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Article *in* The Bone & Joint Journal · December 1992

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UPPER-LIMB SURGERY FOR TETRAPLEGIA

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We reviewed the results of reconstruction of 97 upper limbs in a consecutive series of 57 tetraplegic patients, treated from 1982 to 1990. Of these, 49 had functional and eight had cosmetic reconstructions. The principal functional objectives were to provide active elbow extension, hook grip, and key pinch.

Elbow extension was provided in 34 limbs, using deltoid-to-triceps transfer. Hook grip was provided in 58 limbs, mostly using extensor carpi radialis longus to flexor pollicis longus transfer, and key pinch in 68, mostly using brachioradialis to flexor pollicis longus transfer. Many other procedures were employed.

At an average follow-up of 37 months, 70% had good or excellent subjective results, and objective measurements of function compared favourably with other series. Revisions were required for 11 active transfers and three tenodeses, while complications included rupture of anastomoses and problems with thumb interphalangeal joint stabilisation and wound healing.

We report a reliable clinical method for differentiating between the activity of extensor carpi radialis longus and brevis and describe a successful new split flexor pollicis longus tenodesis for stabilising the thumb interphalangeal joint. Bilateral simultaneous surgery gave generally better results than did unilateral surgery.

Over the past few decades, reconstructive surgery of the upper limb for tetraplegia has become increasingly accepted and refined; the experience of the pioneers of this type of surgery has been reported (Moberg 1975; Zancolli 1975; Lamb and Chan 1983). We have reviewed the results in a large group of patients treated over an eight-year period.

PATIENTS AND METHODS

From 1982 to 1990, we treated surgically a total of 97 upper limbs in 57 tetraplegic patients at the Spinal Injuries Unit, Burwood Hospital, Christchurch, New Zealand. There were 51 males and six females, and the average age at first operation was 27 years (5 to 55). Most of the spinal injuries had resulted from motor-vehicle accidents or sport (Table I).

Patients were not considered for upper-limb surgery until at least one year after injury to ensure that they had reached their plateau of neurological recovery. Each was carefully assessed, often on more than one occasion, by a team which included two upper-limb surgeons, a paraplegist and a hand therapist. The assessment variables included muscle charts (MRC scale), joint mobility, spasm, sensation, motivation and functional requirements.

Table I. Cause of injury in 57 patients suffering tetraplegia

	Number
Motor-vehicle accidents	29
Rugby	17
Diving	6
Falls	3
Skiing	1
Violence	1

A retrospective review of muscle and sensation charts made it possible to classify 69 of the 84 hands that had had surgery (Table II) according to the international

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0301-620X/92/6475 $2.00
J Bone Joint Surg [Br] 1992; 74-B:873-9.

classification for surgery of the hand in tetraplegia (Appendix 1). Of the 34 patients who had been assessed before transfers to restore elbow extension, 26 were in grade 0, four in grade 1, two in grade 2, and in two the grade was not recorded.

It has been stated that it is not possible to determine the strength of extensor carpi radialis brevis (ECRB) without surgical exposure (McDowell, Moberg and House 1986), but we noted early in our series that when both extensor carpi radialis longus (ECRL) and ECRB were of grade 5 power, resisted wrist extension produced a palpable groove between the muscle bellies which was often clearly visible (Fig. 1). This clinical sign has been found to be totally reliable in assessing the availability of ECRL or ECRB for tendon transfer.

Table II. International classification (refer to Appendix 1) of 69 hands before operation

Classification	Number	Classification	Number
0 0	4	Cu 3	6
0 1	6	Cu 4	24
0 2	4	Cu 5	10
0 3	6	Cu 6	3
0 X	3	Cu X	3

Table III. Methods used to improve key-pinch grip

Method	Number
Motored transfers to flexor pollicis longus	
BR	36
PT	15
ECRL or ECRB	4
Flexor pollicus longus tenodesis direct	10
via Guyon's canal	3

Surgical objectives and methods. The main objectives of surgery were to restore elbow extension and provide a key-pinch grip and a hook grip. When possible, bilateral simultaneous surgery was carried out by two surgical teams.

Elbow extension was restored in 34 limbs in 19 patients, 15 patients having simultaneous bilateral surgery. The transfer of the posterior third of deltoid to triceps as described by Moberg (1975) was used, but tibialis anterior, rather than toe extensors, was used to provide the free tendon graft. After operation, elbows were immobilised in full extension in plaster cylinders for six weeks then actively mobilised, allowing an increase of 15° elbow flexion weekly.

Key pinch was provided in 68 limbs mainly by motored transfers, using brachioradialis (BR) or pronator teres (PT) (Table III). Tenodeses were used for 13 thumbs. More recently, we have rerouted flexor pollicis longus (FPL) tendon through Guyon's canal to increase its moment arm (Moberg 1987).

Effective key pinch requires stabilisation of the thumb interphalangeal (IP) joint, and initially this was attempted by arthrodesis using Kirschner wires or screws, but there was a high complication and failure rate. A new split-tenodesis technique was devised by one of the senior authors (SWS). The FPL tendon is split at the level of the thumb IP joint through a longitudinal volar incision. The lateral half of this tendon is then detached distally and passed subcutaneously to be sutured into the extensor tendon (EPL), which had been exposed via a longitudinal dorsal incision (Fig. 2). This operation equalises the pull on the volar and dorsal aspects of the IP joint, stabilising it during thumb flexion. The new procedure has been effective and free of complications in 47 patients.

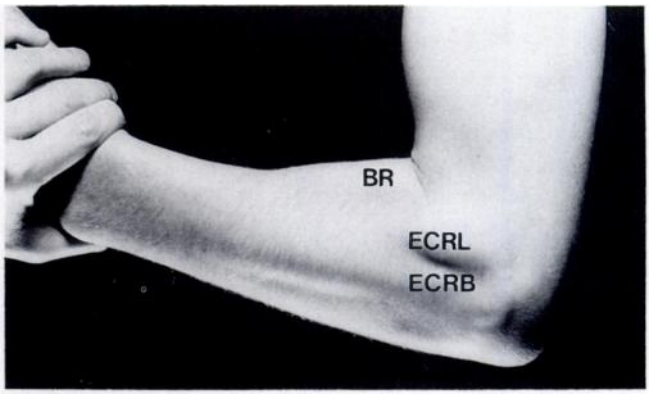

Fig. 1

ECRL and ECRB muscles can be evaluated individually at clinical examination, because they are separated by a groove during resisted wrist extension.

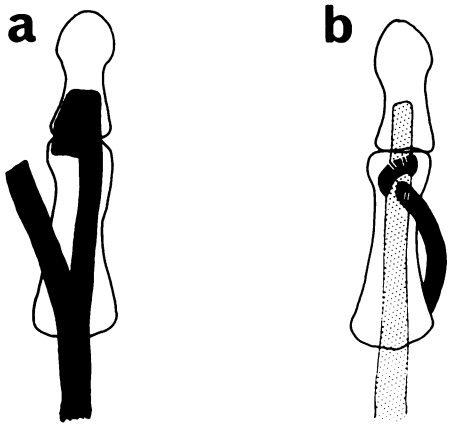

Fig. 2

The split-FPL tenodesis. The radial half of the tendon of FPL is detached (a) and rerouted to be sutured into EPL (b).

Hook grip was provided in 58 limbs mostly by transfers of either BR or ECRL, but in eight cases by flexor digitorum profundus tenodesis (Table IV). After forearm and hand transfers, patients' hands were immobilised in below-elbow casts for three weeks, then actively mobilised. Twenty-six patients had simultaneous bilateral functional reconstruction of their hands.

Other procedures which were used included tailored transfers for wrist extension, Zancolli lassos and various arthrodeses (Table V). The pattern of procedures varied according to motor level as shown in Table VI. All the operations were performed by the two senior authors (AGR and SWS).

Assessment of results. We obtained a subjective assessment by using a locally devised questionnaire (Appendix 2) concerning changes in mobility, dressing, washing and toileting, feeding and drinking, and other items. The first 25 questions were the same as those in the questionnaire of Lamb and Chan (1983), making it possible to compare results directly.

Objective assessment of key pinch was obtained by measuring strength with a Preston pinch meter (European Bissel Heathcare Ltd, Winchester, England) (Fig. 3). Hook-grip strength was measured by Swanson's technique, using a modified sphygmomanometer (Fig. 4), in most patients with the thumb included and then excluded from the grip, to determine the contribution of the thumb to overall grip strength. Strength of elbow extension was measured with the patient supine, using the MRC grading system (Fig. 5). If extensor lag was greater than 30°, the grade was reduced by one level.

Table IV. Methods used to improve hook grip

Method	Number
Motored transfers into finger flexors	
BR	23
ECRL	26
PT	1
Flexor digitorum profundus tenodesis	8

Table V. Other procedures used to improve hand function (excluding revision surgery)

Method	Number
Transfer/tenodesis for:	
wrist extension	13
finger extension	5
thumb extension	10
thumb abduction	3
Joint arthrodeses other than thumb IP joint	11
Zancolli lassos	30 digits (9 hands)
Metacarpal rotational osteotomies	2
Tenotomies	4
Tendon lengthening	4
Others	2

RESULTS

Subjective assessment. Subjective assessment was obtained for 86% of the patients, with an average follow-up of 37 months (5 to 86). Overall, 70% reported good or excellent results, 22% fair and 8% poor. The results are similar if the small group of patients who had cosmetic

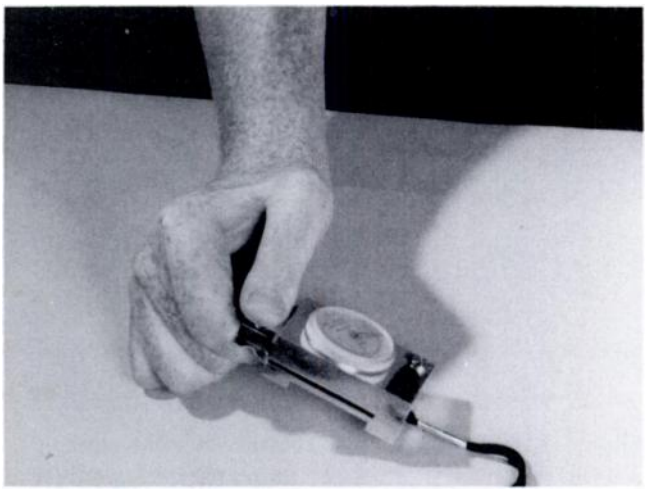

Fig. 3

Measuring key-pinch grip with a Preston pinch meter.

Table VI. Pattern of operations according to motor level

Motor group*	Goals	Common procedures
0 (spastic)	Cosmesis	Wrist arthrodeses
1	Key-pinch grip	BR to ECRL, FPL† tenodesis
2, 3	Key pinch with or without hook grip	BR to FPL with or without FDP tenodesis or BR to FDP and FPL tenodesis
4, 5, 6	Key-pinch grip and hook grip	BR or PT to FPL BR or ECRL to FDP
X (often spastic)	Variable selected goals and procedures	

*Appendix 1
†BR, brachioradialis; ECRL, extensor carpi radialis longus; FDP, flexor digitorum profundus; FPL, flexor pollicus longus; PT, pronator teres

procedures only are excluded. Interestingly, of those who had had bilateral simultaneous surgery for key-pinch grip and/or hook-grip strength 96% had good or excellent results (Table VII). Poor results in individual cases related to finger flexor tightness with difficulty in keeping the fingers out of the palm, to the thumb falling short of the index finger in key pinch, and to dissatisfaction with scars.

Table VII. Subjective results

Group	Number replying	Opinion (*per cent* of group)			
		Poor	Fair	Good	Excellent
All patients	49	*8*	*22*	*41*	*29*
Functional reconstructions	44	*9*	*18*	*41*	*32*
Bilateral functional hand surgery on the same day	24	*4*	*0*	*50*	*46*

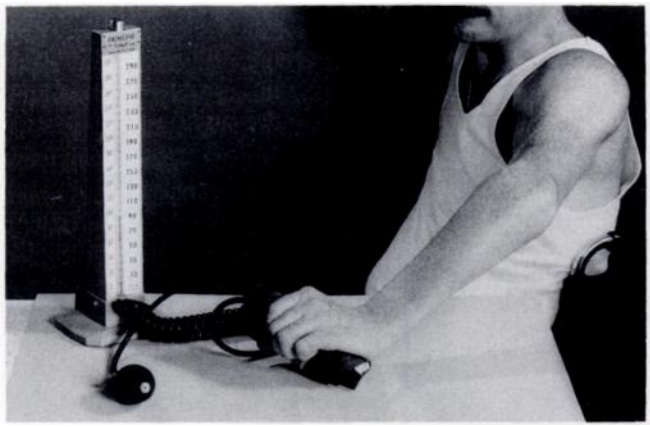

Fig. 4

Measuring grip strength with a sphygmomanometer, using Swanson's technique.

Objective assessment. Objective results were difficult to obtain: the spinal injuries unit serves patients throughout the country, and many of them did not attend the unit for follow-up within the study period. Results were obtained, however, for over 70% of the patients, with an average follow-up of 32 months. Key pinch was measured in 52 of the 68 cases (76%); the average strength was 2.1 kg. Hook grip was measured in 42 of 58 cases (72%); the average strength with the thumb included in the grip was 42 mmHg, and with the thumb excluded 29 mmHg.

Elbow-extension strength was measured in 71% of the patients (Table VIII) who had had deltoid-to-triceps transfers. Of these, 71% had gained grade 3 or 4 strength, but even those with grade 2 strength had a useful increase in hand function, and when sitting were able to control their hand at eye level or above.

Complications. Most of the complications related to the stabilisation of the thumb IP joint with screws or Kirschner wires (Table IX), and this problem has now been overcome by the use of the split-FPL tenodesis, which has been effective and free of complications in 47 cases. All four cases of wound infection resolved with antibiotics. Two wound haematomas required surgical evacuation. Four of the five ruptured anastomoses were successfully re-anastomosed, but the fifth patient declined treatment.

One patient had his PT to FPL transfer reversed, because he felt that the decreased pronation after transfer

Table VIII. Strength of elbow extension in 24 transfers

MRC grade	Number of limbs	*Percentage*
0 (ruptured anastomosis)	1	*4*
2	6	*25*
3	7	*29*
4 (1 kg)	10	*42*

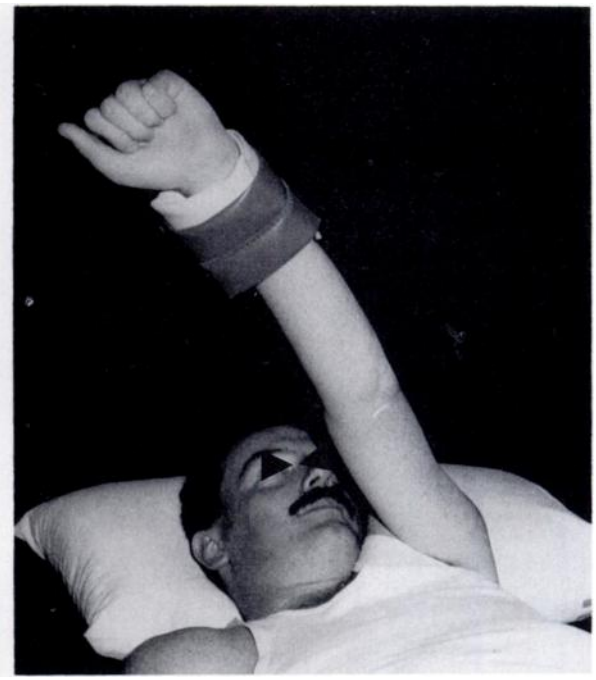

Fig. 5

Measuring the strength of elbow extension.

Table IX. Complications in the whole series

	Number
Relating to thumb IP stabilisation	11
Ruptured anastomoses	5
Wound infections	4
Wound necrosis	2
Haematoma	3
Atelectasis	1
Septicaemia	1

adversely affected his ability to propel his wheelchair. In his case, PT was anatomically reattached, and ECRL was transferred into FPL, with a good result.

DISCUSSION

It is extremely difficult to assess results after this type of surgery. The patients have a great variety of neurological deficits, even from limb to limb, and differing surgical and functional goals. Most have had multiple operations. The subjective results assess the patients' impressions of the overall results, not the individual procedures; objective results may correlate poorly with functional gains. We believe that many patients could have benefited from additional procedures, but, understandably, some were not prepared to persevere with further periods of hospitalisation, surgery and rehabilitation.

Table X. Objective measurements of function reported in other series

	Number of limbs	Measurement
		Key pinch (kg)
Freehafer, Vonhaam and Allen (1974)	4	0.5
House and Shannon (1985)	12	3.5
Ejeskär and Dahllöf (1988)	50	0.7
Gansel, Waters and Gellman (1990)	11	2.2
Vanden Berghe et al (1991)	14	0.7
Present series	52	2.1
		Hook grip (mmHg)
Gansel et al (1990)	11	21
Present series	42	29

It was encouraging that 84% of patients felt that surgery had improved their quality of life and that none had been made worse. Using only the first 25 items of the questionnaire and Lamb's scoring system, the subjective results in our 44 patients who had had functional reconstructions were similar to those in Lamb's 29 patients: 75% of our patients and 83% of Lamb's were graded as good or excellent (Lamb and Chan 1983).

Those who had had bilateral functional hand reconstructions had 96% good or excellent results, and all but three of these 29 patients had had simultaneous bilateral surgery. Those having bilateral surgery tended to have more muscles available for transfer, and their results suggest that simultaneous bilateral surgery should be used whenever possible. Simultaneous operations also have benefits in reducing the overall period of rehabilitation.

Our objective results compared favourably with those from other series (Table X). We found a significantly greater hook-grip strength after using ECRL as a motor (mean 41 mmHg) rather than BR (mean 21 mmHg) ($p < 0.005$, Student's t-test). We found no other statistically significant differences in strength between other techniques, but the numbers were small.

Lamb and Chan (1983) reported better results than ours for deltoid-to-triceps transfer, with 50% obtaining grade 5 power, but they do not comment on the position of the patient during muscle testing. We have found that assessing the patient in a supine position eliminates the contribution of the pectoral girdle muscles in raising the arm above the head, thereby giving a true measure of the strength of elbow extension. We do not believe that it is possible for any transfer to gain true grade 5 strength.

Others have reported problems with stabilising the IP joint of the thumb with Kirschner wires or screws (Lamb and Chan 1983; Vanden Berghe et al 1991). We recommend the use of our split-FPL tenodesis for thumb IP stabilisation: it is simple, effective, potentially reversible, and, in our series, free of complications.

To gain the best possible results, we stress the importance of a team approach through all phases of management, including assessment, surgery and rehabilitation.

Conclusions

1) Upper limb surgery can improve the quality of life of a tetraplegic patient.

2) The split-FPL tenodesis is simple and effective; it solves the problem of stabilising the IP joint of the thumb.

3) It is possible to evaluate reliably ECRL and ECRB by clinical examination.

4) There is no contra-indication to simultaneous bilateral surgery in the well-motivated patient; this decreases the overall period of rehabilitation.

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.

APPENDIX 1

The International Classification for surgery of the hand in tetraplegia

Sensibility	Motor group	Characteristics*
O = Ocular afferents only	0	No muscle below elbow available
Cu = Cutaneous sensibility two-point discrimination on the thumb tip to 1 cm	1	BR
	2	ECRL
	3	ECRB
	4	PT
	5	FCR†
	6	Finger extensors
	7	Thumb extensor
	8	Partial digital flexors
	9	Lacks only intrinsics
	X	Exceptions

*a muscle must be at least grade 4 strength on the MRC scale to be considered available for transfer
†FCR = flexor carpi radialis

APPENDIX 2

Assessment of activities of daily living and overall impressions of surgery in 49 patients after functional surgery of the upper limb, modified from Lamb and Chan (1983).

	Response (*percentage*)				
Activity	**Much worse**	**Worse**	**Unchanged**	**Improved**	**Greatly improved**
Mobility					
1 Raise yourself in seat		*2*	*65*	*27*	*6*
2 Propel wheelchair on level ground		*2*	*47*	*41*	*10*
3 Propel up and down a gentle slope			*45*	*31*	*24*
4 Transfer from wheelchair to bed			*70*	*14*	*16*
5 Drive a car			*49*	*33*	*18*
Dressing					
6 Upper garments			*45*	*43*	*12*
7 Lower garments			*67*	*21*	*12*
Communications					
8 Using a telephone		*2*	*39*	*43*	*16*
9 Writing or typing			*33*	*35*	*32*
10 Handling money		*2*	*35*	*41*	*22*
Washing and toileting					
11 Getting in and out of shower/bath			*65*	*16*	*19*
12 Washing and drying upper limbs			*41*	*47*	*12*
13 Washing and drying lower limbs			*71*	*23*	*6*
14 Cleaning teeth			*47*	*31*	*22*
15 Shaving or applying cosmetics			*45*	*31*	*24*
16 Brushing hair			*49*	*31*	*20*
17 Bladder: use of urodome or catheter		*2*	*78*	*10*	*10*
18 Bowel: inserting suppositories and cleaning after bowel action		*2*	*90*	*4*	*4*
Feeding and drinking					
19 Use of cutlery			*22*	*39*	*39*
20 Cutting meat		*2*	*51*	*22*	*25*
21 Holding a cup or glass		*4*	*28*	*37*	*31*
Miscellaneous					
22 Making a meal or snack			*43*	*24*	*33*
23 Reaching a shelf above		*4*	*43*	*27*	*26*
24 Opening and closing drawers		*4*	*37*	*41*	*18*
25 Operating buttons			*49*	*35*	*16*
26 Turning pages in book/newspapers		*2*	*33*	*39*	*26*
27 Picking up things from the floor	*2*		*41*	*26*	*31*
28 Using a key		*2*	*35*	*39*	*24*
29 Putting a plug into a point		*2*	*35*	*41*	*22*
30 Have your educational/vocational options changed		*2*	*48*	*28*	*12*
31 Were your overall expectations met	*2*	*8*	*43*	*27*	*20*
32 Have you become more independent		*2*	*22*	*41*	*35*
33 Has your self confidence changed		*2*	*33*	*47*	*18*
34 Has the surgery changed your quality of life			*16*	*57*	*27*
35 Any comments					

Points		Results	
Much worse = 0			
Worse = 1	Improved = 3	Poor 0 to 69	Good 85 to 101
Unchanged = 2	Greatly improved = 4	Fair 70 to 84	Excellent 102 to 136

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