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Concentric Versus Delta Bipolar Probes for Intraneural Fascicle Selection: A Rabbit Model Study

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Background: Bipolar stimulating probes are widely used during intraoperative monitoring in nerve surgery. However, there are no reports comparing different types of bipolar probes. We present the differences between 2 different bipolar probes (concentric and Delta) in a rabbit animal model for brachial plexus injury, focusing on their applicability for intraoperative neuromonitoring in peripheral nerve surgery.

Methods: Using a previously described rabbit animal model, the biceps brachii muscle's compound muscle action potentials (CMAPs) were recorded after stimulation with increasing intensities (ranging from 0.2 to 3 mV) of the middle and lower trunks using both concentric and Delta probes. The correlation between stimulus intensity and CMAP amplitude was studied, as well as interstimulus amplitude variability.

Results: Five rabbit brachial plexuses were studied. CMAP amplitude ranged from 0 to 9 mV. No correlation was found between stimulus intensity and CMAP for the Delta probe (Spearman rank test $R = 0.181$; $P = 0.264$). A strong correlation was found between stimulus intensity and CMAP using the concentric probe (Spearman rank test $R = 0.74$; $P = 0.001$). The Delta probe showed less variability (coefficient of variation 0.01 versus 0.1).

Conclusions: Delta probes elicit highly reproducible, high-CMAP amplitude responses even with low-intensity stimuli. Concentric probes produce slightly less reproducible, progressively higher CMAP amplitudes with increasing stimulus intensities. *(Plast Reconstr Surg Glob Open 2026;14:e7851; doi: 10.1097/GOX.0000000000007851; Published online 17 June 2026.)*

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INTRODUCTION

Brachial plexus injuries (BPIs) continue to pose a major reconstructive challenge, with very variable postoperative success rates despite advances in the last decades.[1,2] Research in this field continues to grow, trying to solve unanswered questions such as which is the best stimulation method or the best animal model to study BPI.

Bipolar stimulation probes have been advocated as the superior method for electrophysiological intraoperative studies for both brachial plexus exploration[3] and nerve transfers[4] following BPI. They produce a more selective stimulus compared with monopolar probes, mitigating electric current diffusion and therefore reducing the stimulation of nearby axons.[5,6] Although many bipolar probes are commercially available (double hook, triple hook, fork, Delta or S-shaped, concentric), our bibliographic

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search did not show comparative studies among them in peripheral nerve surgery.

Similarly, in the realm of animal models for BPI, numerous animals have been proposed, ranging from rats[7] to nonhuman primates.[8] Although each model has its own advantages, recent studies[6,9–11] have revisited the anatomy and described a validated model of quantifiable motor functional recovery of the rabbit brachial plexus, making it a strong contender for one of the best animal models for studying BPI.

At our institution, both an S-shaped Delta electrode (Inomed, Emmendingen, Germany) and a concentric bipolar probe (Inomed) are routinely used for brachial plexus fascicle selection in nerve transfer surgery. Recently, our institution published a study using stimulation with the Delta electrode to improve ulnar fascicular nerve transfers.[4] The fascicle with the most flexor carpi ulnaris innervation and the least intrinsic muscle function was identified intraoperatively at different locations of the ulnar nerve using a Delta electrode. Delta probes have the advantage of decreasing stimulus dispersion by isolating the nerve fascicle from the surrounding tissue, whereas concentric probes have the advantage of needing less fascicular dissection before their use, diminishing scarring and potential iatrogenic nerve injury. To date, no studies have compared both probes in the field of fascicle selection for nerve transfers.

Given the lack of comparative studies among bipolar probes, we designed a study to describe the differences between the Delta electrode and a concentric bipolar probe in rabbits. Our objective was 2-fold: first, to identify the better bipolar stimulator for fascicle stimulation to perform a fascicular nerve transfer; and second, to build on the work by previous authors[6,9–11] and to provide electrophysiological data regarding biceps muscle innervation in an animal BPI model. We hypothesize that the Delta electrode is capable of more selective stimulation and has less variability between stimuli, as it isolates the nerve in a fixed manner.

Takeaways

Question: Are there significant differences between commercially available bipolar probes for intrafascicular nerve stimulation?

Findings: Using a rabbit upper brachial plexus model, middle and lower trunks were stimulated with a Delta bipolar probe and a concentric probe, registering the biceps brachii muscle's compound muscle action potentials (CMAPs). The Delta probe showed less interstimulus variability and no correlation between stimulus intensity and CMAP (Spearman $R = 0.181$, $P = 0.264$), whereas the concentric probe showed a strong correlation between stimulus intensity and CMAP ($R = 0.74$, $P = 0.001$), with more variability.

Meaning: Delta probes elicit greater and highly reproducible CMAP amplitudes, whereas concentric probes produce less reproducible, progressively greater CMAP amplitudes.

METHODS

Three adult New Zealand white rabbits (2 males, 1 female) were subjected to a nonsurvival experiment after institutional ethics committee and local government authority approval (PROEX 80.5/23; Madrid, Spain). The study was carried out in accordance with EU Directive 2010/63/EU for animal experiments.

Surgical Procedure

All 3 rabbits were administered an anesthetic combination of medetomidine (0.05 mg/kg; Medeson 1 mg/mL, Urano Vet, Barcelona, Spain) and ketamine (25 mg/kg; Ketamidor 100 mg/mL, VetViva Richter GmbH, Wels, Austria) intramuscularly into the hind limb musculature. Following a 15-minute period to achieve sedation, both ears were clipped, and intravenous (IV) and arterial cannulae were placed in the lateral auricular vein and central auricular artery, respectively. Subsequently, 100% oxygen was delivered via face mask using a T-piece nonrebreathing circuit for 5 minutes, and general anesthesia was induced with IV propofol (administered to effect; 2–4 mg/kg; Proven 2%, Fresenius, Bad Homburg, Germany). After induction, a laryngeal mask airway designed for rabbits (v-gel Advanced Rabbit, Docsinnovent, London, United Kingdom) was inserted, and placement was confirmed with capnography.

Anesthesia was maintained with a propofol constant rate infusion (0.5 mg/kg/min), whereas 100% oxygen was administered via the laryngeal mask airway. IV fluid therapy was performed with lactated Ringer solution (5 mL/kg/h), and electrocardiography, pulse oximetry, capnography, invasive blood pressure, and body temperature were continuously monitored throughout the anesthetic procedure.

The neck, forelimb, and pectoral area were clipped of hair. Both brachial plexuses were explored in each subject. With the rabbit in a supine position, an infraclavicular incision was made, dissecting through loose areolar tissue until the pectoral major muscle was identified. Dissection continued along the lateral/inferior border until the brachial artery and plexus were identified. Dissection was then carried out proximally, retracting the clavicle cranially and dividing the pectoral minor muscle, until the middle trunk and lower trunk were visualized.[6,9] (**See figure, Supplemental Digital Content 1**, which displays the anatomy of the left brachial plexus of a New Zealand white rabbit. Both images showcase the anatomical relationship between the middle trunk, located superiorly/laterally to the subclavian artery, and the lower trunk, located between the subclavian artery and subclavian vein. A, Concentric probe stimulating the lower trunk before fascicle dissection. B, Delta probe stimulating the lower trunk. Notice how the lower trunk is transposed due to the disposition of the probe [M, middle trunk; L, lower trunk; white arrow, subclavian artery; black arrow, subclavian vein; white arrowhead, concentric probe; black arrowhead, Delta probe], **https://links.lww.com/PRSGO/E975**.)

The middle trunk was consistently located superior to the subclavian artery, whereas the lower trunk was found between the subclavian artery and vein. At this point, the electrophysiological study was performed. The same steps

were performed on the contralateral side. After completing the electrophysiological study, all rabbits were euthanized with IV pentobarbital (100 mg/kg; Dolethal 200 mg/mL, Vetoquinol, Madrid, Spain) while under general anesthesia.

Electrophysiological Study

Two recording monopolar needle electrodes were placed on the biceps brachii muscle. First, using a concentric bipolar probe (Inomed), measurements were made on the middle trunk, and afterward on the lower trunk. Second, both trunks were dissected and isolated from surrounding tissues, and measurements were repeated after placing a Delta bipolar electrode in both trunks (Inomed). (**See figure, Supplemental Digital Content 2**, which displays the 2 types of bipolar probes used in our study. A, A bipolar concentric probe is shown, in which both anode and cathode are integrated into a fine tip. B, A Delta concentric probe is shown [Inomed], **https://links.lww.com/PRSGO/E976**.) All compound muscle action potentials (CMAPs) were registered and analyzed using the ISIS IOM Compact 32-channel electrodiagnostic system (Inomed).

Every trunk was stimulated with each probe at increasing intensities (0.2, 0.4, 0.6, 0.8, 1, 1.5, 2, and 3 mA), with a fixed duration of 0.05 ms. Each stimulus intensity was used and recorded 3 times to account for variability.

Statistical Analysis

The average CMAP amplitude was calculated for each stimulus intensity, as well as the amplitude variability across the 3 measurements performed for each stimulus intensity. Correlation between CMAP amplitude and type of probe (concentric versus Delta) was calculated. Correlation between CMAP amplitude and stimulus intensity was also calculated independently for the concentric bipolar probe and the Delta electrode.

Normal distribution was checked with Kolmogorov–Smirnov and Shapiro–Wilk tests ($P < 0.01$), and nonparametric tests were used. Spearman rank correlation coefficient was used to test the correlation between CMAP and type of stimulation; Kruskal–Wallis, Mann-Whitney *U*, and Wilcoxon signed-rank tests were used to assess the correlation between CMAP and stimulus intensity. Variation coefficient and Levene test were used to analyze interstimulus amplitude variability. Analysis was performed using commercially available software (SPSS Statistics 29, IBM Corp., New York).

RESULTS

In total, 6 brachial plexuses were dissected. Data from 5 of them were used for analysis. CMAP amplitude ranged from 0 to 9.3 mV. Mean and SD values of CMAP amplitude depending on stimulus intensity for each probe are detailed in Table 1.

Correlation Between Concentric-elicited and Delta-elicited CMAP

There was no correlation between concentric-elicited and Delta-elicited CMAP. The Delta electrode caused higher amplitude CMAPs compared with the concentric probe when both transmitted the same intensity stimulus. Spearman rank correlation coefficient was *R* equal to 0.144 (low correlation) with no statistical significance ($P = 0.375$). When looking at the lowest intensity stimulus (0.2 mA), no significant correlation was observed ($R = 0.3$, moderate correlation; $P = 0.624$).

Correlation Between Stimulus Intensity and CMAP Amplitude With Delta Electrode

No statistical correlation was found between stimulus intensity and CMAP amplitude. Spearman rank correlation coefficient was *R* equal to 0.181 (low positive correlation), with a *P* value of 0.264 (Fig. 1A).

Correlation Between Stimulus Intensity and CMAP Amplitude With Concentric Probe

There was a statistically significant strong positive correlation between stimulus intensity and CMAP amplitude. Spearman rank correlation coefficient was *R* equal to 0.74 (strong correlation), with a *P* value less than 0.001 (Fig. 1B).

Interstimulus Amplitude Variability

Coefficient of variation (CV; CV = SD/mean) of Delta-elicited CMAP for each stimulus intensity value was 0.01; whereas CV for concentric-elicited CMAP was 0.1. The Levene test showed statistically significant differences between both groups, with less variability for the Delta-elicited CMAP ($P < 0.001$).

DISCUSSION

This study aimed to showcase how both a concentric bipolar probe and a Delta probe (which are typically used for continuous vagal nerve stimulation) work in a BPI animal model. Our results showed clear differences between the probes. The Delta probe showed high CMAP responses even at the lowest stimulus intensity (0.2 mA). Therefore, although no correlation between stimulus intensity and CMAP amplitude was found, these data suggest that the Delta probe reaches supramaximal intensities in the nerve axons even with very low stimulus. This could be beneficial in certain situations in which the objective

Table 1. CMAP Amplitude for Concentric and Delta Probes (Mean ± SD; mV)

	Stimulus Intensity, mA	0.2	0.4	0.6	0.8	1	1.5	2	3
Delta probe	Middle trunk	4.46±2.96	4.34±3.01	4.37±2.94	4.34±2.93	4.33±2.93	4.80±3.20	5.08±3.10	5.93±3.26
	Lower trunk	4.24±3.40	4.28±3.40	4.45±3.26	4.48±3.21	4.51±3.22	4.50±3.15	5.08±3.23	5.37±2.46
Concentric probe	Middle trunk	0.22±0.24	0.30±0.36	0.86±0.61	1.18±0.85	1.37±1.03	1.54±1.20	2.79±1.60	3.86±2.66
	Lower trunk	0.31±0.31	1.05±0.87	2.70±3.45	3.07±3.35	3.15±3.37	3.43±3.29	3.54±3.14	4.05±2.75

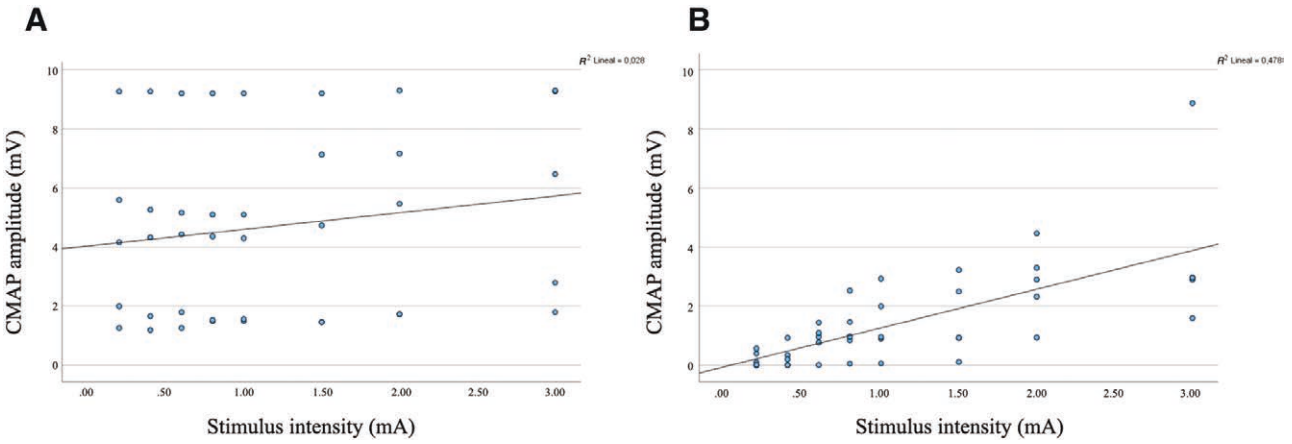

Fig. 1. Graphs showing the correlation between stimulus intensity and CMAP amplitude while using different stimulating probes. A, Analysis for the Delta probe shows a nonstatistically significant low correlation ($R = 0.181$, $P = 0.264$). B, Analysis for the concentric probe shows a statistically significant strong correlation ($R = 0.74$, $P < 0.001$).

is to detect even the slightest activity in a damaged nerve, such as an injured brachial plexus exploration.[3] However, it could also be detrimental in situations in which a precise description of fascicle composition is needed.[4]

On the other hand, the concentric bipolar stimulator showed overall smaller CMAP amplitudes, but a statistically significant positive correlation was present between stimulus intensity and CMAP amplitude. Initially, amplitudes registered with low stimulus settings were smaller than those obtained with the Delta probe; as stimulus intensity was augmented, so was CMAP voltage, eventually reaching similar absolute values to Delta-elicited CMAP. These data support the idea that using a concentric bipolar probe with low-intensity stimuli can be very selective, as it seems to first activate only the predominant component of the nerve/fascicle with less current diffusion to adjacent axons.

As we initially hypothesized, Delta-elicited CMAPs were more reproducible; as per design, this probe isolates the nerve/fascicle from surrounding tissues. In addition, our results showed that concentric bipolar probes have little variability as well (CV = 0.1); however, they are inferior to the Delta probe. We think this variability could be clinically addressed by repeating twice the measurements using the concentric probe and considering its mean value as the definitive one.

Following previous studies describing the rabbit as a BPI animal model,[6,9] in our experiment, the biceps brachii muscle activation was observed when stimulating both the middle and lower trunks of the brachial plexus. This aligns with previous studies in which a double innervation for the biceps brachii muscle in rabbits was described: a proximal branch originating from the middle trunk (C7-musculocutaneous homolog), and a more distal branch originating from the median nerve arising from the lower trunk.[6]

In our study, CMAP voltage ranged from 0 to greater than 9 mV. Previously reported CMAP voltage in a similar animal model tended to have higher values: greater than 24 mV in biceps brachii muscles after middle trunk stimulation[9] and greater than 32 mV in flexor digitorum superficialis after median nerve stimulation.[12] Although the exact stimulus intensity in both aforementioned studies was not explicitly detailed, Mansiz-Kaplan et al[12] did recommend avoiding stimulations greater than 6 mA, which is twice as much as our maximum stimulus. In the present study, we used the most common setting from our daily practice, in which stimulus intensities greater than 3 mA are seldom used. The higher amplitude in CMAP in these studies may be explained by the use of higher intensity stimuli and different recording devices; however, further studies are warranted.

Limitations for our study include a small sample size, the applicability of findings in an animal model to human nerve conduction, and the absence of measures to detect signal jumping and/or retrograde stimulation. As previously suggested, stimulus intensities less than 6 mA should not trigger neighboring nerve activation,[12] but additional measures to detect unwanted activation (ie, recording needle placement in muscles which are not theoretically innervated by the stimulated nerve) could be implemented in future studies.

CONCLUSIONS

The Delta probe can isolate a fascicle and produce a highly reproducible, high-amplitude CMAP even at low stimulus intensity, which can be useful when looking for signals in damaged nerves. The concentric bipolar probe produces a slightly less reproducible, progressively greater CMAP voltage as stimulus intensity is increased, which can be useful for selective fascicle identification. As previously reported, a rabbit's biceps brachii muscle has a dual innervation by the middle and lower trunks of the brachial plexus.

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DISCLOSURES

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