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Super-selective cervical nerve root stimulation in contralateral C7 transfer: An intraoperative study ☆

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HIGHLIGHTS

- Individual contribution of cervical nerve roots to triceps brachii muscle innervation varies between subjects.
- Super-selective cervical nerve root stimulation may prevent permanent motor deficits in partial contralateral C7 transfer.
- A threshold for CMAP amplitudes that allows for surgical decision making is difficult to define.

ABSTRACT

Objective: We designed this study using super-selective intraoperative cervical nerve root stimulation aiming to support decision making about complete or partial contralateral C7 (cC7) nerve root transfer in patients with multiple cervical root avulsion injury.
Methods: Super-selective intraoperative stimulations of anterior, lateral, medial and posterior aspect of C5–C8 nerve roots were performed. Compound muscle action potentials (CMAP) were recorded in the lateral part of the deltoid (DM), long head of biceps brachii (BCM), brachioradial (BRM), long head of triceps brachii (TCM), and extensor digitorum communis (EDC) muscle. Muscle strength was documented immediately after cC7 transfer procedures and on scheduled follow-up visits according to the Medical Research Council (MRC) scale.
Results: In the DM, stimulation of the posterior aspect of C5 resulted in the largest CMAP amplitudes (2.0 mV ± 1.9; 80% ± 28.3). The BCM CMAPs induced by the different aspects of C6 all revealed homogenous stimulation results. Stimulation of the lateral aspect of C7 induced the largest amplitude of TCM CMAPs (1.3 mV ± 1.0; 67.1% ± 43.3). CMAP amplitudes of individual muscles and individual contributions of cervical nerve roots to the TCM varied between subjects. Overall donor side morbidity was low, no permanent motor deficit occurred.
Conclusion: A super-selective intraoperative cervical nerve root stimulation may help minimize donor side morbidity in transfer procedures. Individual differences of cervical nerve root innervation pattern need to be addressed in future electrophysiological studies.
Significance: Our study outlines individual differences of cervical nerve root innervation pattern.

1. Introduction

Intraoperative electrophysiological examination of the healthy brachial plexus in contralateral C7 transfer (cC7) procedures contributed substantially to the anatomical understanding of functional motor innervation of cervical nerve roots (Gu, 1997; Gu et al., 2003; Hu et al., 2008; Li et al., 2011; Yin et al., 2012;

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Zhang et al., 2012). Results of intraoperative cervical nerve root stimulation showed that C5 mainly innervates the deltoid (axillary nerve), C6 the biceps brachii (musculocutaneous nerve), C7 the triceps brachii (radial nerve), and C8 the flexor digitorum superficialis and profundus muscles (median nerve) (Gu, 1997). Most electrophysiological studies focus on C7 muscle innervation as the C7 nerve root is a potent axon donor for transfer procedures in brachial plexus injury. Minimization of donor nerve morbidity is a major goal in C7 and other transfer procedures. A majority of plexus surgeons perform a distinct electrophysiological examination of the C7 nerve root before complete or selective C7 transfer (Sammer et al., 2012; Songcharoen et al., 2001; Terzis and Kokkalis, 2009). Even in experienced hands, with intraoperative electrophysiological monitoring, postoperative donor side morbidity is relatively high. A recent meta-analysis evaluated donor side morbidity independent of intraoperative electrophysiological protocols and found that 74% of patients displayed sensory abnormalities and 20% of patients suffered a new motor deficit, which recovered in 91%. Two percent suffered from a persistent significant loss of motor function (Yang et al., 2015b). There are various protocols of intraoperative electrophysiological testing but they are neither specified nor standardized regarding the effect on outcome (Wiedemayer et al., 2002; Holdefer et al., 2015; Skinner et al., 2016). It is not known, whether different positions of the stimulation probe at the nerve root may have an effect on the amplitude of compound muscle action potentials (CMAP). There are no quantitative data on possible differences of stimulation results due to varying stimulation probe positions at the nerve root. Also, there is no definition of amplitude thresholds for intraoperative decision making in C7 transfer procedures. Moreover, the quantification of the individual contribution of a single nerve root to a target muscle is difficult, as is the comparison between subjects. We therefore conducted this study of a super-selective stimulation of cervical nerve roots C5–C8 in patients who underwent cC7 transfer. We aimed to compare CMAP amplitudes in different patients with similar currents at four different aspects of each nerve root (anterior, lateral, posterior and medial). CMAPs were recorded in the deltoid (DM), biceps brachii (BCM), triceps brachii (TCM), brachioradial (BRM) and extensor digitorum communis (EDC) muscle.

2. Methods

2.1. Patients and study design

Eight patients who underwent a cC7 nerve transfer procedure for unilateral multiple cervical nerve root avulsion injury were included in our study. Consecutively collected prospective data between 07/2012 and 11/2014 were retrospectively analyzed. The study was approved by the local ethics committee (EA 330/2015). C7 transfer procedures included the preparation of the contralateral, intact C5–C8 nerve roots for identification of innervation pattern of upper extremity muscles by super-selective electrical stimulation. Decisions about complete or partial transfer of the C7 nerve root were made after completion of the super-selective stimulation protocol dependent on CMAP amplitudes evoked in C7 innervated muscles and co-innervation of these muscles by the other cervical nerve roots.

2.2. Super-selective electrical stimulation of the intact C5–C8 nerve roots

Only short acting muscles relaxants were used for anesthesia induction. Control measurements for muscle contraction confirmed an intact conduction at the neuromuscular junction. The supraclavicular brachial plexus was dissected and the C5–C8 nerve roots were isolated. Stimulation of the following aspects of cervical nerve roots was performed: anterior, lateral, medial and posterior aspects of C5, C6, C7 and C8 (aC5, lC5, mC5, pC5, respectively). Stimulation of nerve roots was performed with a bipolar concentric 130 mm BCS bajonett probe (Inomed, Emmendingen, Germany) using submaximal stimulation currents of 1 and 2 mA and a single pulse duration of 0.1 ms (Fig. 1A) to allow for super-selective stimulation of different nerve root aspects. Recording procedures were carried out as described elsewhere (Kandenwein et al., 2005). In brief, two 15 mm subdermal needle electrodes (Inomed, Emmendingen, Germany) were placed in a standardized manner with distances of 1.5–2 cm in the middle of the target muscle and connected to the Nicolet Viasys Viking Select System (Natus Medical Inc., Pleasanton, CA, USA). CMAPs of the following muscles were included in the analysis: lateral portion of the deltoid muscle (DM), long head of the biceps brachii muscle (BCM), brachioradialis muscle (BRM), long head of triceps brachii muscle (TCM), and extensor digitorum communis muscle (EDC) (Fig. 1B). Baseline to peak measurements were performed to analyze CMAP amplitudes. The time needed to assess and compare CMAP amplitudes elicited by different nerve root aspects as well as the time needed for discussion and decision making within the team based on these results was evaluated.

Donor side morbidity was assessed by clinical examination immediately postoperatively (days 1–3 after surgery) and during scheduled yearly follow-up visits assessing sensory function qualitatively and muscle strengths semi-quantitatively according to the Medical Research Council scale (MRC) 0–5. Functional outcome was assessed on scheduled follow-up visits, respectively. Presence or absence of neuropathic pain in the injured limb was documented.

2.3. Data analysis

We used IBM SPSS Statistics 23.0 (IBM, Armonk, NY) for statistical analysis. All data are expressed by mean and standard deviation (SD) unless indicated otherwise. Non-parametric tests (Mann Whitney U) were performed due to the small sample size. Statistical significance was set at $p < .05$. To account for inter-individual differences and differences in electrode placement, normalized CMPAP amplitudes were calculated as percent of the maximum CMAP amplitude elicited in a single muscle of each individual patient. Contribution to the TCM was separately calculated in % referring to 100% as the addition of all TCM CMAP amplitudes recorded by each nerve root stimulated.

3. Results

3.1. Patient characteristics, surgical procedures and preliminary functional outcome

Eight male patients with a mean age of 22 years (±12) were included in the study. All patients suffered from multiple proximal cervical nerve root avulsion injury (six right sided, two left sided) after motorcycle trauma in six, mountain-bike accident in one and an unbuckled car accident in another patient. All patients suffered from neuropathic pain of the injured limb at initial presentation. The intraoperative electrical stimulation procedure prolonged surgical time by a mean of 40 min (±18) excluding the time of preoperative patient preparation. Overall surgical time for the cC7 transfer procedure ranged around a mean of 7 h (±1.6). Functional follow-up was available in all patients after a median period of 18.5 months. A recovery of sensitivity in the injured limb was detected in all patients with a follow up period >20 months. Neuropathic pain improved in 50% of patients. Signs of motor recovery