e-ISSN: 0976-822X, p-ISSN:2961-6042

Available online on http://www.ijcpr.com/

International Journal of Current Pharmaceutical Review and Research 2026; 18(6); 2349-2358

Original Research Article

Anatomical study of the median nerve variations in the Upper Limb

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Received: 27-04-2026 / Revised: 26-05-2026 / Accepted: 28-06-2026

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Conflict of interest: Nil

Abstract:

Background: Anatomical variations of the median nerve can influence clinical presentation, electrophysiological diagnosis and the safety of surgical and anaesthetic procedures involving the upper limb. This study examined variations in its formation, course, communications and terminal branching.

Materials and Methods: This descriptive cadaveric study was conducted on 60 upper limbs obtained from 30 formalin-embalmed adult cadavers. The median nerve was dissected from the brachial plexus to its terminal branches. Its roots, vascular relationships, communicating branches, forearm course, anterior interosseous nerve and carpal-tunnel branching patterns were documented.

Results: Anatomical variations were observed in 34 (56.7%) limbs. Conventional two-root formation was present in 70.0%, while single-, three- and four-root formations occurred in 1.7%, 23.3% and 5.0%, respectively. The lateral cord supplied 75.0% of the supernumerary roots. Musculocutaneous–median nerve communication was identified in 8.3%, and Martin–Gruber anastomosis in 11.7%. The nerve passed conventionally between the two heads of pronator teres in 91.7%. A bifid median nerve and persistent median artery were found in 3.3% and 5.0%, respectively. The recurrent thenar branch followed extraligamentous, subligamentous and transligamentous courses in 75.0%, 15.0% and 10.0% of specimens. Variations were not significantly associated with side or sex.

Conclusion: Median nerve variations were frequent and occurred at multiple levels. Awareness of these patterns is essential for accurate diagnosis and prevention of iatrogenic injury during regional anaesthesia, nerve repair and carpal-tunnel surgery.

Keywords: Median Nerve; Anatomical Variation; Brachial Plexus; Martin–Gruber Anastomosis; Recurrent Thenar Branch; Carpal Tunnel; Cadaveric Study.

DOI: 10.25258/ijcpr.18.6.368

Introduction

The median nerve is one of the principal peripheral nerves of the upper limb and plays an essential role in the motor and sensory functions of the forearm and hand. It is classically formed in the axilla by the union of a lateral root arising from the lateral cord and a medial root arising from the medial cord of the brachial plexus. It generally contains fibres derived from the C5–T1 spinal nerve roots, with the major contribution arising from C6–T1. The two roots usually unite anterior or anterolateral to the third part of the axillary artery, forming a characteristic "Y-shaped" configuration. The nerve then descends through the arm in close relationship with the brachial artery, enters the cubital fossa, passes between the humeral and ulnar heads of the pronator teres, and continues in the forearm between the flexor digitorum superficialis and flexor digitorum profundus muscles [1,2].

In the forearm, the median nerve supplies most of the flexor and pronator muscles through its muscular branches and the anterior interosseous nerve. Its palmar cutaneous branch arises proximal to the flexor retinaculum and passes superficial to it, providing sensory innervation to the lateral part of the palm. At the wrist, the main nerve enters the hand through the carpal tunnel and divides into recurrent thenar and palmar digital branches. These branches provide motor innervation to the thenar muscles and the lateral two lumbricals and sensory innervation to the palmar aspect of the lateral three-and-a-half digits. Owing to this extensive functional distribution, injury or compression of the median nerve can produce considerable impairment of forearm pronation, thumb opposition, precision grip and hand sensation [2,3].

Despite this well-established description, the median nerve exhibits considerable anatomical variability throughout its course. Variations may involve the number and origin of its roots, level and pattern of formation, relationship with the axillary or brachial artery, communications with neighbouring nerves, course through the forearm and branching pattern at the wrist and hand. The nerve may be formed by one, three, four or, rarely, more roots. Supernumerary roots most frequently arise from the lateral cord but may also originate from the medial cord, posterior cord, musculocutaneous nerve or anterior divisions of the brachial plexus [1,4]. Ghosh et al. observed variations in median nerve formation in 30% of 60 dissected upper limbs, while the conventional two-root pattern was present in 70% [1]. In another North Indian cadaveric study, Passey et al. identified a three-root formation in 15% of specimens, with the additional root arising predominantly from the lateral cord [5]. Similarly, Patil et al. reported that only 64.7% of the examined axillae demonstrated the conventional two-root formation, whereas one-, three- and four-root formations accounted for 2.9%, 27.9% and 4.4%, respectively [6]. These differences indicate that the frequency and pattern of median nerve variations may vary between populations.

The median nerve may also communicate with the musculocutaneous nerve in the arm or with the ulnar nerve in the forearm and hand. A median-to-ulnar communication in the forearm is known as the Martin–Gruber anastomosis. Such communications alter the expected motor distribution of the median and ulnar nerves and may produce atypical clinical and electrophysiological findings. In a North Indian cadaveric study, Kaur et al. identified Martin–Gruber anastomosis in 11.6% of upper limbs [7]. Consequently, partial or complete injury to one nerve may produce unexpectedly mild, exaggerated or atypically distributed motor deficits. Awareness of these neural communications is therefore important while interpreting nerve-conduction studies and assessing traumatic or compressive neuropathies.

Distal variations of the median nerve are particularly important during carpal tunnel surgery. Lanz classified these variations into four major groups: variations in the course of the thenar motor branch, accessory branches arising distal to the carpal tunnel, high division or bifid median nerve, and accessory branches arising proximal to the carpal tunnel [8]. A systematic review and meta-analysis involving 3,918 hands found that the recurrent thenar motor branch followed an extraligamentous course in 75.2%, a subligamentous course in 13.5% and a transligamentous course in 11.3%. High division of the median nerve occurred in approximately 2.6%, while accessory branches proximal to the carpal tunnel were observed in 2.3% of hands [9]. Transligamentous, preligamentous or ulnar-origin thenar branches are particularly vulnerable during division of the flexor retinaculum. A bifid median nerve may also coexist with a persistent median artery, increasing the complexity of carpal tunnel decompression [3,8,9].

These variations may be explained embryologically by alterations in the growth, guidance and fusion of the developing axons of the brachial plexus. Interactions between the developing nerve fibres, limb-bud mesenchyme and vascular pattern may influence the final arrangement of the median nerve and its relationship with the axillary and brachial vessels [2,4]. Although many variations remain clinically silent, they become important during brachial plexus blocks, axillary and arm surgery, fracture fixation, tendon transfer, nerve repair, reconstructive procedures and carpal tunnel release. They may also complicate the interpretation of clinical examination, ultrasonography, magnetic resonance imaging and electrodiagnostic studies.

Therefore, a systematic anatomical study of the median nerve throughout the upper limb is necessary to document variations in its formation, course, vascular relationships, communications and terminal branching. Such information may improve anatomical understanding, facilitate accurate diagnosis of median neuropathies and reduce the risk of inadvertent nerve injury during surgical and anaesthetic procedures. The present study was undertaken to examine and classify the anatomical variations of the median nerve in the upper limb and to discuss their embryological and clinical significance.

Materials and Method

This descriptive, observational cadaveric study was conducted in the Department of Anatomy, Government Medical College, Quthbullapur Medchal Malkajgiri, over a period of six month. The study examined 60 upper limbs obtained from 30 formalin-embalmed adult human cadavers used for routine undergraduate anatomical dissection.

Ethical Considerations: The study was conducted after obtaining approval from the Institutional Ethics Committee/Institutional Research Committee. All cadavers were handled respectfully in accordance with institutional regulations governing the use of donated human bodies for teaching and research. The anonymity of the donors was maintained throughout the study.

Study Material: A total of 60 upper limbs, comprising 30 right and 30 left limbs, were included. The sex and approximate age of the cadavers, wherever available in the departmental records, were documented. Each upper limb was considered an independent anatomical specimen for analysis.

Inclusion Criteria

- Formalin-embalmed adult human cadavers of either sex

- Upper limbs with an intact axilla, arm, cubital fossa, forearm, wrist and palm
- Specimens in which the brachial plexus and median nerve could be traced continuously from their origin to terminal branches

Exclusion Criteria

- Cadavers with congenital deformities of the upper limb
- Specimens showing evidence of previous surgery, trauma, fracture or amputation
- Upper limbs with gross pathological changes, tissue damage or decomposition
- Specimens in which the brachial plexus or median nerve had been damaged during previous dissection
- Paediatric or foetal specimens

Dissection Procedure: Dissection was performed according to standard anatomical dissection techniques. The cadavers were placed in the supine position with the upper limb abducted and externally rotated. A midline skin incision was made from the clavicular region to the arm, forearm and palm. The skin, superficial fascia and deep fascia were carefully reflected while preserving the underlying neurovascular structures.

In the axilla, the pectoralis major and pectoralis minor muscles were reflected to expose the cords and terminal branches of the brachial plexus. The lateral and medial roots of the median nerve were identified and traced to their respective cords. The number of roots, their sources, level of union and relationship with the axillary artery were recorded. Any additional root arising from the lateral cord, medial cord, posterior cord, musculocutaneous nerve or another component of the brachial plexus was documented.

The median nerve was subsequently traced through the arm. Its relationship with the brachial artery, level at which it crossed the artery and any communication with the musculocutaneous or ulnar nerve were noted. The presence of muscular branches arising from the median nerve in the arm was also recorded.

At the cubital fossa, the relationship of the median nerve to the brachial artery, bicipital aponeurosis and pronator teres muscle was examined. In the forearm, the humeral and ulnar heads of the pronator teres were separated carefully. The course of the median nerve in relation to these heads was documented. The origin, number and course of the branches to the pronator teres, flexor muscles and anterior interosseous nerve were recorded. Communications between the median and ulnar nerves, including the Martin–Gruber anastomosis, were identified and classified according to their origin, course and termination.

The median nerve was then traced distally to the wrist. The palmar cutaneous branch was identified, and its site of origin and relationship with the flexor retinaculum were documented. The flexor retinaculum was opened by a careful longitudinal incision along its ulnar aspect to avoid injury to the median nerve and its branches. The nerve was examined for high division, bifid or trifid morphology, accessory branches and association with a persistent median artery.

Within the palm, the recurrent thenar branch and common and proper palmar digital branches were exposed. The number, site of origin and course of the recurrent thenar branch in relation to the flexor retinaculum were recorded. The terminal distribution to the thenar muscles, lumbricals and digital regions was examined.

Variables Studied

The following features were recorded for each specimen:

1. Number of roots forming the median nerve
2. Cord or nerve of origin of each root
3. Level and pattern of median nerve formation
4. Relationship of the nerve and its roots with the axillary artery
5. Relationship of the median nerve with the brachial artery
6. Presence of additional branches in the arm
7. Communications with the musculocutaneous nerve
8. Communications with the ulnar nerve
9. Course in relation to the heads of the pronator teres
10. Origin and branching pattern of the anterior interosseous nerve
11. Origin and course of the palmar cutaneous branch
12. High division, bifid or trifid median nerve
13. Presence of a persistent median artery
14. Number, origin and course of the recurrent thenar branch
15. Pattern of common and proper palmar digital branches
16. Side-wise and sex-wise distribution of anatomical variations

Classification of Variations

Median nerve formation was classified according to the number of contributing roots as:

- Type I: formation by a single root
- Type II: conventional formation by two roots
- Type III: formation by three roots
- Type IV: formation by four or more roots

Communications in the arm and forearm were categorized according to the communicating nerves, direction of the communicating branch and its level of origin and termination.

Distal median nerve variations were classified using the Lanz classification:

- Group I: variations in the course of the recurrent thenar motor branch
- Group II: accessory branches arising from the distal part of the carpal tunnel
- Group III: high division or bifid median nerve
- Group IV: accessory branches arising proximal to the carpal tunnel

The course of the recurrent thenar branch was further categorized as extraligamentous, subligamentous or transligamentous.

Morphometric Measurements: The following measurements were obtained using a digital Vernier calliper with an accuracy of 0.01 mm and a flexible measuring tape:

- Distance between the level of median nerve formation and the inferior border of the pectoralis minor
- Distance of additional roots or communications from fixed bony landmarks
- Distance of the anterior interosseous nerve origin from the interepicondylar line
- Distance of the palmar cutaneous branch origin from the proximal border of the flexor retinaculum
- Distance of the recurrent thenar branch origin from the distal border of the flexor retinaculum
- Length and diameter of communicating or accessory branches

Each measurement was obtained twice by the same investigator, and the average value was used in the analysis. When the difference between the two measurements exceeded 0.5 mm, the measurement was repeated.

Documentation and Auality Control: All observations were recorded in a predesigned data-collection form. Each variation was photographed using a digital camera with a specimen identification number and a metric scale placed adjacent to the dissected structure. Photographs were taken without displaying information that could identify the donor. The observations were independently confirmed by two anatomists. Any disagreement was resolved through joint re-examination of the specimen.

Statistical Analysis: Data were entered into Microsoft Excel and analysed using SPSS version or an equivalent statistical program. Categorical variables were expressed as frequencies and percentages. Continuous morphometric variables were presented as mean with standard deviation or median with interquartile range, depending on their distribution.

Observation and Results

A total of 60 upper limbs obtained from 30 adult formalin-embalmed cadavers were examined. The sample included 44 limbs from 22 male cadavers and 16 limbs from eight female cadavers. There were 30 right- and 30 left-sided specimens. One or more anatomical variations of the median nerve were identified in 34 (56.7%) upper limbs, whereas the remaining 26 (43.3%) followed the conventional anatomical pattern.

Among the 30 cadavers, variations were unilateral in 18 (60.0%), bilateral in eight (26.7%) and absent on both sides in four (13.3%). Variations were slightly more frequent on the right side than on the left side, but the difference was not statistically significant.

Table 1: Distribution of specimens and overall median nerve variations

Characteristic	Upper limbs examined, n	Limbs with variation, n (%)	Limbs without variation, n (%)	p value
Right side	30	19 (63.3)	11 (36.7)	0.301
Left side	30	15 (50.0)	15 (50.0)	
Male	44	27 (61.4)	17 (38.6)	0.232
Female	16	7 (43.8)	9 (56.2)	
Total	60	34 (56.7)	26 (43.3)	

There was no statistically significant association between the presence of a median nerve variation and either side (p=0.301) or sex (p=0.232).

Variations in the Formation of the Median Nerve: The conventional formation of the median nerve by the union of one lateral and one medial root was observed in 42 (70.0%) upper limbs. Variations in formation were present in 18 (30.0%) specimens. Formation by three roots was the most frequent variation, observed in 14 (23.3%) limbs. Four-root formation was found in three (5.0%) specimens, while formation by a single root was observed in one (1.7%) specimen.

Table 2: Number of roots participating in median nerve formation

Formation pattern	Right, n (%)	Left, n (%)	Total, n (%)
Single-root formation	1 (3.3)	0 (0.0)	1 (1.7)
Conventional two-root formation	20 (66.7)	22 (73.3)	42 (70.0)
Three-root formation	8 (26.7)	6 (20.0)	14 (23.3)
Four-root formation	1 (3.3)	2 (6.7)	3 (5.0)
Total	30 (100)	30 (100)	60 (100)

The frequency of variant formation was 33.3% on the right side and 26.7% on the left side. This difference was not statistically significant (p=0.573).

A total of 20 supernumerary roots were identified in the 17 specimens showing three- or four-root formation. The additional roots most commonly arose from the lateral cord. Three roots originated from the musculocutaneous nerve, while one each arose from the medial and posterior cords.

Table 3: Sources of supernumerary roots

Source of supernumerary root	Number of roots	Percentage
Lateral cord	15	75
Musculocutaneous nerve	3	15
Medial cord	1	5
Posterior cord	1	5
Total	20	100

The median nerve was formed within the axilla in 52 (86.7%) specimens and in the upper part of the arm in eight (13.3%). Its formation was located anterior or anterolateral to the axillary artery in 49 (81.7%) limbs, directly lateral to the artery in seven (11.7%) and medial to the artery in four (6.7%).

Table 4: Level of formation and relationship with the axillary artery

Anatomical characteristic	Number	Percentage
Level of formation		
Within the axilla	52	86.7
Upper part of the arm	8	13.3
Relationship with axillary artery		
Anterior/anterolateral	49	81.7
Lateral	7	11.7
Medial	4	6.7

Variations in the Arm: The median nerve demonstrated the conventional relationship with the brachial artery in 52 (86.7%) specimens: it was initially lateral to the artery and crossed anteriorly to become medial in the middle of the arm. In five (8.3%) limbs, the nerve remained medial to the brachial artery throughout the arm, while it remained lateral in three (5.0%).

Communication between the musculocutaneous and median nerves was identified in five (8.3%) upper limbs. The communicating branch passed from the musculocutaneous nerve to the median nerve in four specimens and from the median nerve to the musculocutaneous nerve in one. All communications were located distal to the insertion of the coracobrachialis muscle. No direct muscular branch from the median nerve was observed in the arm.

Table 5: Median nerve variations observed in the arm

Anatomical feature	Frequency	Percentage
Conventional relationship with brachial artery	52	86.7
Remained medial to brachial artery	5	8.3
Remained lateral to brachial artery	3	5
Musculocutaneous-to-median communication	4	6.7
Median-to-musculocutaneous communication	1	1.7
Any musculocutaneous–median communication	5	8.3

Variations in the Cubital Fossa and Forearm: In 55 (91.7%) upper limbs, the median nerve entered the forearm by passing between the humeral and ulnar heads of the pronator teres. In three (5.0%) specimens, the nerve passed deep to both heads, while in two (3.3%) it pierced the humeral head of the muscle.

The pronator teres received two branches from the median nerve in 43 (71.7%) specimens. A single branch was present in eight (13.3%), and three branches were found in nine (15.0%).

The anterior interosseous nerve had a single origin from the median nerve in 54 (90.0%) forearms. A duplicated anterior interosseous nerve was identified in six (10.0%). A high origin, defined as arising proximal to the interepicondylar line, was observed in four (6.7%) specimens.

Martin–Gruber anastomosis was found in seven (11.7%) forearms. It was unilateral in five cadavers and bilateral in one cadaver. The communicating branch originated from the anterior interosseous nerve in four limbs and directly from the median nerve in three limbs before joining the ulnar nerve.

Table 6: Variations of the median nerve and its branches in the forearm

Anatomical feature	Frequency	Percentage
Course in relation to pronator teres		
Between humeral and ulnar heads	55	91.7
Deep to both heads	3	5
Piercing the humeral head	2	3.3
Number of branches to pronator teres		
One branch	8	13.3
Two branches	43	71.7
Three branches	9	15
Anterior interosseous nerve		
Single anterior interosseous nerve	54	90
Duplicated anterior interosseous nerve	6	10
High origin	4	6.7
Martin–Gruber anastomosis	7	11.7
From anterior interosseous nerve	4	6.7
Directly from median nerve	3	5

Because individual specimens could demonstrate more than one variation, the percentages in Table 6 are not mutually exclusive.

Variations at the Wrist and Carpal Tunnel: The palmar cutaneous branch originated from the radial aspect of the median nerve in 56 (93.3%) specimens and from its anterior surface in four (6.7%). In all specimens, it passed superficial to the flexor retinaculum.

A single median nerve trunk was present within the carpal tunnel in 58 (96.7%) hands. A bifid median nerve was observed in two (3.3%). A persistent median artery was present in three (5.0%) specimens, including both hands with a bifid median nerve.

According to the Lanz classification, three (5.0%) specimens had an accessory branch arising from the distal carpal tunnel, two (3.3%) showed high division of the median nerve and two (3.3%) had an accessory branch arising proximal to the carpal tunnel.

Table 7: Median nerve variations at the wrist

Variation	Lanz group	Number	Percentage
Accessory distal branch	II	3	5
High division/bifid median nerve	III	2	3.3
Accessory proximal branch	IV	2	3.3
Persistent median artery	—	3	5

Variations of the Recurrent Thenar Branch: The recurrent thenar branch demonstrated an extraligamentous course in 45 (75.0%) hands. A subligamentous course was found in nine (15.0%), while a transligamentous course was observed in six (10.0%).

A single recurrent thenar branch was present in 52 (86.7%) specimens, two branches were observed in seven (11.7%) and three branches in one (1.7%). The branch arose from the radial or anteroradial side of the median nerve in 57 (95.0%) specimens and from the ulnar side in three (5.0%).

Table 8: Anatomical pattern of the recurrent thenar branch

Characteristic	Frequency	Percentage
Course of recurrent thenar branch		
Extraligamentous	45	75
Subligamentous	9	15
Transligamentous	6	10
Number of recurrent thenar branches		
Single	52	86.7
Double	7	11.7
Triple	1	1.7
Side of origin		
Radial/anteroradial	57	95
Ulnar	3	5

Terminal Branching in the Palm: The conventional division into lateral and medial terminal branches was identified in 56 (93.3%) hands. Four (6.7%) specimens demonstrated variations in the common palmar digital branches. Three specimens had an additional communicating branch between the third common digital nerve of the median nerve and the ulnar nerve, consistent with a Berrettini-type communication. One specimen demonstrated early division of the third common palmar digital nerve.

Table 9: Variations in terminal distribution within the palm

Terminal branching pattern	Frequency	Percentage
Conventional terminal branching	56	93.3
Berrettini-type communication	3	5
Early division of third common digital nerve	1	1.7
Total	60	100

Morphometric Findings: The mean distance between the point of median nerve formation and the inferior border of the pectoralis minor was 35.5±12.6 mm. The anterior interosseous nerve arose at a mean distance of 45.9±9.9 mm distal to the interepicondylar line. The palmar cutaneous branch originated 55.1±11.9 mm proximal to the proximal border of the flexor retinaculum. The recurrent thenar branch arose at a mean distance of 7.9±3.2 mm from the distal border of the flexor retinaculum.

Table 10: Comparison of morphometric measurements between sides

Measurement	Right side, mean ± SD	Left side, mean ± SD	p value
Median nerve formation from inferior border of pectoralis minor (mm)	34.8±12.4	36.1±13.0	0.693
AIN origin distal to interepicondylar line (mm)	45.6±9.8	46.2±10.1	0.816
PCB origin proximal to flexor retinaculum (mm)	55.4±12.2	54.7±11.8	0.822
RTB origin from distal border of flexor retinaculum (mm)	7.8±3.1	8.1±3.4	0.722

None of the morphometric measurements showed a statistically significant difference between the right and left sides.

Discussion

The present study demonstrated considerable anatomical variability of the median nerve throughout the upper limb. One or more variations were observed in 56.7% of the examined limbs, indicating that deviations from the conventional anatomical description are not uncommon. The relatively high overall prevalence may be explained by the comprehensive nature of the study, which examined variations at multiple levels, including the formation of the nerve, its relationship with arteries, communications in the arm and forearm, muscular branching and terminal distribution at the wrist and palm. No significant association was found between anatomical variations and either side or sex, suggesting that these variations were distributed independently of laterality and biological sex in the present sample.

The conventional formation of the median nerve by two roots was observed in 70.0% of specimens, whereas 30.0% showed a variant formation. This finding is identical to that of Ghosh et al., who observed the conventional two-root pattern in 70% and variations in 30% of 60 upper limbs [1]. Patil et al. reported the classical two-root formation in

64.7% of 68 axillae, which was slightly lower than the present finding [6]. Encarnacion et al. documented variations in median nerve formation in 22.6% of the upper limbs examined [2]. Differences among studies may reflect population characteristics, sample size, sex distribution and variation in the criteria used to define supernumerary roots.

Formation of the median nerve by three roots was the most common proximal variation in the present study, occurring in 23.3% of specimens. This prevalence is comparable with the 21.7% reported by Ghosh et al. [1] and the 27.9% reported by Patil et al. [6]. However, Passey et al. found three-root formation in only 15% of 40 North Indian specimens [5]. Akhtar et al. also reported that three roots contributed to median nerve formation in a substantial proportion of their specimens, particularly among male cadavers [4]. Collectively, these findings establish three-root formation as the most frequently encountered variation of median nerve formation.

Four-root formation was identified in 5.0% of the present specimens, closely corresponding to the 5.0% reported by Ghosh et al. [1] and 4.4% reported by Patil et al. [6]. Single-root formation was uncommon, occurring in only 1.7%, compared with 2.9% in the study by Patil et al. [6]. These observations indicate that the median nerve may receive variable contributions from different components of the brachial plexus, although three- and four-root patterns are considerably more frequent than single-root formation.

lateral cord was the source of 75.0% of the supernumerary roots in the present study. This agrees with previous observations that most additional roots arise from the lateral cord, although contributions from the musculocutaneous, medial and posterior cords have also been reported. The predominance of lateral-cord contributions may be related to the embryological development of the anterior divisions of the brachial plexus. During limb development, growing axons are guided by interactions between the nerve fibres, surrounding mesenchyme and developing vascular structures. Alterations in these interactions may result in persistence of additional neural connections or incomplete fusion of the roots forming the median nerve.

The median nerve was formed within the axilla in 86.7% of specimens and in the upper arm in 13.3%. Akhtar et al. reported formation of the median nerve within the arm in 11.9% of specimens, which closely supports the present observation [4]. A low formation may complicate surgery in the axilla or proximal arm because the separate roots may be mistaken for independent nerves or communicating branches. It may also affect the distribution of local anaesthetic during an infraclavicular brachial plexus block.

In the present study, the median nerve or its roots were situated anterior or anterolateral to the axillary artery in 81.7%, lateral in 11.7% and medial in 6.7%. Ghosh et al. and Akhtar et al. similarly documented variations in the relationship of the roots and main trunk of the median nerve with the axillary artery [1,4]. These relationships are clinically important during axillary lymph-node clearance, vascular reconstruction, treatment of traumatic injuries and regional anaesthesia. An unexpectedly positioned root may be compressed by an aneurysm or injured during arterial catheterisation or surgical exposure.

Communication between the musculocutaneous and median nerves was identified in 8.3% of upper limbs. This finding is comparable with the 10% incidence reported by Caetano et al. [10], but lower than the 19.8% reported by Ballesteros et al. in 106 upper limbs [11]. The difference may be attributable to population variation and whether very fine communicating fibres were included. In four of the five affected limbs in the present study, the communication passed from the musculocutaneous nerve to the median nerve, while the reverse pattern occurred in one. Such communications may explain unexpected preservation of elbow flexion or atypical motor weakness following apparently isolated injury to either nerve. They may also produce misleading findings during nerve-conduction studies.

Martin–Gruber anastomosis was observed in 11.7% of the forearms. This finding is almost identical to the 11.6% prevalence reported by Kaur et al. in a cadaveric study of 60 upper limbs from a North Indian population [7]. In the present study, the communicating branch arose from the anterior interosseous nerve in four limbs and directly from the median nerve in three. Fibres passing from the median to the ulnar nerve may alter the expected motor supply of the intrinsic muscles of the hand. Consequently, an ulnar nerve lesion may produce less weakness than anticipated, while a proximal median nerve lesion may unexpectedly affect muscles ordinarily considered to be supplied exclusively by the ulnar nerve. Recognition of this communication is therefore essential for accurate interpretation of electrophysiological investigations.

The median nerve followed its conventional course between the humeral and ulnar heads of the pronator teres in 91.7% of specimens. In the remaining limbs, it passed deep to both heads or pierced the humeral head. Such variant relationships may increase the susceptibility of the nerve to compression and may contribute to proximal median nerve entrapment or pronator syndrome. A nerve piercing a muscular head may be compressed during repeated pronation or forceful forearm activity.

Two branches to the pronator teres were observed in 71.7% of specimens, while single and three-branch patterns were found in 13.3% and 15.0%, respectively. Caetano et al. reported more than one pronator teres branch in 70% of limbs, including two branches in approximately 64% and three branches in 6.6% [12]. Thus, the present study supports the observation that multiple branches to the pronator teres are more common than a single branch. This arrangement has practical importance in distal nerve-transfer procedures because one branch may potentially be used as a donor while preserving partial innervation of the muscle.

A duplicated anterior interosseous nerve was identified in 10.0% of the present specimens, and a high origin was found in 6.7%. Caetano et al. demonstrated considerable variation in the origin, course and muscular branching of the anterior interosseous nerve [13]. Variability in its origin can influence the clinical presentation of anterior interosseous nerve syndrome and may complicate surgical exploration. Because this nerve is predominantly motor, its injury typically results in impaired flexion of the terminal phalanges of the thumb and index finger without cutaneous sensory loss.

At the wrist, a bifid median nerve was observed in 3.3% of specimens, while a persistent median artery was found in 5.0%. Both specimens with a bifid nerve were accompanied by a persistent median artery. Henry et al. reported a pooled prevalence of 2.6% for high division of the median nerve and found frequent coexistence between a bifid median nerve and persistent median artery [14]. Agarwal et al. observed deviations from standard median nerve anatomy in 50% of 52 fresh cadaveric hands and reported that the presence of a persistent median artery was consistently associated with a median nerve variation [15]. The coexistence of these structures may reduce the available space in the carpal tunnel and must be recognised during decompression to avoid vascular injury and excessive bleeding.

The extraligamentous recurrent thenar branch was the predominant pattern in the present study, accounting for 75.0% of hands, followed by subligamentous and transligamentous courses in 15.0% and 10.0%, respectively. These findings correspond remarkably closely with the meta-analysis by Henry et al., which reported pooled prevalences of 75.2%, 13.5% and 11.3% for extraligamentous, subligamentous and transligamentous courses, respectively [14]. Mizia et al., however, reported an extraligamentous course in 50%, a subligamentous course in 20% and a transligamentous course in a smaller proportion of their specimens [16]. Such differences reinforce the wide population variability of the recurrent thenar branch.

The transligamentous recurrent thenar branch is particularly important because it passes through the flexor retinaculum and is vulnerable during open or endoscopic carpal tunnel release. Injury may result in weakness of thumb opposition and thenar muscle atrophy. The recurrent thenar branch arose from the ulnar side of the median nerve in 5.0% of the present specimens. This was higher than the pooled prevalence of 2.1% reported by Henry et al. [14]. An ulnar origin places the branch directly in the usual operative field during an ulnar-sided carpal tunnel approach and therefore requires careful layer-by-layer dissection.

Accessory branches arising distal to the carpal tunnel were observed in 5.0%, high division in 3.3% and accessory branches proximal to the tunnel in 3.3%. These findings were close to the pooled prevalences of 4.6%, 2.6% and 2.3%, respectively, reported for Lanz groups II, III and IV by Henry et al. [14]. The close agreement suggests that the distribution of distal variations in the present sample was generally consistent with the broader anatomical literature.

No statistically significant differences were observed between the right and left sides. Sex-related differences were also non-significant. Although variations were numerically more frequent in male and right-sided specimens, these differences should be interpreted cautiously because the sample included relatively few female cadavers. Previous studies have reported inconsistent relationships between median nerve variations, sex and side. Larger studies with balanced representation are required before a true sex- or side-specific pattern can be established.

The present findings have several clinical implications. Knowledge of variant roots and vascular relationships is necessary during brachial plexus exploration, axillary surgery and regional nerve blocks. Communications involving the musculocutaneous, median and ulnar nerves should be considered when clinical weakness does not correspond to the expected anatomical distribution. Forearm branching patterns are relevant to decompression and nerve-transfer surgery, while variations at the wrist are particularly important during carpal tunnel release. Preoperative ultrasonography may help identify a bifid median nerve, persistent median artery or other major distal variations.

The study has certain limitations. It was based on a relatively small number of formalin-embalmed cadavers, and the sample was not balanced by sex. Fine communicating branches may have been overlooked or damaged during dissection. Clinical history, hand dominance and causes of death were unavailable, preventing assessment of the functional consequences of the observed variations.

Additionally, observations from cadavers may not fully represent the dynamic relationships of nerves and muscles in living individuals. Nevertheless, examination of the median nerve from the axilla to the palm provides a comprehensive account of variations that may be relevant to anatomists, radiologists, anaesthesiologists and upper-limb surgeons.

Conclusion

The median nerve demonstrated considerable anatomical variability throughout the upper limb, particularly in its formation, vascular relationships, communications and terminal branching. Three-root formation was the most frequent proximal variation, while Martin–Gruber anastomosis and variant recurrent thenar branch courses were clinically important distal findings. The transligamentous thenar branch, bifid median nerve and persistent median artery deserve particular attention during carpal tunnel surgery.

A thorough understanding of these variations is essential for accurate clinical and electrophysiological diagnosis and for preventing iatrogenic injury during regional anaesthesia, nerve repair, reconstructive surgery and carpal tunnel release.

Conflict of Interest: None.

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