

Innervation Patterns of the Pronator Teres Muscle and Their Possible Role in Neurotization: A Systematic Review of Cadaveric Studies

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ABSTRACT

Background: Contrary to the classic anatomical description, many recent studies have reported wide variations in branching patterns and location of motor branches that are supplying the pronator teres muscle. To understand these variations and their implications in surgical procedures of the nerve transfers, a systematic review was performed on the innervation of pronator teres muscle from cadaveric studies.

Methods: A systematic literature search was performed in databases such as Medline, PubMed, Google Scholar, SciELO, ScienceDirect, Cochrane reviews and orthopedics textbooks using the search terms “pronator teres nerve branches”; AND “number” OR “location” OR “length” OR “diameter” yielded 545 article links. Articles were evaluated according to PRISMA guidelines.

Results: A total of twenty cadaveric studies including 648 branches have registered 52.9% of two branch innervation pattern followed by 31.3%-single branch pattern; 13.5%-three branch pattern; 1.7%-four branch pattern, and 0.4%-five branch patterns, respectively. Of the 403 branches studied for their location in relation with the humeral intercondylar line, most branches were located distal to the line (50.3%), followed by 32.7% (proximal to it) and 16.8% at the line, respectively. The distance of branches located proximal and distal to humeral intercondylar line was in the range of 1.25–10 cm, and 1.1–7.5 cm, respectively. The mean length and diameter of nerves reported were 4.37 ± 2.43 cm, and 1.5 mm, respectively.

Conclusions: Our data defined the morphometrics of nerve branches and they often met the required diameter for neurotization procedures. Our findings also demonstrated that the morphometrics, branching pattern and their location vary between populations and this information is very vital for surgeons during the nerve transfers.

KEYWORDS

pronator teres; innervation; morphometrics; neurotization

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INTRODUCTION

Median nerve (Mn) is one of the important branches arising from C5–T1 roots via medial and lateral cords of the brachial plexus. After its formation, Mn descends through the arm along with brachial artery to reach the cubital fossa. Here it is closely related to the pronator teres muscle (PTM). PTM is a fusiform muscle that has a humeral head and an ulnar head. Humeral head extends from the medial epicondyle of humerus and medial intermuscular septum, and an ulnar head that originates from the coronoid process of the ulna. Both heads run downwards and merge to form a common flexor tendon, which inserts at the mid-portion of the lateral surface of radius (1, 2). The usual anatomical description is that the median nerve passes between two-headed PTM and gives a branch to it before entering the forearm (Fig. 1a and 1b). This branching site could be at a variable distance proximal to the elbow joint (3). Contrary to the classic description, many recent studies have reported variability in the motor branches of Mn that are supplying PTM. And these branches are located at a variable distance either proximal or distal to the humeral intercondylar line (HIL) or at the level of HIL (4–9). In cases, where more than one branch to the PTM is present, these remain as an effective alternative surgical option for nerve transfer procedures (5, 8, 10, 11). To this, a recent experimental study treating lower brachial plexus injury in rats confirmed that the PTM branches seem to be a better donor than the other nerves in their electrophysiological and histological examination (12).

Although a lot of clinical information is available on their role in nerve transfer procedures, the basic anatomical details facilitating the identification of these nerve branches is not so comprehensively reported in the literature. Despite their clinical importance, there is no accurate data available on the number, location and morphometrics of the nerves in association with ethnicity, gender and side. Therefore, we critically reviewed the available

literature regarding the innervation patterns of PTM and quantitatively interpreted the pooled data. We hope that this quantitative data may give a broader perspective to surgeons in avoiding iatrogenic injuries to these nerve branches and harvesting them safely for neurotization procedures.

MATERIALS AND METHODS

SEARCH STRATEGY AND INCLUSION-EXCLUSION CRITERIA

A thorough search was made mainly using the electronic databases such as Medline, PubMed, Google Scholar, Scielo, ScienceDirect, Cochrane reviews and orthopedics textbooks. The keywords for search used were as follows; [“(pronator teres nerve branches”) AND “number OR location OR length OR diameter”)]. To arrive at a standard dataset, we have strictly confined our search criteria to the cadaveric studies by excluding all the case reports, case series, letter to editor and brief communications from other clinical sources. The mean pooled data on PTM branches,

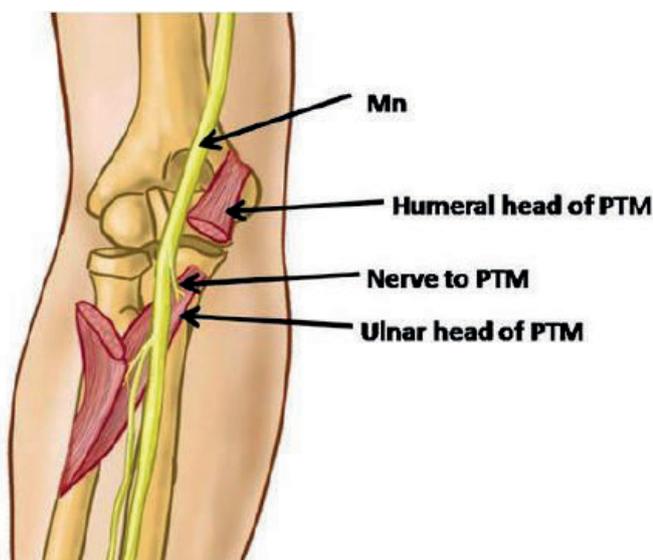


Fig. 1a Schematic diagram showing the pronator teres muscle with its innervation.

Mn: median nerve; PTM: pronator teres muscle.



Fig. 1b A cadaveric dissection showing the pronator teres muscle with its innervation (two branch pattern).

* Showing the PTM branches. Mn: median nerve; PTM: pronator teres muscle.

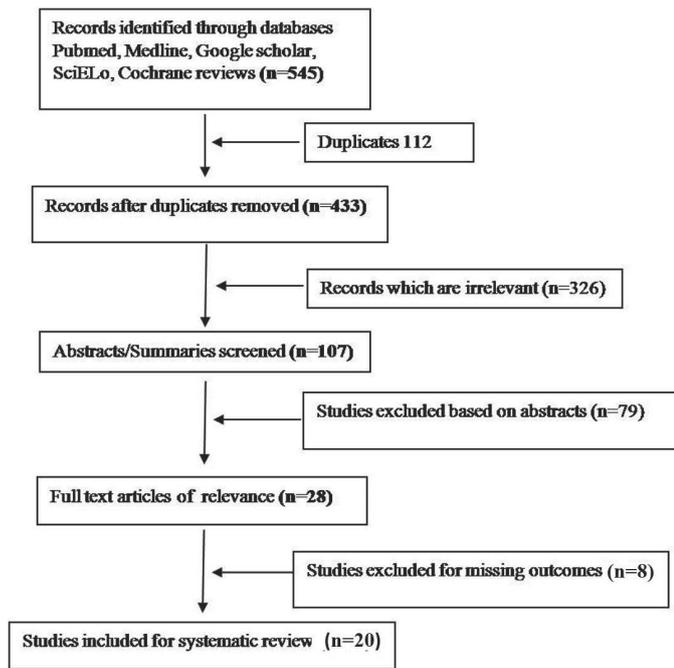


Fig. 2 Showing the application of selection criteria as per PRISMA guidelines.

their location with regards to HIL and their side and gender-based values were set to be the outcomes of our study. The references of the included articles were checked, and duplicates were deleted. We have not set restrictions on

date or language of the studies. Initial screening on titles and abstracts of the articles were done to obtain the full-text articles (Fig. 2). The data collection was done using the guidelines of Preferred Reporting Items for Systematic reviews and MetaAnalyses (PRISMA) checklist (13). Search strategy was carried out independently by two authors and no conflict was noticed.

STATISTICAL ANALYSIS

Extracted data included the country of study, sample size, number of the PTM branches and their length, the diameter and location. The mean ± SD were calculated for all the outcomes independently by two observers and no conflict was noticed. Then the mean values of all the outcomes were analyzed as per the population using SPSS Version 23.0 (USA).

RESULTS

A total of twenty cadaveric studies met the inclusion criteria (Fig. 2). All the limbs are of adults with an age ranging from 20–89 years. Five studies (4, 8, 10, 17, 22) reported their gender distribution with 69 males and 56 females from the total sample. Six studies (7, 17, 21, 23, 25, 26) have reported data on 159 left and 154 right limbs. Tables 1 and 2 show the characteristics of limbs with PTM and their branches.

Tab. 1 Characteristics of the included studies.

Studies (year)	Region	Sample size of limbs	Type of study	Age (Years)	Male	Female	Left	Right
Sunderland, 1978 [14]	UK	20	Cadaveric	NR	NR	NR	NR	NR
Fuss and Wurzl, 1990 [15]	Austria	50	Cadaveric	NR	NR	NR	NR	NR
Gunther et al., 1992 [16]	USA	20	Cadaveric	NR	NR	NR	NR	NR
Canovas et al., 1998 [4]	France	10	Cadaveric	70–85	4	6	NR	NR
Chantelot et al., 1999 [17]	France	50	Cadaveric	NR	20	30	25	25
Tung and Mackinnon, 2001 [5]	USA	31	Cadaveric	NR	NR	NR	NR	NR
Alves et al., 2004 [18]	Brazil	18	Cadaveric	NR	NR	NR	NR	NR
Safwat and Abdel-Meguid, 2007 [6]	Saudi Arabia	23	Cadaveric	NR	NR	NR	NR	NR
Demirci et al., 2007 [19]	Turkey	34	Cadaveric	NR	NR	NR	NR	NR
Tubbs et al., 2011 [10]	USA	20	Cadaveric	60–89	12	8	NR	NR
Pushpalatha et al., 2011 [20]	India	50	Cadaveric	NR	NR	NR	NR	NR
Bindurani et al., 2013 [21]	India	50	Cadaveric	20–50	NR	NR	26	24
Yang et al., 2014 [22]	China	30	Cadaveric	NR	18	12	NR	NR
Gupta et al., 2015 [23]	India	24	Cadaveric	NR	NR	NR	12	12
Olewnik et al., 2017 [7]	Poland	50	Cadaveric	NR	NR	NR	26	24
Basanagouda and Halagatti, 2017 [24]	India	62	Cadaveric	NR	NR	NR	NR	NR
Caetano et al., 2018 [8]	Brazil	30	Cadaveric	NR	15	NR	NR	NR
Gaikwad et al., 2018 [25]	India	39	Cadaveric	NR	NR	NR	20	19
Bertelli et al., 2020 [9]	Brazil	32	Cadaveric	NR	NR	NR	NR	NR
Vantmuri and Joshi, 2020 [26]	India	100	Cadaveric	25–70	NR	NR	50	50

NR: not reported.

Tab. 2 Outcomes of different studies on the number of branches to PTM.

Studies (year) & Region	Gender/ side	Number of PTM branches				
		One	Two	Three	Four	Five
Sunderland (1978) – UK [14]	Overall	7	14	0	0	0
Fuss and Wurzl (1990) – Austria [15]	Overall	14	22	10	4	0
Gunther et al. (1992) – USA [16]	Overall	1	6	3	0	0
Canovas et al. (1998) – France [4]	Overall	0	10	0	0	0
Chantelot et al. (1999) – France [17]	Overall	28	13	1	0	0
Tung and Mackinnon (2001) – USA [5]	Overall	8	16	5	1	0
Alves et al. (2004) – Brazil [18]	Overall	NS	NS	NS	NS	NS
Demirci et al. (2007) – Turkey [19]	Overall	4	19	10	1	0
Safwat and Abdel-Meguid (2007) – Saudi Arabia [6]	Overall	0	23	0	0	0
Tubbs et al. (2011) – USA [10]	Overall	NS	NS	NS	NS	NS
Pushpalatha et al. (2011) – India [20]	Overall	34	14	2	0	0
Bindurani et al. (2013) – India [21]	Overall	28	18	4	0	0
	Right	16	7	1	0	0
	Left	12	11	3	0	0
Yang et al. (2014) – China [22]	Overall	NS	NS	NS	NS	NS
Gupta et al. (2015) – India [23]	Overall	5	12	5	2	0
	Right	4	9	3	2	0
	Left	1	3	2	0	0
Olewnik et al. (2017) – Poland [7]	Overall	7	26	10	0	0
Basanagouda and Halagatti (2017) – India [24]	Overall	47	13	2	0	0
Caetano et al. (2018) – Brazil [8]	Overall	9	21	0	0	0
Gaikwad et al. (2018) – India [25]	Overall	1	9	21	3	3
	Right	0	3	11	1	2
	Left	1	6	10	2	1
Bertelli et al. (2020) – Brazil [9]	Overall	0	32	0	0	0
Vantmuri and Joshi (2020) – India [26]	Overall	10	75	15	0	0
	Right	3	40	7	0	0
	Left	7	35	8	0	0

PTM: pronator teres muscle; NS: not specified from their respective studies.

OUTCOMES ON THE NUMBER OF PTM BRANCHES

Of 648 branches studied from twenty studies have registered 52.9% of two branch innervation pattern) followed by 31.3% (for single-branch pattern); 13.5% (for three-branch pattern); 1.7% (for four-branch pattern) and 0.4% (for five-branch pattern), respectively. Pooled data of the branching pattern are listed in Tables 2 and 3. The percentage of single branches was in the range of 0–53.8% varying from population to population. The Saudis followed by Turkish population had the lowest single branches. The highest value was found among French population. The two-branch pattern was in the range of 43.6–100%. The Indian followed by Austria and French populations had the lowest double branches while the highest value was found in Saudi population.

In case of three branching pattern, Saudi, Brazilian and British followed by French population had the lowest triple branches. The highest value was found among Turkey and Poland populations. Whereas the percentage of four branching pattern was low in almost all the populations in the range of 0–2.9%. Only one study (25) reported five branches in three specimens (2 right and 1 left). 211 branches reported from four studies (21, 23, 25, 26) have analyzed the branching pattern in relation with side and no statistically significant differences ($P > 0.05$) found between right and left branching patterns. None of the studies have analyzed branching pattern in relation with sex (Table 2). Two studies from USA (10) and China (22) are not included in data as they did not mention the number of branches explicitly as per our search.

Tab. 3 Showing population wise percentages of the branches to PTM.

Country	% Single branches	% Double branches	% Triple branches	% Four branches	% Five branches
Saudi Arabia [6]	0	100	0	0	0
Turkey [19]	11.7	55.8	29.4	2.94	0
Brazil [8, 9, 18]	14.5	85.4	0	0	0
Poland [7]	16.2	60.4	23.2	0	0
USA [5, 10, 16]	22.5	55	20	2.5	0
Austria [15]	28	44	20	8	0
UK [14]	33.3	66.6	0	0	0
India [20, 21, 23-26]	38.6	43.6	15.1	1.54	0.9
France [4, 17]	53.8	44.2	1.92	0	0

PTM: pronator teres muscle.

OUTCOMES ON THE BRANCHING PATTERN OF PTM BRANCHES IN RELATION WITH HIL

Ten of twenty studies comprising 403 PTM branches have reported their location in relation with HIL (Table 4). Of 403 branches studied, majority (203 branches – 50.3%) located distal to HIL. Whereas 132 out of 403 branches (32.7%) located proximal to HIL, followed by 68 of 403 branches (16.8%) at the level of HIL. The French population reported zero percentage of branches located proximal to HIL while Indians having the highest percentage (55.9%). The American (0%) followed by French (1.4%) and Brazilian population (5.8%) reported the lowest branches at HIL while Indians having the highest (86.7%). Regarding branches located distal to HIL, it was observed that the British population had low percentage (3.9%) while the Indian population having the highest (50.2%) (Table 4). None of the studies have analyzed branching pattern in relation with sex (Table 4). Only one study (23) conducted on 52 branches from Indian population did explicitly analyze distance of the branches from HIL in relation with side and no significant differences ($P > 0.05$) found between right and left sides (Table 4).

Tab. 4 Outcomes of different studies on anatomical location of the branches with reference to HIL.

Studies (year) and Region	Type of study	Gender/ Side	Number of branches		
			Proximal to HIL	At HIL	Distal to HIL
Sunderland, 1978 – UK [14]	Cadaveric	Overall	8	4	8
Canovas et al., 1998 – France [4]	Cadaveric	Overall	0	1	9
Tung and Mackinnon, 2001 – USA [5]	Cadaveric	Overall	7	0	24
Alves et al., 2004 – Brazil [18]	Cadaveric	Overall	14	NR	7
Safwat and Abdel-Meguid, 2007 – Saudi Arabia [6]	Cadaveric	Overall	23	0	23
Gupta et al., 2015 – India [23]	Cadaveric	Overall	7	27	18
		Right	4	12	11
		Left	3	15	7
Basanagouda and Halagatti, 2017 – India [24]	Cadaveric	Overall	33	0	29
Caetano et al., 2018 – Brazil [8]	Cadaveric	Overall	14	NR	7
Gaikwad et al., 2018 – India [25]	Cadaveric	Overall	26	32	55
Bertelli et al., 2020 – Brazil [9]	Cadaveric	Overall	NR	4	23

HIL: humeral intercondylar line; NR: not reported.

Fourteen studies that presented population-wise data on the distance of branches located proximal and distal to HIL is shown in Table 5. The branches located proximal and distal to HIL in the range of 1.25–10 cm, and 1.1–7.5 cm, respectively (Fig. 3). None of the studies reported the distances in relation with sex.

Tab. 5 Outcomes on the distance of PTM nerve branches from HIL.

Studies (year) and Region	Distance of branches from HIL (cm)	
	Proximal	Distal
Sunderland, 1978 – UK [14]	7.0	2.3
Fuss and Wurzl, 1990 – Austria [15]	3.5	5.5
Gunther et al., 1992 – USA [16]	4.5	3.5
Canovas et al., 1998 – France [4]	7.1	2.4
Tung and Mackinnon, 2001 – USA [5]	1.25	1.35
Alves et al., 2004 – Brazil [18]	4.9	1.5
Bindurani et al., 2013 – India [21]	1.31	1.2
Yang et al., 2014 – China [22]	NR	3.87
Gupta et al., 2015 – India [23]	10.0	3.0
Olewnik et al., 2017 – Poland [7]	NR	5.3
Basanagouda and Halagatti, 2017 – India [24]	5.0	7.5
Caetano et al., 2018- Brazil [8]	6.8	2.8
Gaikwad et al., 2018 – India [25]	2.5	1.1
Bertelli et al., 2020 – Brazil [9]	1.5	3.8

PTM: pronator teres muscle; HIL: humeral intercondylar line; NR: not reported.

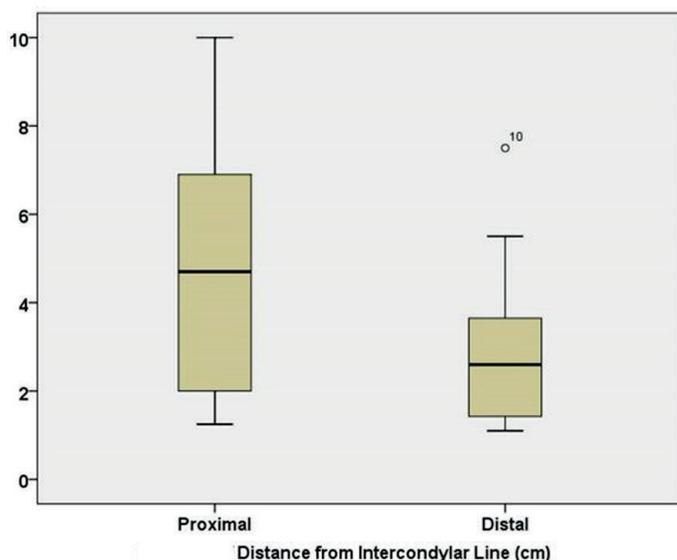


Fig. 3 Showing the distance of PTM branches located proximal and distal to HIL.

HIL: humeral intercondylar line.

OUTCOMES ON THE MEAN LENGTH AND DIAMETER OF PTM BRANCHES

Six studies (5, 8–10, 18, 22) reported the mean length and three studies (8–10) reported the diameter of PTM branches. The mean length of proximal PTM branches reported from two studies (5, 9) was 2.45 ± 0.25 cm, ranged from 2.2 ± 0.8 cm (USA) to 2.7 ± 8 cm (Brazil). The mean length of distal branches was 3.35 ± 0.45 cm, ranged from 2.9 ± 1.0 cm (USA) to 3.8 ± 1.5 cm (Brazil). Four studies (8, 10, 18, 22) reported the mean length (without specifying the proximal and distal branches) as 5.85 ± 2.38 cm, ranged from 3.6 cm (USA) to 9.6 cm (China). Overall, mean length of the nerves from all reported studies is 4.37 ± 2.43 cm. Only one study from Brazil (9) reported the mean diameter of proximal and distal PTM branches and these were 1.4 ± 0.4 mm and 1.3 ± 0.4 mm, respectively. In two reported studies (8, 10) the mean diameter (without specifying the proximal and distal branches) was 1.5 mm. None of the studies analyzed length and diameter of the nerves in relation with sex and side (Table 6).

Tab. 6 Outcomes of different studies on morphometry of the PTM branches.

Studies (year) and Region	Type of study	Gender/Side	Nerve length (cm)	Nerve diameter (mm)
Tung and Mackinnon, 2001 – USA [5]	Cadaveric	Overall	2.2 ± 0.8 (P); 2.9 ± 1.0 (D)	NR
Alves et al., 2004 – Brazil [18]	Cadaveric	Overall	6.2	NR
Tubbs et al., 2011 – USA [10]	Cadaveric	Overall	3.6	1.5
Yang et al., 2014 – China [22]	Cadaveric	Overall	9.64 ± 0.71	NR
Caetano et al., 2018 – Brazil [8]	Cadaveric	Overall	4.0 ± 1.2	1.5 ± 0.6
Bertelli et al., 2020 – Brazil [9]	Cadaveric	Overall	2.7 ± 8 (P); 3.8 ± 15 (D)	1.4 ± 0.4 (P); 1.3 ± 0.4 (D)

P: proximal branch; D: distal branch; NR: not reported.

DISCUSSION

Our study revealed considerable variations in the innervation pattern of PTM contrary to the classic description of anatomical textbooks. We found majority of the branches (52.9%) are two in number and most of the branches are located distal to HIL (50.3%) from the reported studies. Knowledge on the number and location of branches is very important for clinicians in planning the appropriate type of electrostimulation in rehabilitation process to

restore the motor function (6, 27). It is very surprising to see the data on number of PTM branches in relation with gender; side is very vague and quite often not reported in the published studies. The French followed by American population having a low percentage of branches located proximal to HIL. The American followed by French and Brazilian populations having the lowest branches at HIL while Indians having the highest. Whereas the British having low percentage of branches distal to HIL while Indians having the highest (Table 4). We firmly believe that the above comparison and knowledge of knowing their population wise distances from the HIL (Table 5) can be of help while undertaking the surgical intervention procedures associated with pronator teres syndrome, pronator teres rerouting or neurotomy etc.

The quantitative anatomical studies investigating PTM nerve morphometrics are found to be relatively rare. This finding is unexpected given the widespread use of PTM nerves in neurotization procedures. During neurotization procedures, surgeons usually face a challenge in searching an adequate nerve which has an appropriate length and diameter. From our analysis, we found that the length of PTM nerves ranging from 2.2–9.6 cm (Table 6). Predominantly, studies reported measuring the length of PTM branches from their point of origin (from Mn) to the point where they enter the muscle. Our observation of wide variation in the length of branches is up to 7.4 cm. The nerve length is shown to vary between populations. Our analysis reported the nerve length is shortest in Americans while Chinese having the longest. Despite using the same anatomical landmarks for measurements in both studies, they are seen to have significantly different values (Table 6). The reason for this wide variation could be the differences in usage of embalmed vs. fresh cadavers or the length of limb or age of the cadaveric sample. Our data shows that the branches are in enough length to reach the important motor nerves such as anterior interosseous nerve (AIN), radial nerve branches to extensor carpi radialis brevis (ECRB), extensor carpi radialis longus (ECRL) and posterior interosseous nerve (PIN). Caetano et al. (8) based on findings in 12 limbs reported that one of the PTM branches is too long to be connected to the PIN distal to the emergence of the nerve to supinator muscle.

We analyzed the mean diameter of PTM branches from 82 limbs of three studies (Table 6). The mean diameter of the proximal and distal branches of PTM reported from studies is: 1.45 ± 0.5 mm; 1.3 ± 0.4 mm, respectively. Two studies (8, 10) on 50 limbs have reported the mean diameter of nerve as 1.5 mm without specifying the proximal and distal measurements. The reported mean diameter of these nerves is almost compatible and corresponding to the mean diameters of AIN, ECRL and ECRB. Few studies have reported the mean diameter of AIN as 1.6 mm (28); 1.7 mm (8) and 2.0 mm (29), respectively. The mean diameter of PTM branches from our analysis is almost corresponding to 94%; 88% and 75% of the mean diameter of AIN from the above reported studies. In addition to AIN, the mean diameter of branches for the ECRL (1.5 ± 0.6 mm) and ECRB (1.4 ± 0.7 mm) reported by Caetano et al. (8) are also corresponding to 100% and

90% of the diameter of PTM branches observed by us. On the other hand, studies have also reported the diameter of PIN as 3.0 ± 0.5 mm (8, 30) and the compatibility of PTM branches to PIN from these reports seems to be 50%. Our analysis on the above compatibilities further supported by a recent histomorphometric study, wherein, the PTM branches are seen to have an average of 646 and 599 myelinated fibers in both proximal and distal branches, respectively. These myelinated fibers are more or less close to the 548 and 457 fibers of ECRB reported (9, 31). The above comparison of diameter differences and nerve fibers might give an explicit idea about selecting the donor nerve for neurotization procedures. It may not be possible to get a 100% accurate donor nerve with identical structure of the recipient nerve at both macro and microarchitectural properties. Few papers published in the past on animal experiments have demonstrated that the axonal multiplication between donor and recipient was 1 : 3 (32) and at least 30% of the original motor neurons are required to achieve normal muscle function (33). Therefore, the donor nerve must have at least 30% of the number of axons of the receptor nerve (34). And the quantitative data which we have procured from the literature is clearly supporting the assumption that the PTM branches are compatible (50–100%) to all the nearby motor nerves.

In conclusion, our pooled data demonstrated that the innervation patterns of PTM branches vary between populations in terms of their number, location, and morphometry. These variations between number, length, diameter, and their placement in relation with HIL could be a result of anatomical dissections they have performed on embalmed vs. fresh cadavers. Although such procedural bias could exist, the larger pooled data of our study could give a standard dataset about their morphometry and we firmly believe that this data is of help for surgeons in comparing donor and recipient sites pre-operatively.

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AUTHOR CONTRIBUTIONS

BKP: Conceptualized and designed the study, reviewed the literature, compiled all the data, drafted the manuscript. MVRS: Independently reviewed the literature, involved in thorough checking of all the data and references. Both authors approved the final manuscript submitted for publication.

COMPETING INTERESTS

The authors declare that they have no competing interests associated with this manuscript.

ABBREVIATIONS

AIN: Anterior Interosseous Nerve
 ECRB: Extensor Carpi Radialis Brevis,
 ECRL: Extensor Carpi Radialis Longus
 HIL: Humeral Intercondylar Line
 Mn: Median nerve
 PIN: Posterior Interosseous Nerve
 PTM: Pronator Teres Muscle

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