martin-Gruber to FDP, *T* transverse communication

None of the specimen displayed any anomalous muscle (such as the anconeus epitrochlearis) or any other connections (such as the Marinacci connection) in the dissected region.

Discussion

During its course in the forearm, the ulnar nerve was classically described as giving off two motor branches: the first to the FCU and the second to the FDP [1, 33]. Several studies, however, showed a great variability in branching

Table 3 Martin-Gruber connections

Origin	Nb of cases	Variations
Median	5	1 communicating br. with ulnar br. to FDP + direct br. to FDP
		1 direct br. to FDP
AIN	4	2 communicating br. with ulnar br. to FDP
		1 direct br. to FDP

Br branch, *AIN* Anterior interosseous nerve, *FDP* flexor digitorum profundus

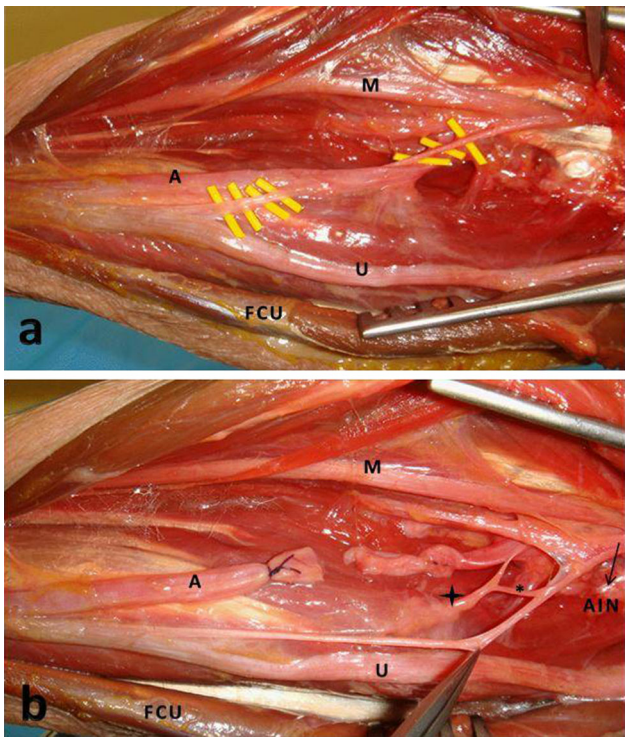

Fig. 2 Martin-Gruber connection, case number 12; right forearm. **a** The Martin-Gruber connection passes behind the ulnar artery; **b** after ligation of the ulnar artery, the Martin-Gruber is better visualized. Note the communication branch (*asterisks*) between Martin-Gruber and the branch from the anterior interosseous nerve to FDP (*star*). *A* ulnar artery, *AIN* anterior interosseous nerve, *M* median nerve, *U* ulnar nerve

patterns and in the number of branches [11, 17, 18, 27, 32]. In the present study, the number of muscular branches ranged from two to five.

Innervation of the FCU is done by multiples branches [18, 27, 30, 31]. Gonzales et al. [11] found as many as 6 branches. In our dissections, their number ranged from 1 to 4, similar to that reported by Marur et al. [18]. The majority of branches (56.9 %) originated from the posterior aspect of the nerve, 29.4 % from its medial aspect and 13.7 % from the lateral one. Previous descriptions were different, showing 35 % from the ulnar aspect and 65 % from the radial [11] or 50 % from a dorsal branch and 50 % from a ventral branch [17].

In all of our cases, the first muscular branch of the ulnar nerve was to the FCU as previously reported in the literature [17, 18, 31, 32]. This first branch arose proximal to or at the medial epicondyle in 4 of our 20 dissections (20 %): 1.5 cm above the medial epicondyle in two, 2.0 cm above in one, and at the same level in one. In Sunderland and Hughes's study on 20 specimens, the proportion was 10 % (at the level of the epicondyle in one, and 4 cm above the epicondyle in one) [27]. There are other mentions in the literature of similar cases [11, 18]. The average location of its origin was 1.4 cm distal to the medial epicondyle (min: −2.0, max: 3.8 cm), similar to the average 1.5 cm reported by Marur et al. [19].

The mean diameter of all branches to the FCU was 0.14 cm, larger than the average 0.1 cm reported in the study of Tubbs et al. [30]. The average length of these branches was 3.4 cm and we did not find literature data to compare this value.

We observed one (18 cases) or two (2 cases) branches to the FDP and this was also supported by other anatomical studies [18, 30]. The mean distance from the medial epicondyle to the origin of its first (or single) branch was 5.0 cm (min: 2.8, max: 8.7 cm). It has been reported diversely in the literature, varying from 2.7 to 5.0 cm [4, 8, 17, 18, 30]. The average diameter of all branches to the FDP was 0.2 cm, quite similar to the value of 0.21 cm reported by Tubbs et al. [30]. The mean length of these branches was 3.3 cm in our study and 5.6 cm in Tubbs et al. [30]. In all cases but one, the branches to the FDP originated from the radial aspect of the ulnar nerve.

Although it was traditionally thought that the AIN innervates the lateral half of the FDP and the ulnar nerve the medial half, different anatomical variations have been described [3, 20, 26]. In a recent study, Oh et al. [20] dissected 50 upper limbs and found six patterns of innervation. In the most common one (50 %) the median nerve innervated all FDP muscles and the ulnar nerve innervated the FDP muscles of the 3rd, 4th, and 5th digits. In our study, we did not follow the intramuscular course of the FDP branch and, thus, we are not able to state the true contribution of this branch to the different heads of the FDP muscle.

For a better understanding of the results, we have grouped our cases according to the number of muscular branches arising from the ulnar nerve, as suggested by Marur et al. [18]. However, we found more branching patterns than reported by these authors, which evidences

the great variability in the distribution of the motor branches of the ulnar nerve. In our study, most cases were included in Group II (three branches), followed by Group III (four branches) whereas in Marur's study, most cases were in Group I (two branches) followed by Group II.

Data from the literature suggest that all motor branches are originating in the proximal third of the forearm [18]. This was not true in three of our cases, where some branches originated more distally, but in all cases they arose within in the proximal half of the forearm. In no case did the ulnar nerve give off muscular branches after it was joined by the ulnar artery. Therefore, we feel that this point can be used as a safe distal landmark for the dissection of the motor branches of the ulnar nerve in the forearm. The mean distance from the medial epicondyle to the point where the ulnar artery joined the ulnar nerve was 12.3 cm (min: 10.0, max: 17.0 cm).

In one case, a small branch to the flexor digitorum superficialis was found arising from a common trunk which also gave branches to FCU and FDP. This participation of the ulnar nerve to the flexor digitorum superficialis innervation has already been reported [2].

The incidence of Martin-Gruber connections (MGCs) in the literature varies widely. In literature review dedicated to the MGC, Leibovic and Hasting reported an average incidence of 17 % [16], whereas it was present in 45 % in our series, and from 5 to 44 % in the rest of the literature [4, 12, 13, 18, 19, 23, 24, 28, 31]. The percentage differences, however, may be due to the small number of samples in our study and in other series (Marur et al., 37 upper limbs; Shu et al., 72 upper limbs), whereas some studies performed more than 100 dissections (Nakashima—108; Rodriguez et al.—140, and Taams—112).

The origin of the MGC can also vary and although the median nerve was traditionally described as the nerve of origin, the AIN was also found as the origin of this connection in many studies [19, 23, 28]. In our nine cases, five MGCs branched from the median and four from the AIN. In all cases, the MGC traveled deep to the ulnar artery (Fig. 2), as reported in three other publications [18, 28, 31]. In some of our dissections, it could have easily been mistaken for a vessel. As pointed by Marur et al. [18], we observed that the connection of the MGC to the ulnar nerve was always distal to the origin of the FDP branch. Differently from other works which describe the MGC as a single branch that runs directly from its origin to the ulnar nerve and does not give off any branch [31], we observed in 5 of our 9 MGCs, a communicating branch between the MGC and the ulnar branch to FDP (two cases), or between the MGC and the AIN branch to the FDP (one case), or a direct branch from the MGC to the ulnar half of the FDP (three cases) (Table 2). The mean diameter of the MGC was 0.09 cm and the mean distance between the medial epicondyle and the point where it reached the ulnar nerve was 9.8 cm (min: 6.2, max: 12.0 cm), Taams found an average distance of 8.4 cm (min: 5, max: 12 cm) [25]. In all our cases, the MGC connects the ulnar nerve by its radial aspect.

In 2002, Rodriguez-Niedenführ et al. [22] proposed a classification for the MGC based on the number of branches reaching the ulnar nerve: Patter I, one branch, and Patter II, two branches. Patter I was further divided into three sub-types based on the level at which the anastomotic branch arose from the median nerve or one of its branches. According to this classification, all our cases of MGC fell into sub-types Ib (five cases) and Ic (four case). There were no sub-types Ia, nor any Patter II, may be due to the limited number of dissections performed.

In spastic upper limbs, the FCU muscle is usually the main deforming factor of the wrist into flexion and ulnar deviation. This deformity causes a great disability, hindering proper flexion of the fingers and impairing grip strength. It is also a factor of cosmetic concern, especially in young teenagers. Although selective neurectomy is a known treatment for spastic foot [8], its use is not widespread for the upper limb. Among others, selective neurectomy of the muscular branches to the FCU, and in some cases to the FDP is helpful. A good knowledge of muscular nerve supply and its anatomical variations is required to perform this surgery.

Our measurements of the diameter of each motor branch have shown values ranging from 0.05 to 0.3 cm, which is amenable to a partial neurectomy. If thinner branches were encountered during surgery, they would not be suitable for this technique.

Conclusion

Selective neurectomy of the motor branches of the ulnar nerve in the forearm may be indicated in selected cases for treatment of upper limb spasticity. Taking into account the results of former studies [26] and the result of our study, we suggest that an ideal approach to the motor branches to the FCU should start 4 cm above the medial epicondyle, and extend distally to 50 % of the length of the forearm or to the point where the ulnar artery joins the ulnar nerve. During the dissection, the ulnar nerve should be elevated so as not to miss those motor branches originating from its posterior aspect. For selective neurectomy of the FDP, its branch from the ulnar nerve should be looked for between 2.8 and 8.7 cm distal to the medial epicondyle, and one should be aware of the possibility of a second, more distal branch.

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