The effect of vascular pedicle preservation on blood flow and clinical outcome following ulnar nerve transposition

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- Ulnar nerve

- Blood flow
- Cubital tunnel syndrome
- Laser Doppler flowmeter
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Abstract

Purpose: To evaluate the efficacy of a technique to preserve the extrinsic vascular supply to the ulnar nerve after transposition and its effect on blood flow and clinical outcome.

Methods: We included 36 patients with cubital tunnel syndrome. The patients were randomly selected to undergo vascular pedicles-sparing surgery for anterior ulnar nerve transposition (VP group) or nerve transposition and artery ligation (non-VP group). Blood flow to the ulnar nerve was estimated at 3 locations in the cubital tunnel intraoperatively before and after transposition using a laser Doppler flowmeter. Clinical results at 3, 6, and 12 months after surgery were also compared between the 2 groups.

Results: The blood flow before the ulnar nerve transposition was not significantly different between the groups. Blood flow at all 3 locations after the ulnar nerve transposition was significantly higher in the VP group than in the non-VP group. Blood flow in the non-VP group reduced to values between 28% and 52% from the preoperative baseline values. After surgery, no significant differences were observed in the clinical results between the groups, except for the Disabilities of the Arm, Shoulder, and Hand scores at 12 months after surgery, which was greater in the non-VP group.

Discussion: The procedure of preserving the extrinsic vascular pedicles can prevent compromise of blood flow to the ulnar nerve immediately after nerve transposition. However, this procedure had no correlation to improved recovery of ulnar nerve function after surgery.

Therapeutic study investigating treatment results
Level of Evidence: II

INTRODUCTION

Several procedures are available for the treatment of cubital tunnel syndrome (CubTS). Subcutaneous anterior ulnar nerve transposition may be the procedure of choice for CubTS caused by elbow osteoarthritis (OA) because of the following biomechanical changes: 1) the cubital tunnel floor in an elbow with OA is abnormally shallow owing to the presence of osteophytes or deformity of the elbow joint 2) the distance from the center of rotation of the elbow joint to the course of the ulnar nerve becomes greater, which may result in increased tension on the nerve; 3) cubital tunnel pressure has been found to be greater in OA elbows than in non-OA elbows [1]; and 4) The anteriorly transposed ulnar nerve is not stretched with maximum degree of elbow extension because maximum degree of extension is restricted by elbow OA. One drawback of subcutaneous anterior transposition, however, is the possible compromise of the blood supply to the nerve after extensive dissection[2-4]. Restoration of intraneural blood flow is critical for recovery of peripheral nerve function after chronic compression [5-7]. Therefore, preserving the vascular pedicles of the ulnar nerve using the subcutaneous anterior transposition technique could have the advantage of better clinical results; however, it has disadvantages such as longer operative time, the need to perform careful dissection, and further vascular damage. Ogata et al.[8] demonstrated that anterior transposition without a vascular pedicle was associated with a significant decrease in regional blood flow to the ulnar nerve in their monkey models.

In light of this, a method for anterior transposition of the ulnar nerve that preserves the extrinsic nutrient arteries was developed [4,9]. While this method is theoretically appealing and has been evaluated in several series [4,8-12], the data are insufficient for conclusive evaluation of results because of lack of blood flow measurements or because

of problems in the study design. Therefore, whether this procedure has a positive effect on clinical outcomes remains unclear. To date, animal or human data that directly assess blood flow using this technique have been limited [4,8-13].

The purposes of the present study were to investigate changes in blood flow to the ulnar nerve *in vivo* in humans and their effects on clinical results of ulnar nerve transposition with or without preservation of the vascular pedicles.

MATERIALS AND METHODS

Patients

Institutional review board approval was obtained before commencing this study. The principal inclusion criterion was CubTS associated with elbow OA with a sensory or motor deficit confirmed by physical examination and nerve conductive studies. The exclusion criterion was CubTS caused by idiopathic or conditions other than OA, including contusion, dislocation, and fracture. Patients with tardy ulnar nerve palsy associated with cubitus valgus or varus were also excluded, as were those with a history of decompression of the ulnar nerve. The OA changes in the affected elbows were evaluated based on anteroposterior, lateral, and cubital tunnel radiographs [14]. Elbows classified as grade 3, 4, or 5 of the Kellgren-Lawrence scale [15] were considered to have OA. A total of 36 patients (29 men and 7 women) met the inclusion criteria and were enrolled in the study. Their mean age was 66 years (range, 51–80). The mean restricted extension angle of the elbow joint was 14° (range, 0–35°), and the mean flexion angle was 122° (range, 105–145°). The most common physical findings were a Tinel sign at the cubital tunnel, a positive elbow flexion test[14,16], decreased strength of the abductor digiti minimi and first dorsal interosseous muscle, and sensory disturbance in the

distribution of the ulnar nerve. Electrodiagnostic studies confirmed decreased motor ulnar nerve conduction (MCV) and/or sensory ulnar nerve conduction velocities across the affected elbow (<50 m/s). The patients were randomly selected on the day of surgery via an independent observer by choosing one of 2 opaque envelopes containing a card that indicated the patient to undergo vascular pedicles-sparing surgery for anterior ulnar nerve transposition (VP group) or nerve transposition and artery ligation (non-VP group). Multiple surgeons, who are coauthors of this study, performed the surgeries using a uniform procedure at a single institution.

Surgical procedure

A curved skin incision approximately 13 cm long was made posterior to the medial epicondyle. The medial antebrachial cutaneous nerve was preserved. The ulnar nerve was identified at the proximal end of the cubital tunnel, and the cubital tunnel retinaculum, composed of the deep investing fascia of the flexor carpi ulnaris (FCU) muscle and the arcuate ligament of Osborne[17], was incised. The arcade of Struthers[18] was incised, and the medial intermuscular septum of the arm was resected for 10 cm proximal to the medial epicondyle to allow anterior displacement of the nerve without tension or kinking. The articular branch of the ulnar nerve was cut. If the tension of the most proximal motor branch to the ulnar head of the FCU was too tight for transposition, it was cut or dissected from the main nerve trunk. Any cysts or loose bodies in the cubital tunnel were removed.

We identified the 3 main extraneural arteries in all the cases, namely the superior ulnar collateral artery (SUCA), inferior ulnar collateral artery (IUCA), and posterior ulnar recurrent artery (PURA; Figs. 1 and 2) [4,12,19,20]. The SUCA generally originates

from the brachial artery at an average of 179 mm proximal to the medial epicondyle and runs parallel with the nerve. The IUCA originates from the brachial artery at an average of 66 mm proximal to the medial epicondyle and travels deep and posterior to the intermuscular septum, eventually passing beneath the ulnar nerve. The PURA originates from the ulnar artery at an average of 73 mm distal to the medial epicondyle and passes deep and posterior to the nerve in a distal-to-proximal direction [20]. The portion of the SUCA running parallel to the ulnar nerve was initially identified without difficulty. We could then locate the IUCA below the ulnar nerve for the SUCA anastomosis. We next identified the PURA, which formed an anastomosis with the IUCA. The PURA was located approximately 3 cm distal to the medial epicondyle.

In the VP group, we preserved the connection between the 3 main extraneural arteries and the ulnar nerve when we performed the dissection and transposition of the ulnar nerve. Any small vessels arising from the collateral artery to the ulnar head of the FCU or triceps were coagulated so that the ulnar nerve could be transposed with the 3 main extraneural arteries without tension. If the IUCA turned out to be under excessive tension when the ulnar nerve was transposed, it was also coagulated. After transposition, pulsation of the SUCA, IUCA, and PURA was confirmed visually. In the non-VP group, the 3 extraneural arteries were identified, coagulated, and cut to disconnect them from the ulnar nerve. The remainder of the procedure was performed as for the VP group.

Flow measurement and analysis with noncontact laser blood flowmeter

The usefulness of the laser Doppler flowmeter for studies of peripheral nerves has been verified [21-24]. Continuous blood flow of the ulnar nerve was measured with a laser Doppler flowmeter with a noncontact probe (FLO-N1 with a CS-N probe, Omegawave,

Tokyo, Japan). The probe has a polarized laser [25-27] (Fig. 3A) that is intended to eliminate reflections from the tissue surface and an electronic circuit with a rapid contact time intended to reduce artifacts caused by temporal changes in the distance between the probe and the tissue [26]. The flow in milliliters per 100 g/min is calculated based on the Doppler shift. The maximum depth measured by the noncontact probe is approximately 1 mm.

In all the patients from both groups, 3 points were marked over the epineurium of the medial aspect of the ulnar nerve after incision of the cubital tunnel retinaculum. Point P was 2 cm proximal to the medial epicondyle, point M was at the epicondyle, and point D was 2 cm distal to the medial epicondyle (Figs. 2 and 3B). After deflation of the tourniquet, bipolar coagulation was performed to arrest bleeding. Ten minutes after the deflation of the tourniquet, the blood flow in the ulnar nerve trunk was measured with the probe placed 1 cm from the epineural surface at each of the designated points by transmitting the laser beam at a 90° angle to the tissue for 10 s and then beginning the measurement, which continued for 20 s. The average blood flow within 20 s was automatically calculated (Log Worx, Omegawave), and instantaneous changes in blood flow were displayed on the amplifier. The examiner was blinded to these values. Blood flow was measured at all the 3 points under each of the following conditions before ulnar nerve transposition: (1) maximum extension of the elbow joint and (2) 90° flexion of the elbow joint. After performing the measurements, we transposed the ulnar nerve without inflating the tourniquet. The blood flow measurements were performed after the initial dissection and exposure of the ulnar nerve but before any vascular dissection. Then, blood flow was measured again at all the 3 points under the following conditions: (1) maximum extension of the elbow joint after ulnar nerve transposition and (2) 90°

flexion of the elbow joint after ulnar nerve transposition. For data analysis, to verify whether there were differences between the VP and non-VP groups before transposition, the blood flow values on each point were compared between the 2 groups. Blood flow was measured at maximum elbow extension and 90° elbow flexion to avoid displacement of the ulnar nerve anteriorly over the medial epicondyle with further flexion of the elbow. For data analysis after transposition of the ulnar nerve, blood flow values at each elbow position on each point were compared between the VP and non-VP groups. In the comparison between the 2 groups, the ratio of the blood flow at each elbow position on each point before and after transposition to the blood flow at point P in the extended position before transposition was used for analysis to eliminate the influence of blood pressure variance.

Preoperative and postoperative clinical evaluation

The following clinical data were obtained for analysis. The McGowan classification[28] was applied for evaluation of CubTS grade as follows: grade I, neuropathy without muscle weakness; grade II, neuropathy involving muscle weakness with wasting; and grade III, neuropathy involving interosseus palsy with severe muscle wasting. The Japanese version of the Disabilities of the Arm, Shoulder, and Hand questionnaire (DASH-JSSH) [29] was administered to all the patients. A MCV was obtained using a Neuropack M1 (Nihon Kohden Corp, Tokyo, Japan). The recording surface disc electrode was placed over the abductor digiti minimi muscle, and the ulnar nerve was stimulated proximal and distal to the cubital tunnel. The difference in onset latency of the compound muscle action potential and the distance of the stimulation site were used to calculate the MCV.

Grip strength was measured using a Jamar dynamometer (Sammons Preston Rolyan, Bolingbrook, IL), and pinch strength was measured using a pinch gauge (Sakai Medical Co. Ltd., Tokyo, Japan). The mean value of 3 measurements was used for the analysis. For sensory evaluation, the 2-point discrimination (2PD) test (a 2-point discriminator; Sakai Medical Co. Ltd., Tokyo, Japan) and Semmes-Weinstein (SW) monofilament test (a nylon monofilament set; Sakai Medical Co. Ltd.) were used. The measurements were obtained from the little and index fingers. The measurements from the 2PD and SW tests were interpreted based on international criteria [30-32].

These clinical data were recorded before surgery and repeated at 3, 6, and 12 months after surgery. The data were compared between the VP and non-VP groups. For continuous variables (i.e., the DASH score, MCV, grip strength, and pinch strength), improvement from the preoperative to postoperative values was also compared between the VP and non-VP groups.

Statistical analysis

Because the normality of the blood flow values and ratios were not normally distributed, we logarithmically transformed the data, yielding a normal distribution by the Kolmogorov-Smirnov test. The transformed data were then used for subsequent statistical analyses. The unpaired *t* test was used for comparison of the blood flow ratios between the 2 groups. For clinical data, group comparisons using the McGowan classification, 2PD test, and SW test within the same follow-up period were performed using the Fisher exact test. Comparisons between the DASH scores, MCV, grip strength, and pinch strength were performed using the Mann-Whitney *U* test.

Statistical significance was inferred for Ps < 0.05.

RESULTS

Comparison of blood flow during surgery

A total of 20 patients underwent subcutaneous ulnar nerve transposition with vascular pedicles, and 16 patients underwent subcutaneous ulnar nerve transposition without a vascular pedicle. No significant differences were found between the 2 groups in terms of age, sex, affected side, arc of elbow motion, comorbidities, or McGowan classification (Table 1). No significant differences in blood flow to the ulnar nerve before transposition were observed between the 2 groups (Table 2).

In the VP group, no IUCA was identified in 2 of the 20 patients. The SUCA and PURA were identified in all the 20 patients. In the non-VP group, the SUCA, IUCA, and PURA were identified in all the 16 patients. No other arteries were identified besides the 3 main collateral arteries. In 1 patient in the VP group, the IUCA was coagulated and cut owing to excessive tension during anterior transposition. All the 3 arteries supplying the nerve were preserved in the remaining 17 patients in the VP group. During surgery, obvious pseudoneuroma of the ulnar nerve was identified proximal to the entrapment site in 32 of the 36 patients. No significant differences in blood flow to the ulnar nerve were observed regardless of pseudoneuroma.

After transposition, the blood flow ratios with the elbow at maximum extension at points P, M, and D were significantly greater in the VP group than in the non-VP group (Table 3). With the elbow at 90° flexion, the differences in blood flow ratio between the 2 groups were significant at all the 3 points (Table 3). In the power analysis, the statistical power of the comparison data of blood flow after transposition of ulnar nerve was from 50% to 99%. No change in maximum elbow flexion and extension arc was

observed after surgery in each patient because we only performed ulnar nerve transposition without arthroplasty.

Postoperative clinical evaluation

During the postoperative period, 1 patient in the VP group died at 3 months after surgery from an unrelated cause. One patient in the non-VP group was lost to follow-up at 3 months after surgery. One patient in the VP group was lost at 6 months after surgery, and 1 patient in the non-VP group died at 12 months after surgery. Therefore, the follow-up rates (expressed as percentage of all the cases followed up at each period) were 94% at 3 months, 92% at 6 months, and 89% at 12 months.

No significant differences in parameters were found between the groups before surgery (Table 4) and 3 and 6 months after surgery (Tables 5 and 6). No significant differences in parameters were found between the groups, except in the DASH scores at 12 months after surgery (Table 7). In the power analysis, the statistical power of the DASH scores at 12 months after surgery was 41%.

Regarding the improvement value, no significant differences in DASH score, MCV, grip strength, and pinch strength were found (Tables 5–7).

DISCUSSION

In our institution, 75% of the CubTS cases were associated with elbow OA. This is high in comparison with those in previous studies reporting CubTS [33-35] but similar to those reported in other Japanese studies [36-38]. The prevalence of elbow OA is variable among races and increases with the ratio of patients in the population who perform

heavy labor. In the present study, all the patients were Japanese, most of whom were farmers or heavy laborers.

Blood flow in the nerve is supplied by extrinsic and intrinsic sources. Regarding the ulnar nerve around the elbow, 3 extrinsic sources were identified, namely the SUCA, IUCA, and PURA in previous cadaver studies. According to the anatomical study by Kato et al [12]. 1 to 5 nutrient vascular pedicles originate from the SUCA, IUCA, and PURA and are connected to the extrinsic artery over the epineurium of the ulnar nerve. These vessels join the nerve via the fascia and anastomose with the intrinsic system of the nerve [6,20]. The intrinsic system is composed of all the vessels within the epineural sheath. In general, the nutritional supply of the nerve is essential for normal nerve conduction and axonal transport. Therefore, restoration of intraneural blood flow is critical for recovery of peripheral nerve function following chronic compression[5-7].

In CubTS, the pressure in the cubital tunnel is increased [1,36] . An increase in intrafascicular tissue pressure will result in a marked decrease in intrafascicular blood flow [6]. In addition, the strain in the ulnar nerve in CubTS was increased[39]. Blood flow in the stretched nerve was found to be decreased [40] . Decreased intraneural blood flow may impede recovery of the ulnar nerve function after anterior transposition.

For subcutaneous anterior transposition, extensive dissection around the nerve may

cause compromise of the extrinsic blood supply to the transposed nerve. For this drawback, the modified anterior subcutaneous transposition to retain the collateral arteries of the ulnar nerve to preserve blood flow was developed [9]. While this method is theoretically appealing and has been shown to have good clinical results in several series[4,9-12], how extrinsic blood flow affects clinical results is unknown because of the lack of randomized comparative studies.

Our results showed no apparent differences in the recovery of nerve function (the McGowan classification grade, MCV, grip strength, pinch strength, 2PD, and SW test results) after surgery, regardless of vascular pedicle preservation. The DASH score was found to be slightly better in the VP group than in the non-VP group after 12 months. Such differences in DASH score may be attributed to other sources of morbidity such as pain from elbow OA or other upper arm OA, which the patients did not declare, rather than to ulnar nerve function. Furthermore, the DASH score was slightly lower before surgery in the VP group than in the non-VP group, although the differences were not significant. The initial differences could be partly responsible for the significant differences at 12 postoperative months.

The blood flow result showed that 28% to 52% of the baseline blood flow on the ulnar nerve trunk was maintained immediately after transposition without a vascular pedicle, indicating that the nerve could maintain the blood flow on some level only by intraneural nutrient supply. Given the anastomoses between the intrinsic longitudinal vascular network inside the nerve and the extrinsic regional vessels approaching the nerve trunk [20] , if 1 system was excluded, the other system could compensate for the

deficit. This compensatory blood flow through additional connections to the intrinsic and extrinsic blood flow has been shown by Maki et al [13], who reported that blood flow in the nerve was regionally increased 45 minutes after extrinsic blood supply was stopped in a rabbit sciatic nerve model. In a monkey model, blood flow immediately after anterior ulnar nerve transposition without a vascular pedicle decreased by approximately 40% but returned to baseline levels 3 days after surgery [8]. Therefore, there was a possibility that the intraneural blood flow without extraneural vascular pedicle after surgery was maintained or even compensatorily increased, as in the delay flap phenomenon, although we did not perform an initial measurement of the intraneural blood flow and measured blood flow only once immediately after transposition. In cross-chest ulnar nerve grafting for contralateral C7 neurotization in brachial plexus palsy, Waikakul et al[41] reported that connection between the distal end of the ulnar nerve and proximal part of the contralateral C7 root without revascularization obtained a similar result to that with revascularization. This indicated that intrinsic blood flow to the nerve is more profound than extrinsic blood flow. Our hypothesis that anterior ulnar nerve transposition with the vascular pedicle preserved would result in better functional recovery after surgery was dispelled. We assume that if nerve continuity is intact, the extraneural vascular pedicle can be ligated or cut in transposing the ulnar nerve.

Our study had several limitations. First, blood flow was measured only 1 time after the division of the 3 extraneural arteries. We did not estimate the relative contribution of each artery to blood flow to the nerve. Second, blood flow measurements were restricted to the blood flow on the surface of the nerve. Third, the maximum degree of elbow extension varied with the severity of each patient's OA. Fourth, blood flow was examined after release of nerve compression under the Osborne ligament. Fifth, the

number of patients for the data of MCV was limited because the compound muscle action potential could not be always detected in all the patients. Sixth, this study group was a subset of patients with CubTS, not the general population with CubTS, because they all had OA of the elbow. Finally, the statistical analyses were underpowered to detect small differences in the clinical parameters because of the small number of patients in each group and the small effect size, which might have weakened the only difference observed in the clinical follow-up examination.

Despite the limitations of the current study, preserving vascular pedicles can prevent compromise of blood flow to the ulnar nerve immediately after nerve transposition procedures. However, these differences have no correlations to recovery of nerve function.

Legends

Figure 1: The relationship between the ulnar nerve and extraneural arteries in the cadaver elbow after India ink with latex was transfused into the brachial artery.

SUCA: superior ulnar collateral artery; IUCA: inferior ulnar collateral artery; PURA: posterior ulnar recurrent artery

Figure 2: The diagram depicting the locations of the 3 common vascular pedicles to the ulnar nerve and the 3 points at which the laser Doppler flow measurements were obtained.

The heavy line indicates the points coagulated and cut in the non-VP group. The open circle indicates the points measured by laser Doppler flowmeter.

Point P was marked 2 cm proximal to the medial epicondyle. Point M was marked at the epicondyle. Point D was marked 2 cm distal to the medial epicondyle.

Figure 3: Noncontact probe and blood flow measurement points on the ulnar nerve

A: Noncontact probe (CS-N type; Omegawave Inc., Tokyo, Japan). **B**: Blood flow measurement points. Point P was marked 2 cm proximal to the medial epicondyle. Point M was marked at the epicondyle. Point D was marked 2 cm distal to the medial epicondyle.

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Table 1. Patient characteristics

	Vascular Pedicles (VP) group	Non-VP group	
Number of Patients	20	16	
Mean age ± S.D. (years)	68 ± 8	64 ± 9	n.s. †,¶
Percentage of males (%)	80	81	n.s. ‡
Right side (%)	75.0	68.8	n.s. ‡
Mean arc of elbow joint (degrees)	110 ± 8	106 ± 13	n.s. †
Diabetes mellitus (cases)	1 (5%)	2 (12%)	n.s. ‡
Smoker (cases)	6 (30%)	2 (12%)	n.s. ‡
McGowan classification§ (cases)			
Grade II	10	9	
Grade III	10	7	n.s. ‡

¶: n.s.: not significant. †: Mann-Whitney *U* test. ‡: chi-square test.
§ : No patients had neuropathy classified as grade I.

Table 2. Comparison of the ratio of blood flow before transposition of the ulnar nerve in vascular pedicles (VP) and non-VP patients.

		VP group		Non-VP group		*P*s value
Elbow position	Ulnar nerve	Mean†	(95% C.I.†,‡)	Mean†	(95% C.I.†,‡)	
Maximum extension	Point P	1	(1–1)	1	(1–1)	
	Point M	1.15	(0.87–1.53)	1.00	(0.68–1.53)	0.528
	Point D	1.28	(1.00–1.64)	1.27	(0.90–1.81)	0.992
90° Flexion	Point P	0.99	(0.89–1.09)	0.87	(0.73–1.04)	0.178
	Point M	0.98	(0.73–1.32)	0.93	(0.62–1.39)	0.793
	Point D	1.02	(0.79–1.32)	0.94	(0.64–1.39)	0.734

†: These values are retransformed from logarithmic transformed values.
‡: 95% CI: 95% confidence interval.

Table 3. Comparison of the ratio of blood flow after transposition of the ulnar nerve in the vascular pedicles (VP) and non-VP patients.

		VP group		No-VP group		*P*s value
Elbow position	Ulnar nerve	Mean†	(95% C.I.†,‡)	Mean†	(95% C.I.†,‡)	
Maximum extension	Point P	0.93	(0.76–1.13)	0.50	(0.34–0.73)	0.006*
	Point M	0.92	(0.70–1.21)	0.28	(0.17–0.45)	< 0.001*
	Point D	1.01	(0.55–0.95)	0.50	(0.31–0.81)	0.012*
90° Flexion	Point P	0.89	(0.66–1.20)	0.38	(0.27–0.54)	< 0.001*
	Point M	0.79	(0.63–1.11)	0.28	(0.18–0.45)	< 0.001*
	Point D	0.88	(0.65–1.19)	0.52	(0.33–0.83)	0.048*

†: These values are retransformed from logarithmic transformed values.

‡: 95% CI: 95% confidence interval.

Table 4. Comparison of the clinical data in vascular pedicles (VP) and non-VP patients before surgery.

		VP group (20 cases)	Non-VP group (16 cases)	*P*s value
McGowan classification (cases)	I	0	0	0.749 †
	II	10	9	
	III	10	7	
DASH (points)		28 ± 21	36 ± 17	0.223 ‡
MCV (m/s) #		35.9 ± 8.5 (15 cases)	36.6 ± 14.5 (14 cases)	0.880 ‡
Grip strength (kg)		24 ± 7	26 ± 10	0.385 ‡
Pinch strength (kg)		6.2 ± 1.9	7.0 ± 1.9	0.089 ‡
2PD¶ (cases)	Normal	3	1	0.772 †
	Fair	4	2	
	Poor	4	5	
	Untestable	9	8	
SW test § (cases)	Green	1	0	0.559 †
	Blue	3	5	
	Purple	10	6	
	Red	6	4	
	Untestable	0	1	

†: Fisher exact test. ‡: Mann-Whitney *U* test.
#: The number of measurable cases is shown inside the parentheses.
¶: 2PD: Two-point discrimination. The interpretation scale for 2PD is as follows: normal, <6 mm; fair, 6–10 mm; poor, 11–15 mm; and untestable, >16 mm.
§ : SW test: Semmes-Weinstein test. The interpretation of the monofilament grade scale is as follows: normal (indicated as green), 1.65–2.83 filament markings; diminished light touch (blue), 3.22–3.61 filament markings; diminished protective sensation (purple), 3.84–4.31 filament markings; loss of protective sensation (red), 4.56–6.65 filament markings; and untestable, >6.65 filament markings.

Table 5. Comparison of the clinical data in vascular pedicles (VP) and non-VP patients at 3 months after surgery.

		VP group (19 cases)	Non-VP group (15 cases)	*P*s value
McGowan classification (cases)	I	0	0	1 .000†
	II	12	10	
	III	7	5	
DASH (points)		20 ± 20	29 ± 18	0.083‡
Improvement value		7 ± 12	8 ± 15	1.000‡
MCV (m/s) #		43.0 ± 9.7 (16 cases)	46.8 ± 9.8 (12 cases)	0.559‡
Improvement value		10.6 ± 5.6 (13 cases)	9.0 ± 12.1 (12 cases)	0.943‡
Grip strength (kg)		26 ± 10	27 ± 10	0.784‡
Improvement value		2 ± 6	1 ± 3	0.274‡
Pinch strength (kg)		6.5 ± 2.1	7.3 ± 2.2	0.179‡
Improvement value		0.2 ± 1.1	0.4 ± 0.6	0.656‡
2PD¶ (cases)	Normal	4	2	0.896 †
	Fair	4	3	
	Poor	5	3	
	Untestable	6	7	
SW test § (cases)	Green	2	1	0.834†
	Blue	5	3	
	Purple	9	6	
	Red	3	4	
	Untestable	0	1	

†: Fisher exact test. ‡: Mann-Whitney *U* test.
#: The number of measurable cases is shown inside the parentheses.
¶: 2PD: Two-point discrimination. The interpretation scale for 2PD is as follows: normal, <6 mm; fair, 6–10 mm; poor, 11–15 mm; and untestable, >16 mm.
§ : SW test: Semmes-Weinstein test. The interpretation of the monofilament grade scale is as follows: normal (indicated as green), 1.65–2.83 filament markings; diminished light touch (blue), 3.22–3.61 filament markings; diminished protective sensation (purple), 3.84–4.31 filament markings; loss of protective sensation (red), 4.56–6.65 filament markings; and untestable, >6.65 filament markings.

Table 6. Comparison of the clinical data in vascular pedicles (VP) and non-VP patients at 6 months after surgery.

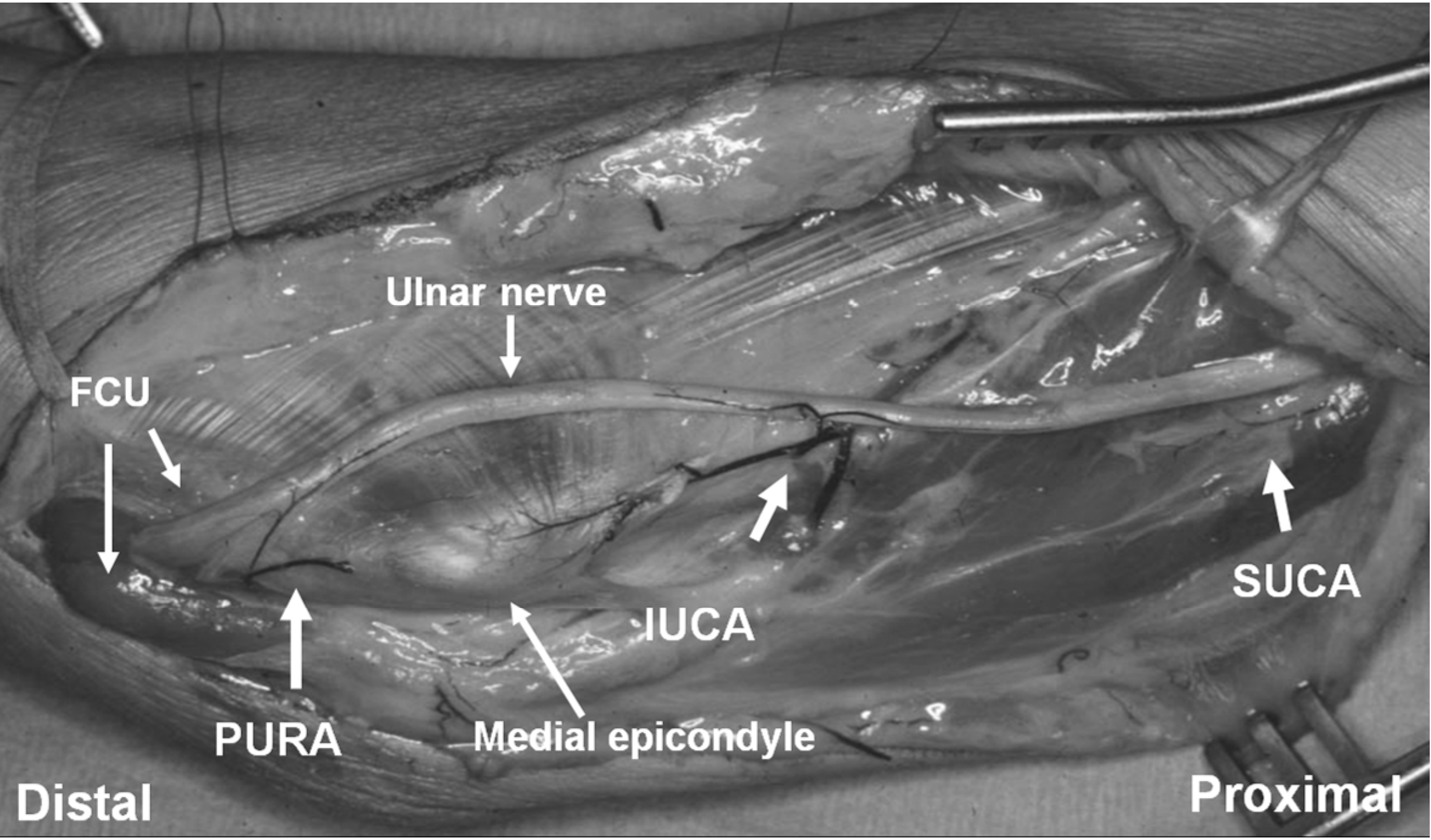
		VP group (18 cases)	Non-VP group (15 cases)	*P*s value
McGowan classification (cases)	**I**	2	0	0.383 †
	II	10	12	
	III	6	3	
DASH (points)		20 ± 21	31 ± 20	0.075 ‡
Improvement value		7 ± 10	7 ± 17	0.689‡
MCV (m/s) #		44.7 ± 9.1 (16 cases)	42.0 ± 16.2 (12 cases)	0.95 ‡
Improvement value		11.9 ± 6.1 (13 cases)	4.4 ± 18.6 (12 cases)	0.446‡
Grip strength (kg)		26 ± 9	27 ± 11	0.613 ‡
Improvement value		3 ± 5	1 ± 5	0.351‡
Pinch strength (kg)		7.0 ± 2.1	7.7 ± 2.4	0.274 ‡
Improvement value		0.7 ± 1.3	0.7 ± 0.9	0.562‡
2PD¶ **(cases)**	**Normal**	6	3	0.762 †
	Fair	6	4	
	Poor	2	3	
	Untestable	4	5	
SW test § **(cases)**	**Green**	4	2	0.275
	Blue	7	2	
	Purple	4	7	
	Red	3	4	
	Untestable	0	0	

†: Fisher exact test. ‡: Mann-Whitney *U* test.
#: The number of measurable cases is shown inside the parentheses.
¶: 2PD: Two-point discrimination. The interpretation scale for 2PD is as follows: normal, <6 mm; fair, 6–10 mm; poor, 11–15 mm; and untestable, >16 mm.
§ : SW test: Semmes-Weinstein test. The interpretation of the monofilament grade scale is as follows: normal (indicated as green), 1.65–2.83 filament markings; diminished light touch (blue), 3.22–3.61 filament markings; diminished protective sensation (purple), 3.84–4.31 filament markings; loss of protective sensation (red), 4.56–6.65 filament markings; and untestable, >6.65 filament markings.

Table 7. Comparison of the clinical data in vascular pedicles (VP) and non-VP patients at 12 months after surgery.

		VP group (18 cases)	Non-VP group (14 cases)	*P*s value
McGowan classification (cases)	**I**	3	0	0.297 †
	II	10	11	
	III	5	3	
DASH (points)		16 ± 20	29 ± 21	0.049 ‡
Improvement value		11 ± 14	10 ± 17	0.762‡
MCV (m/s) #		48.6 ± 9.8 (17 cases)	49.0 ± 12.8 (14 cases)	0.444 ‡
Improvement value#		15.2 ± 10.4 (13 cases)	12.2 ± 11.3 (14 cases)	> 0.999‡
Grip strength (kg)		28 ± 11	29 ± 11	0.735 ‡
Improvement value		4 ± 7	3 ± 5	0.385‡
Pinch strength (kg)		7.5± 2.1	7.9 ± 2.8	0.442 ‡
Improvement value		1.3 ± 1.8	1.0 ± 1.2	0.613‡
2PD¶ (cases)	**Normal**	8	3	0.590 †
	Fair	6	6	
	Poor	1	2	
	Untestable	3	3	
SW test § (cases)	**Green**	6	2	0.190 †
	Blue	8	5	
	Purple	4	4	
	Red	0	3	
	Untestable	0	0	

†: Fisher exact test. ‡: Mann-Whitney *U* test.
#: The number of measurable cases is shown inside the parentheses.
¶: 2PD: Two-point discrimination. The interpretation scale for 2PD is as follows: normal, <6 mm; fair, 6–10 mm; poor, 11–15 mm; and untestable, >16 mm.
§ : SW test: Semmes-Weinstein test. The interpretation of the monofilament grade scale is as follows: normal (indicated as green), 1.65–2.83 filament markings; diminished light touch (blue), 3.22–3.61 filament markings; diminished protective sensation (purple), 3.84–4.31 filament markings; loss of protective sensation (red), 4.56–6.65 filament markings; and untestable, >6.65 filament markings.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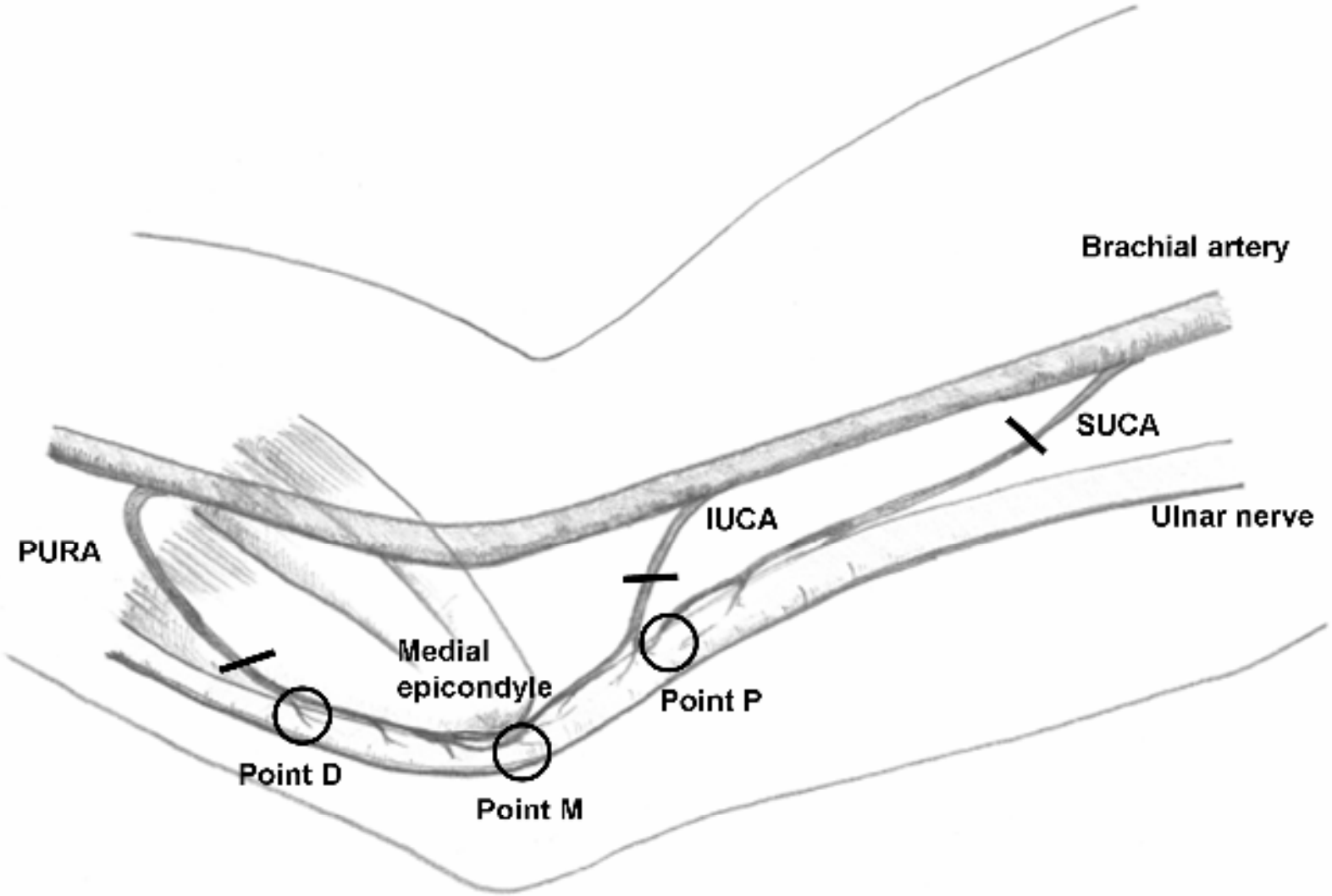
SUCA
IUCA
PURA
Medial epicondyle
Distal
Proximal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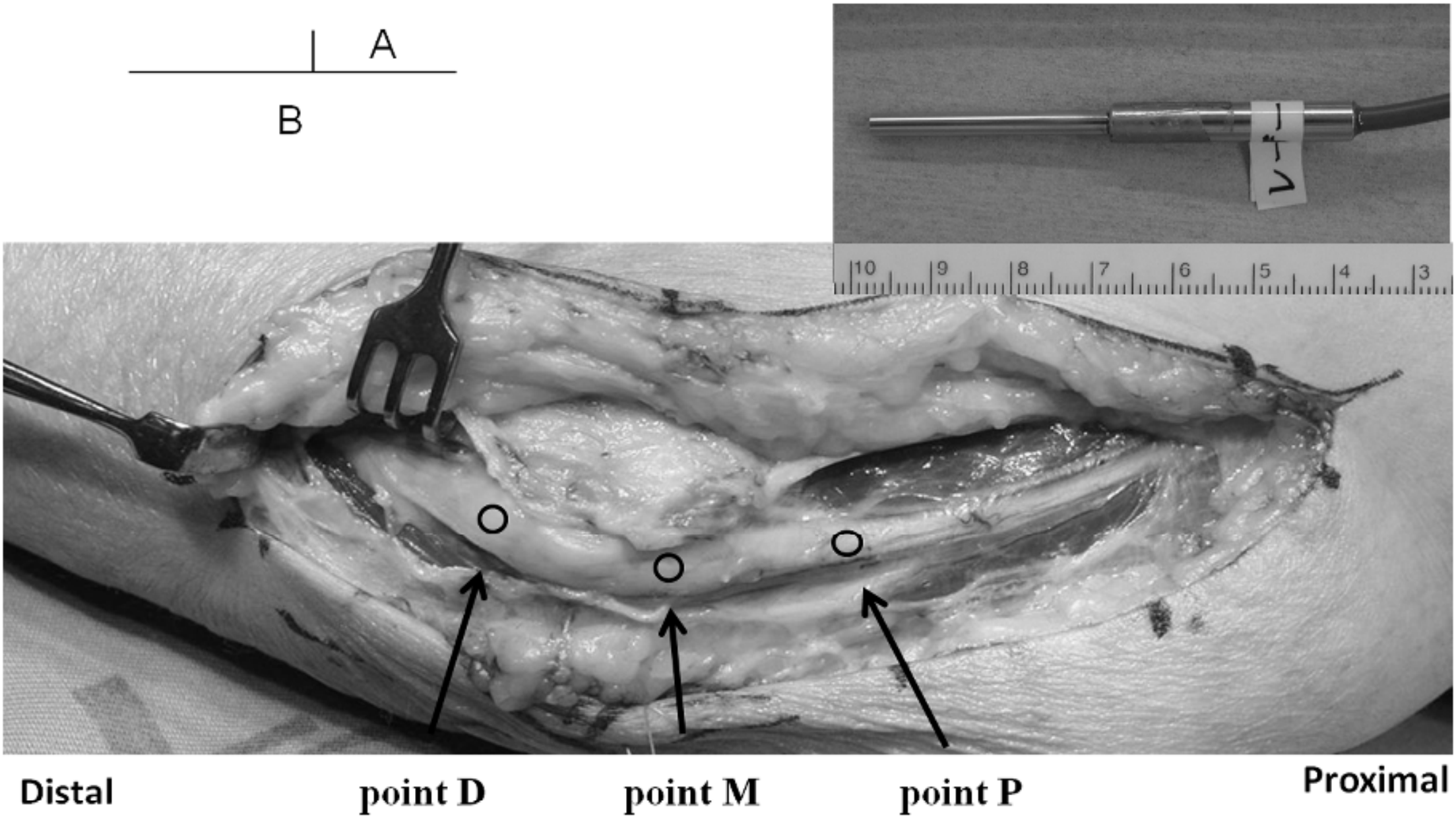
SUCA
IUCA
Ulnar nerve
PURA
Medial
epicondyle
Point P
Point D
Point M


A
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10
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