Pronating osteotomy of the radius for forearm supination contracture in high-level tetraplegic patients

TECHNIQUE AND RESULTS

We report the results of performing a pronating osteotomy of the radius, coupled with other soft-tissue procedures, as part of an upper limb functional surgery programme in tetraplegic patients with supination contractures.

In total 12 patients were reviewed with a mean follow-up period of 60 months (12 to 109). Pre-operatively, passive movement ranged from a mean of 19.2° pronation (-70° to 80°) to 95.8° supination (80° to 140°). A pronating osteotomy of the radius was then performed with release of the interosseous membrane. Extension of the elbow was restored post-operatively in 11 patients, with key-pinched reconstruction in nine.

At the final follow-up every patient could stabilise their hand in pronation, with a mean active range of movement of 79.6° (60° to 90°) in pronation and 50.4° (0° to 90°) in supination. No complications were observed. The mean strength of extension of the elbow was 2.7 (2 to 3) MRC grading.

Pronating osteotomy stabilises the hand in pronation while preserving supination, if a complete release of the interosseous membrane is also performed. This technique fits well into surgical programmes for enhancing upper limb function.

A supination contracture can be defined as an inability to stabilise the hand in pronation. It occurs as a result of an imbalance between the functional supinator muscles, mainly the biceps brachii and supinator, and the hypotonic paralysed pronators. Initially a supination contracture can be reduced with abduction and internal rotation of the shoulder, but over time it becomes permanent as the biceps brachii and the interosseous membrane contract. Apart from looking ‘odd’, a supination contracture seriously impedes hand function, which albeit rudimentary, is very important to the tetraplegic patient. Correction of the supination deformity enhances the usefulness of any remaining functional muscles by the enabling key-pinched.

Unlike obstetric brachial plexus injuries, supination contractures in tetraplegic patients occur infrequently and only arise in high-level tetraplegia, groups 1 to 3 of the International Classification of Surgery of the Hand in Tetraplegics, corresponding to neurological levels C5 and C6. It is generally agreed that functional upper limb surgery programmes should aim to restore the pronated position of the forearm, elbow extension and key-pinched.

The treatment of a supination contracture is difficult and controversial, and few studies offer a specific therapeutic strategy for tetraplegic patients. None propose a global strategy for functional upper limb rehabilitation. Zancolli suggested a pronator transfer of the biceps tendon in association with release of the interosseous membrane release, for fixed contractures. However, rerouting the biceps risks both overcorrection and slackening, with unpredictable results in patients with a fixed deformity despite interosseous membrane release.

This study aimed to describe a pronating osteotomy of the radius for correcting a supination contracture in the adult tetraplegic patient, and to evaluate the functional results using a complete upper limb rehabilitation programme in this group of patients.

Patients and Methods

A total of 12 isolated pronating osteotomies of the radius in eight high-level tetraplegic patients with a supination contracture were retrospectively reviewed. The mean post-operative follow-up period was 60 months (12 to 109). All patients gave informed consent. Their mean age at the time of surgery was 37 years (24 to 54), and the mean time between spinal injury and surgery was 73 months (14 to 287). From a neurological...
point of view, the lowest useful motor level was C5 in seven cases and C6 in five. The mean American Spinal Injury Association (ASIA) motor score was 16.2 (12.5 to 20.0) out of 100. According to the International Classification of Tetraplegics, four cases were group 1, five group 2 and three group 3 (Table I).

None of our patients had active extension of the elbow. Anterior stabilisation of the shoulder was poor owing to paralysis of the pectoralis major.

The passive range of pronation and supination was measured with a goniometer. Pre-operatively, none of the patients could stabilise their forearm in pronation. Mean passive pronation was 19.2° (-70° to 80°), mean supination was 95.8° (80° to 140°), and the mean deficit in passive elbow extension was 19° (0° to 40°). In eight of the 12 a fixed supination contracture was present, with passive pronation < 40°. Mean passive wrist extension was 82° (40° to 90°) and mean passive flexion was 15° (70° to -20°) (Table II).

**Table I. Demographic data and associated surgical procedures**

<table>
<thead>
<tr>
<th>Patients</th>
<th>Side</th>
<th>Age at osteotomy (years)</th>
<th>Time between SCI and POR (months)</th>
<th>ASIA score (motor score)</th>
<th>International classification</th>
<th>Lesion level</th>
<th>Degree of pronation osteotomy</th>
<th>Complete release of IOM</th>
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<th>Second stage</th>
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<td>G2</td>
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<td>60 -</td>
<td>Osteotomy</td>
<td>BB to TB transfer + Passive KP</td>
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</tr>
<tr>
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<td>80 -</td>
<td>Osteotomy + BB to TB transfer</td>
<td>Passive KP</td>
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<tr>
<td></td>
<td>L</td>
<td>23</td>
<td>14</td>
<td>8</td>
<td>G2</td>
<td>C6</td>
<td>80 -</td>
<td>Osteotomy + BB to TB transfer</td>
<td>Passive KP</td>
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</tr>
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<td>70 +</td>
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<td>70 +</td>
<td>Osteotomy</td>
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<td>76</td>
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<td>Osteotomy</td>
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SCI, spinal cord injury; POR, pronating osteotomy of the radius; ASIA, American Spinal Injury Association; IOM, interosseous membrane; BB, biceps brachii; TB, triceps brachii; KP, key-pin; BR, brachioradialis; FPL, flexor pollicis longus; ECRB, extensor carpi radialis brevis

**Surgical technique: pronating osteotomy of the radius.** The senior author (BC) performed every operation, with the patient under general anaesthesia. After application of a tourniquet the osteotomy was performed through an anterior forearm approach. The pronator teres muscle, which was atrophied in each case, was released from the radius. The interosseous membrane was exposed and divided throughout its length. Care was taken to preserve the integrity of the anterior and posterior interosseous pedicles (Fig. 1).

A mid-diaphyseal transverse osteotomy was performed after inserting proximal and distal marking pins perpendicular to the axis of the diaphysis of the radius. The mean angle of pronation after osteotomy, measured by the marking pins to the distal segment, was 74° (60° to 90°). Osteosynthesis was performed using a seven-hole 3.5 mm dynamic compression plate.
Intra-operatively, the final position of the hand was checked after fixing the osteotomy to ensure that it allowed at least 50° of pronation and at least 50° passive supination. Where another surgical procedure took place during the same operation, a pronating osteotomy of the radius was performed first. Post-operatively, a cast immobilised the elbow and the wrist for three weeks. Its position was determined by the type of tendon transfer associated with the pronating osteotomy of the radius. The elbow was maintained in extension after a biceps-to-triceps transfer to restore active elbow extension, and in flexion following brachioradialis to extensor carpi radialis brevis (ECRB) transfers. Forearm mobilisation was initiated within the range of movement obtained intra-operatively.

Associated procedures within the functional upper limb surgery programme. The pronating osteotomy of the radius was the sole procedure in one limb in only one patient. The other 11 interventions required a two-stage procedure, involving functional upper limb surgery with key-pinch reconstruction (Table I). In four patients, the first stage was a pronating osteotomy of the radius. In the second stage, the biceps brachii was transferred to the triceps brachii and a key-pinch reconstruction was performed. In two further cases the brachioradialis was transferred to the extensor carpi radialis brevis to restore active extension of the wrist along with a pronating osteotomy of the radius in the first stage. During the second stage, the biceps brachii was transferred to the triceps and the key-pinch reconstruction was carried out. In the five remaining cases stage one included a pronating osteotomy and biceps to triceps transfer with a key-pinch reconstruction in the second stage in four (Table I).

Data collection. Each patient was clinically reviewed by an independent clinician. The ability to stabilise the forearm in pronation and to achieve active extension of the wrist during key-pin without supination was evaluated. The passive range of movement in pronation and supination was assessed with the elbow in 90° of flexion.

Active of daily living. Patients’ functional autonomy was evaluated pre-operatively and at final review using the Quadriplegia Index Factor. The maximum period of autonomy was also recorded. This parameter is defined by the amount of time a patient can spend alone without requiring help from a third party. The Modified University of Minnesota Tendon Transfer Functional Improvement Questionnaire was also used. This assesses the improvement in 30 general activities typically performed by tetraplegic patients, and requires patients to classify their functional abilities before and after surgery as ‘much better’ (2 points), ‘better’ (1 point), ‘no change’ (0 points), ‘worse’ (-1 point), and ‘much worse’ (-2 points). The minimum possible score when all answers are ‘much worse’ is -60. The maximum possible score when all answers are ‘much better’ is 60.

### Table II. Range of movement and functional results

<table>
<thead>
<tr>
<th>Patients</th>
<th>Side</th>
<th>Pronation pre-op/final follow-up (°)</th>
<th>Supination pre-op/final follow-up (°)</th>
<th>Wrist flexion pre-op/final follow-up (°)</th>
<th>Wrist ext. pre-op/final follow-up (°)</th>
<th>Elbow deficit ext. pre-op/final follow-up (°)</th>
<th>Elbow extension strength (MRC)</th>
<th>QIF† initial/review (0/100)</th>
<th>Total autonomy time initial/review (minutes)</th>
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<td>40/90</td>
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<td>-20/10</td>
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<td>-40/-20</td>
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<td>-40/-20</td>
<td>2.5</td>
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* MRC, Medical Council Research  
† QIF, Quadriplegia Index Factor  
‡ NA, not available

Fig. 1

Photograph of an anterior forearm approach showing a section of the interosseous membrane along its entire length. Pronating the forearm creates a wider gap between the radius and the ulna.
Statistical analysis. P-values were calculated using non-parametric tests, as our population did not have a normal distribution nor similar variances. The Mann-Whitney U test was used to compare patients with and without complete interosseous membrane release, and those with or without fixed supination contractures. Wilcoxon’s signed ranks test was used to compare the range of pronation and supination before and after treatment. A p-value of < 0.05 was deemed significant.

Results
At the final follow-up, all osteotomies united. None of the plates needed to be removed, and there were no cases of infection, hardware failure, forearm synostosis or complex regional pain syndrome. However, in the month following surgery two patients were temporarily transferred to intensive care because of respiratory difficulties.

Pronating osteotomy of the radius. At final review, every forearm was stable in pronation (Figs 2 and 3). Pronation increased to a mean of 79.6° (60° to 90°) at the final follow-up (p < 0.01). Conversely, supination decreased significantly to a mean of 50.4° (0° to 90°) (p < 0.01) at the end of the study. The mean arc of movement from full supination to full pronation increased, albeit not significantly (Wilcoxon, p = 0.45), from a mean of 115° (10° to 170°) to a mean of 130° (90° to 170°) (Table II).

The difference in the range of pronation and supination at final follow-up between patients who had a fixed supination contracture (mean pronation 76.9° (60° to 90°), mean supination 53.2° (0° to 90°) and those who had a flexible supination contracture, mean pronation 85° (80° to 90°), mean supination 45° (20° to 50°), was not statistically significant (Mann-Whitney, pronation p = 0.22, supination p = 0.18). In the first three cases, where the interosseous membrane was only partially divided, a significant diminution in the range of supination, mean 20.0° (0° to 40°) was observed, compared with those cases in which the interosseous membrane was completely divided, regardless of whether the supination contracture was fixed or flexible, mean 60.6° (30° to 90°) (p = 0.04) (Fig. 4).

Results of the functional upper limb surgery programme. Active wrist extension without forearm supination was achieved for each patient. The mean strength of extension of the elbow at final review was 2.7 (2 to 3), according to the Medical Research Council scale, with a mean deficit in active extension of -8.9° (0° to -30°) (Table II).

In terms of functional autonomy, the Quadriplegia Index Factor increased significantly (p ≤ 0.01) from a mean of 19.2 (9.8 to 31) pre-operatively to a mean of 28.9 (16.5 to 40.3) at final follow-up. The duration of maximum autonomy increased by a mean of 183.5 minutes, from 82.5 (30 to 180) minutes to 266 (120 to 360) minutes (p = 0.02). Pre-operatively, all eight patients required help for the slightest activity, such as holding a small object or a drink. At the final review, for the three patients who did not have an indwelling urinary catheter or a penile sheath, complete autonomy was increased by two to three hours, while a third party inserted...

Fig. 2
Photograph of supination attitude in a high-level tetraplegic patient, group 2 of the Giens international classification. Pre-operative range of passive pronation and supination. The hand is functionally unusable: no grip is possible.

Fig. 3
Photograph of the post-operative position of the hand, stable in pronation with no recurrence of the supination attitude.
a urinary catheter or applied a penile sheath. The other five patients only needed help with meal preparation.

The functional evaluation using the Activities of Daily Living Functional Questionnaire showed great satisfaction, with a mean score of 15.7 (11 to 22). Activities in which patients reported the greatest improvement were the manipulation of small objects; the ability to feed themselves with the help of technical aids (excluding cutting food) and the ability to use a conventional joystick controller on an electric powered wheelchair. However, patients remained unable to dress themselves or to move unaided from a wheelchair to another seat.

All patients considered the operation highly beneficial, and said they would have it again. It should be noted that seven of the eight patients underwent the complete programme of functional upper limb surgery with key-pinchof reconstruction, and that all patients with bilateral impairments asked for surgery on both sides.

Discussion
Studies that specifically discuss the correction of supination contractures in tetraplegic patients following a spinal cord injury are rare. This impairment is encountered almost exclusively in tetraplegic patients with high-level lesions, when pronator teres is completely paralysed. Supination contractures in tetraplegic patients can be functionally catastrophic, because the tenodesis action of the wrist is impaired, and thus any upper limb surgery programme is doomed to fail. The first stage of the surgical programme must correct this contracture, and the technique must be integrated into an overall strategy for functional upper limb rehabilitation.

Our results show that a pronating osteotomy of the radius is a reliable technique. In every case in this series the hand was stabilised in pronation, allowing a basic key-pinchof each patient. We observed no relapse into the supination deformity, as the biceps was transferred to the triceps to restore elbow extension in almost every case. However, for the cases in which the biceps brachii was transferred during the second stage of surgery, we observed a tendency towards reduced passive pronation. Similarly, in previous reports of rotational forearm osteotomy without biceps brachii transfer after obstetric brachial plexus injuries, supination frequently recurred. In light of our results, we recommend correcting the muscle imbalance between the supinator and pronator muscles to avoid the return of the deformity.

Our experience shows that the role of the pronating osteotomy of the radius may be extended to treat fixed supination contracture through complete release of the interosseous membrane.

Zancolli described release of the interosseous membrane during re-routing of the biceps brachii for supination contracture treatment in two patients with flexible supination contractures who subsequently recovered active pronation of 50° to 60°. In contrast, Gellman et al obtained comparable results in eight patients without
releasing the interosseous membrane, even in cases with fixed deformities. However, two patients suffered a complete loss of supination due to overcorrection. Gellman et al.\textsuperscript{10} insisted on conserving 45° of supination. The fixed supination contractures in our series had ranges of movement similar to the flexible supination contractures at final follow-up. Comparing the first three upper limbs that underwent limited release of the interosseous membrane (just enough to allow osteosynthesis placement) with the rest of the series, we observed that failure to completely divide the interosseous membrane does limit residual supination.

Our results show similar ranges of movement for both pronation and supination at final follow-up to those obtained by re-routing the biceps.

Even though few tools are sensitive enough to assess the highest-level tetraplegic patients, the functional analysis of our patients was very positive. We noticed that patients who had been reduced to a state of total dependence after their spinal cord injury had regained a degree of autonomy by the final review.

Most daily activities require the forearm to be in a pronated position. Because of this, a supination contracture must be corrected as part of a systematic overall programme for upper limb reconstruction that includes restoring extension of the elbow. A pronating osteotomy of the radius fits well into the functional upper limb surgery programme as it preserves the biceps, allowing transfer to the triceps to restore active extension of the elbow. This technique is useful when anterior stabilisation of the shoulder by the pectoralis major is insufficient as found in all our patients.\textsuperscript{21,22} The alternative, of transferring the posterior deltoid to the triceps brachii in patients with a paralysed pectoralis major, is problematic, because it causes the shoulder to roll backwards during extension of the elbow. In our series, biceps brachii transfer results were modest, but good enough to position the hand at an above-the-shoulder level.

A complete functional upper limb surgery programme for high-level tetraplegic patients with a supination contracture requires several operations, which should be coordinated (Fig. 5).

A pronating osteotomy of the radius can always be undertaken in conjunction with another operation. In patients who have retained active extension of the wrist (groups 2 and 3 of the International Classification), pronation osteotomy of the radius is best performed with biceps to triceps transfer, as the two approaches are quite distinct and the osteosynthesis of the pronating osteotomy of the radius with a dynamic compression plate does not hinder the biceps transfer rehabilitation. Active or passive key-pinch construction can be carried out at a later stage. However, when patients have no extension of the wrist (group 1) it is preferable to transfer the brachioradialis to the extensor carpi radialis brevis at the same time as the pronating osteotomy of the radius. Biceps to triceps transfer and passive key-pinch construction can be carried out at a later date. Reducing surgery to two stages avoids exhausting these patients, for whom the
results of such a programme will always remain modest. We suggest that the biceps should be rerouted to correct a flexible supination contracture in high-level tetraplegics only in exceptional cases, when patients have retained good anterior stabilisation of their shoulder, thus allowing the transfer of the posterior deltoid to the triceps. The basis for treating a supination contracture lies in the suppression of the supinating action of the biceps, either by transferring it to the triceps or by giving it a pronating function.

This study has certain limitations. First, it is retrospective, owing to the relatively low prevalence of supination contractures in tetraplegic patients. Our oldest records in this series date from ten years ago, which is why we only used tests that had been validated at the time of the initial functional evaluation assessment. Another difficulty involved the evaluation of the results from a pronating osteotomy of the radius in tetraplegic patients. Range of movement is only one parameter, and although the stability of the forearm in pronation seems to be more important for function, it is difficult to quantify objectively. Functionally, few scales are sensitive enough to highlight improvements in high-level tetraplegia,\(^{23}\) for which reason we used the Quadriplegia Index Factor and maximum autonomy time. Nevertheless, the study remains homogeneous because all of the patients were treated at the same institution according to the same surgical and rehabilitation protocol.

A supination contracture in tetraplegic patients represents a complex surgical challenge. Our results show that a pronating osteotomy of the radius can help correct it effectively, and that it integrates well into a functional upper limb surgical programme.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References