SURGICAL RECONSTRUCTION OF THE UPPER LIMB IN TRAUMATIC TETRAPLEGIA

A REVIEW OF 41 PATIENTS

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A review is presented of 41 patients with traumatic tetraplegia on whom reconstructive surgery of the upper limb was carried out. Twelve patients were followed up for more than 10 years after operation and the average period overall was seven and a half years. Tendon transfers were made with the aim of providing extension of the elbow or restoring a useful grasp or a combination of both. The assessment was carried out on four main aspects: the function of the elbow, the function of the hand, the ability to carry out the activities of daily living and the effect of the surgical reconstruction on the personal and social achievement of the patient.

About 500 new spinal cord injuries occur annually in the United Kingdom (approximately one per 100 000 of the population). Nearly 60 per cent affect the cervical area (Lamb 1979) and many are now so well managed initially that there is a long life expectancy, similar to those with dorsolumbar injuries. The problem is world-wide and commonly affects young and healthy people.

Much has been achieved to help the paraplegic patient adjust to disability but, obviously, the tetraplegic patient has more of a problem. There has been a prevailing attitude against surgical reconstruction of the upper limb in tetraplegia and a review of some modern authoritative textbooks on spinal cord injury shows little reference to this sort of reconstruction (Guttmann 1973; Sutton 1973; Hardy and Rossier 1975).

Moberg (1978), and Hanson and Franklin (1976) have reported that as many as 75 per cent of tetraplegic patients would prefer restoration of function to the upper limb to that of any other function that they have lost.

MATERIAL AND METHODS

This paper reviews the results of operations on the upper limbs of 41 tetraplegics over a 20-year period (approximately one in five of those patients with cervical cord injuries seen and assessed by the senior author during that time). Thirty-eight patients were men and three were

women. Their ages ranged from 21 to 59 years and the average age was 29 years. Severe cervical flexion injuries from four types of injury had resulted in complete cord damage in all patients. The types of injury were as follows: traffic accident (21 patients); diving (10 patients); fall (seven patients); and sports injuries (three patients).

Classification

Classification based upon the vertebral level of injury is meaningless for planning of management and comparison of results. We believe that the loss of function in the upper limb and an assessment of the available muscle power are what matters. On this basis, patients can be divided into six groups (Table I). Groups 3 to 6 can be helped by operation.

Most patients fit into a characteristic pattern or group and therefore a plan of management can be formulated. The pattern is usually the same in each arm but in three patients it differed on the two sides. Moberg (1975) has emphasised that the presence of sensation in

Table I. Classification of 41 patients based on available muscle function (classification scheme by Lamb and Landry 1972)

Available muscle function	Number of patients
1. Shoulder shrug only	—
2. As in Group 1 plus shoulder abduction and elbow flexion	—
3. As in Group 2 plus wrist dorsiflexion, pronation and supination	17
4. As in Group 3 plus flexor carpi radialis	3
5. As in Group 4 plus elbow extension	16
6. As in Group 5 plus finger extension	5

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the hand is important before planning any operation; in fact, he places the same importance on this as on the muscle charting. All patients in this series underwent careful testing to assess their ability to feel light touch and pin-prick; these abilities were found to be present on the radial side of the hand in all 41 patients. The authors have not found two-point discrimination to be of any value in the assessment of patients before operation and consider it unnecessary to carry out any complicated grading by sensory assessment.

Operative procedures

Several operative procedures have been described for the tetraplegic including provision of a hook grip by flexor tenodesis (Street and Stambaugh 1959); reconstruction of a flexor-hinge hand by arthrodesis (Nickel, Perry and Garrett 1963) and more recently a key-grip by tenodesis of the flexor pollicis longus (Moberg 1975, 1978). However, most procedures have consisted of various types of tendon transfer (Lamb 1963; Zancolli 1968; Freehafer 1969; Lamb and Landry 1971, 1972; Maury, Guillaumat and François 1973; Curtis 1974; Freehafer, Vonhaam and Allen 1974; Zancolli 1975; House, Gwathmey and Lundsgaard 1976).

The patients in this series were treated by tendon transfers (with the alternative in recent years of tenodesis of flexor pollicis longus; Moberg 1975, 1978) and this paper reviews the indication, techniques and results of tendon transfers in this group.

Assessment before operation

In selecting patients we have adopted the following 10 guidelines. First, useful tendon transfer is unlikely in injuries above the fifth cervical segment. Secondly, spasticity has been found to be a clear contra-indication to successful tendon transfer. Fortunately it is rare in complete cord injuries, being much more evident in partial lesions. Thirdly, contractures of the upper limb joints should be prevented or, where they have developed, must be corrected first. Fourthly, tendon transfer is only indicated in a complete lesion which shows no improvement in muscle charting after a minimum of six months from injury or in an incomplete lesion where all progress has stopped. Fifthly, active dorsiflexion of the wrist is essential before successful tendon transfer to restore hand function can be considered. There is no place for arthrodesis of the wrist. Sixthly, the general principles regarding tendon transfer such as power, amplitude, direction of pull, supple joints and integrity of the muscle units must be strictly followed (Bunnell 1948). Seventhly, no procedures should compromise existing function. Eighthly, adequate sensation for function in the hand is needed. Ninthly, patients with painful paraesthesiae in the hands (an unusual situation) are usually unsuitable for reconstruction. And finally, the surgeon must assess that the patient is strongly motivated to gain greater independence, will be co-operative in a fairly prolonged

programme and does not expect too much improvement. We have found it very valuable to show patients who have had successful operations to those who are contemplating submitting to one.

Operative management

The main aims have been the restoration of active elbow extension and the provision of a grip.

Restoration of elbow extension. Transference of the posterior third of the deltoid to motor the triceps (Moberg 1975) was performed on 16 limbs in 10 patients. This converts the transferred portion of deltoid into a two-joint muscle but has caused no functional loss at the shoulder as perceived by the patient (Fig. 1). We have found the recommended post-operative regime to give satisfactory results. The elbow is immobilised in extension by plaster for six weeks and thereafter graduated flexion exercise is instituted with an increase of not more than 15 degrees per week over the first six weeks.

In one patient biceps to triceps transfer was done as advocated by Zancolli (1975) but proved unsuccessful.

Provision of a hand grip. The types of operative procedures and the number of patients they were used upon are summarised in Table II.

Table II. Operative procedure

Procedure	Hands	Patients
Extensor carpi radialis longus to flexor digitorum profundus; brachioradialis to flexor pollicis longus	45	31
Flexor pollicis longus tenodesis	7	6
Flexor pollicis longus tenodesis plus extensor carpi radialis longus to flexor digitorum profundus	5	4

Extensor carpi radialis longus to flexor digitorum profundus. This is a synergistic transfer in which dorsiflexion of the wrist potentiates the effects of the transfer. The amplitude of excursion provides strong flexion of the fingers fully into the palm (Fig. 2).

Brachioradialis to flexor pollicis longus. Brachioradialis has sufficient amplitude to flex the thumb provided it is freed fully from its deep fascial attachments up to its musculotendinous junction. It needs the opposing action of elbow extension to be fully effective. Hence when the elbow extension is lacking this should be restored by deltoid transfer before operating on the hand.

The aim of these transfers is to provide mass finger flexion for grasp, and independent thumb flexion for key-pinch against the side of the middle phalanx of the index finger (Fig. 3), a type of prehension commonly adopted spontaneously in some types of paralytic hand. Details of the operative technique have been previously described (Lamb and Landry 1972). However, it is important to emphasise here the adjustment of tension in these transfers. As most grasping is done from a wheel-chair

Fig. 1

Fig. 2

Figure 1—Active elbow extension enables the patient to put objects on a shelf.

Figure 2—Hand grip after tendon transfer.

Figure 3—The provision of a key-pinch allows the patient to pick up large and small objects with good visual control.

Fig. 3

with the elbow flexed about 45 degrees, this should be the position of the elbow when the transfer is carried out. The tension on the operating table is such that when the wrist is flexed, the finger and thumb joints are fully extended; and when the wrist is fully dorsiflexed, the fingers are semiflexed and the thumb pulp approximates the side of the middle phalanx of the index in the key-pinch position. The wrist is immobilised in a neutral position for three weeks, but during this period passive movement of the digits is allowed. Active movement of the digits usually improves slowly over a period, reaching its zenith between three and six months after operation.

Flexor pollicis longus tenodesis. Since 1974 the Moberg procedure in reconstructing lateral pinch (key-pinch) of the thumb has been performed on seven hands in six patients. First, flexor pollicis longus is tenodesed to the volar surface of the radius so that when the wrist is actively dorsiflexed the thumb opposes the radial side of the index finger to give a strong key-pinch. Then, the interphalangeal joint of the thumb is stabilised by passing a strong Kirschner wire across it in the extended position. A threaded wire is more secure but less easy to insert. Stabilisation of the joint by a polypropylene peg has proved most effective in two patients recently.

Flexor pollicis longus tenodesis plus extensor carpi radialis longus to flexor digitorum profundus. In five hands the Moberg procedure was performed together with the

transfer of the radial carpal extensor to the finger flexors. **Other procedures.** In the early period of the series, the provision of a thumb pulp to finger-tip pinch, in the absence of functioning thenar muscles, was attempted in 18 hands by the following procedures (Lamb and Landry 1971, 1972). First, by using the superficial tendon of the ring finger in a standard method of opponensplasty (Bunnell 1948) but as a passive tenodesis only (seven times). This usually stretched and became ineffective. Secondly, by dividing extensor pollicis brevis at its musculotendinous junction and transposing it subcutaneously across to the pisiform and suturing it to extensor carpi ulnaris (twice). Thirdly, by a standard opponensplasty of the paralysed superficial tendon of the ring finger followed by transfer of the flexor carpi radialis into superficialis as motor (six times). This worked very effectively. Fourthly, by extensor digiti minimi transferred to abductor pollicis brevis (once). Finally by flexor carpi radialis elongated with palmaris longus or plantaris tendon as a primary opponensplasty (twice).

These procedures were performed at a time when it was thought to be important to restore pulp-to-pulp prehension between thumb and finger. It became clear that this was too ambitious in all but the lower cervical lesions and it was decided to concentrate on a side-pinch between thumb and index finger. Moberg was independently working to the same goal but achieving this in a different manner.

RESULTS

In this retrospective survey, the average follow-up period after operation was seven years and five months and the range was from six months to 25 years. Twelve patients (30 per cent) have been followed for more than 10 years.

Of the 41 patients, four have died, three live abroad and five were not available for interview and evaluation. These 12 patients were assessed from their case records. All other patients were evaluated in four main aspects by two assessors who had not been involved in the operative management; the aspects were elbow function, hand function, activities of daily living, and personal and social achievement.

Elbow function. Active elbow extension against gravity was restored in all patients, and in 10 elbows this restoration was full. In two elbows a flexion contracture of 20 degrees, present before operation but corrected conservatively, had recurred. In four elbows there was an extension lag of 15 degrees which did not affect the function of the arm. The power of elbow extension as assessed by the MRC scale is shown in Table III. All patients with power of Grade 4 or above were able to lift a five pound weight above their heads and put the weight on a shelf above (Fig. 1).

Table III. Power of elbow extension as assessed by the MRC scale

Triceps power	Number of elbows	Number of patients
Grade 5	8	5
Grade 4	5	3
Grade 3	3	2
Total	16	10

All 10 patients considered the operative procedure beneficial. The main advantages described were: the ability to raise the body from the wheel-chair (this is helpful in preventing pressure sores); the increased ability to steady the body in a chair or bed when eating and working; the increase in power available for propelling the wheel-chair; the ability to reach a shelf above the head without fear of buckling of the elbow (Fig. 1). Most patients valued the improvement of the elbow more than that of the hand grip. After one side was operated on, they usually asked for operation on the other side.

One patient, despite a disappointing result to the surgeon of a Grade 3 transfer bilaterally found a definite improvement when the elbows were stabilised. This was the only patient who failed to regain power 4+ or 5 of elbow extension. Constant review is necessary and one patient, who was poorly motivated and lacked proper supervision after leaving hospital, lost extension power and developed a flexion contracture. Further in-patient

physiotherapy restored useful function and this has been maintained.

Hand function. A late review of hand function was only possible in 27 patients. Of these there were 48 hands upon which operations had been carried out. In the remaining six hands there had been no operation for various reasons.

Hand function was assessed by the tests and scoring system detailed in Appendix I. It will be seen (Table IV) that the points assessment system graded more than two thirds as excellent or good and nearly one-quarter as fair.

Table IV. Results of functional testing of 48 hands

Grade*	Number of hands	Operated hands assessed (per cent)
Excellent	5	10
Good	28	58
Fair	11	23
Poor	4	9

* See Appendix I for the tests and scoring system used.

The two patients (four hands), with poor results were treated early in the series and made encouraging improvement in the initial stages. Both became dependent on an institutional setting, and at the time of the review, some 15 years after operation, their hand function was barely improved. Both did not regret undergoing operation and claimed that there was no deterioration from their original status. The six untreated hands had scores of less than 50 points, and there was a marked functional difference between the two sides. The patients all recognised the tremendous improvement, but for personal and domestic reasons declined to have an operation on their other hand.

The hand function of the patients who were not available for assessment was reviewed from the case records. A different set of parameters had been used after operation and the results were therefore not directly comparable to the present hand score. But they all demonstrated a significant improvement after the operative procedures, both subjectively and objectively.

In no patient was there any impairment of hand function after operation. Invariably the better motivated patients made significant use of the improved function to regain independence in various daily activities. Those who pursued higher education found the improved key-pinch particularly helpful in writing and typewriting with an adapted stick.

Activities of daily living. Twenty-nine patients were available for assessment of activities of daily living. The results were graded (Table V) using tests and a scoring system shown in Appendix II. None of the patients considered that their functional capability had in any

way deteriorated after operation. The majority claimed a most significant improvement in basic activities such as washing, eating and using the toilet. This resulted from an ability to hold glasses and cups (Fig. 4), to wash limbs and to brush hair, to turn on taps, and to improve bladder compression and insertion of suppositories. The change from complete reliance on others to self-care was certainly a great psychological achievement. Patients were more mobile: their ability to propel a wheel-chair was improved and seven patients became able to drive a car. Better ability to use a telephone and a typewriter were distinct advantages (Fig. 5). There was a significant correlation between the results of the testing of hand function and the testing of activities of daily living.

Table V. Results of testing of activities of daily living in 29 patients

Grade*	Number of patients	Percentage
Excellent	7	24
Good	17	59
Fair	5	17
Poor	0	0

*See Appendix II for the tests and scoring system used

Fig. 4

Showing a strong grip of a full cup.

Fig. 5

Use of a telephone.

In those patients not available for interview, the assessment of activities of daily living was made from their records. At varying intervals from four months to five years after the operation a similar assessment had been made by occupational therapists. The significant finding was that, as with the interviewed group, in the majority there was a recognition of substantial improvement in self-care. In no single case was any specific loss of function reported.

Personal and social achievement. The improvement in upper limb function facilitated the development of personal interests, hobbies and sports activities such as knitting, drawing, table-tennis and archery. One of our patients became a fishing champion. Three patients continued to pursue studies. Eight went back to employment while three were actively engaged in voluntary work such as the Citizens Advice Bureau and the Handicapped Sports Club.

DISCUSSION

Various surgical methods have been described to improve the hand grip of patients with tetraplegia. A two-stage procedure to restore flexion and extension of the fingers was advocated by Lipscomb, Elkins and Henderson (1958). Zancolli reported that three-quarters of his 97 patients had partial or complete survival of the sixth cervical segment and he also recommended a two-stage procedure, first restoring extension and then flexion of the digits (Zancolli 1968, 1975).

However, in reconstruction of the tetraplegic hand, simplicity is most desirable (Lamb and Landry 1972; Moberg 1978). With limited motor units available for transfer, we believe it is too ambitious to restore both flexion and extension of the digits.

In previous reports (Lamb 1963; Lamb and Landry 1971, 1972) we have concentrated on the provision of grasp by tendon transfer and release by dropping the wrist. This regime has been shown in our review to give consistent improvement in prehension. The key-pinch of thumb to side of the index finger (Fig. 3) is usually stronger and more useful than the three-point pulp pinch. In addition the patient can more readily see what is being held and this gives a much better feedback proprioception. The significance of this aspect has also been emphasised by Moberg (1975, 1978).

A difficulty which may develop after this procedure is that the thumb may flex into the palm prematurely when the wrist is dorsiflexed thus obstructing the finger flexion. This can be overcome by learning to hold the thumb out against the side of a table or chair while the fingers are being flexed, then bringing the thumb against the side of the index finger. On four occasions, because the thumb flexed excessively, arthrodesis of the metacarpophalangeal joint or interphalangeal joint was found useful. These and other complications after surgery in this series are listed in Table VI. Moberg's (1978) procedure on the thumb obviates this problem.

Table VI. Complications

Complications	Number of cases	Management
<i>Early</i>		
Overactive brachioradialis to flexor pollicis longus transfer leading to hyperflexion of metacarpophalangeal joint of thumb	2	Stabilisation of metacarpophalangeal joint with Kirschner-wire and plication and shortening of extensor pollicis longus
Stretching of tendon transfer	1	Exploration and resuturing
Adherence of tendon transfer	1	Tenolysis
Local abscess	1	Incision and drainage
Hyperflexion at interphalangeal joint of thumb	1	Arthrodesis of interphalangeal joint
Pin loosening and protrusion in Moberg's stabilisation of thumb	1	Kirschner-wire stabilisation of joint
Pin loosening and protrusion in Moberg's stabilisation of thumb	2	Re-insertion with threaded Kirschner-wire
Pin track infection	1	Removal of Kirschner-wire
<i>Late</i>		
Weakened dorsiflexion of wrist following transfer of extensor carpi radialis longus (still more than power 3)	6	Transfer of brachioradialis to reinforce extensor carpi radialis brevis in one patient with particular weakness
Flexion contracture of fingers with incomplete straightening of the interphalangeal joints on flexing the wrist	6 (moderate) 4 (severe)	Corrected by splintage and physiotherapy
Flexion contracture of elbow recurring after deltoid and triceps transfer	1	Serial splintage and physiotherapy

In our experience of seven hands in which the Moberg procedure of stabilising the thumb was combined with our usual tendon transfer to restore finger flexion, the results were good. The occasional complication with the stabilising pin as reported by Smith (1981) can usually be solved with a threaded Kirschner wire. The recent use of a polypropylene peg to stabilise the interphalangeal joint of the thumb has given encouraging results.

A detailed assessment of hand function in tetraplegic patients after operation has not been described in most published series. While recognising the difficulty in designing a suitable protocol, we feel that some kind of objective testing would be useful in comparing results. The hand score adopted in this review was an attempt to quantify the myriads of variables in hand function. Ideally the same tests should be performed before and after operation and it is our intention to do this in the future. The assessment must be interpreted in the light of the opinion of both patient and surgeon. In our review there is a close similarity between the objective examination by the assessor and the opinions of the surgeon and the patient.

There is no doubt that provision of a useful key-grip and active finger-flexion facilitates gripping (Figs 2 and 3), turning keys and carrying objects with a handle. The provision of bimanual hand function is of great benefit (Fig. 6). However, regular supervision is necessary to guard against the development of late contractures of the interphalangeal joints. Of the 27 patients reviewed, 11 had some degree of contracture of the fingers, although

not sufficient to affect function. Such a complication might jeopardise the excellent function gained initially after operation and requires regular stretching to keep the joints supple in the absence of active extension. Supervision by a physiotherapist is helpful although difficult to arrange. Late contractures are probably due to the lack of proprioception and antagonists, and their prevention is just as important as the reconstruction.

Some weakness of wrist dorsiflexion became apparent after tendon transfer in four patients with moderate

Fig. 6

Bimanual dexterity is much improved after reconstruction. On the right thumb, tendon transfers have been made. On the left thumb, Moberg tenodesis and stabilisation of the interphalangeal joint have been effected. Tendon transfers to restore finger flexion are present on both sides.

impairment to the overall hand function. It is difficult to differentiate between extensor carpi radialis longus and extensor carpi radialis brevis on clinical examination and if their power is in doubt, Moberg's test of exposing the tendons under local anaesthesia and measuring the strength of each muscle by attachment of a cord and weights should be employed (Moberg 1978). No patient suffered any sensory impairment after operation, and in assessment the two-point discrimination test with a paper clip was between 4 and 15 millimetres (average nine millimetres).

The prospect of useful function being restored must

not be exaggerated before operation. It is helpful for patients to see those who have undergone successful operation.

Usually we have requests for operation as a result of direct referral from other patients, and the best indicator of satisfaction with procedures is that most patients request further surgery.

As Bunnell stated: "To the patient who has nothing initially, a little becomes a lot". Reconstructive surgery on the upper limbs of young patients with traumatic tetraplegia is a most interesting, demanding and yet at the same time rewarding work.

APPENDICES

Appendix I. Score sheet and grading system for the assessment of hand function

Test	Score	Test	Score
<i>Grasp</i>	<i>Right Left</i>	<i>Right Left</i>	
1. Block, 3-inch		16. Oblong, 4-pound	
2. Block, 2-inch		<i>Pinch</i>	
<i>Cylindrical grasp</i>		17. Ball, 2-inch	
3. Pipe, ¾-inch		18. Index finger with thumb	
4. Pipe, 1½-inch		19. Middle finger with thumb	
<i>Lifting 2-inch cylinder</i>		20. Pick up a pin	
5. Weight, 1-pound		<i>Hook grip</i>	
6. Weight, 2-pound		21. Lift bucket, weight of 2 pounds	
7. Weight, 4-pound		22. Lift bucket, weight of 10 pounds	
8. Weight, 8-pound		<i>Ligament grip</i>	
9. Weight, 10-pound		23. Turn a mortise key	
<i>Key-grip</i>		<i>Bimanual dexterity</i>	
10. Circle, 1-inch		24. Assemble 1-inch nut and bolt	
11. Circle, 2-inch		25. Unscrew 2-inch jar lid	
12. Circle, 3-inch		<i>Total score =</i>	
13. Circle, 4-inch			
14. Oblong, 1-pound			
15. Oblong, 2-pound			
Criteria	Score	Points	Grade
Performs the test with no difficulty	4	> 90	Excellent
Performs the test slowly	3	70-89	Good
Completes the test but takes an abnormally long time or has great difficulty	2	50-69	Fair
Performs the test partially	1	< 50	Poor
Cannot perform the test	0		

Appendix II. Score sheet and grading system for the assessment of a score for activities of daily living

Activity	Score	Activity	Score
<i>Mobility</i>		12. Washing and drying upper limbs	
Use of wheel-chair, hand driven or electric		13. Washing and drying lower limbs	
1. Raise self in seat		14. Clean teeth	
2. Propelling on level ground		15. Shaving or applying make-up	
3. Propelling up and down a gentle slope		16. Brush hair	
4. Transfer from wheel-chair to bed		17. Bladder	
5. Ability to drive a car		18. Bowel	
<i>Dressing</i>		<i>Feeding and drinking</i>	
6. Upper garment		19. Use of cutlery	
7. Lower garment		20. Cut meat	
<i>Communication</i>		21. Hold cup or glass	
8. Using a telephone		<i>Miscellaneous</i>	
9. Writing or typing		22. Making meal or a snack	
10. Handling money		23. Reaching a shelf above	
<i>Washing and toilet</i>		24. Opening and closing drawers	
11. Getting in and out of a bath		25. Operating button (e.g. on a television)	
		<i>Total score =</i>	
Criteria	Score	Points	Grade
Improved	4	> 90	Excellent
Unchanged	2	70-89	Good
Worse	0	50-69	Fair
		< 50	Poor

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