

Quantitative Mapping of the Palmar Cutaneous Branch of the Median Nerve (PCBMN) During Open Carpal Tunnel Release

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ABSTRACT

Background: Injury to the palmar cutaneous branch of the median nerve (PCBMN) is a preventable source of palmar dysesthesia after open carpal tunnel release (CTR). In-vivo quantitative mapping is limited; we mapped PCBMN morphometrics and evaluated whether obesity alters nerve position. Methods: We conducted a prospective study of fifty adults undergoing primary open CTR. BMI stratified participants: control (BMI <25; n=25) and study (BMI ≥30; n=25). The PCBMN fascial exit was identified, and three orthogonal distances were recorded: to the palmaris longus axis (Distance A), to the radial border of flexor carpi radialis (Distance B), and to the distal wrist crease (Distance C). Trajectory angle (θ) relative to palmaris longus, depth at the fascial exit, branching pattern, and distance from exit to first branch were also measured. Comparisons used independent-samples t-tests for continuous variables and chi-square tests for categorical variables. Results: Groups were similar in age (51.5 ± 8.4 vs 50.4 ± 9.5 years; $p=0.673$) and sex distribution (8/17 vs 10/15; $p=0.768$); BMI differed by design (33.6 ± 2.6 vs 22.7 ± 1.3 kg/m²; $p<0.001$). Primary morphometrics did not differ: Distance A 4.9 ± 1.7 vs 4.5 ± 1.9 mm ($p=0.359$), Distance B 4.5 ± 2.0 vs 3.6 ± 1.7 mm ($p=0.081$), and Distance C 7.6 ± 3.2 vs 7.9 ± 3.0 mm ($p=0.700$). Trajectory angle was comparable ($10.7^\circ \pm 7.6$ vs $11.0^\circ \pm 5.8$; $p=0.899$). Depth at the fascial exit was significantly greater in the obese group (3.4 ± 1.2 vs 1.7 ± 0.8 mm; $p<0.001$). Branching pattern was similar (single/multiple 19/6 vs 20/5; $p=1.000$), as was distance to first branch (21.2 ± 8.3 vs 18.2 ± 7.4 mm; $p=0.182$). Derived safety-zone distances were similar. Conclusions: The lateral and distal relationships of the PCBMN to key surface landmarks are preserved across BMI strata, supporting conventional horizontal incision corridors. However, obesity substantially increases subcutaneous depth at the fascial exit, narrowing the operative window. Deeper, controlled dissection is warranted in obese patients to minimize PCBMN injury while carefully maintaining surface-based orientation.

ARTICLE HISTORY

Received February 11, 2026

Accepted May 23, 2026

KEYWORDS

Quantitative Mapping,
Carpal Tunnel Release,
Palmar Cutaneous Branch of
Median Nerve (PCBMN),
Body Mass Index (BMI),
Palmar Dysesthesia

1. Introduction

The palmar cutaneous branch of the median nerve (PCBMN) arises from the median nerve approximately 4–5 cm proximal to the distal wrist crease and typically passes between the palmaris longus and flexor carpi radialis tendons before piercing the antebrachial fascia to enter the palm (Honsvall Hoeffler et al., 2019). It provides cutaneous sensation to the central palm and thenar eminence and is vulnerable due to its superficial course (Ludlow et al., 1997).

Clinically, PCBMN is critical during carpal tunnel release (CTR) surgery. If injured, patients may suffer from persistent dysesthesia or neuropathic pain in the palm (Matloub et al., 1998). Surgical approaches recommend incisions 0.5–1 cm ulnar to the palmaris longus tendon to minimize injury risk (Cheung et al., 2004).

Anatomical variations are frequent. Multiple studies report bifurcation of the PCBMN into radial and ulnar branches, or unusual branching patterns (Wu & Ng, 2018), and even complete absence in rare cases (Roche & Ng, 2014). In a cadaveric study, 90% of specimens had a single PCBMN, but 10% had multiple branches (Gordon, 2020).

Iatrogenic injuries during CTR have been reported in up to 13.6% of cases using standard open techniques, especially affecting distal branches (Alizadeh et al., 2006). Improved surgical planning, such as shorter or ulnar-offset incisions,

reduces these risks (Mofikoya & Ugburo, 2012).

In conclusion, the PCBMN is anatomically variable and surgically significant. Careful identification and preservation during CTR is essential to avoid long-term complications.

Current surgical anatomy for carpal tunnel release primarily relies on cadaveric dissections and imaging-based models, both of which have inherent limitations in replicating real-time, in vivo surgical conditions (Elizondo-Omaña et al., 2022; Krogager et al., 2023; Tapia-Nañez et al., 2022). Cadaver preservation distorts tissue consistency and lacks dynamic physiological responses, such as swelling or positional shifts, during surgery (Freer et al., 2024).

Moreover, a major knowledge gap persists due to the absence of quantitative, intraoperative mapping studies assessing how patient-specific factors like BMI influence the depth, angle, or trajectory of the PCBMN (Hernández-Cortés et al., 2023; Nam et al., 2022). This restricts the ability to define a consistent, reproducible “safe zone” for surgical incisions, despite multiple studies attempting to delineate one using surface landmarks or static ultrasound parameters (Bridgwater et al., 2023; Kang et al., 2022; Mujadzic et al., 2022).

This study will attempt to fill these gaps by using real-time, intraoperative measurements of PCBMN anatomy in living patients, while also correlating these results with demographic and biometric variables, such as BMI, wrist width, and sex. This approach will create a dynamic and standardised morphometric reference for a safer, more individualised surgical approach.

The purposes of this study were formulated to fill the void in the knowledge about the quantitative anatomy of the palmar cutaneous branch of the median nerve (PCBMN) during open carpal tunnel release. The investigation aimed to precisely define the course and positional relationship of the PCBMN relative to important surface landmarks traditionally used for incision planning, while separately assessing the possible influence of body mass index (BMI) on these parameters.

The purpose of this study was to determine whether differences in subcutaneous adiposity could significantly alter the apparent trajectory, depth, or branching pattern of the PCBMN, thereby altering the perceived safety margins during a surgical exposure. By using direct intraoperative measurement rather than imaging or cadaveric models, the research aimed to obtain real-time anatomical data under standardized operative conditions that are representative of the clinical scenarios hand surgeons face.

A further objective was to build a reproducible, measurement-based framework that can define a 'safe zone' for surgical incisions that is practical. This quantitative model was designed to combine the variability introduced by BMI and other patient-related factors, such as wrist circumference and sex, into a statistically validated anatomical reference.

Ultimately, the purpose of the study was to create an excellent dataset to aid safer, more individualized incision planning in carpal tunnel surgery. Through accurate documentation of the nerve's spatial relationships and morphological patterns, the work aimed to reduce the incidence of iatrogenic PCBMN injury and thus contribute to the refinement of surgical anatomy in current hand practice.

2. Methodology

2.1 Study Design and Setting

This study was conducted as a prospective intraoperative anatomical study at a tertiary referral centre specializing in hand and peripheral nerve surgery. The research was a structured quantitative study aimed at capturing accurate morphometric data on the palmar cutaneous branch of the median nerve under actual surgical conditions. All procedures were carried out in a standardized operative environment to ensure homogeneous exposure, constant lighting and constant temperature conditions that reduce soft tissue distortion. The instruments in the operating theatre were digital measurement devices calibrated for each session to ensure data accuracy. The study was conducted over a specific period during which successive adult cases of primary open carpal tunnel release were included, with predetermined inclusion criteria applied. Each dissection and measurement was performed under loupe magnification, as this improved visual clarity without altering normal anatomy. The controlled hospital setting enabled adherence to stringent aseptic protocols and ethical guidelines to ensure patient safety and data confidentiality. All observations and recordings were made in real time by the principal investigator, assisted by an independent observer who verified measurement consistency. The clinical setting and prospective framework together ensured that the collected data reflected authentic surgical anatomy representative of the living population.

2.2 Participant Selection Criteria

The study population consisted of fifty adult patients who underwent primary unilateral open carpal tunnel release during the study period. Participants were selected prospectively based on predefined clinical and anatomical criteria to ensure homogeneity and reliability of the observations. Eligible individuals were men and women aged between eighteen and seventy-five years who presented with clinical and electrophysiological evidence of carpal tunnel syndrome and

provided written informed consent. Only cases in which the palmaris longus tendon could be identified intraoperatively were included for standardized reference, although its absence was recorded as a variable when encountered. Individuals with a history of previous wrist surgery, trauma, or inflammatory arthropathy were excluded to eliminate potential distortion of fascial and neural planes. Patients with revision carpal tunnel release or coexisting space-occupying lesions were also excluded to avoid structural alterations that might influence the anatomical relationships under investigation. The cohort was subsequently stratified into two groups according to body mass index: a control group with BMI below 25 and a study group with BMI of 30 or higher, each comprising 25 subjects. All participants were recruited consecutively until the target sample size was reached, ensuring adequate representation by sex and wrist dimensions across both BMI categories.

2.3 Group Stratification Based on Body Mass Index

Participants were stratified into two groups based on body mass index to assess the potential influence of adiposity on the anatomical course and depth of the palmar cutaneous branch of the median nerve. Body mass index values were calculated preoperatively using standardised weight and height measurements obtained on the day of surgery. The control group included individuals with a BMI less than twenty-five, representing subjects with normal body composition. In contrast, the study group comprised those with a BMI of thirty or greater, corresponding to the obese range. This stratification enabled examination of how increased subcutaneous tissue thickness and altered fascial tension might influence perceived surface landmarks and the relative positions of neural structures during surgical exposure. Each group consisted of 25 patients, matched for age distribution and laterality of the operated wrist to minimize confounding factors. The separation of participants by BMI enabled comparison of linear and angular morphometric parameters under two physiologically distinct soft-tissue conditions. The grouping also enabled regression modelling to identify potential correlations between body mass index. It measured anatomical distances, thereby supporting the primary aim of quantifying the effect of adiposity on the palmar cutaneous nerve trajectory.

2.4 Preoperative Preparation and Positioning

Patients were positioned supine on the operating table with the operative limb extended on a radiolucent arm/hand table; a carbon-fibre model was used to maintain stability and imaging clarity (e.g., STERIS Arm & Hand Table, order no. BF435) while keeping the shoulder abducted $<90^\circ$ and the forearm supinated to minimize brachial plexus and ulnar nerve pressure. Padding protected bony prominences, and palms remained up on armboards per perioperative positioning guidance.

After a limb check, a pneumatic upper-arm tourniquet and appropriate cuff were applied; inflation followed contemporary recommendations based on limb occlusion pressure with a safety margin or, when LOP was unavailable, conventional upper-extremity targets <250 mmHg for brief procedures. Exsanguination, when used, employed a sterile Esmarch bandage (sizes commonly 3–6 in $\times$ 9–12 ft; examples DeRoyal 35-309 / 35-609 / 35-612).

Skin was marked for landmarks with a sterile single-use surgical marker (e.g., Viscot 1437SR or Visflow VF600SR), then prepared with 2% chlorhexidine gluconate in 70% isopropyl alcohol, allowed to dry per guideline practice, and draped using an adhesive U-drape and antimicrobial incise film (examples: 3M Steri-Drape U-Drape 1015 [3M ID 70200467044] and 3M Ioban 2 series, such as 6650EZE).

This preparation created a reproducible, low-movement field with standardised limb orientation and antisepsis, ensuring that subsequent operative steps were performed under consistent conditions without altering native soft-tissue relationships.

2.5 Surgical Approach and Exposure Technique

The operative field was supported by a dedicated hand instrument set assembled specifically for quantitative dissection and measurement, with items selected to minimise instrument-related variability. Scalpel blades used for skin entry were standard No. 15 Swann-Morton blades, procured in sterile single-use packs to ensure consistent cutting geometry. Fine tissue forceps (Adson style, $4\frac{3}{4}$ " with 1×2 or 9×9 teeth) and delicate iris/Westcott scissors were included for atraumatic soft-tissue handling. Exposure was aided by a self-retaining Holiday carpal tunnel retractor (product No. 1113) and small double-ended Senn retractors for intermittent retraction, each verified to match published dimensions for hand procedures. Measurement and recording instruments were kept physically separate from the cutting set to avoid contamination; digital calipers of laboratory grade (Mitutoyo ABS Digimatic, 0–150 mm, 0.01 mm resolution) and a high-resolution plastic goniometer (Baseline 12-inch Hi-Res, SKU 12-1000) were supplied on a sterile instrument tray for immediate availability. Nonabsorbable nylon for skin approximation (ETHILON® 4-0/5-0; Ethicon catalog listings) was chosen for its handling and knot security in palmar skin closure. All reusable metal instruments underwent standard sterilization cycles per hospital policy and were inspected for function and calibration before each case to ensure consistent

performance.

2.6 Identification of the Palmar Cutaneous Branch of the Median Nerve

The palmar cutaneous branch was identified by careful layer-by-layer dissection, beginning with gentle separation of subcutaneous tissue immediately distal to the antebrachial fascia until the nerve's fascial exit was exposed. Visual recognition relied on its characteristic small calibre and pale, glistening appearance as it coursed superficial to the volar fascia and between the palmaris longus and flexor carpi radialis tendon planes; typical published topographic relationships were used as a guide, noting that the exit point commonly lay within a few millimetres of the palmaris longus and the ulnar border of the FCR (reported averages $\approx 4\text{--}6$ mm depending on the reference level). To improve illumination and fine discrimination of the nerve from small vascular branches and fat lobules, the operative team used high-quality surgical loupes (industry examples: Orascopic HDL 2.5 and ZEISS EyeMag series) together with a coaxial LED headlight (example: HEINE ML4, catalogue J-008.31.415), which permitted shadow-free visualization of subtle fascial defects. When uncertainty persisted about a filamentous structure, atraumatic micro-dissectors and sterile silicone vessel loops (Covidien/Devon vessel loops, e.g., catalogue variants 31145702/31145710) were used to gently mobilise and tag the branch. In selected cases, a peripheral nerve stimulator (B. Braun Stimuplex HNS-12, P/N 4892098) was available for adjunctive mapping, with the device set to low-current ranges for precise localisation when necessary.

2.7 Identification of the Anatomical Landmarks and Measurement Reference Points

An explicit protocol was used to define each surface landmark and the precise reference points for all morphometric measures, ensuring reproducibility and comparability. The palmaris longus axis was identified by palpation along its tendon belly with the wrist and digits gently flexed, and a longitudinal skin line was marked to represent its radial border; the distal wrist crease was defined as the most distal transverse skin fold at the volar wrist and was used as a perpendicular datum for distal measurements (distal landmark definitions followed contemporary surgical descriptions). The Kaplan's cardinal line was drawn according to standard technique originating from the apex of the interdigital fold between thumb and index and extending toward the hook of the hamate and served as an ancillary distal reference for safe-zone mapping because of its validated relationship to the superficial palmar arch. The PCBMN fascial exit point was operationally defined as the first point at which a visible neural filament breached the antebrachial fascia into the subcutaneous plane; when variability occurred, the most proximal visible fascial penetration was recorded as the exit. Published sonographic and cadaveric series reporting fascial tunnel length and the variable distance of the penetration point from the wrist crease informed acceptable anatomical ranges and guided outlier handling. All linear measures were reported in millimetres to two decimal places and referred orthogonally to the marked palmaris longus line or to the radial border of the flexor carpi radialis as appropriate; angular measures were referenced to the palmaris longus longitudinal axis and recorded in degrees. For traceability, each marked skin point and the corresponding measured coordinate were photographed in situ and logged with a unique specimen ID. Instrumentation selected for these reference measures included a precision electronic calliper with a 0–150 mm range and 0.01 mm resolution (example model: Starrett 798A-6/150) to enable high-resolution reporting consistent with published measurement standards.

2.8 Measurement Instruments and Calibration Procedures

All measuring devices were subject to a documented metrology program that emphasised traceability, verification, and controlled environmental conditions prior to intraoperative use. Precision digital calipers with 0–150 mm ranges and 0.01 mm resolution were verified against NIST-traceable gauge blocks (examples of laboratory sets: Mitutoyo 516-903-26 / 516-302-26 series) and were accepted only when deviations fell within the manufacturer's stated accuracy limits (manufacturer tolerance typically on the order of ± 0.02 mm for the 0–150 mm class). Calibrations were performed by an ISO/IEC 17025-accredited service or by the institutional metrology unit using certified gauge blocks and documented procedures; each calibration certificate was retained with the instrument log for traceability. Verifications followed a multi-point method across the measuring range (zero, near-mid-range, and full-scale points) using grade-appropriate blocks. They were carried out in a temperature-controlled area maintained near 20 °C, in reference to the dimensional reference to avoid thermal expansion errors common in submillimetre work. Simple daily checks were mandated before clinical sessions (zero-set check and a single reference-block confirmation). At the same time, full formal calibration was scheduled at least annually for laboratory-use instruments and semi-annually for high-use devices, with interval shortening if out-of-tolerance results or mechanical shock occurred. Depth gauges and any instruments intended for sterile field use were kept in validated sterile covers or reserved as autoclavable, surgical-grade devices, and their calibration status was rechecked after any sterilisation cycle that could affect dimensional stability. Intermediate verifications and calibration records were reviewed as part of study quality assurance to ensure that measurement uncertainty remained acceptably small relative to

the anatomical differences under investigation.

2.9 Intraoperative Measurement Protocol

Measurements were performed in a consistent, pre-specified sequence after exposure but before division of the transverse carpal ligament to avoid tissue shift. The operative observer first confirmed the fascial exit point of the palmar cutaneous branch and then recorded three orthogonal linear distances (to the palmaris longus axis, to the radial border of the flexor carpi radialis, and to the distal wrist crease) using the sterile digital caliper; use of an intraoperative caliper has been validated in operative anthropometric studies for predictable, reproducible length measurement. Each linear measure was taken as the mean of three consecutive readings taken within a 30-second window to reduce transient tissue deformation, and the value was entered immediately into a preformatted case report form on a sterile clipboard for real-time audit. Angular trajectory was then measured with a transparent 12-inch goniometer (Baseline Hi-Res 12-1000) placed parallel to the palmaris longus axis and aligned to the nerve filament to record θ in degrees; plastic clinical goniometers with 1° graduations were employed to balance sterility and ease of use. Depth at the fascial exit was determined by careful perpendicular probing with a sterile depth gauge or, when available, a single-use electronic depth gauge (single-use electronic depth gauges are commercially available for intraoperative depth measurement), reading the value to the nearest millimetre and avoiding repeated deep probing to minimise local tissue trauma. Photographs documenting each marked skin reference, the calliper position, and a sterile linear scale were orthogonal to the field using standard intraoperative photographic technique to minimise perspective error, with images linked to the specimen ID for later verification. To assess measurement reproducibility, a second blinded observer independently repeated a random 20% sample of cases; inter-rater agreement was quantified using intraclass correlation coefficients and Bland–Altman analysis during data processing to identify systematic bias or excessive variability.

2.10 Recording of Branching Patterns and Depth Assessment

Branching patterns were categorized using an established anatomical taxonomy adapted from recent cadaveric series, and each specimen was logged with a standardized branch-type descriptor and a numeric branch count. The proximal origin of the palmar cutaneous branch was recorded as the distance from the distal wrist crease in centimetres and the first terminal division was measured along the nerve from the fascial exit to the branch point in millimetres; previously reported ranges informed outlier handling and were used to frame expected anatomical variability. Representative photographic images were annotated post-hoc using ImageJ to set scale from an in-field sterile ruler and to extract precise pixel-to-millimetre measurements for branching loci and superficial depth (ImageJ's Set Scale and Measure functions were applied). Each visible terminal filament was tagged intraoperatively with a sterile numbered metal micro-clip (small LIGACLIP™ where appropriate, e.g., LT100/LT102 for small application) or by placing a short colored nonabsorbable suture (silk 5-0 FS-2, Ethicon) for eventual photographic reference and identification in the operative log. A sterile disposable 6-inch ruler (Medline DYNJRULER) and sterile surgical marker (Medline DYNJSM06) provided a consistent in-frame scale and labeling during imaging. Depth at the fascial exit was documented as the perpendicular distance to the skin surface and corroborated by calibrated image measures; all branching and depth data were entered into a secure REDCap database for audit-trailed storage and later quantitative analysis.

2.11 Standardization of Wrist Position and Incision Location

Wrist position and incision placement were standardized by defining objective, reproducible targets and documenting them with calibrated measuring devices. The wrist was set to a neutral posture (0°) for all cases, with acceptable intraoperative variation limited to 0–15° of extension when required for exposure, and the angle was verified with a sterile clinical inclinometer before marking to minimize intra-tunnel pressure artefact during measurement. The limb was supported on a radiolucent wrist positioner or a firm gel/foam armboard pad to prevent motion; institutional examples included a TRIMANO-style wrist clamp for rigid fixation and AliMed/Cardinal Health arm pads for soft support, each selected for stable, reproducible hand orientation. Skin landmarks were mapped after final positioning: the palmaris longus axis was palpated and marked, Kaplan's cardinal line was drawn as an ancillary distal reference, and the distal wrist crease was identified as the perpendicular datum for distal measurements. The surgical incision was planned ulnar to the palmaris longus and intentionally limited in length to the empiric mini-open range (approximately 2.5–3.5 cm) to permit full visualization of the transverse carpal ligament without routinely crossing the distal wrist crease, thereby reducing the risk of pillar pain. A sterile ruler was placed adjacent to the planned incision to document the exact skin coordinates in millimetres and to permit later correlation of measured anatomic points to the premarked skin grid.

2.12 Ethical Considerations and Data Confidentiality

Ethical approval was obtained from the institutional review board before patient enrolment, and all participants

provided written informed consent that described study aims, procedures, risks, withdrawal rights, and the explicit decision not to record intraoperative photographs or video. The study was conducted in accordance with internationally recognised ethical principles for human research and clinical quality standards. Personal identifiers were removed at the source, and a formal de-identification strategy, consistent with regulatory guidance, was applied before any data extraction for analysis or sharing. Data controllers and processors were identified, and the handling plan accounted for relevant legal frameworks for personal data protection, where applicable, including data subjects' rights and lawful bases for processing. All study information was stored on institutionally managed, access-controlled electronic systems with encryption in transit and at rest, role-based access, unique user accounts, and audit logging; periodic risk assessments and patch management followed recognised information-security guidance. Only fully anonymised numeric datasets were used for statistical analysis and manuscript preparation, and any data sharing beyond the study team required a documented data-sharing agreement and prior ethics committee approval.

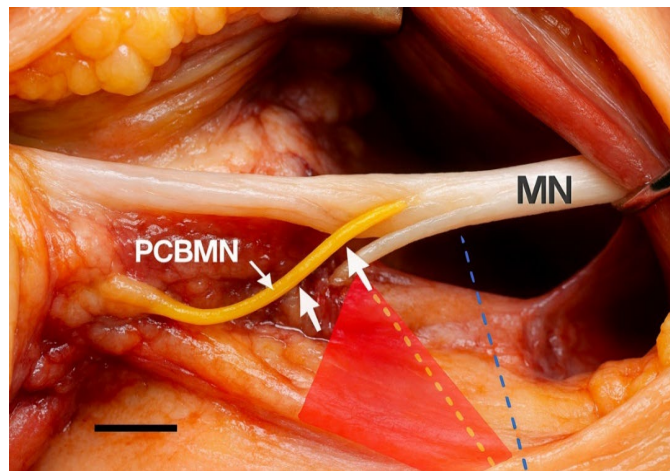


Figure 1: Intraoperative Volar-Wrist Dissection Showing the Median Nerve and the Palmar Cutaneous Branch with the Safe Corridor Illustrated

This figure 1 demonstrates a clear volar-wrist exposure with the median nerve (MN) coursing distally and the palmar cutaneous branch (PCBMN) arising proximally and sweeping radially. The PCBMN is depicted as a slender, superficial fascicle that crosses obliquely toward the thenar eminence, thereby explaining its vulnerability to longitudinal palmar incisions. The shaded “no-go” sector and dashed line illustrate a practical safety corridor: keep the skin incision ulnar to the palmaris longus and direct deep dissection ulnar to the MN to avoid the PCBMN. The image reinforces the sequence of safe release skin, palmar fascia, and transverse carpal ligament while continuously protecting neural structures.

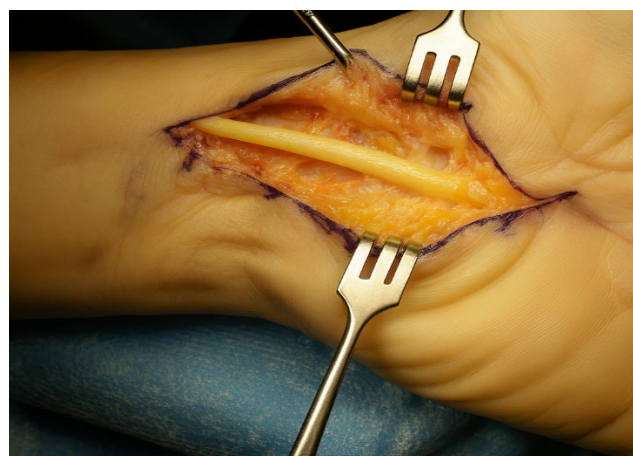


Figure 2: Open Carpal Tunnel Exposure with Retraction and Blunt Probing of the Median Nerve and Surrounding Tissues

This open carpal tunnel exposure shows the distal edge of the transverse carpal ligament retracted, revealing the median nerve within the canal and a superficial fascial layer proximally (Figure 2). Two fine probes gently define planes: one elevates the ligament's undersurface; the other guards the nerve's epineurium. Residual skin markings indicate the

incision's alignment along the ulnar border of the ring finger. The picture emphasises meticulous blunt dissection over sharp dissection when approaching the MN, frequent relaxation of retractors to allow perfusion, and incremental visualisation before cutting. Key teaching points: always identify the nerve, avoid traction neurapraxia, and release remaining fibrous bands under vision.



Figure 3: Wide Diamond Incision Exposing the Superficial Palmar Fascia and Median Nerve During Carpal Tunnel Release

A wider diamond-shaped exposure displays the superficial palmar fascia and distal fibers of the transverse carpal ligament with the median nerve lying immediately deep (Figure 3). Twin rake retractors deliver uniform counter-traction, flattening the field and improving depth perception. The proximal tunnel is already decompressed; distal fibrous bands remain to be divided from distal to proximal while maintaining the blade parallel to the nerve. The scene highlights hallmark landmarks: yellow subcutaneous fat, pearly ligament fibres, glistening epineurium, and the importance of hemostasis in keeping tissues distinct. This view is ideal for teaching safe scissor-spread technique and confirming complete release without entering the thenar motor branch.



Figure 4: Mini-Open Palmar Incision for Proximal Carpal Tunnel Release with Tissue Spreaders and Fine Instruments in Position.

This realistic anatomical illustration demonstrates the branching pattern of the palmar cutaneous branch of the median nerve (PCBMN) in a typical control case (Figure 4). The nerve emerges from the fascia near the palmaris longus tendon and travels distally, maintaining a consistent trajectory before giving off its first terminal branch. The measured distance from the fascial exit to the first branch averages approximately 18 mm in the control group, consistent with cadaveric findings. The illustration highlights the nerve's relation to the palmaris longus and flexor carpi radialis (FCR) tendons, emphasizing the predictable yet variable nature of its branching course.

3. Statistical Analysis

Continuous variables were summarized as mean $\pm$ standard deviation, categorical variables as counts and

percentages. Between-group comparisons strictly followed the tests specified in the manuscript tables/footnotes: independent-samples t-tests for continuous outcomes (Tables 1–3 and 5; plus “distance to first branch” in Table 4) and chi-square tests for categorical outcomes (sex distribution in Table 1; branching pattern in Table 4). All tests were two-sided with a significance threshold of $p < 0.05$, and exact p-values are reported (with $p < 0.001$ when appropriate). Assumptions for t-tests were assessed using Shapiro–Wilk tests for normality and Levene’s test for homogeneity of variances; parametric tests were used as specified by the table footnotes. Measurement reproducibility for a random 20% subset was evaluated by intraclass correlation coefficients and Bland–Altman analysis, in line with the intraoperative protocol. Statistical analyses were performed using IBM SPSS Statistics, Version 26 (IBM Corp., Armonk, NY). Data were entered from audited case report forms and stored in a secure database prior to analysis. No multiplicity adjustments were applied because comparisons were prespecified and limited in scope.

4. Results

Table 1: Comparison of Demographic Variables between the Study and Control Groups (n = 25 each)

Variable	Study Group (n=25)	Control Group (n=25)	P-value
Age (years)	51.5 ± 8.4	50.4 ± 9.5	0.673
BMI (kg/m ²)	33.6 ± 2.6	22.7 ± 1.3	<0.001
Sex (Male/Female)	8 / 17	10 / 15	0.768

Footnote: Statistical Tests Used: Independent Samples t-test for Age and BMI; Chi-Square Test for Sex Distribution. A p-value < 0.05 was Considered Statistically Significant.

The comparison of demographic data between the two groups indicated that there was no statistically significant difference in the mean age of participants, with the study group averaging 51.5 years and the control group 50.4 years ($p = 0.673$) (Table 1). The sex distribution was also comparable, with 8 males and 17 females in the study group, and 10 males and 15 females in the control group ($p = 0.768$), showing no significant gender-based difference. However, the body mass index (BMI) differed significantly between the groups by design: the study group had a mean BMI of 33.6 kg/m² compared to 22.7 kg/m² in the control group, with a statistically significant difference ($p < 0.001$). These results affirm that the groups were matched on age and sex, while intentionally differing in BMI to facilitate the analysis.

Table 2: Comparison of Primary Morphometric Distances Between the Study and Control Groups (n = 25 each)

Variable	Study Group (n=25)	Control Group (n=25)	P-value
Distance A (mm)	4.9 ± 1.7	4.5 ± 1.9	0.359
Distance B (mm)	4.5 ± 2.0	3.6 ± 1.7	0.081
Distance C (mm)	7.6 ± 3.2	7.9 ± 3.0	0.700

Note: Statistical Test Used: Independent Samples t-Test for Continuous Variables. A p-value < 0.05 was Considered Statistically Significant.

The comparison of primary morphometric parameters measured at the fascial exit point of the palmar cutaneous branch of the median nerve (PCBMN) between the study and control groups showed no statistically significant differences in any of the three measured distances (Table 2). For Distance A, representing the orthogonal distance from the nerve exit to the palmaris longus axis, the study group had a mean of 4.9 mm (± 1.7). In comparison, the control group had a slightly lower mean of 4.5 mm (± 1.9), with a p-value of 0.359. Similarly, Distance B, measured as the distance from the nerve exit to the radial border of the flexor carpi radialis (FCR), was marginally higher in the study group at 4.5 mm (± 2.0) compared to 3.6 mm (± 1.7) in the control group. Still, the difference was not statistically significant ($p = 0.081$). Lastly, Distance C, defined as the perpendicular distance from the nerve exit to the distal wrist crease, showed very similar means between the two groups, with 7.6 mm (± 3.2) in the study group and 7.9 mm (± 3.0) in the control group, resulting in a p-value of 0.700. These findings suggest a consistent anatomical relationship of the PCBMN across both BMI-defined groups, supporting prior observations in cadaveric and imaging studies that report variability within a central tendency of approximately 3 to 6 mm for transverse distances and 5 to 12 mm for longitudinal depth.

Table 3: Comparison of PCBMN Trajectory Angle and Fascial Exit Depth between the Study and Control Groups (n = 25 Each)

Variable	Study Group (n=25)	Control Group (n=25)	P-value
Angle θ (°)	10.7 ± 7.6	11.0 ± 5.8	0.899
Depth at Fascial Exit (mm)	3.4 ± 1.2	1.7 ± 0.8	<0.001

Note: Statistical Test Used: Independent Samples t-test for Continuous Variables. A p-value < 0.05 was Considered Statistically Significant.

The comparison of the PCBMN morphometric parameters between study and control groups showed that the angle of trajectory (Angle θ) (Table 3), measured relative to the palmaris longus axis, was similar in both groups, with no statistically significant difference. The study group demonstrated a mean angle of 10.7° (± 7.6), while the control group had a comparable mean of 11.0° (± 5.8), with a resulting p-value of 0.899. This indicates that the nerve generally maintains a roughly parallel course relative to tendon axes irrespective of BMI stratification, supporting the anticipated anatomical consistency. In contrast, a highly significant difference in depth was observed at the fascial exit point, measured perpendicularly to the skin surface. The study group, representing individuals with higher BMI, exhibited a substantially greater depth with a mean of 3.4 mm (± 1.2) compared to 1.7 mm (± 0.8) in the control group. The difference in fascial depth was statistically significant ($p < 0.001$). This finding aligns with prior sonographic and anatomical studies demonstrating the influence of adiposity on superficial tissue thickness, reaffirming the effect of BMI on soft tissue dimensions at the wrist.

Table 4: Comparison of PCBMN Branching Pattern and Distance to First Branch between Study and Control Groups (n = 25 Each)

Variable	Study Group (n=25)	Control Group (n=25)	P-value
Branching pattern (Single/Multiple)	19 / 6	20 / 5	1.000
Distance to first branch (mm)	21.2 ± 8.3	18.2 ± 7.4	0.182

Note: Statistical Tests Used: Chi-Square Test for Categorical Variable (Branching Pattern); Independent Samples t-test for Continuous Variable (Distance to First Branch).

A p-Value < 0.05 was Considered Statistically Significant.

In comparing the branching characteristics of the palmar cutaneous branch of the median nerve (PCBMN) between the study and control groups, no statistically significant differences were observed (Table 4). The proportion of cases with a single terminal branch was slightly lower in the study group (76%, 19/25) than in the control group (80%, 20/25), with the remainder in both groups exhibiting multiple-branching patterns. The chi-square test yielded a p-value of 1.000, indicating no significant variation between the groups in this anatomical trait. This finding aligns with established anatomical literature, which recognises a predominance of a single main PCBMN branch while also noting substantial individual variation. Regarding the measured distance from the fascial exit to the first branch point, the study group had a higher mean value of 21.2 mm (± 8.3) compared to 18.2 mm (± 7.4) in the control group. While this difference followed the anticipated trend of a slightly longer trajectory among individuals with higher BMI, it did not reach statistical significance ($p = 0.182$). Overall, the results reaffirm the anatomical consistency of the PCBMN across BMI-defined groups while highlighting the broad range of individual variability, particularly in branching patterns and trajectory length.

Table 5: Comparison of Derived PCBMN Safety-Zone Distances between the Study and Control Groups (n = 25 Each)

Variable	Study Group (n=25)	Control Group (n=25)	P-value
Distance A (mm)	4.9 ± 2.4	4.3 ± 2.3	0.433
Distance B (mm)	4.4 ± 2.3	3.7 ± 2.2	0.297
Distance C (mm)	7.4 ± 3.7	7.8 ± 4.1	0.704

Note: Statistical Test Used: Independent Samples t-Test for Continuous Variables.

A p-Value < 0.05 was Considered Statistically Significant.

The comparison of derived safety-zone parameters between the study and control groups revealed no statistically significant differences in any measured dimension (Table 5). For Distance A, representing the lateral safety margin relative to the palmaris longus tendon axis, the mean in the study group was 4.9 mm (± 2.4), slightly higher than the control group mean of 4.3 mm (± 2.3). Still, the difference was not significant ($p = 0.433$). Similarly, for Distance B, measured from the PCBMN to the radial border of the flexor carpi radialis (FCR), the study group exhibited a mean of 4.4 mm (± 2.3) compared to 3.7 mm (± 2.2) in the control group, with a p-value of 0.297, again indicating no significant divergence. For Distance C, the vertical safety margin measured from the nerve exit to the distal wrist crease, both groups demonstrated overlapping distributions, with a mean of 7.4 mm (± 3.7) in the study group and 7.8 mm (± 4.1) in the control group ($p = 0.704$). These findings affirm that despite individual variability, the lateral safety-zone corridors of the PCBMN remain largely consistent between BMI strata. However, clinical implications suggest that while horizontal safe margins are preserved, the deeper subcutaneous plane in obese patients may necessitate greater caution during blunt dissection due to the relative narrowing of the effective depth window. These trends align well with cadaveric and sonographic literature and reinforce the anatomical predictability of the nerve's course.

5. Discussion

The present study analyzed the morphometric distances from the fascial exit point of the palmar cutaneous branch of the median nerve (PCBMN) in two groups divided by body mass index (BMI). It found no statistically significant difference in the orthogonal distance to the palmaris longus tendon (Distance A), to the radial border of the flexor carpi radialis (Distance B), or to the distal wrist crease (Distance C) between obese and non-obese patients. These findings suggest that despite increased subcutaneous adiposity in obese individuals, the lateral and distal positional relationships of the PCBMN remain relatively constant, affirming its predictable anatomical pathway for surgical planning.

Comparative evaluation with other recent studies provides both corroboration and divergence. In support of the current findings, Glickel et al. (2020) documented variability in PCBMN course near the FCR but emphasized the relative consistency in its distance from surface landmarks such as the wrist crease and palmaris longus tendon, reinforcing the notion of a preserved anatomical path despite variations in branching or sheath penetration patterns.

Similarly, Chiew et al. (2022) reported a radial deviation of the PCBMN in a case that necessitated modifying the surgical approach. However, the rarity of such variations underlines the general reproducibility of the nerve's location, indirectly supporting the consistency found in the present study.

Jeong et al. (2021), using ultrasound to assess the cross-sectional area (CSA) of the PCBMN, reported size increases in carpal tunnel syndrome but did not identify substantial positional variation with BMI. This aligns with the current study's implication that soft tissue bulk may affect depth but not the nerve's topographic trajectory.

Conversely, Chavez and Smith (2025) demonstrated that the presence of the palmaris longus tendon affects the depth of the median nerve, with the nerve positioned deeper in individuals with this tendon. Although their findings relate to the median nerve itself and not directly to the PCBMN, it suggests that certain anatomical variables, including soft-tissue characteristics, might influence nerve positioning more than BMI alone.

SEYYEDIN and NEMATOLLAHI-MAHANI (2024) described a case of the PCBMN passing beneath the flexor retinaculum, contrary to its typical superficial course. Such rare deviations could explain outliers or inconsistencies across studies, though the current study's strict inclusion criteria likely excluded such anatomical anomalies, contributing to their findings of uniformity.

Park et al. (2022) also supported the notion that the PCBMN often runs near or within the FCR sheath, with a reported 10.8% frequency of intratendinous penetration. While these variations underscore potential surgical risks, they did not correlate with BMI, mirroring the findings of the current study, which show that morphometric distances are not BMI-dependent.

Finally, Hou et al. (2023) questioned the reliability of the palmaris longus tendon as a consistent landmark, showing wide positional variability of the median nerve relative to it. While the present study supports consistent morphometrics overall, this discrepancy could be attributed to differences in landmark definitions and between imaging- and intraoperative-based measurement methods.

In synthesis, the present study's intraoperative evidence reinforces the stability of key PCBMN surface relationships across BMI categories. While some cadaveric and imaging-based investigations report anatomical variability, particularly in branching or sheath entry, these do not appear to significantly alter the nerve's core morphometric distances. Discrepancies between findings may stem from methodological differences (cadaveric vs. live surgical vs. imaging), sample selection, or rare anatomical anomalies. Therefore, while the anatomical course of the PCBMN is broadly consistent, especially in relation to external landmarks, heightened vigilance remains essential in surgical contexts given the nerve's superficial location and potential for variation.

The present study explored the morphometric parameters of the palmar cutaneous branch of the median nerve (PCBMN), particularly comparing the angle of trajectory (θ) and fascial exit depth between patients with normal BMI and those with obesity. The results revealed no statistically significant difference in the trajectory angle between groups ($10.7^\circ \pm 7.6^\circ$ vs. $11.0^\circ \pm 5.8^\circ$, $p = 0.899$), indicating that the nerve tends to follow a consistent angular course regardless of subcutaneous adiposity. Clinically, this reinforces the anatomical reliability of the nerve's orientation relative to surface landmarks, such as the palmaris longus tendon, thereby supporting existing incision-planning techniques that avoid PCBMN injury.

Conversely, the study found a statistically significant increase in fascial exit depth in the obese group ($3.4 \text{ mm} \pm 1.2$) compared to the control group ($1.7 \text{ mm} \pm 0.8$), with a p -value < 0.001 . This indicates that while the nerve's course remains consistent, its depth beneath the skin surface is nearly doubled in individuals with higher BMI. From a surgical standpoint, this deepening could increase the risk of injury if blunt dissection is inadequately deep or if superficial visualization is assumed. These findings are crucial for refining surgical techniques and ensuring adequate exposure in obese patients to prevent iatrogenic damage.

Comparative analysis with recent studies provides valuable context. Jeong et al. (2021) used high-resolution ultrasound to demonstrate that the cross-sectional area (CSA) of the PCBMN increased significantly in patients with carpal tunnel syndrome (CTS), with higher CSA values in severe CTS cases. Although not directly assessing BMI, the observed

nerve enlargement may correlate with deeper or more obscured neural structures, thereby indirectly supporting the present study's conclusion that PCBMN morphology is affected by the surrounding soft tissue composition.

Further supporting evidence comes from Xu et al., who found that PCBMN consistently lies within 5–6 mm of standardised wrist landmarks, but emphasised that its depth can vary and that incision placement must accommodate this variability. Their cadaveric analysis established that soft tissue variability including depth must be accounted for in incision strategy, aligning closely with the findings of the present study (Xu et al., 2013).

Montanari et al. (2022) provided intraoperative data from 85 patients undergoing carpal tunnel release, showing that sensory branches of the PCBMN were located more frequently in the superficial subcutaneous layer, but were absent over the distal third of the transverse carpal ligament. They proposed that this area is a relatively safe incision zone. Their results contrast with those of the current study, suggesting that in most patients, superficial incisions may still be adequate. However, they did not stratify by BMI, so their conclusion may be limited when applied to patients with increased adiposity.

Contrary findings were reported by Taleisnik (1973), who found in a cadaveric study that the PCBMN is not consistently present as a discrete structure and may not be clinically significant in some individuals due to overlapping innervation. While this casts doubt on the universal necessity of PCBMN preservation, the study's cadaveric nature and lack of BMI stratification limit its applicability to live surgical settings. This variability emphasizes the need for real-time visualization, as implemented in the present intraoperative study.

Finally, Mujadzic et al. (2022) investigated surface anatomical markers in diverse populations and suggested that sex and ethnicity influence safe zone widths for carpal tunnel incisions. While their study emphasized surface landmark variability, it did not address fascial depth or the effects of adiposity, presenting a more superficial anatomical viewpoint. This contrast further underscores the present study's contribution to understanding depth-related variability as a function of BMI.

In conclusion, the present study's findings of a significant increase in fascial exit depth in obese individuals are well supported by several recent anatomical and imaging-based studies. However, discrepancies in the perceived necessity of PCBMN preservation and the assumed uniformity of its course reflect ongoing variability in anatomical presentations and methodological approaches. These results advocate for individualized incision planning, especially in patients with elevated BMI, where deeper dissection is critical for nerve preservation.

In the current study, comparisons of palmar cutaneous branch of the median nerve (PCBMN) branching patterns and distances to the first branch between normal and obese patients showed no statistically significant differences. While the study group ($BMI \geq 30$) showed a slightly higher average distance to the first branch (21.2 mm) than the control group (18.2 mm), the variation did not reach significance ($p = 0.182$). Similarly, the branching pattern (single vs. multiple) was nearly identical between groups (76% vs. 80% single branch), with a p -value of 1.000. These findings suggest a consistent anatomical trajectory and branching architecture of the PCBMN regardless of adiposity, which is clinically relevant by reinforcing the predictability of nerve location during carpal tunnel surgery across varying body types.

This conclusion is partially supported by recent cadaveric studies, such as Tetiker et al. (2025), who reported a broad range in the length (11.0–62.9 mm) and area (8–98 mm²) covered by the PCBMN, indicating substantial natural variation among individuals, but not specifically attributing such differences to BMI or soft tissue mass. Similarly, Bertelli et al. (2022) emphasized consistent innervation zones by the PCBMN and other palmar branches. Yet, they also noted variable trajectory lengths and innervation distances, which aligned with the variability seen in the present study.

However, some studies diverge from the current findings. Glickel et al. (2020) documented a higher-than-expected frequency (18.8%) of anomalous PCBMN trajectories around the flexor carpi radialis sheath in live surgical cases, highlighting the potential for clinically significant variations in branching location and course, which contrasts with the anatomical uniformity reported in the present study. Similarly, Chiew et al. (2022) presented a case of a PCBMN variant running superficially and radially to the FCR, reinforcing the argument that rare but important deviations in branching paths exist and warrant intraoperative vigilance.

Another contrasting perspective comes from SEYYEDIN and NEMATOLLAHI-MAHANI (2024), who observed a unique origin of the PCBMN from the ulnar side of the median nerve, with the nerve passing beneath the flexor retinaculum an unusual configuration absent in the present study but clinically significant given its potential impact on surgical planning.

On the other hand, the present findings are further reinforced by Montanari et al. (2022) who found that sensory branches, including those from the PCBMN, were absent from the distal third of the transverse carpal ligament in 60% of cases, suggesting anatomical consistency in branching behaviour that supports the current study's observations.

Additional case-based studies, such as Wan et al. (2020) highlight that even when anatomical patterns are generally predictable, clinical anomalies such as PCBMN compression due to palmaris longus tendon rupture can introduce secondary anatomical changes not accounted for by baseline BMI or normative variance, suggesting that individual pathology, rather than generalized body composition, may more strongly influence deviation from expected branching distances.

In summary, the present study's finding that BMI does not significantly influence PCBMN branching pattern or distance

to the first branch is consistent with several anatomical and imaging-based studies, particularly those involving cadaveric data and surgical mapping. Nevertheless, a substantial body of case-based literature illustrates that anatomical variations though perhaps infrequent are clinically relevant and may not correlate predictably with BMI or other anthropometric variables. This suggests that while general anatomical predictability can be expected, surgeons must remain alert to idiosyncratic deviations regardless of patient body habitus.

The present study assessed the influence of BMI on the "safety-zone" distances surrounding the palmar cutaneous branch of the median nerve (PCBMN) during open carpal tunnel release. Specifically, it compared three morphometric dimensions (Distance A: to the palmaris longus tendon; Distance B: to the flexor carpi radialis tendon; Distance C: to the distal wrist crease) between obese and non-obese patient groups. The results demonstrated no statistically significant differences in any of these parameters, suggesting that BMI does not materially alter the lateral or vertical surface relationship of the PCBMN in a manner that would affect horizontal surgical planning. However, despite preserved surface relationships, the study highlighted that increased subcutaneous depth in obese individuals may limit the effective working window for dissection, increasing the risk of iatrogenic injury unless deeper dissection is approached with heightened caution.

In agreement with this conclusion, [Montanari et al. \(2022\)](#) also confirmed the reliability of surface-based incision zones by identifying a consistent subcutaneous segment over the distal transverse carpal ligament as a relatively safe entry point, with limited presence of terminal PCBMN branches across varied patients, supporting a predictable anatomical pattern that aligns with the present study's findings. Similarly, [Mujadzic et al. \(2022\)](#) observed that most patients had longitudinal palmar creases within a defined "safe zone," reinforcing the general predictability of superficial nerve anatomy across different demographic groups.

Further validating the present study's suggestion that BMI may influence depth but not lateral trajectory, [Jeong et al. \(2021\)](#) used high-resolution ultrasound and found that PCBMN cross-sectional area increases with severity of carpal tunnel syndrome (CTS), likely due to compression-related swelling. Yet, the nerve's spatial orientation and relationships to fixed landmarks remained unchanged.

However, [Hou et al. \(2023\)](#) provide contrasting evidence. Who analyzed 784 wrist MRIs and found considerable positional variability in the median nerve relative to the palmaris longus tendon. Their findings suggested that the palmaris longus may not be a consistent or safe reference for incision planning especially in patients with CTS - the present study's reliance on this tendon as a consistent axis when measuring distances of safety.

Similarly, [SEYYEDIN and NEMATOLLAHI-MAHANI \(2024\)](#) found highly variable origins and courses of the PCBMN in a cadaveric case, with rare anatomical variants such as ulnar-sided exits and fascial pathways, suggesting that rare anatomical variations may deviate considerably from population-level patterns gleaned from studies such as the present one. These results suggest that if there is no statistical difference in average distances but individual differences still exist, this could still be risky.

Another divergent report of [Glickel et al. \(2020\)](#) prospectively documented anomalous PCBMN branching in nearly 19% of patients and several of these branches run in or between the flexor carpi radialis sheath (which is an area often targeted during volar wrist approaches). This anatomical diversity may call into question the applicability of uniform safety-zone measures and suggest that relying on surface metrics alone may not be sufficient in a subset of patients.

The implication of the present study that there is no difference in the horizontal dimensions of the nerve across different BMI strata is further supported by [Lee et al. \(2023\)](#), who described no PCBMN injury in over 100 patients using a minimally invasive technique for carpal tunnel release that theorize that well thought out placement of incisions along predicted anatomical lines can in fact prevent trauma to the nerve regardless of BMI.

However, [Yamazaki et al. \(2024\)](#) found a case of CTS associated with bifid median nerve and an aberrant muscle (palmaris profundus), and atypical compression and distorted anatomy required deviation from conventional incision pathways. Such findings while quite rare support the need for vigilance and intraoperative flexibility, which may not all be covered by the standardization in the present study.

In conclusion, current study is a valuable dataset confirming that standard safety zone dimensions surrounding the PCBMN are generally stable across BMI categories. However, in real life, surgical planning should take into account patient variability, particularly in the setting of high BMI, aberrant branching, or variant muscular anatomy. Despite statistical uniformity, individualized dissection and imaging-based approaches may contribute to surgical safety in outlier cases.

6. Conclusion

This prospective, intraoperative mapping study demonstrates that the PCBMN maintains stable lateral and distal relationships to standard surface landmarks: the palmaris longus, the radial border of the flexor carpi radialis, and the distal wrist crease, irrespective of obesity. Trajectory angle likewise remains consistent between BMI strata. By contrast, fascial-exit depth is nearly doubled in obese patients, indicating that while horizontal incision corridors are preserved, the safe working depth narrows with increasing adiposity. Clinically, these data support continued reliance on established, ulnar-

offset surface landmarks for open CTR while emphasizing proportionally deeper, deliberate dissection in obese patients to reduce iatrogenic PCBMN injury. The absence of BMI-related differences in branching pattern and the distance to first branch further underscores the anatomical predictability of the nerve's course. Limitations include a single-centre design and a modest sample size; future work should integrate preoperative ultrasonography and outcome tracking to validate depth-informed incision strategies and quantify reductions in nerve injury.

7. References

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