Long-Term Outcome of Brachial Plexus Reimplantation After Complete Brachial Plexus Avulsion Injury

Carolina Kachramanoglou, Thomas Carlstedt, Martin Koltzenburg, David Choi

■ BACKGROUND: **Complete brachial plexus avulsion injury is a severe disabling injury due to traction to the brachial plexus. Brachial plexus reimplantation is an emerging surgical technique for the management of complete brachial plexus avulsion injury.**

■ OBJECTIVE: **We assessed the functional recovery in 15 patients who underwent brachial plexus reimplantation surgery after complete brachial plexus avulsion injury with clinical examination and electrophysiological testing.**

■ METHODS: **We included all patients who underwent brachial plexus reimplantation in our institution between 1997 and 2010. Patients were assessed with detailed motor and sensory clinical examination and motor and sensory electrophysiological tests.**

■ RESULTS: **We found that patients who had reimplantation surgery demonstrated an improvement in Medical Research Council power in the deltoid, pectoralis, and infraspinatous muscles and global Medical Research Council score. Eight patients achieved at least grade 3 MRC power in at least one muscle group of the arm. Improved reinnervation by electromyelography criteria was found in infraspinatous, biceps, and triceps muscles. There was evidence of ongoing innervation in 3 patients. Sensory testing in affected dermatomes also showed better recovery at C5, C6, and T1 dermatomes. The best recovery was seen in the C5 dermatome.**

■ CONCLUSIONS: **Our results demonstrate a definite but limited improvement in motor and sensory recovery after reimplantation surgery in patients with complete brachial plexus injury. We hypothesize that further improvement may be achieved by using regenerative cell technologies at the time of repair.**

INTRODUCTION

Avulsion of one or more roots is seen clinically in approximately 70% of severe brachial plexus (BP) traction injuries. Complete BP avulsion injury is a severe, disabling injury, predominately affecting young men in high-energy motorcycle accidents due to traction to the BP when the rider falls on the shoulder.[1]

Historically, attempts to restore function were limited to nerve transfers. Nerve transfers involve the sacrifice of the function of a lesser-valued donor muscle to revive function in the recipient nerve and muscle, with subsequent reinnervation.[2] Nerve-transfer techniques allow return of some function, but the overall recovery remains poor.[3-5] In recent years, BP reimplantation has been introduced and offers an alternative surgical strategy for the treatment of BP avulsion injury.[6-13] This operation involves the implantation of avulsed ventral roots into the anterolateral aspect of the spinal cord.[10] Regenerating motor fibers travel through the reimplanted nerve roots to reinnervate target muscles.[6,8,14-20]

The aim of this observational study was to assess the degree of functional recovery in the affected arm of patients who have undergone BP reimplantation surgery after complete (C_5 through to T_1 nerve roots) BP avulsion injury. The motor and sensory functions were assessed both clinically and by the use of

Key words
- Brachial plexus
- Brachial plexus avulsion
- Brachial plexus reimplantation surgery

Abbreviations and Acronyms
BP: Brachial plexus
CMAP: Compound muscle action potential
DASH: Disabilities of the Arm, Shoulder, and Hand
EMG: Electromyelography
FDS: Flexor digitorum superficialis
MRC: Medical Research Council
MUAP: Motor unit action potential
PSW: Positive sharp waves
SCV: Sensory conduction velocity
SD: Standard deviation
SF-36: Short Form-36
SNAP: Sensory nerve action potential

Spinal Repair Unit, UCL Institute of Neurology, London, England, United Kingdom

To whom correspondence should be addressed: Carolina Kachramanoglou, M.D., M.B.B.S. [E-mail: carolina.kachramanoglou@nhs.net]

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electrophysiological tests. Patient satisfaction and experience was assessed with the use of patient-reported questionnaires.

METHODS

The surgical procedure is accepted as a standard of care in the National Health Service, and outcome assessment was performed as routine clinical care.

Patient Selection

Patients were identified retrospectively after inspection of the surgical records and a log provided by the surgeons for complete BP injury and BP reimplantation procedures. Initially, hospital records were reviewed for evidence of a completely paralyzed arm, complete loss of sensation from C5 to T1, evidence of the Tinel sign, and Horner syndrome at presentation. The diagnosis of complete BP avulsion was confirmed by open exploration of the BP. Correlation also was made with other investigations when available, including preoperative computed tomography myelography and preoperative electrophysiology tests.

The indication for BP reimplantation surgery was evidence of complete (C5–T1) BP injury for which alternative treatment was not available, recommended, or deemed to result in a significant neurologic improvement. The reimplantation procedure was performed as soon as possible after the time of injury and within 4 weeks. Delays were sometimes encountered as the result of multiple injuries requiring more urgent management, time for transfer to our unit, bed availability, and the patients' overall clinical condition.

BP Reimplantation Procedure

The reimplantation procedure was performed as described in Carlsted et al.[8,10] In brief, the patient was placed in the lateral position with the affected side up and the head held in a Mayfield clamp with the neck slightly flexed. The operating table was positioned 15° head up to minimize venous congestion and bleeding. A supraclavicular skin incision was made and extended laterally in parallel to the clavicle and cranially in a vertical line towards the mastoid process. The spinal accessory nerve was identified and protected as it emerged from the dorsal aspect of the upper part of the sternocleidomastoid muscle. The BP was then identified and dissected. Subsequently, the lateral masses of C5–C7 and transverse process of T1 were approached between the levator scapulae and the posterior and medial scalenus muscles, and the longissimus muscle was split longitudinally to approach the spine. The paravertebral muscles were dissected from the hemilaminae and C5–C7 hemilaminectomy, and medial one-third facetectomy was performed. The denticulate ligaments were cut and held by stay sutures, and the spinal cord was rotated gently to bring its ventrolateral aspect into view.

A nerve graft was taken from the superficial radial nerve or medial cutaneous nerve of the forearm. The avulsed C5–T1 roots were trimmed distally to the level of normal-appearing nerve root or to the junction with the ventral root in an attempt to remove the dorsal root ganglia. The nerve grafts were stitched to the avulsed roots, retrieved through or around the intervertebral foramina, and implanted into the spinal cord by making 2–3 mm longitudinal slits in the pia mater of the spinal cord, as close as possible to the ventral root exit zone. The grafts are positioned 1–2 mm deep to the pia mater in the spinal cord and the retained by the use of fibrin glue around the outside of the nerve sheath and pia of the spinal cord. Spinal cord monitoring was performed throughout the procedure to avoid an injury to the spinal cord, particularly when tilted and during reimplantation of the roots. No perioperative or postoperative complications related to the surgical procedure were observed.

Motor and Sensory Clinical Assessment

All patients were assessed clinically based on the Medical Research Council (MRC) scale to estimate limb and axial muscle strength. A summated muscle score based on the MRC clinical scale also was used to assess global power in the affected arm ("global MRC score"). This was obtained by assessing 7 upper limb muscles or muscle groups for MRC motor power. Muscles assessed were the deltoid (C5–C6 root values)/supraspinatous (C4–C6), infraspinatous (C5–C6), pectoralis (C5–C6), biceps brachii (C5–C6), triceps (C6–C8); for wrist movements extensor carpi radialis (C5–C6) and ulnaris (C7–C8)/flexor carpi radialis (C6–C7) and ulnaris (C7–C8, T1); and for finger movements the flexor digitorum superficialis (C7–C8, T1) and profundus (C7–C8, T1)/flexor digiti minimi (C7–C8, T1)/flexor pollicis (C8–T1)/extensor digitorum (C7–C8)/extensor indicis (C7–C8)/extensor pollicis brevis (C8–T1) and longus (C7–C8, T1) interossei (C8–T1). MRC scores for each muscle/muscle groups were then added together to obtain the "global MRC score," ranging from 0 to 35.

All patients underwent sensory testing, which included 1) light touch using cotton wool; 2) pinprick with a blunt pin; 3) vibration sense with the use of a 128-Hz tuning fork; 4) proprioception; and 5) cold temperature sense with a tuning fork at room temperature and tested 3 times. These were tested clinically at the shoulder, elbow, and wrist. The patient was asked to close his eyes during the examination. The unaffected arm was examined first. In addition, the presence of Horner syndrome was documented and the Tinel sign was tested.

Outcome Measures

To gain an insight into the way patients perceive their health and the impact of their disability to their quality of life, 4 validated patient-reported outcome measures were used. Patients completed these questionnaires independently. The validated patient-reported outcome measures used are described in the paragraphs to follow.

First, the visual analog scale (VAS) was used to assess the severity of pain. If a patient reported referred sensations, defined as sensations that are perceived to emanate from other areas of the body distinct from the body part being stimulated, a more detailed examination was conducted, and patients were asked to describe the sensation and location to the best of their ability. Perceived sensations were drawn on a schematic diagram of the arm. Patients were told that the sensitivity of the upper arm was assessed and were not informed of the possibility of experiencing abnormal or referred sensations. Similarly, when patients reported an insensate area within a dermatome, a more careful examination was performed in an attempt to localize the insensate region, which was drawn on a schematic diagram of the arm. Finally, observations of allodynia also were recorded, defined as pain

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