Flexor carpi ulnaris tendon transfer to the split brachioradialis tendon to restore supination in paralytic forearms

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Inability to actively supinate the forearm makes common activities of daily living and certain vocational activities awkward or impossible to perform. A total of 11 patients with deficient supination of the arm underwent transfer of the tendon of flexor carpi ulnaris to the split tendon of brachioradialis with its bony insertion into the radial styloid left intact. Active supination beyond neutral rotation was a mean of 37.2° (25° to 49.5°) at a minimum follow-up of three years, representing a significant improvement (95% confidence interval 25 to 50, p < 0.001). Functional evaluation of the hand after this transfer showed excellent and good results in ten patients and fair in one.

The split tendon of brachioradialis as an insertion for transfer of the flexor carpi ulnaris appears to provide adequate supination of the forearm without altering the available pronation and avoids the domination of wrist extension sometimes associated with transfers of the flexor carpi ulnaris to the radial extensors of the wrist.

Inadequate supination of the forearm in paralytic disorders is a disabling problem for patients and frustrates their ability to perform activities of daily living (ADL), such as eating with the hands (customary in the Indian sub-continent), washing the face and grooming, or opening doors by turning a handle or knob. With a normal shoulder joint capable of abduction and external rotation, the arm and the forearm positioned away from the body allow for adequate hand function with simulated forearm supination. However, where essential activities require that the hand be near the body with the shoulder adducted, no rotary manoeuvre of the proximal joint is possible to position the forearm in ‘supination’ to allow satisfactory function in ADL.

Transfer of the flexor carpi ulnaris to the extensor carpi radialis longus (ECRL) or brevis was designed to provide the dual function of supination of the forearm and extension of the wrist.

Supination of the forearm may be achieved by re-routing the tendon of pronator teres or the brachioradialis around the radius and back to their own sites of insertion, thereby converting their respective primary function to supination of the forearm. In transfer of the flexor carpi ulnaris to the ECRL/ECRB extension of the wrist may eventually dominate and supination of the forearm is lost or becomes inadequate, with persistent dorsiflexion of the wrist leading to significant loss of palmar flexion. In re-routing the pronator teres, anatomical studies reveal a ‘windlass effect’ after transfer, preventing efficient active supination beyond the neutral position. In re-routing the tendon of brachioradialis, additional release of the pronator teres and the pronator quadratus is performed. The ability of the patient to pronate the forearm normally can therefore be affected.

In an attempt to provide pure supination without the limitations of the above techniques we have transferred the tendon of flexor carpi ulnaris to a slip of the split brachioradialis tendon in patients with loss of active supination due to paralysis from various causes.

Patients and Methods

Between 2001 and 2004, transfer of the flexor carpi ulnaris to the split tendon of brachioradialis was performed in 11 patients to restore isolated supination of the forearm. The loss of supination was seen in patients with paralysis due to one of four conditions (Table I). The mean age of the patients was 21.5 years (9 to 45). There were seven males and four females. The selection criteria for this procedure were the absence of active forearm supination but a free passive range of supination of at least 45° beyond the mid-forearm position (neutral rotation), adequate wrist extension of 30° or more with at least grade 3 power on the MRC scale, or a stable...
wrist that had already been fused, and patients with minimal or no spasticity. All 11 patients selected for the procedure had power of the flexor carpi ulnaris of MRC grade 4 or 5. For patients with cerebral palsy, the criteria included a modified Ashworth score < 3 and a Gschwind group 3 or 4 where there is no active supination. Surgical technique. The musculotendinous unit of the flexor carpi ulnaris is delineated at its distal two-thirds either through two short longitudinal incisions, one in the distal forearm and another in the mid-forearm (used in four children), or by the conventional single long incision on the ulnar border of the forearm, extending from just proximal to the wrist crease up to the proximal third of the forearm. The flexor carpi ulnaris muscle is released from the ulna up to the junction of its proximal and middle thirds, according to the van Heest technique for mobilising the distal two-thirds of this muscle, and freed from the fascia binding it to other flexor muscles. The tendon is then transected proximal to its insertion into the pisiform bone. The whole distal two-thirds of the musculotendinous unit is wrapped in a saline-soaked gauze pad and taken across the dorsum to ascertain that the muscle crosses the middle third of the forearm during the formal subcutaneous re-routing. Another short incision is then made over the dorsoradial aspect of the forearm just proximal to the dorsal wrist crease. The superficial radial cutaneous nerve is retracted radially to expose the insertion of the distal end of the tendon of the brachioradialis into the radial styloid. A double-pronged blunt hook is used to lift the delineated tendon gently off its bed, and it is then split longitudinally up to its insertion into the radial styloid, leaving the bony insertions of the split halves intact. The volar half of the split brachioradialis is then incised 5 cm proximal to its insertion, and its free end swung freely in a dorsoulnar direction to serve as attachment for the tendon of flexor carpi ulnaris. Next, this tendon is tunnelled radially in the dorsal subcutaneous plane and brought into the incision on the radial side. Its end is held with the tip of a clamp and gently pulled to confirm that it glides freely in a straight line. The forearm is held in maximum available supination with the elbow in 90° flexion, and the tendon of flexor carpi ulnaris is anastomosed to the split tendon of brachioradialis using the Pulvertaft tendon-weave technique (Fig. 1), completing the anchor-age with 3/0 or 4/0 Ethibond (Ethicon Excel, Johnson & Johnson International, St. Stevens-Woluwe, Belgium) sutures. The tourniquet is released, haemostasis is secured and the closure completed. Two well-fitting, lightly padded, above-elbow plaster of Paris (POP) slabs extending to the distal palmar crease are applied to the dorsal and volar aspects (sandwich slabs) to maintain the position as described above. On the third post-operative day, before the patient is discharged, wet POP rolls are wrapped around the slabs, incorporating them into a cast.

Post-operative regime. The cast and sutures are removed after three weeks and a supervised three-stage hand therapy regime is started as an outpatient. In stage I the patient is taught to initiate supination with gravity eliminated and to attempt wrist flexion and ulnar deviation while maintaining the elbow in flexion. In stage II the patient is encouraged to attempt supination against gravity while keeping the elbow in flexion. In stage III, the forearm is maintained in the maximum attained supination and the patient is allowed to extend the elbow gradually. Each stage lasts for a week to ten days. An above-elbow half-tubular thermoplastic splint or a reinforced new POP splint is used to maintain the elbow at 90° and the forearm in maximum supination during the three-stage programme. After satisfactory completion of the third stage, the patient is taught how to pick-up, basic ADL and receiving with an open palm. The same splint is taken home and used as a night splint for an additional 12 weeks.
Evaluation. Patients were assessed every three or four months for the first year, depending on their proximity to the hospital, and thereafter once or twice annually. All the patients in this study had a minimum follow-up of three years (mean 44.6 months, 36 to 65). The range of effective supination, beyond the neutral or mid-position of the forearm, at the final follow-up was recorded by a therapist who was not informed about the nature of the surgery carried out. A scoring system which combined the range of post-operative supination with the patient’s ability to complete certain ADLs was developed (Table II). The scores were graded as follows: eight to ten points, excellent; five to seven, good; three to four, fair; and two points or fewer, poor. The confidence interval and p-value were calculated. Statistical analyses of the active and passive supination were performed using SPSS for Windows version 11 (SPSS, Chicago, Illinois), with further paired t-tests of these values.

Results

The results are set out in Table III.

Active supination was restored from full pronation to beyond the neutral mid-forearm position in all patients. The range of supination beyond neutral was considered to be the effective supination that would help patients to carry out functional activities. It was restored to a mean of 37.2° (25° to 49.5°) (95% confidence interval 25 to 50, p < 0.001). Patients with a better pre-operative range of passive supination demonstrated a better range of active supination at follow-up. According to the evaluation criteria, three patients were graded excellent, seven were graded as good, and one had a fair outcome. There were no poor results. The excellent results were seen in two patients with poliomyelitis and a boy brought late with obstetric brachial plexus palsy (Fig 2). All patients retained their ability to pronate the forearm to the pre-operative angle.

Discussion

Weak supination restricts function of the forearm and hand and affects ADLs such as eating with the hand, receiving objects with the open palms held together, as is customary in south Asia, washing the face, and opening doors with a knob or unlocking one with a key.

Normal supination of the forearm is brought about by the supinator muscle, which is responsible for slow unrestricted supination, assisted by biceps brachii for fast supination.

Table II. Scoring system to evaluate forearm supination following flexor carpi ulnaris tendon transfer to the split tendon of brachioradialis

<table>
<thead>
<tr>
<th>Range of active supination</th>
<th>Points given*</th>
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<tbody>
<tr>
<td>Full range</td>
<td>4</td>
</tr>
<tr>
<td>&gt; 45°</td>
<td>3</td>
</tr>
<tr>
<td>0° to 45°</td>
<td>2</td>
</tr>
<tr>
<td>0° (forearm mid-position)</td>
<td>1</td>
</tr>
<tr>
<td>&lt; 0°</td>
<td>0</td>
</tr>
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*an excellent outcome: eight to ten points; good: five to seven; fair: three to four; poor: two points or fewer

Table III. Improvement in function on post-operative evaluation after flexor carpi ulnaris tendon transfer to the split brachioradialis tendon

<table>
<thead>
<tr>
<th>Number</th>
<th>Age (yrs)</th>
<th>Gender</th>
<th>Side</th>
<th>Diagnosis*</th>
<th>Passive pre-operative supination</th>
<th>Active post-operative supination beyond neutral</th>
<th>Final score</th>
<th>Grade†</th>
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<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>M</td>
<td>R</td>
<td>BPI</td>
<td>70</td>
<td>45</td>
<td>8</td>
<td>E</td>
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<tr>
<td>2</td>
<td>18</td>
<td>M</td>
<td>R</td>
<td>CP</td>
<td>50</td>
<td>30</td>
<td>5</td>
<td>G</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>M</td>
<td>L</td>
<td>BPI</td>
<td>75</td>
<td>50</td>
<td>7</td>
<td>G</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>F</td>
<td>R</td>
<td>OBPP</td>
<td>45</td>
<td>30</td>
<td>5</td>
<td>G</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>F</td>
<td>R</td>
<td>CP</td>
<td>60</td>
<td>45</td>
<td>6</td>
<td>G</td>
</tr>
<tr>
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<td>18</td>
<td>M</td>
<td>R</td>
<td>PPRP</td>
<td>80</td>
<td>60</td>
<td>9</td>
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</tr>
<tr>
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<td>G</td>
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<td>F</td>
<td>L</td>
<td>PPRP</td>
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<td>65</td>
<td>9</td>
<td>E</td>
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<tr>
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<td>45</td>
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<td>R</td>
<td>BPI</td>
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<td>0</td>
<td>4</td>
<td>F</td>
</tr>
<tr>
<td>11</td>
<td>19</td>
<td>F</td>
<td>R</td>
<td>CP</td>
<td>45</td>
<td>25</td>
<td>5</td>
<td>G</td>
</tr>
</tbody>
</table>

* BPI, brachial plexus injury; CP, cerebral palsy; OBPP, obstetric brachial plexus paralysis; PPRP, post poliomyelitis residual paralysis
† E, excellent; G, good; F, fair

Values of active and passive supination are measured in degrees beyond the mid-forearm (neutral rotation) position
resisted and unresisted supination.16 However, the biceps generate most of their torque while in pronation, and may not produce supination beyond the neutral position of the forearm if not assisted by a functioning supinator.17 One or both of these muscles is weak or paralysed in conditions such as the Erb's form of obstetric brachial plexus palsy, cerebral palsy, adult upper trunk brachial plexus injury and post poliomyelitis residual paralysis. A dynamic transfer is required to enable supination, prevent pronation contracture and improve hand function.

Transfer of the flexor carpi ulnaris to the ECRL/ECRB tendon (Green-Banks procedure)2-3 remains a classic procedure in the reconstruction of hands in patients with cerebral palsy to achieve extension of the wrist and supination of the forearm, providing significant cosmetic and functional improvement.7,18 Anderson and Thomas14 also recommended this procedure to manage hyperpronation of the forearm with wrist flexion seen in children with post poliomyelitis residual paralysis. However, the transfer of the flexor carpi ulnaris to ECRL/ELRB may fail to sustain supination of the forearm when its role as a wrist extensor dominates.4 Furthermore, with persistent dorsiflexion of the wrist, palmar flexion may be lost.7 We have noticed this problem in our long-term follow-up of certain hands in cerebral palsy, but still feel that the Green-Banks procedure is appropriate for severely spastic hands to serve the dual purpose of defunctioning the spastic flexor-adductor action of the flexor carpi ulnaris at the wrist while obtaining the all-important wrist extension after its transfer to ECRL/ELRB. With pronation deformities in spastic hands in cerebral palsy, it is recommended that release procedures be performed initially to unmask any latent active supination, failing which tendon transfers are advised.10 In our study, children with cerebral palsy having little or no spasticity (modified Ashworth score < 3)9 were selected for transfer of flexor carpi ulnaris to the split brachioradialis tendon as this avoided the need for a release procedure.

In order to obtain supination without wrist extension, the re-routing of pronator teres4,5 or bachioradialis6 has been described. Anatomical studies have shown a ‘windlass effect’ of the former after its re-routing around the radius, making it inefficient in supinating the forearm beyond the neutral position.19 Despite this, Sakellarides et al4 found 66° of active supination in cerebral palsy hands, and recently Amrani, Dendane and El Alami20 recorded an average of 75° of supination in obstetric brachial plexus palsy patients after re-routing of pronator teres. In both these series the recipients were young children, and presents an interesting hypothesis that growing children are capable of overcoming biomechanical constraints placed on extrinsic musculotendinous transfers in the forearm because of their natural drive and facility to improve dexterity and range of function. Obtaining isolated forearm supination after re-routing of the tendon of brachioradialis6 is achieved with the additional release of both pronators. Cadaver studies have confirmed the need to release the pronators to obtain supination beyond neutral.19 We do not release the pronators with our procedure to avoid the possibility of a late fixed supination deformity. The inability to pronate the forearm will be as functionally disabling as the inability to supinate it.

The results of our operation compare favourably with the above procedures. Certain features are integral to the success of the technique:

1. The distal two-thirds of the flexor carpi ulnaris musculotendinous unit was mobilised in all our transfers to the split brachioradialis in order to obtain a straight line of pull and increase the moment arm.9 This technique also improves the power and range of supination.

2. The split brachioradialis tendon slip used to anchor the flexor carpi ulnaris has its bony insertion in the radial styloid left intact so as to ensure force transmission directly to bone. This slip provides a longer lever arm for supination.

3. We used a 5 cm length of the split brachioradialis tendon in order to make good any shortfall in length of the transferred flexor carpi ulnaris, as the latter is often found to be short by 2 cm to 4 cm after re-routing. This is probably due to the myostatic contracture and adaptive
shortening of a normally functioning flexor carpi ulnaris muscle in a wrist held in persistent flexion by paralysed or weak extensors. We have recorded a similar inadequacy in length of the transferred flexor carpi ulnaris musculotendinous unit when proximal advancement of the common flexor origin to the humerus (Steindler’s flexorplasty) has already been performed to restore elbow flexion in patients with injury to the upper brachial plexus.

In our rehabilitation programme for paralytic upper limbs, staged reconstructive procedures at the shoulder, hand and wrist take precedence over the correction of rotational deficiency of the forearm. Flexor carpi ulnaris tendon transfer to the split brachioradialis tendon is then added if the patient wants active supination, and if this is thought likely to improve function. We consider our modification ideal for achieving active supination where active wrist extension is adequate, or where the wrist is already stabilised by arthrodesis. This procedure can be successfully performed in all paralytic conditions to augment function of the hand.

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References