The lateral approach to intraspinal re-implantation of the brachial plexus
A TECHNICAL NOTE

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Intraspinal re-implantation after traumatic avulsion of the brachial plexus is a relatively new technique. Three different approaches to the spinal cord have been described to date, namely the posterior scapular, anterolateral interscalenic multilevel oblique corpectomy and the pure lateral. We describe an anatomical study of the pure lateral approach, based on our clinical experience and studies on cadavers.

Avulsion of the brachial plexus from the spinal cord is the most severe form of injury to the nerves supplying the upper limbs. Recovery of function tends to be minimal and remains limited even after extensive muscle and nerve transfers. Re-implantation of the brachial plexus is a relatively new procedure with an encouraging functional outcome. To date, three surgical approaches have been used, namely, the posterior subscapular, anterolateral interscalenic multilevel oblique corpectomy and the pure lateral. An endoscopic transforaminal approach has also been described, but this lies outside the scope of our paper.

We have attempted to use the anterior oblique corpectomy and direct posterior hemilaminectomy approaches and found that they had their limitations. The posterior subscapular approach has been described in one clinical case. However, extensive laminectomies and/or facetectomies are needed to reach the site of implantation. Additionally, simultaneous access to the intra- and extraspinal portions of the plexus is often desirable. Consequently, the technique has not been widely adopted.

The anterolateral multilevel oblique corpectomy approach has been reported in ten cadaver and four clinical cases. It is derived from that described by George, Gauthier and Lot for cervical spondylotic myelopathy and tumours and gives access to the brachial plexus from its rootlets at the exit zone of the ventral root to its terminal branches. Nonetheless it has been stated that “re-implantation of dorsal roots into the spinal cord remains impossible”. Long-term clinical follow-up remains limited.

We therefore currently use a modification of the lateral approach, first described by Henry. The pure lateral approach for intraspinal re-implantation of the brachial plexus is described below. We believe that this gives an excellent exposure for re-implantation and also allows us to explore the more distal parts of the injured brachial plexus.

Materials and Methods

Two cadaver anatomical dissections were carried out at the Royal College of Surgeons of England, one using the oblique corpectomy, and the other the pure lateral approach. In addition, 15 patients underwent re-implantation of the brachial plexus.

Position. The patient is positioned in the true lateral position (Fig. 1), with the head secured by a Mayfield Headrest (Mayfield; Integra NeuroSciences, Andover, United Kingdom). Care is taken to avoid undue pressure on the opposite arm to protect the radial nerve and the leg to avoid pressure on the common peroneal nerve. The operating table is tilted head-up to prevent venous congestion, especially of the epidural veins.

Incision and approach. A single, long, transverse incision is made starting at the jugular notch. It runs parallel to, and approximately two fingerbreadths above the clavicle, heading towards the spinous process of C7. The skin is undermined both proximally and distally. Traction sutures are then placed in the skin. These allow a wide exposure of both the anterior and posterior aspects of the neck, and also give access to the stumps of the brachial plexus proximally at the external foramina of C5 to T1, as well as distally, deep to the clavicle. Since the incision is in the line of the skin creases, it leaves a cosmetically acceptable scar. The platysma and deep cervical fascia are incised and the sternocleidomastoid muscle...
identified. Dissection continues predominantly behind this muscle. The accessory nerve is formally identified as it enters trapezius, two or three fingerbreadths below the tip of the mastoid. Its identity is confirmed with a nerve simulator. The superficial cervical plexus, comprising the lesser occipital, greater auricular, transverse cervical and supravclicular nerves, is also formally identified.

Deep to the posterior border of sternocleidomastoid there are several muscles. It is possible to palpate the anterior and posterior tubercles of the mid and lower cervical spine. This is a bloodless plane. It is gently dissected with a Cobb periosteal elevator combined with the judicious use of bipolar coagulation. The most superficial muscles are separated first. From anterior to posterior, these are: the scalenus anterior, scalenus medius, scalenus posterior and levator scapulae. The posterior external jugular vein lies on the levator scapulae, before crossing the posterior border of sternocleidomastoid, and joining the external jugular vein. Below the posterior external jugular vein lies the transverse or superficial cervical artery, a branch of the thyrocervical trunk. Together with the corresponding transverse cervical vein, it crosses the scalenus muscles and levator scapulae in the lower aspect of the posterior triangle. Deep to levator scapulae lies splenius cervicis. Scalenum anterior arises from the anterior tubercles of the transverse process of C3-6, scalenus medius from the anterior aspect of the posterior tubercles of the transverse processes of C3-7, while scalenus posterior arises from the posterior tubercles of C4-6. The levator scapulae and splenius cervicis are attached to the posterior tubercles above the relevant region (C1-4).

Deep to scalenus medius, scalenus posterior and splenius cervicis lie the longissimus cervicis and iliocostalis cervicis portions of the erector spinae muscles (Fig. 2). Longissimus cervicis arises from the posterior tubercles of C2-6, and
iliocostalis cervicis from the posterior tubercles of C4-6. These muscles are detached to give direct access to the transverse processes and the anterior and posterior tubercles. The anterior intertransversarii pass between adjacent costal lamellae in front of the foramen transversarium from C1-2 to C7-T1 and are separated by the ventral rami of spinal nerves from the posterior intertransversarii (Fig. 3). The latter muscles have medial slips, which pass between adjacent transverse processes from C1-2 to C7-T1, and lateral slips, which pass between adjacent costal lamellae. In addition, the intertransverse ligaments consist of irregular fibres connecting adjacent transverse processes.

Dissection of the posterior tubercle and part of the lateral mass is then undertaken using a combination of Leksell ronguers (Miltex Inc., New York) and Capener gouges (Medicon eG, Tuttlingen, Germany). Bone fragments are saved for use as onlay graft at the end of the procedure. As the dura and vertebral artery are approached, dissection is continued using a range of Kerrison punches (Ruggles TM; Integra NeuroSciences) and the Midas Rex drill (Midas Rex; Medtronic, Minneapolis, Minnesota). The final stages are performed with an operating microscope. The vertebral artery is identified and protected. It does not require mobilisation. At this level, it is quite a large structure with a surrounding sheath. The venous plexus which surrounds it is not as troublesome as it can be at the atlantoaxial joint. Partial resection of the lateral mass and facet complex is needed to gain good access to the spinal cord. This does not destabilise the spine since half of the ipsilateral facet is preserved as well as the contralateral structures and the disc.

**Re-implantation.** The lateral aspect of the spinal cord and its dural coverings are identified. It is usually possible to see the position of the avulsed nerve root with a localised pseudomeningocele at the relevant levels. The dura is opened along this line. Traction sutures are attached (4-0 vicryl; round-bodied needle), and, with the operating microscope, it is possible to see the denticulate ligament, from which the anterior and posterior components of the spinal cord may be identified. Because of the recent injury, the spinal cord is usually slightly swollen and relatively amorphous. Two to three small longitudinal stab incisions of 2 mm to 3 mm are made in the pia mater using a number 16 blade. These are sited as close as possible to the exit zone of the ventral root of the spinal cord. The superficial
radial nerve, taken from the forearm, is used as a graft, and is carefully introduced into the prepared spinal cord, about 1 mm deep to its surface, and secured with Tisseal fibre and glue (Immuno AG, Baxter International Inc., Vienna, Austria). The nerve-root grafts are then connected to the retrieved distal stumps of the nerve-roots. These are again secured with Tisseal fibre and glue in a sheath of dura replacement material (Dura Repair; Medtronic). The coverings of the spinal cord are not formerly re-sutured, but are covered with a loose layer of dural repair with the edges sealed using Tisseal fibre and glue. Morcellised bone from the lateral mass resection is combined with demineralised bone matrix putty (DBX; Synthes Ltd; Welwyn Garden City, United Kingdom) and laid over the area of bone resection.

Post-operatively, cerebrospinal fluid is diverted for five days via a lumbar drain, which is set to drain between 15 ml/hour to 20 ml/hour. A cervical collar is not used. Radiological surveillance includes dynamic radiography at three and six months and at one year.

Results
In the 15 patients on whom we have performed this approach, there have been no cases of symptomatic, persistent collection or leakage of cerebrospinal fluid and no evidence of delayed instability or deformity.

Discussion
The pure lateral approach to the brachial plexus allows access to both the intra- and extraspinal parts of the plexus. Encouraging long-term functional recovery after this technique of reimplantation has already been reported.2,3,12,13 It continues to be our approach of choice.

Biomechanical studies have shown that the medial half of the facet joint can be removed without destabilising the spine.14 The approach, which we describe predominantly removes the lateral aspect of the facet joint. Since the contralateral facet joint is intact, the remaining posterior elements are untouched and the anterior column is unaffected, the lateral approach should not destabilise the spine.

Oblique corpectomy, as pioneered and popularised by George et al9 is a well-established, safe and reliable procedure for a number of spinal conditions. It does not destabilise the spine9,15 and no special instrumentation is necessary. However, it requires bilateral incisions since the approach is to the opposite side and there is a greater theoretical risk of post-operative swelling, damage to the recurrent laryngeal nerve and problems with the airway. Access to the spinal cord for implantation is limited in our experience. Table I compares the three surgical techniques and illustrates the advantages of the pure lateral approach.

Our technique will have some use in the treatment of other spinal conditions, such as the dumb-bell tumour of neurofibromatosis and other intradural lesions. Special instrumentation is not required and stability is not affected. The neurological results of re-implantation are the subject of a further study, as will the endoscopic transforaminal approach to the spinal cord.

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References

Table I. Comparison of the approaches to re-implantation of the brachial plexus

<table>
<thead>
<tr>
<th>Clinical cases</th>
<th>Incision(s)</th>
<th>Spinal cord and BP* access</th>
<th>Extent of bony resection</th>
<th>Spinal stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subscapular5</td>
<td>Longitudinal, following medial border of scapula, extending to occiput in the midline</td>
<td>Acceptable</td>
<td>Laminctomy with partial facetectomy</td>
<td>Good</td>
</tr>
<tr>
<td>Limoc†7,8</td>
<td>Longitudinal, following medial border of SCM,† extending to suprasternal notch and laterally to deltoid</td>
<td>Acceptable</td>
<td>Resection of anterior transverse process, with oblique drilling of vertebral body</td>
<td>Good</td>
</tr>
<tr>
<td>Pure lateral (current study)</td>
<td>Transverse almost extending from anterior to posterior midline</td>
<td>Good</td>
<td>Posterior tubercle and part of lateral mass</td>
<td>Good</td>
</tr>
</tbody>
</table>

* brachial plexus
† lateral interscalenic multilevel oblique corpectomy
‡ sternocleidomastoid


