Innervation of the Flexor Digitorum Profundus: A Systematic Review

L'innervation du tendon fléchisseur profond: une analyse systématique

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Abstract

Purpose: The aim of this study was to review the innervation of the flexor digitorum profundus (FDP). **Methods:** In PubMed and Scopus, terms (Flexor digitorum profundus OR FDP) AND (innervation OR nerve) were used, resulting in 233 and 281 papers, respectively. After excluding 142 duplicates, 73 abstracts were reviewed. Forty-seven abstracts were excluded, 26 full papers were reviewed, and 17 papers were analyzed. **Results:** In most cases (97.6%), the index FDP was innervated by the anterior interosseous nerve (AIN). Dual innervation from the AIN and ulnar nerve (UN) was observed in 2.4% of papers. In majority (76.8%), the middle FDP received dual innervation from the AIN and the UN. The rest was innervated by the AIN only (22.0%) or the UN only (1.2%). In most cases (85.4%), the ring FDP was innervated by the UN only. The rest (14.6%) received dual innervation from the AIN and the UN. In majority of cases (64.6%), the little FDP was innervated by the UN only. The rest (35.4%) received dual innervation from the AIN and the UN. The AIN entered the FDP at 107.63 (8.80) mm from the elbow, corresponding to 26.75% (2.17%) of the forearm length, measured proximally. The average number of AIN branches to the FDP was 2.27 (1.33). The average number of UN branches to the FDP was 1.37 (0.94). In 8.8% of limbs, a communicating branch supplied the FDP. Among the limbs with a communicating branch, 32.3% had branches supplying the FDP. **Conclusion:** The results of this study may be useful in managing nerve injury patients.

Résumé

Objectif : La présente étude visait à analyser l'innervation du tendon fléchisseur profond (TFP). **Méthodologie :** Dans PubMed et Scopus, les chercheurs ont utilisé les termes *Flexor digitorum profundus* OU FDP ET *innervation* OU *nerve* et ont obtenu 233 et 281 articles, respectivement. Après avoir exclu 142 articles dédoublés, ils ont examiné 73 résumés et en ont exclu 47. Ils ont parcouru 26 articles complets et en ont analysé 17. **Résultats :** Dans la plupart des cas (97.6%), le TFP de l'index était innervé par le nerf interosseux antérieur (NIA). Les chercheurs ont observé la double innervation par le NIA et le nerf ulnaire (NU) dans 2.4% des cas. Le TFP du majeur était doublement innervé par le NIA et le NU dans la majorité des cas (76.8%). Les autres cas étaient innervés seulement par le NIA (22.0%) ou par le NU (1.2%). Dans la plupart des cas (85.4%), le TFP de l'annulaire était seulement innervé par le NU. Les autres (14.6%) étaient doublement innervés par le NIA et le NU. Le TFP de l'auriculaire était seulement innervé par le NU dans la majorité des cas (64.6%). Les autres (35.4%) étaient doublement innervés par le NIA et le NU. Le NIA pénétrait dans le TFP à 107.63 (8.80) mm du coude, ce qui correspond à une mesure proximale de 26.75% (2.17%) de la longueur de l'avant-bras. Il y avait une moyenne de 2.27 (1.33) ramifications du NIA vers le TFP et de 1.37 (0.94) ramification du NU vers le TFP. Dans 8.8% des membres, une ramification communicante alimentait le TFP; 32.3% étaient alors dotés de ramifications alimentant le TFP. **Conclusion :** Les résultats de la présente étude peuvent être utiles pour la prise en charge des patients ayant une lésion nerveuse.

Keywords

forearm, innervation, fingers, anatomy, regional

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Figure 1. Selection process of the papers included in this study.

Introduction

Gray's Anatomy states that the medial part of the flexor digitorum profundus (FDP; muscle bellies of the little and ring finger) is innervated by the ulnar nerve (UN), while the lateral part (muscle bellies of the middle and index fingers) is innervated by the anterior interosseous branch of the median nerve, C8 and T1.¹

However, the findings of recent papers differ from those reported in the classical literature. The FDP receives 1 to 5 branches from the anterior interosseous nerve (AIN).² Contrary to common knowledge, flexion of the distal phalanx of the ring and little fingers has been found to be preserved in patients with high UN lesions.³ The aim of this study was to perform a systematic review of the innervation of the FDP.

Materials and Methods

In a search of PubMed and Scopus, the search terms (Flexor digitorum profundus OR FDP) AND (innervation or nerve) were used, resulting in 233 and 281 papers, respectively. Once

142 duplicates were excluded, 372 titles were examined and 73 abstracts were reviewed.

Studies that did not study the innervation of the FDP were excluded. Among the 73 abstracts, 47 were excluded and 26 full papers were reviewed. Among the 26 full texts, 17 papers were excluded and 8 mined papers were added, leading to a total of 17 papers that were ultimately analyzed (Figure 1, Table 1).^{2,4-19} We followed “Preferred Reporting Items for Systematic Reviews and Meta-Analyses” guidelines in this study.²⁰

No restrictions on language and publication form were imposed. However, the resulting papers were all in English, except for 1 in Chinese. All articles were read by 2 independent reviewers who extracted data from the articles.

Results

Characteristics of the Papers

Of the 17 papers included in this systematic review, 9 were published in Asia, 2 in North America, 2 in South America, 1 in

Table 1. Characteristics of the Papers.

Authors	Year	C	Number		Sex		Side	
			Cadaver	UL	Male	Female	Right	Left
Nakashima ⁴	1993	As	54	108	13	12		
Bhadra et al ⁵	1999	N	10	20				
Segal et al ⁶	2002	N	10	12	6	4		
Lee et al ⁷	2005	As	68	102	38	19		
Marur et al ⁸	2005	As	19	37	15	4		
Hwang et al ⁹	2007	As	11	21	3	8		
Oh et al ¹⁰	2009	As	25	50	18	7		
Essa and Abdelghany ¹¹	2009	Af		20				
Li et al ¹²	2010	As	15	30				
Won et al ¹³	2010	As	20	40				
Dolderer et al ¹⁴	2011	E		19	8	11		
Loukas et al ¹⁵	2011	E	25	50	13	12		
Albay et al ¹⁶	2013	As	58	116	32	26		
Bindurani et al ¹⁷	2014	As		50			24	26
Parot and Leclercq ²	2016	E	22	22	13	9	11	11
Cavalheiro et al ¹⁸	2016	S	50	100	46	4		
Caetano et al ¹⁹	2016	S	50	100	46	4		
Total			437	897	251	120	35	37

Abbreviations: Af, Africa; As, Asia; C, continent; E, Europe; N, North America; S, South America; UL, upper limb.

Africa, and 3 in Europe (Table 1).^{2,4-19} In all 17 papers, innervation of the FDP was observed by cadaver dissection. Twelve papers specified the sex of the cadavers (251 males, 120 females),^{2,4,6-10,14-16,18,19} and 2 papers specified the laterality (37 left limbs, 35 right limbs).^{2,18}

Innervation of the Index, Middle, Ring, and Little FDP

Three papers (82 limbs) discussed the innervation of the FDP (Figure 2, Table 2).^{5,6,10}

Index FDP. In most cases ($n = 80$, 97.6%), the index FDP was innervated by the AIN. Dual innervation from the AIN and the UN was only observed in 2 (2.4%) cases. Innervation by the AIN was significantly more common than UN-only innervation or dual innervation ($P < .001$, analysis of variance [ANOVA], Tukey).

Middle FDP. In the majority of cases ($n = 63$, 76.8%), the middle FDP received dual innervation from the AIN and the UN. The rest was innervated by the AIN only ($n = 18$, 22.0%) or by the UN only ($n = 1$, 1.2%). Dual innervation was significantly more common than AIN-only innervation ($P < .001$, ANOVA, Tukey), and AIN-only innervation was more common than UN-only innervation ($P = .001$, ANOVA, Tukey).

Ring FDP. In most cases ($n = 70$, 85.4%), the ring FDP was innervated by the UN only. The rest ($n = 12$, 14.6%) received dual innervation from the AIN and the UN. Innervation by the UN was significantly more common than dual innervation

Figure 2. Innervation of the index, middle, ring, and little FDP (%). A indicates anterior interosseous nerve; D, dual innervation of anterior interosseous nerve and ulnar nerve; FDP, flexor digitorum profundus; U, ulnar nerve.

($P < .001$, ANOVA, Tukey), and dual innervation was more common than AIN-only innervation ($P = .004$, ANOVA, Tukey).

Little FDP. In the majority of cases ($n = 53$, 64.6%), the little FDP was innervated by the UN only. The rest (29, 35.4%) received dual innervation from the AIN and the UN. Innervation by the UN was significantly more common than dual innervation ($P < .001$, ANOVA, Tukey), and dual innervation was more common than AIN-only innervation ($P < .001$, ANOVA, Tukey).

Entry Point of the AIN

Five papers with 110 limbs discussed the entry point of the AIN to the FDP (Table 3).^{5,9,11,12,14} Among them, 3 papers (69 limbs) measured the direct distance from a landmark (Table 3, top),^{11,12,14} while 3 papers (71 limbs) localized the entry point in terms of the proportion of the length and/or width of the forearm (Table 3, bottom).^{5,9,12}

The AIN entered the FDP at 107.63 (8.80) mm from the elbow, and at 26.75% (2.17%) of the length of the forearm, measured proximally. The entry points to the index FDP (90.5 [8.42] mm) and the middle FDP (93.27 [7.90] mm) were located nearer to the elbow than the entry points to the ring FDP (102.89 [8.43] mm) or little FDP (119.48 [9.66] mm; $P < .001$, ANOVA, Tukey). The entry point of the little FDP was furthest from the elbow ($P < .001$, ANOVA, Tukey).

Table 2. Innervation to Index, Middle, Ring, and Little FDP.

Authors	Index FDP			Middle FDP			Ring FDP			Little FDP			N
	AIN	UN	Dual	AIN	UN	Dual	AIN	UN	Dual	AIN	UN	Dual	
Bhadra et al ⁵	20	0	0	4	1	15	0	20	0	0	20	0	20
Segal et al ⁶	12	0	0	10	0	2	0	2	10	0	12	0	12
Oh et al ¹⁰	48	0	2	4	0	46	0	48	2	0	21	29	50
Total	80	0	2	18	1	63	0	70	12	0	53	29	82

Abbreviations: AIN, anterior interosseous nerve; Dual, innervations from AIN and UN; FDP, flexor digitorum profundus; N, number of upper limbs; UN, ulnar nerve.

Table 3. Entry Point of Anterior Interosseous Nerve (AIN).

Authors	Year	N	AIN Entry Point to FDP (mm)
Li et al ¹²	2010	30	Index 90.5 (8.42) Middle 93.27 (7.90) Ring 102.89 (8.43) Little 119.48 (9.66) From the line between the medial and lateral epicondyles of humerus Subtotal: 101.54 (4.31)
Essa and Abdelghany ¹¹	2009	20	128.2 (37.5) distal to articular line of elbow
Dolderer et al ¹⁴	2011	19	95.6 (25.04) from transepicondylar line
Total		69	107.63 (8.80)
AIN Entry point to FDP (%)			
Li et al ¹²	2010	30	Index 33.76 (3.14) Middle 34.90 (2.96) Ring 38.61 (3.16) Little 45.12 (3.65) Subtotal: 38.10 (1.62)
Bhadra et al ⁵	1999	20	30 (6) of forearm length
Hwang et al ⁹	2007	21	36 (4) of forearm length
Total		71	26.75 (2.17)

Abbreviations: AIN, anterior interosseous nerve; FDP, flexor digitorum profundus; N, number of upper limbs.

Number of AIN Muscular Branches to the FDP

Four papers (110 limbs) discussed the number of AIN muscular branches to the FDP (Table 4).^{2,5,11,17} The average number of branches to the FDP was 2.27 (1.33). Most frequently, 1 (53.3%) branch entered the FDP, followed by 2 (24.4%) branches and 3 (16.7%) branches. However, in 5 (5.6%) cases, 4 branches entered the FDP. The presence of 1 branch was significantly more frequent than the presence of 2, 3, or 4 branches ($P < .001$, ANOVA, Tukey).

Number of UN Muscular Branches to the FDP

Three papers (173 limbs) discussed the number of UN muscular branches to the FDP (Table 5).^{5,8,16} The average number of UN branches to the FDP was 1.37 (0.94). Most frequently, 1 (95.4%) branch entered the FDP, followed by 2 (4.6%)

Table 4. Number of AIN Muscular Branch to FDP.

Authors	N of branches				Total N (Branch)	Total N (Upper Limb)	Mean (SD)
	1	2	3	4			
Bhadra et al ⁵					88	20	4.4
Parot and Leclercq ²	8	7	5	0	37	20	1.85 (0.81)
Essa and Abdelghany ¹¹	0	7	8	5	58	20	2.90 (0.79)
Bindurani et al ¹⁷	40	8	2	0	62	50	1.24 (0.52)
Total	48	22	15	5	245	110	2.27 (1.33)

Abbreviations: AIN, anterior interosseous nerve; FDP, flexor digitorum profundus; N, number, SD, standard deviation.

branches. In no cases did 3 or 4 branches enter the FDP (0%). The presence of 1 branch was significantly more common than the presence of 2 branches ($P < .001$, ANOVA, Tukey).

Table 5. Number of UN Muscular Branch to FDP.

Authors	N of branches		Total N (Branch)	Total N (Upper Limb)	Mean (SD)
	1	2			
Bhadra et al ⁵			78	20	3.9
Marur et al ⁸	33	4	41	37	1.11 (0.31)
Albay et al ¹⁶	113	3	119	116	1.03 (0.16)
Total	146	7	238	173	1.37 (0.94)

Abbreviations: FDP, flexor digitorum profundus; N, number; SD, standard deviation; UN, ulnar nerve.

Table 6. Communicating Branches Between UN and AIN.

Authors	N		Total
	Comm (+)	FDP supplied by Comm	
Won et al ¹³	34		40
Loukas et al ¹⁵	8		50
Parot and Leclercq ²	3	2	20
Marur et al ⁸	7	7	37
Nakashima ⁴	23	6	108
Lee et al ⁷	40	16	102
Cavalheiro et al ¹⁸	27	5	100
Caetano et al ¹⁹	27	5	100
Total	169	41	557

Abbreviations: AIN, anterior interosseous nerve; Comm, communicating branches; FDP, flexor digitorum profundus; N, number of upper limbs; UN, ulnar nerve.

Communicating Branches Between the UN and the AIN

Eight papers (169 limbs) discussed the presence of a communicating branch between the UN and the AIN (Table 6).^{2,4,7,8,13,15,18,19} Six papers (41 limbs) discussed the presence of a communicating branch supplying the FDP.^{2,4,7,8,18,19}

In 41 (8.8%) of the 467 limbs, a communicating branch supplied the FDP.^{2,4,7,8,18,19} Among the 127 limbs that contained a communicating branch, 41 (32.3%) had a branch supplying the FDP.

Discussion

The UN was not the only nerve innervating the ring and little FDP. In more than one-third of cases, the little FDP received dual innervation from the AIN and the UN. In 14.6% of cases, the ring FDP received dual innervation from the AIN and the UN. In 8.8% of cases, the FDP was supplied by a communicating branch between the AIN and the UN.^{2,4,7,8,18,19}

Nerve communication (reflecting anatomical variations) between the median nerve and UN occurring in the forearm has been known as Martin-Gruber anastomosis.¹⁸ Brandsma reported a case who demonstrated the absence of finger clawing despite a complete UN lesion at the elbow. He stated that the Martin-Gruber anastomosis benefited this patient by eliminating the need for surgical restoration of lumbrical function.²¹

These findings explain the preservation of flexion in the distal phalanx of the ring and little fingers in patients with high UN lesions.³ The AIN entered the FDP at 107.63 (8.80) mm from the elbow, corresponding to 26.75% (2.17%) of the length of the forearm, measured proximally. These data will be helpful in surgical approaches and the injection of botulinum toxin.

The average number of AIN branches to the FDP was 2.27 (1.33). The average number of UN branches to the FDP was 1.37 (0.94). Anterior interosseous nerve branches were significantly more common than UN branches ($P < .001$, independent 2-sample t test). These results may be useful in the development and refinement of nerve-transferring techniques.

Some anatomical studies have focused on FDP innervation. In this systematic review, we reviewed 897 limbs that had been dissected. Only 2 papers indicated that the dissected limbs were from the right or left side, meaning that we had insufficient data to compare the right and left sides. In the papers that measured the point where the nerve entered the FDP, different anatomical landmarks were used. Therefore, we experienced some difficulties in summarizing the data.

In the majority (76.8%), the middle FDP received dual innervation from the AIN and the UN. In most cases, the ring FDP (85.4%) and the little FDP (64.6%) were innervated by the UN only. Thereafter, patients with AIN injury or UN injury are expected to be able to flex their middle finger using dual innervation.

In this systematic review, dual innervation was found in cadaver study, and the nerves were not stimulated to verify motor contribution, or the resultant strength preserved after sectioning one branch or the other. Further studies are needed to verify motor contribution.

The AIN entered the FDP at 107.63 (8.80) mm from the elbow, corresponding to 26.75% (2.17%) of the forearm length, measured proximally. In the patients with laceration at proximal one-fourth of forearm, injury of AIN should be suspected.

In this article, we performed a systematic review of the innervation of the FDP. The results of this study may be useful in managing nerve injury patients.

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Declaration of Conflicting Interests

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