THE HAND IN QUADRIPLEGIA

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INJURIES of the cervical region with damage to the spinal cord occur frequently in young people. There may be an over-all increase in the frequency of these injuries and many, which would have had a fatal outcome a few years ago, are now so well managed initially that the patient survives and may have a long life expectancy. There can be few conditions which cause such complete and sudden severe disablement in a young healthy individual.

Whereas a great deal has been done in the past 25 years to help the paraplegic to adjust to his disability and to regain a useful place in society, this is largely possible because of the normal upper limb function. The patient with cervical cord involvement will have a varying degree of upper limb function ranging from the very high lesion with only some limited shoulder motion to the lower cervical lesion where only intrinsic hand function is impaired.

In all of these patients some help can be provided with the aim of making the patient more self-sufficient and independent and, where possible, of returning to the home.

In a small number of these surgery may offer a way of improving hand function to further the goal of independence and this paper describes the results of the transfer of tendons in a group of young quadriplegics. In the majority there was no finger or thumb function and the aim was to provide some grasp prehension.

It is appreciated that the management of the upper limbs is only a small part in the total care of the patient by all members of the team in the spinal unit.

It is, however, of vital importance to obtain all possible independence for the quadriplegic and while there are many ways of trying to achieve this, *e.g.* use of the mouth, simple aids improvised by the intelligent occupational therapist and complicated electronic devices, there is a small number where surgery, and, in particular, tendon transfer, can prove of value.

It is the authors' belief that many patients are denied this unnecessarily.

In the early management of the patient with cervical cord damage an accurate assessment of muscle power, graded according to Medical Research Council standards must be made and repeated at monthly intervals. It has been the authors experience in a series of 113 patients over the past 12 years that any muscle which has no function both at first examination and one month later will show no recovery. On the other hand, a muscle with a flicker of voluntary movement at these early examinations may recover very dramatically and progressively over 12 or 18 months. Having this basis of remaining muscle power as a guide the surgeon can assess the functional capabilities of the upper limbs and plan his overall management.

The average wheelchair-bound quadriplegic wishes to perform daily activities such as:

Washing, shaving and similar functions;
Dressing and undressing;
Toilet.

In order to do this some sort of prehension is required backed up by movement of the elbow, at least of flexion, and some stability at the shoulder and wrist. There are varying ways in which this upper limb function may be simulated or provided (Garrett *et al.*, 1964; Lamb, 1963).

1. Help from someone else. In the authors' opinion this way out of the problem is too often accepted by the patient and may preclude entirely permanent return to the home.

2. Splints, gadgets and aids. There is no doubt that much benefit can be provided by splints. Many of these must be powered to flex elbow or dorsi-flex wrist and to control a hand splint for thumb to fingertip prehension (Nickel *et al.*, 1963). The patient who is severely disabled by gross weakness of both upper limbs will often tolerate such splintage because of the functional benefit, but the application and the removal of the apparatus may be beyond the individual or his relatives at home and in the authors' experience the benefits obtained in a hospital environment are seldom enjoyed at home to the same extent. Much benefit in hand function can also be obtained by strapping, or otherwise fixing to the hand, knives, forks, spoons, pens, etc. However, surely if the patient's own hand can be provided with prehension this must be better and there is no doubt that in some patients this can be possible surgically.

3. Surgery. This has a limited but very valuable place in the management of the quadriplegic hand. In the authors' opinion many patients have been denied the possible benefits of such surgical procedures by the ignorance of their medical advisers who have often been adversely influenced by the bad results of ill-advised and poorly performed operations. While tenodesis (Wilson, 1956; Street and Stambaugh, 1959); surgical construction of the flexor hinge hand (Nickel *et al.*, 1963); nerve transfers or grafts may very occasionally have their place, tendon transfers are the main procedures available (Boyes and Bunnel, 1964; Brand, 1958; Freehafer, 1969; Lamb, 1963; Lipscomb *et al.*, 1958; Phalen and Miller, 1947; White, 1960; and Zancolli, 1969). The authors stress that these have only been performed in a small percentage of cases of cervical cord injury (25 out of 113 cases) and that there are sound contra-indications.

1. No useful transfer of tendons is possible in injuries above the fifth cervical segment.

2. No transfer of tendons is usually necessary in injuries below the eighth cervical segment.

3. No transfer is indicated in complete lesions showing no change in muscle charting in under 6 months from injury or in incomplete lesions until at least 2 years from injury.

4. Tendon transfers are contra-indicated in the presence of spasticity, which is more frequent in partial than complete injuries.

5. Active dorsi-flexion of the wrist is essential before tendon transfer is carried out. There is no place for arthrodesis of the wrist in this condition.

6. The rules of successful tendon transfer laid down by Mayer (1916); Boyes and Bunnell (1964); Bunnell (1948); Steindler (1939), and others regarding power, amplitude, direction of pull, supple joints and integrity of the muscle unit must be strictly followed.

7. Satisfactory sensation in the hand is needed.

If these precautions are taken the results can be very gratifying and no patient in this series has been made worse or has sacrificed any function by these procedures. The results of 25 patients in whom 72 tendon transfers have been carried out are reviewed in this paper (Table I). All operations were performed by one

TABLE I

1958-1969

Number of cervical cord injuries	113
Number of patients having surgery	25
Number of operations	52
Number of tendon transfers	72

surgeon (D. W. L.). Of the 25 patients who underwent surgery 22 were available for follow-up. 1 lives abroad and 2 had died. These 3 were assessed on reports in case-notes. All patients were evaluated by one author (R. M. L.). The patient's opinion was the single most important factor in determining the result. Patients were not listed as improved if they did not feel that they had gained benefit from surgery. The results were assessed in two categories, *i.e.* surgical and functional. The former was assessed at follow-up by the examiner, the latter by patient and examiner, and supplemented by assessment in activities of daily living by the occupational therapist both before and after operation. In most patients there was loss of finger and thumb flexion and extension and of opposition. In a few instances there was only loss of intrinsic thenar and finger function. In all cases operation was carried out to try and provide grasp prehension.

It is useless to classify patients into certain groups according to the apparent anatomical levels of cord damage. What matters is which muscles are still active and a knowledge of the function which has been lost, *e.g.* elbow flexion, wrist dorsi-flexion, finger flexion, etc. A careful assessment should be made in each patient and all muscles available for transfer tabulated and matched against the desired functional restoration.

On the basis of available muscle power we have divided the patients into 7 groups (Table II). It is stressed that a monthly charting of muscle power is

TABLE II

Classification of Cervical Cord Injuries

Groups based on available muscle power

1. Shoulder shrug.
2. As Group 1 plus shoulder abduction and elbow flexion.
3. As Group 2 plus pronation/supination, wrist dorsi-flexion.
4. As Group 3 plus F.C.R. (Lipscomb).
5. As Group 4 plus elbow extension.
6. As Group 5 plus finger extension.
7. Loss of intrinsic function only.

carried out, and under no circumstances would surgery be carried out under 6 months from injury. On the other hand, there is definite disadvantage in delaying too long, and a patient will decline operation if it interferes with a return to home.

During the period following injury it is essential that paralysed muscles and inactive joints are not allowed to develop deformities and contractures.

Careful positioning of the fingers and thumbs, especially with the thumb abducted and the metacarpo-phalangeal joints flexed, is essential. Regular gentle passive movements of all joints incapable of active motion is necessary.

While an attempt has been made to fit each patient into a group depending on the function retained, as was also done by Garrett *et al.* (1964), it is realised that there is some overlap and not all cases fit into a neat pattern. While most patients have a similar neurological level in both arms this is also not always the case. Most patients do, however, fit into a characteristic pattern or group and by an early assessment and understanding of this a basis for management is obtained.

MANAGEMENT

Groups 1 and 2

Surgery has nothing to offer.

Electronic aids and power assisted splints and appliances have most to offer here.

Group 3 (13 cases—11 improved, 2 not improved)

A wrist driven flexor hinge splint (Nickel *et al.*, 1963) has been used in many of these patients but its long term use has been disappointing as most patients discard the splint after going home. Nickel has described the surgical construction of the flexor hinge hand but this is a difficult procedure and in the authors' opinion is only indicated in the hand which has developed incorrectible deformity and contracture as a result of lack of care in the early phase of management. It is in this type of case that Wilson (1956) described a flexor tenodesis but in the one case seen by the authors where this had been performed the result was a useless hood hand.

In the authors' experience a much more valuable procedure is to potentiate the natural tenodesing effect of the long flexors when the wrist is dorsi-flexed by transference of one of the radial carpal extensors to the deep digital flexors. This has been performed on 33 occasions (Table III). The extensor carpi radialis

TABLE III

Transfers performed

Group 3 (13 patients)	Group 4, 5, 6 (6 patients)	Group 7 (6 patients)
E.C.R.L.→F.D.P.	E.C.R.L.→F.D.P.	Opponensplasty
B.R.→F.P.L.	B.R.→F.P.L.	
	F.C.R.→Opposition	

brevis has been left to dorsi-flex the wrist, a most essential function. The extensor carpi radialis longus has been transferred to the flexor profundus and brachio-radialis to flexor pollicis longus. In the first 11 cases the transfer was taken through a large window cut in the interosseus membrane above the pronator quadratus in order to get a straight line of pull. It is necessary to mobilise both muscles well up the forearm and, in particular, the brachio-radialis, to obtain sufficient amplitude. Both muscles have a high neuro-vascular supply and high

mobilisation is safe. It was found, however, that this proximal mobilising allowed the muscles to be transferred round the radial side of the forearm without difficulty and giving a satisfactory line of pull, and this has been the procedure in the last 10 cases. The object of providing strong finger flexion has been uniformly successful regardless of route.

In the early cases, in order to diminish the danger of adhesion of the transferred tendon in the interosseus membrane early passive movement of fingers was allowed. Normally after tendon transfer a period of 3 weeks immobilisation is practised but in these cases this deliberate policy of early movement with risk of the suture line pulling away was employed, without apparent loss of power. The most important point in the operative technique is the tension at which the transfers are sutured. This must be estimated very carefully so that in full dorsi-flexion of the wrist the fingers are flexed into the palm and in palmar flexion of the wrist the fingers extend.

It is essential that when the wrist drops into palmar flexion the fingers open widely to allow release of any object. Any persistence of fixed flexion of the fingers with the wrist flexed will harm the patient and means that the transfer is too tight. This is particularly likely to happen if there is any spasticity and this is why surgery should be absolutely avoided in any case where the paralysis is not usually flaccid.

By these transfers strong finger flexion has been obtained. Very satisfactory flexion of the I-P joint of thumb is also obtained (in 2 cases this has gradually become less effective due to stretching at the suture line). There is usually an effective and strong side pinch prehension against the index finger. In the hope of providing thumb to fingertip pinch, and in the absence of any suitable motor for tendon transfer, an attempt has been made to provide an opposition tenodesis so that when the wrist is dorsi-flexed for grasp the thumb is pulled round. This has been done in one of two ways:

1. By using the ring finger sublimis in a standard method of opponensplasty (Bunnell, 1948) but as a tenodesis only (7 times).
2. Dividing extensor pollicis brevis at its musculo-tendinous junction and transporting it subcutaneously across to the pisiform and suturing it to extensor carpi ulnaris (twice).

Both these methods have initially been promising but have gradually lost their effect and it is our belief that it is better to teach the patient to get a good pinch to side of index.

Group 4

This is the group described by Lipscomb and associates (1958) who utilised a two-stage operation to try and provide both flexion and extension of digits. While the authors have utilised this method it has not proved as successful as the procedure described in Group 3. Accordingly, in this Group, where the flexor carpi radialis is active, we have concentrated on providing active digital flexion by tendon transfer and producing passive extension of digits to release grasp by wrist flexion.

The loss of active wrist flexion has not been found to be a disadvantage to the patient and the flexor carpi radialis has, therefore, been used as a motor, elongated by a free graft, to provide opposition. In two patients a standard opponensplasty of ring sublimis followed by transfer of flexor carpi radialis into the paralysed sublimis has worked satisfactorily.

Groups 5 and 6 (5 cases—all improved)

The same procedures are carried out as in Group 4. In Group 5 the presence of active elbow extension is of great functional benefit and enhances immeasurably the over-all function of the upper limb. In those cases, (Group 6), where finger extension is also present, the results of tendon transfer to restore flexion of fingers and thumb are the most satisfactory.

Group 7 (6 cases—6 improved)

In the low cervical injuries the patient has normal elbow and wrist control. There is normal flexion and extension of the digits but the intrinsic muscles are paralysed. It is very seldom that a claw hand deformity, such as is seen in leprosy, will develop but should it do so the procedure described by Brand (1958) would be applicable. In most cases the main loss of function is the lack of abduction/opposition of the thumb due to thenar paralysis and a standard opponensplasty (Bunnell, 1948) will provide excellent improvement in hand function.

It is appreciated that the function following these methods of tendon transfer in Groups 3, 4, 5 and 6 can never approach the normal. In the absence of a suitable number of motors for transfer to provide complete movement it is felt that the restoration of flexion power of fingers and thumb for grasp is the essential and release of grip is provided passively by dropping the wrist (except in Group 6 where there is some active digital extension).

No patient has regretted having surgery. The objectives are made clear and it is most important that the patient does not expect too much. As is not infrequent in surgery, the benefits were often most apparent in the more intelligent patient. All patients who had one side operated requested that the other be done. After success had been obtained in the first few patients subsequent patients in the spinal centre came requesting operation.

There were no complications from surgery, and of particular value in a patient susceptible to chest infections, who had possibly had a tracheostomy and also probably a cervical spine stabilisation, was the routine use of Biers intravenous regional anaesthesia.

While the results of surgery are progressively better from Group 3 downwards and are particularly valuable in Groups 6 and 7, it is felt that even in Group 3 the results have been worthwhile (Table IV). As Bunnell has stated, 'When one has nothing, a little is a lot!'.

TABLE IV

Results

Group 3		Group 4, 5, 6		Group 7	
11	improved	5	improved	6	improved
2	unimproved	1	unimproved	0	unimproved
0	made worse	0	made worse	0	made worse
13	Total	6	Total	6	Total

A movie, showing the upper limb function of many of the patients both before and after surgery, has been prepared and a composite film illustrative of 4 patients was shown to illustrate the paper. The clinical details of these patients are summarised overleaf.

Case 1. A. M. (aged 30). Dislocation of C5 vertebra on C6 as a result of motor accident. Patient presented as an example of Group 3. Operation on the left hand carried out on 30.9.65, 5 years after injury. Operative procedure: Brachio-radialis transferred to flexor pollicis longus and extensor carpi radialis longus to flexor digitorum profundus. These tendon transfers were taken through the interosseus membrane. An opposition tenodesis using the ring finger sublimis was performed at the same time.

The film was taken 1 year post operatively showing excellent powerful flexion of fingers and thumb. The opposition tenodesis was not a success. Full passive extension of the digits was obtained to release grasp by dropping the wrist. Many activities of daily living showed a significant and worthwhile functional improvement following the tendon transfer.

Case 2. R. H. (aged 20). Injury sustained in a motor accident due to dislocation of the 5th cervical vertebra on the 6th. Patient presented as an example of Group 5.

Operation left hand 21.9.67, 9 months following no change in initial muscle chart. The tendons of brachio-radialis and extensor carpi radialis longus were transferred to the flexor pollicis longus and flexor digitorum profundus respectively and routed through the interosseus membrane. At the same time an opposition transfer using the flexor carpi radialis as the motor was carried out. This motor was elongated by using the extensor pollicis brevis tendon divided at its musculo-tendinous juncture. The tendons were united and the line of pull routed through a pulley in the flexor carpi ulnaris. Very satisfactory and powerful active flexion of digits and thumb was obtained but as the opposition transfer gave disappointing function it was revised on 8.2.68 and satisfactory abduction/opposition was then obtained.

Operation on the right side was carried out on 5.4.68, 15 months after the accident. The same tendon procedures were carried out to provide finger and thumb flexion but on this occasion the tendons of E.C.R.L. and B.R., having been mobilised far proximally in the forearm, were re-routed round the radial side of the forearm. Opposition transfer was carried out on 2.5.68. On this occasion a standard opposition transfer using the paralysed ring finger sublimis tendon was used. The flexor carpi radialis was then transferred into the musculo-tendinous junction of the ring finger sublimis to act as motor. The degree of opposition was initially unsatisfactory and the transfer was revised on 24.7.69.

The movie was taken 1 year following this operation and showed excellent active flexion of fingers and thumbs and active abduction and opposition of both thumbs.

Case 3. R. H. (aged 29). Injury sustained by a fall off a haystack resulting in dislocation of C7 on T1. A complete cord lesion was sustained and the patient presented as an example of Group 6. There was no change in the muscle charting during the first 7 months following injury.

Operation on the left side was carried out on 20.3.69, 7 months after injury. The extensor carpi radialis longus and brachio-radialis tendons were transferred to the flexor digitorum profundus and flexor pollicis longus tendons respectively and re-routed round the radial side of the forearm. An opposition transfer was carried out on 12.6.69, 10 months after injury. The flexor carpi radialis was used as the motor and elongated with a free plantaris graft taken through a pulley in the flexor carpi ulnaris.

On 8.10.69 (14 months after the injury) operation was carried out on the right side. Transfer of extensor carpi radialis longus and brachio-radialis tendons was carried out in the same fashion and the tendons re-routed round the radial side. No opposition transfer has been carried out on this side.

The movie was taken 1 year after the final operation and showed excellent function of grasp of fingers and thumb. There was a significant improvement in function on the right side where the opposition transfer had been carried out as compared to the left side

where this had not yet been done. As this patient was an example of Group 6, having normal digital extension, the over-all function of the hands was very good.

Case 4. D. G. (aged 23). This patient presented with a complete cord injury and on the right side was an example of Group 6 and on the left side initially as Group 5 but with a flicker of digital extension which slowly improved over a period of 1 year to 18 months but never regained full normal power. Both hands were left completely devoid of flexion of digits and thumb and intrinsic activity.

Operation on the right hand was carried out 6 months following injury as there had been no change in the muscle charting. Transfer of the extensor carpi radialis longus and the brachio-radialis to the flexor digitorum profundus and flexor pollicis longus respectively was carried out through the interosseus membrane. Initial function was good but after a few weeks there was no active flexion of the thumb. The site of transfer of the brachio-radialis to the flexor pollicis longus was, therefore, explored but the result was disappointing and this is the only failure in the group of cases where the brachio-radialis has been used as the motor to provide thumb flexion. Abduction opposition of thumb was provided by transfer of the flexor carpi radialis round the pulley in the flexor carpi ulnaris and elongating the tendon by use of the extensor pollicis brevis which had been sectioned at its musculo-tendinous junction and re-routed across the palm of the hand towards the pisiform.

This patient was very pleased with the improvement in the function of his hand and while he had returned to his home, which was a considerable distance from the hospital, he came back 2 years after his injury requesting that the same procedure should be done on the left hand. Muscle charting showed that there had been no change and he presented a picture halfway between Group 5 and Group 6 with weak digital extension.

At operation the extensor carpi radialis longus and the brachio-radialis tendons were transferred through the interosseus membrane to provide flexion of fingers and thumb. There was inadequate operative time to perform an opposition transfer at the same time and he was due to return to have this done in a few weeks but at this time was in hospital with a urinary tract infection. Opposition transfer has not since been carried out on this side.

This man has now come to live in Edinburgh and was available for review 5 years after the first operation. This has been the most dramatic and significant improvement of all the patients in this series and the film demonstrated his powerful grip and ability to drive a motor car with full control of brake, gears and steering wheel.

It will be noted that in these 4 cases 3 methods of providing abduction opposition of the thumb has been used. In all cases the motor has been the flexor carpi radialis but its method of elongation has differed. In all cases the transfer has worked very effectively although on 2 occasions subsequent revision was required and the tendon was found to be adherent in the region of the pulley in the flexor carpi ulnaris. The use of the extensor pollicis brevis tendon is a neat and time consuming method but in this limited number of cases the suture line to the flexor carpi radialis is very close to the pulley and is more liable to become adherent. It seemed that the most powerful abduction opposition of the thumb in this type of case is provided by elongation of the flexor carpi radialis with a free tendon graft from the plantaris. In this way the suture line can be made more proximally in the forearm and is unlikely to stick at the pulley.

In all those cases where the flexor carp radialis was used to provide opposition abduction of the thumb the loss of an active wrist flexor appeared to cause no functional loss to the patient.

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