37. Dawood RM, Craig JOMC, Todd-Pokrapek A, Arenson AJ, Anerite GC, Johnson B. The simplicity of the procedure means that further refinement of technique and equipment is necessary; and understanding of the inherent abilities and potential of the peripheral nervous system to heal, regenerate and adapt to changes.
populate distal neural tubes, the finding that axons can carry many more impulses, i.e. are not area-specific, the finding that the brain has the capacity to interpret impulses that arrive by detour routes, and the finding that selective orientation of axons regarding sensation and motor function is an integral function of the nerve and need not be imposed by surgical and chemical means. Many of these findings could only be made after ETSNS was performed in humans, with whom it was possible to communicate intelligibly. In animal studies, even in the primate, the interpretation of the various modalities of sensation and the voluntary contraction of muscles is not possible.

Many neurotrophic and neurotropic factors have been discovered. These are essential for the maintenance of nerve structure and function, for promoting recovery of injured nerve, and for stimulating regeneration should it be needed.

Neurotrophic factors mainly maintain the integrity of nerves. The end of a sectioned distal nerve produces neurotropic factors which ‘recruit’ axons to fill the neural tubes. This ‘summoning force’ is so overwhelming that the donor axons sprout out superfluous axons. Because of the abundance of these newly sprouted axons, only the minority will find an empty neural tube. The rest will atrophy.

The histological experimental results indicate that the majority of neural tubes are re-populated by the new sprouting axons, unlike the situation with end-to-end nerve sutures. The effect of the neurotropic factors is so strong that these lateral sprouts even cross through the epineurium. However, it has been shown that the result of lateral sprouting and populating of the recipient nerve is more organised and abundant when an epineural ‘window’ is made before the neurorrhaphy is done (and F Viterbo et al. — unpublished data).

Historically ETSNS has been practised on a very limited scale with only sporadic reports. However, the exact technique and eventual results are not known for certain. Axonal damage probably occurred because of the large ‘windows’ created and the crude instruments available. Follow-up reports on results have not been forthcoming.

**METHOD**

The proximal end of the distal part of the injured nerve is ‘freshened’ by serial cuts with a sharp knife until a healthy-looking cut surface is seen.

An intact nearby matching nerve is selected to act as host nerve. An epineural window is created on the side of the host nerve on the same plane as the approaching receiving nerve. Care is taken not to damage any axons in the host nerve (Fig. 1).

The recipient nerve is sutured to the epineural window using four 8/0 Prolene sutures, in much the same way as an end-to-side arterial suture. The suture line should be free of tension, and kinking of the nerve should be avoided (Fig. 2). The proximal end of the injured nerve is buried in soft tissue.

**Fig. 1. The technique of end-to-side (ETS) suture. An epineural window is made to receive the proximal end of the distal part of the injured nerve. Four of five 8/0 Prolene sutures keep the ETS suture in place. Note: (i) the axons of the host nerve should not be damaged; (ii) the ETS suture should not be under tension; (iii) the ETS suture should be done to the host nerve in the same plane as the approach of the injured nerve to prevent any kinking.**

**Fig. 2. Example of ETSNS in the baboon.**

Postoperative care includes splinting for 14 days if the suture line is near a joint. After brachial plexus ETSNS surgery, a supportive sling is worn for 2 - 3 weeks.

**MATERIAL**

**Experimental animal**

As experimental model the chacma baboon (Papio ursinus) was used. The ETSNS technique was used in 12 baboons, i.e. to suture 24 nerves. Twelve ulnar nerves were sutured end-to-side (ETS) to the median nerve and 12 median nerves were sutured to the ulnar nerve at the wrist level.

These nerve sutures were used for a variety of experiments of various post-suture time intervals, including clinical observations for re-innervation, electroconduction and histology.
Among the findings were the following:

1. Early, prolific lateral sprouting of axons from the host nerve is seen (Fig. 3).

2. The recipient nerve is near normally populated by the new axons, which show the typical wavy pattern (Fig. 4).

3. The baboons did not show any signs of distress, did not mutilate themselves, had no trophic changes or ulcers, and used and moved their hands in the same way as they had before the operation. No evidence of loss of donor nerve function was noted.

4. Sensory electroconduction studies showed early recovery with a clear recordable pattern and conduction across the ETS suture line (Fig. 5).

5. Motor electroconduction studies showed a high contraction peak and typical scatter pattern due to demyelinisation. This is a normal phenomenon after nerve suture (Fig. 6).

6. Specimens taken 2 years after surgery do not show any evidence of loss or atrophy of donor axons beyond the suture line.

In the experimental animal it is obviously not possible to evaluate quality of sensation, modalities of sensation (e.g. two-point discrimination, vibration, proprioception, light touch), voluntary movements of extrinsic and intrinsic muscles, and any cross-over sensations or movements.

Human patients

To date 50 patients with a variety of peripheral nerve lesions have been operated on, but Table I reflects the first 33 cases (up to March 1999). The results in the first 22 cases indicated remarkable recovery. This prompted us to use this technique as the method of choice in patients who might otherwise have needed a nerve graft or neurotisation.

Although this is not a homogeneous group, with the location and type of injuries all differing from each other and the timing of surgery dictated by a host of factors, the re-innervation of the
target organs (skin and muscles) is most encouraging. The following results are observed:

1. Since ETSNS is done much closer to the target organs re-innervation occurs much sooner.
2. Axonal advancement is 1.5 - 2 mm per day on average, again contributing to earlier recovery.
3. Light touch recovers first when mixed nerves are sutured.
4. Sweat appears with or soon after sensory recovery.
5. Unpleasant feelings often seen with end-to-end nerve sutures, such as hypersensitivity, a burning sensation and paraesthesiae, have not been observed.
6. The sensory pattern has a normal anatomical distribution.
7. Crossover sensation is seen in some cases, i.e. a sensory stimulus in a re-innervated area may produce a similar feeling in an area supplied by the donor nerve. This is not an unpleasant experience and does not seem to bother the patient.
8. No sensory loss has been seen in the donor area.
9. The fingerprints recover with the sensory recovery. They look and feel normal.

Fig. 7. Recovery of biceps muscle 2 years after ETSNS of the musculocutaneous nerve to the posterior cord of the brachial plexus.

Fig. 8. ETSNS of ulnar nerve to median nerve at wrist level. This is a photocopy image of the patient's hand. The crosses represent sensation. On 18 July 1997 (a) clawing (ulnar negative hand) is clearly visible. On 8 April 1998 (b), 9 months after ETSNS, the clawing has disappeared, indicating re-innervation of the intrinsic muscles. (Reproduced from Hand Surgery 1998; 3(1), with permission.)
<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (yrs)</th>
<th>Gender</th>
<th>Side</th>
<th>Cause of injury</th>
<th>Date of injury</th>
<th>Area</th>
<th>Nerves sutured</th>
<th>Date of surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Me 1</td>
<td>1</td>
<td>26</td>
<td>F</td>
<td>Gun shot</td>
<td>5 Feb 1996</td>
<td>Forearm injury</td>
<td>Median nerve to ulnar nerve (prox. to wrist)</td>
<td>12 Feb 1996</td>
</tr>
<tr>
<td>Me 2</td>
<td>2</td>
<td>19</td>
<td>M</td>
<td>MVA</td>
<td>13 Oct 1989</td>
<td>Brachial plexus injury</td>
<td>Median nerve to ulnar nerve (prox. to wrist)</td>
<td>27 Jun 1996</td>
</tr>
<tr>
<td>Me 3</td>
<td>3</td>
<td>25</td>
<td>M</td>
<td>Knife stab</td>
<td>16 Jan 1996</td>
<td>Brachial plexus injury</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>24 Oct 1996</td>
</tr>
<tr>
<td>He 1</td>
<td>1</td>
<td>4</td>
<td>M</td>
<td>Gun shot</td>
<td>15 Sep 1996</td>
<td>Upper arm injury</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>23 Jan 1997</td>
</tr>
<tr>
<td>Le 1</td>
<td>5</td>
<td>50</td>
<td>M</td>
<td>Fan blade cut</td>
<td>4 Apr 1997</td>
<td>Forearm injury</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>15 May 1997</td>
</tr>
<tr>
<td>Me 4</td>
<td>6</td>
<td>22</td>
<td>M</td>
<td>Infracavicular stab</td>
<td>28 Sep 1996</td>
<td>Brachial plexus injury</td>
<td>Musculocutaneous nerve to posterior cord</td>
<td>3 Jun 1997</td>
</tr>
<tr>
<td>Me 5</td>
<td>7</td>
<td>33</td>
<td>M</td>
<td>Knife stab</td>
<td>15 Mar 97</td>
<td>Forearm injury</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>14 Jul 1997</td>
</tr>
<tr>
<td>Me 6</td>
<td>8</td>
<td>23</td>
<td>M</td>
<td>MVA</td>
<td>1 Jul 1995</td>
<td>Forearm injury</td>
<td>Ulnar nerve to median nerve forearm (prox. to wrist)</td>
<td>18 Sep 1997</td>
</tr>
<tr>
<td>Le 2</td>
<td>9</td>
<td>32</td>
<td>F</td>
<td>MVA</td>
<td>29 Nov 1996</td>
<td>Brachial plexus injury</td>
<td>Musculocutaneous nerve to median nerve</td>
<td>16 Oct 1997</td>
</tr>
<tr>
<td>Be 1</td>
<td>10</td>
<td>24</td>
<td>M</td>
<td>MVA</td>
<td>6 Jan 1996</td>
<td>Brachial plexus injury</td>
<td>Musculocutaneous nerve to median nerve</td>
<td>28 Oct 1997</td>
</tr>
<tr>
<td>Me 7</td>
<td>11</td>
<td>30</td>
<td>M</td>
<td>Stab wound</td>
<td>24 May 1997</td>
<td>Cut at wrist level</td>
<td>Ulnar nerve to median nerve (at wrist level)</td>
<td>17 Nov 1997</td>
</tr>
<tr>
<td>Ce 1</td>
<td>12</td>
<td>37</td>
<td>M</td>
<td>Crush injury, middle finger</td>
<td>5 Feb 1995</td>
<td>Amputated middle finger</td>
<td>Ring finger digital nerve to index finger digital nerve</td>
<td>20 Nov 1997</td>
</tr>
<tr>
<td>Le 3</td>
<td>13</td>
<td>25</td>
<td>M</td>
<td>MVA</td>
<td>15 Jan 1996</td>
<td>Brachial plexus injury</td>
<td>Musculocutaneous nerve to long nerve of Bell</td>
<td>5 Dec 1997</td>
</tr>
<tr>
<td>Se 1</td>
<td>14</td>
<td>35</td>
<td>M</td>
<td>Angle grinder cut, palm of hand</td>
<td>26 Jan 1997</td>
<td>Palm cut</td>
<td>Digital nerve to digital nerve</td>
<td>11 Dec 1997</td>
</tr>
<tr>
<td>Me 8</td>
<td>15</td>
<td>26</td>
<td>M</td>
<td>MVA</td>
<td>20 May 1996</td>
<td>Brachial plexus injury</td>
<td>Upper trunk to middle trunk</td>
<td>11 Dec 1997</td>
</tr>
<tr>
<td>Me 9</td>
<td>16</td>
<td>44</td>
<td>F</td>
<td>Severance of ulnar nerve</td>
<td>3 Feb 1998</td>
<td>Forearm cut</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>8 Feb 1998</td>
</tr>
<tr>
<td>Ne 1</td>
<td>17</td>
<td>4</td>
<td>M</td>
<td>MVA, degloving at elbow</td>
<td>15 Feb 1997</td>
<td>Ulnar nerve cut at elbow level</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>11 Feb 1998</td>
</tr>
<tr>
<td>Me 10</td>
<td>18</td>
<td>32</td>
<td>M</td>
<td>Knife stab wound</td>
<td>1 Jan 1997</td>
<td>Ulnar nerve cut at elbow level</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>12 Feb 1998</td>
</tr>
<tr>
<td>Ke 1</td>
<td>19</td>
<td>36</td>
<td>M</td>
<td>Knife stab wound</td>
<td>28 Aug 1997</td>
<td>Forearm open wound</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>12 Feb 1998</td>
</tr>
<tr>
<td>Me 11</td>
<td>20</td>
<td>26</td>
<td>M</td>
<td>Glass cut, median nerve</td>
<td>15 Oct 1996</td>
<td>Forearm open wound</td>
<td>Median nerve to ulnar nerve (prox. to wrist)</td>
<td>5 Mar 1998</td>
</tr>
<tr>
<td>Ne 2</td>
<td>21</td>
<td>39</td>
<td>M</td>
<td>Glass cut, median nerve</td>
<td>21 Oct 1997</td>
<td>Forearm open wound</td>
<td>Median nerve to ulnar nerve (prox. to wrist)</td>
<td>16 Mar 1998</td>
</tr>
<tr>
<td>Ve 1</td>
<td>22</td>
<td>38</td>
<td>F</td>
<td>Cut ulnar nerve after neurolysis</td>
<td>20 Oct 1997</td>
<td>Elbow</td>
<td>Ulnar nerve to median nerve</td>
<td>17 Feb 1998</td>
</tr>
<tr>
<td>Ne 3</td>
<td>23</td>
<td>40</td>
<td>M</td>
<td>Cut ulnar nerve by grinder</td>
<td>25 Aug 1997</td>
<td>Forearm open wound</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>26 Mar 1998</td>
</tr>
<tr>
<td>Me 12</td>
<td>24</td>
<td>30</td>
<td>M</td>
<td>Cut, ulnar nerve 14 Feb 1998</td>
<td></td>
<td>Forearm open wound</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>16 Jul 1998</td>
</tr>
<tr>
<td>He 2</td>
<td>25</td>
<td>42</td>
<td>M</td>
<td>Cut, digital nerve of index finger</td>
<td>15 Jan 1998</td>
<td>Wound on volar aspect of hand</td>
<td>Digital nerve to digital nerve</td>
<td>11 Jun 1998</td>
</tr>
</tbody>
</table>
Table I Continued

<table>
<thead>
<tr>
<th>No.</th>
<th>No. of surgery undertaken</th>
<th>Sex</th>
<th>Age</th>
<th>Injury</th>
<th>Site of surgery</th>
<th>Cause of nerve damage</th>
<th>Resection date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Me 13</td>
<td>26 26</td>
<td>M</td>
<td>1</td>
<td>Glass cut ulnar nerve</td>
<td>Forearm open wound</td>
<td>Ulnar nerve to median nerve</td>
<td>29 Mar 1998</td>
</tr>
<tr>
<td>Ve 2</td>
<td>27 45</td>
<td>M</td>
<td>1</td>
<td>Glass cut ulnar nerve</td>
<td>Forearm open wound</td>
<td>Ulnar nerve to median nerve</td>
<td>23 Sep 1998</td>
</tr>
<tr>
<td>We 1</td>
<td>28 38</td>
<td>F</td>
<td>r</td>
<td>MVA</td>
<td>Cut elbow</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>31 Jul 1998</td>
</tr>
<tr>
<td>Me 14</td>
<td>29 35</td>
<td>M</td>
<td>1</td>
<td>Stab wound</td>
<td>Brachial plexus injury</td>
<td>Upper trunk to lower trunk of brachial plexus</td>
<td>28 Jul 1998</td>
</tr>
<tr>
<td>Me 15</td>
<td>30 40</td>
<td>F</td>
<td>r</td>
<td>Glass cut ulnar nerve</td>
<td>Forearm open wound</td>
<td>Ulnar nerve to median nerve</td>
<td>15 Oct 1998</td>
</tr>
<tr>
<td>Ne 4</td>
<td>31 3</td>
<td>M</td>
<td>r</td>
<td>MVA passenger, car rolled</td>
<td>Degloving forearm injury</td>
<td>Ulnar nerve to median nerve (prox. to wrist)</td>
<td>29 Dec 1998</td>
</tr>
<tr>
<td>Ne 5</td>
<td>32 21</td>
<td>M</td>
<td>r</td>
<td>Knife stab</td>
<td>Brachial plexus injury</td>
<td>Musculocutaneous nerve to medial cord</td>
<td>25 Sep 1998</td>
</tr>
<tr>
<td>Re 1</td>
<td>33 13</td>
<td>M</td>
<td>r</td>
<td>Fractured humerus cut radial nerve</td>
<td>Mid shaft humerus Radial nerve to median nerve</td>
<td>13 Mar 1998</td>
<td></td>
</tr>
</tbody>
</table>

No. = sequence of surgery undertaken; M = male; F = female; I = left; r = right; MVA = motor vehicle accident; prox. = proximal.

10. Static two-point discrimination slowly improved over 2 years, even reaching 3 mm.

11. Motor function of large (i.e. biceps) (Fig. 7) and small (i.e. intrinsic hand) muscles recovered (Fig. 8, a and b). This recovery was observed even beyond 2 years, and was closely influenced by specific rehabilitative therapy, which concentrated on specific muscle rehabilitation rather than gross function, e.g. elbow flexion involving a group of muscles.

12. Co-contraction or functional confusion of muscles was not seen, again indicating that nerves may act as generalised conduits for impulses, rather than once-off area-dedicated conductors.

13. Although histologically the nerves at the suture area showed a neuroma-like pattern, no painful or sensitive neuromas or even hypersensitivity with percussion over the anastomosis site developed.

14. The results of re-innervation are less successful in patients treated more than 6 months after injury.

**DISCUSSION**

ETSNS is a practical option to innervate motor and sensory end organs. Our results are very encouraging, and at least match those of end-to-end nerve suture and do better than nerve grafting. Patients had fewer side-effects such as neuroma formation at the suture site and unpleasant sensory feelings.

ETSNS is a simple alternative to re-innervate lost sensory and/or motor function. The possibility of 'borrowing' axons from virtually any neighboring intact nerve opens up a wide spectrum of options.

The ability and desire of an intact nerve to sprout laterally, to do this selectively for sensory and motor axons, to populate the injured distal recipient nerve fully, and to carry many more impulses than once thought, all without any unpleasant side-effects (e.g. neuromas), has been drastically underestimated. Of course, much research and clinical observation still needs to be done to understand and quantify this remarkable phenomenon.

The importance of specific rehabilitation must be emphasised. Paralysed muscles and anaesthetic skin need to be re-educated. Paralysed muscles are often 'amputated in the brain' and need to be re-kindled, re-educated or awakened when innervation takes place. This form of therapy has been well documented. Sensory rehabilitation is important. For both sensory and motor rehabilitation the professional skills of occupational therapists are strongly recommended.

No evidence of motor or sensory deficit was observed in the donor area. In the experimental animal (most recently the rat) histology and actual counting of axons before and after ETSNS did not reveal any damage to the axons. How the nerve manages to carry impulses to and from various target organs remains a mystery, and here further neurophysiological investigations are required.

Nerves treated more than 6 months after injury do not respond as well as those treated more promptly. This is because increased fibrous tissue in the distal recipient nerve prevents axons from growing down neural tubes. Owing to the atrophy (Wallerian degeneration) of the recipient nerve, the amount of neurotropic factors which stimulate axonal sprouting is probably also reduced.

In this report I do not attempt to explain how all this happens. I merely report on experimental findings in the non-human primate and clinical findings over 3 years in a diverse group of patients. However, I do claim that this new technique to re-establish sensory and/or motor function does work in the human, that it simplifies many of our present techniques (e.g.
obviate nerve grafts), and that it presents us with new treatment options (e.g. motorising biceps and deltoid muscles, and restoring brachial plexus integrity in some avulsion injuries).

**CONCLUSION**

ETNS is a well-established surgical technique to restore lost motor and sensory function. Technically it is a simple, easy procedure. Because any suitable neighboring intact nerve can be used as host for a distal injured nerve, many new management options become available, including the restoration of avulsed brachial plexus injuries and doing away with nerve grafts, thereby reducing morbidity and operation time. The functional results of ETSNS can only be fully evaluated in the human patient who is able to co-operate, especially in the rehabilitation phase, with whom it is possible to discuss the nuances of sensation.

A special word of thanks is due to Professor E J Rauenheimer, Head of the Department of Oral Pathology and Oral Biology, Faculty of Dentistry, MEDUNSA, for the meticulous histology investigations.

**References**


**New sports medicine titles from BMJ Publishing . . .**

**Sports Medicine Handbook**
Edited by Domnall MacAulay

Bringing together the latest thinking on the subject, Benefits and Hazards of Exercise will be welcomed by all involved in sport and sports medicine, from sports medicine physicians and physiotherapists to general practitioners and trainers. It will also be of interest to those involved in health promotion and public health. Discussing both the physiological effects of exercise in the healthy, and the potential risks to those with specific conditions, this authoritative text with contributions from leading experts worldwide covers an aspect of growing concern in sport. Contents include: optimal physical activity for health, physical activity promotion and adoption, intermittent exercise patterns, psychological wellbeing, effects of exercise in heat: altitude training, the athlete's heart, altered reproduction function in male athletes, sudden death and cardiovascular disease in young athletes, athletic performance and jet lag, exercise and the older woman, diabetes and hypertension, overtraining, viral illness and sport, and general practice implications. Each chapter provides a continuing medical education element in the form of MCQs or essay questions. Together with summary boxes for quick reference these features make the book of lasting usefulness to all in sports medicine.

**Benefits and Hazards of Exercise**
Edited by Domnall MacAulay

**September 1999, 393 pp, soft cover, ISBN 1-85271-321-7**

Orders:
The South African Medical Association, Private Bag X1, Pinelands 7430.
Tel (021) 531-3081, fax (021) 531-4126,
e-mail: jstrydom@samedical.org
Prepayment required by cheque, Visa/Mastercard or bank deposit.
Limited local stock.

November 1999, Vol. 89, No. 11  SAMJ