

TENDON TRANSFERS TO IMPROVE GRASP IN PATIENTS WITH CERVICAL SPINAL CORD INJURY

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PARALYSIS occurring with injury to the spinal cord in the cervical region produces severe disability. Loss of function affects the upper limb to varying degrees depending on the level of injury. Injury at various levels of the spinal cord causes paralyses of different groups of muscles so that patients can be placed in groups according to the sensation and active functioning muscles present.

Instead of using neurological levels alone which may be quite variable it has been the practice at the Spinal Cord Injury Unit at Highland View Hospital to group patients according to the presence of certain voluntarily functioning muscles. These groups are reproducible in many patients and serve to predict functional goals and to plan treatment.

Management of the upper limbs represents only a small part in the total care of the spinal cord injured patient but it is of utmost importance if optimum rehabilitation of the severely handicapped patient is to be achieved. While many ways are available to achieve maximum independence in these patients a small number will benefit from tendon transfers.

It should be emphasised that this report deals with a very small percentage of spinal cord injury patients. It was found that rehabilitation of these patients improved with centralised care so that the majority eventually developed good hand function considering the degree of paralysis. It became obvious that after a good rehabilitation programme and delay of one or two years, the needs of the patient as he returned to a useful place in society could be more effectively assessed by patient, physician and health related personnel. Therefore, tendon transfers to improve hand function on patients with cervical spinal cord injury should not be considered for all paralysed patients, but, for a small group, perhaps less than ten per cent, whose function does not compare with others with similar paralyses.

The purpose of this communication is to classify patients according to the sparing of sensation and muscle activity, give indications and contraindications to tendon transfer, describe transfers that are of value, and to evaluate results.

CLASSIFICATION

During the past 13 years over 350 patients with cervical spinal cord injury have been observed. Instead of classifying these patients according to neurological level or injured vertebra alone, it made good sense to determine what voluntary function existed in the upper limbs. Neurological levels vary so much in these patients that a simple classification using neurological levels is much too inaccurate.

Consequently, a classification was developed which had significance when determining functional status, treatment planning and consideration for surgery.

It should be stressed that non-surgical care of the hand was the method of choice in the spinal cord injured patient and that in a small number of patients when this proved unsatisfactory tendon transfer was used. The following classification was useful for all patients regardless of the method of hand care.

Group I included those patients who had high cervical lesions and had no voluntary function of the wrist and hand. These patients fit into two sub-groups: those who had only shoulder shrug and no arm control (usually considered fourth cervical level), and those who had only elbow flexion and shoulder control of varying strengths (fifth cervical level). No tendon transfers were done for these patients. This pattern was usually seen with patients having fractures and dislocations above the fifth cervical vertebrae.

Group II included those patients who had shoulder control and elbow flexion (not conforming to any specific neurological level). Wrist extension was present but of insufficient strength to give automatic finger grasp by the tenodesis effect. Eight patients out of this group had tendon transfers and were the subject of a previous paper (Freehafer & Mast, 1967).

Group III patients had shoulder control, elbow flexion, brachioradialis, and two radial wrist extensors (sixth cervical level). These patients usually had fracture dislocation of the fifth and sixth cervical vertebrae. Fourteen hands out of this group had tendon transfers.

Group IV patients were similar to those in group III but had triceps, pronator teres and flexor carpi radialis in addition (seventh cervical level). Some of these patients had weak finger flexors and extensors. This group was characteristic of those patients with injuries involving the sixth and seventh cervical vertebrae. Seven hands out of this group of patients had tendon transfers.

Group V included those patients who had almost all upper limb muscles functioning voluntarily except for varying degrees of weakness of the intrinsic muscles of the hand (eighth cervical level). Fractures and dislocations of the seventh cervical and first thoracic vertebrae were usually seen with this group. Eight hands had tendon transfers.

Group VI included a small number of patients with partial paralysis who did not fit into these groups or any neurological level and were included as other. One patient underwent tendon transfer.

METHODS

All patients had spinal cord injury at some level of the cervical cord with severe paralysis. There were 24 patients aged between 16 and 51 with 30 hands who underwent tendon transfers. There were 18 males and five females. All patients were in groups II, III, IV and V. Eight patients in group II having brachioradialis transfer to enhance wrist extension will not be discussed here since they were the subject of a previous communication (Freehafer & Mast, 1967).

No hand surgery was done until the patient had undergone a programme of rehabilitation. All patients were carefully observed after surgery. The longest follow-up was 13 years and the shortest was one year with an average of five years.

All patients underwent a programme of hand care previously described involving proper posturing of the upper limb with splints, and active and passive

range of motion (Lamb, 1963; Freehafer, 1969). All patients of groups III and IV were given wrist-driven hinge splints and taught to use them functionally. Not all of them continued their use but most used them for several specific tasks such as eating, grooming, application of external catheter drainage, writing and others. Much emphasis was placed in having the patients increase strength of wrist extension in order to more effectively close the paralysed fingers. In positioning the hand it was important that full wrist flexion open the fingers and complete wrist extension close the fingers in an automatic fashion. The ideal posture for splinting was one with about 15° to 30° wrist extension, 45° to 60° metacarpophalangeal joint flexion, 30° to 45° proximal interphalangeal joint flexion and the thumb abducted. A small amount of finger flexion contracture or spasticity of the finger flexors was desired to provide the most useful tenodesis effect. Patients with good automatic grasp were not advised to have tendon transfers and only those with inability to effectively grasp or pinch underwent surgery.

All of the patients who underwent tendon transfer had sensation of the thumb, index and middle fingers. However many of the patients with higher levels had diminished sensation.

Spasticity of a mild nature was not a deterrent to hand surgery. It often provided useful automatic grasp when present in finger flexors. Severe spasticity usually caused some deformity and was a contraindication to tendon transfer.

Patients were evaluated before and after surgery using a variety of tests. These included activities of daily living performance, patient and physician satisfaction, manual muscle testing, measured force of gross grasp, lateral pinch and palmar pinch of thumb to index and middle fingers, range of motion and dexterity. Dexterity was evaluated by measuring time required for four simple tests: (1) Transferring blocks to a box. (2) Transferring kidney beans to a jar. (3) Transferring playing cards from a deck holder to a card holder. (4) Writing.

SURGERY

In general, the operations done were for opponensplasties to provide thumb to finger pinch and transfers to the flexor digitorum profundus to give voluntary finger flexion. While nothing new was added in the techniques of transferring tendons some clarification is necessary since different methods were used from time to time. Because of the severe degree of paralysis often present, the paucity of transferrable tendons, the variation in muscle strengths of functioning muscles, the undesirability to perform multiple surgery on these unfortunate patients, the surgeon must continually alter his approach to fit the particular needs of each individual patient.

Opponens Transfers. Usually the tendon of the paralysed flexor digitorum superficialis of the ring finger was removed from its insertion and rerouted across the palm and inserted into the abductor pollicis tendon using the distal edge of the deep transverse carpal ligament as the pulley (Royle, 1938; Thompson, 1942). The flexor carpi radialis, the brachioradialis and the extensor carpi radialis longus were used as motors in that order of preference if their strengths were good or better. The flexor carpi radialis was the easiest muscle to use. The use of one of the two radial wrist extensors carries some risk since loss of wrist extension

in these patients is disastrous. The extensor carpi radialis brevis is the most effective wrist extensor in spinal cord injury patients and should not be moved.

The proper tension of the transferred tendon was tested at surgery by extending wrist and producing good thumb to index finger pressure at about 45° wrist extension. On wrist flexion the thumb separated from the index finger.

Occasionally, the extensor carpi radialis longus was transferred around the ulnar border of the forearm (Phalen & Miller, 1947; White, 1960; Henderson, 1962) and anastomosed to the paralysed extensor pollicis brevis which was rerouted across the palm of the hand, its insertion being uninterrupted.

When the brachioradialis muscle was used as a motor for opposition the tendon was divided in mid forearm. The muscle was mobilised up to the elbow in order to obtain an excursion of three centimetres. The proximal end was then transferred toward the volar aspect of the forearm and attached to the tendon of the ring flexor digitorum superficialis which had previously been inserted into the abductor pollicis.

Flexor Digitorum Profundus Transfers. To restore voluntary finger flexion, either the flexor carpi radialis, pronator teres, brachioradialis or extensor carpi radialis longus muscles were used.

Proper tension was obtained by achieving full finger flexion with good tension with the wrist at 45° extension. With the wrist flexed the fingers automatically opened.

Three patients had flexion of the ulnar three fingers but the index finger remained extended. The index profundus was sutured to the rest of the profundus tendons as described by Omer (1968).

Post-operative immobilisation was four weeks followed by a splint for another four to six weeks. Gentle assisted active range of motion was begun after removal of the cast.

RESULTS

Only one patient was worse but he had been improving until he developed ascending paralysis and loss of function. This was probably due to a traumatic syrinx of the spinal cord.

The period of convalescence in these severely paralysed patients was always prolonged and associated with marked weakness, swelling and discomfort. This was decidedly different from what one expects with tendon transfers for milder disabilities. Presumably the absence of most of the motor power of the hand and forearm accounted for this. The use of splints after cast removal was essential to reduce this morbidity. This period of time varied but it usually took eight to ten weeks after surgery before patients were comfortable without splints and about three months before reasonably good function could be expected.

All patients showed increased manual muscle power following transfers.

Functional achievement was improved in all patients following tendon transfer. Gains were never great but nevertheless significant giving satisfaction to patient, therapists and physicians. The important functions of the spinal cord injured patient such as transfers, push ups, wheel chair propulsion, automobile driving, with hand controls, dressing, eating, grooming and other activities of daily living

were never made worse by tendon transfer. As a matter of fact, following tendon transfer patients could effectively grasp objects with good strength so that dressing, eating, grooming, bathing, writing, buttoning and other activities were much easier to perform.

Appearance of hands after tendon transfer was sometimes disappointing. Scars were obvious and often multiple. The only consistent deformity was flexion contracture of the proximal interphalangeal joints when finger flexor power was restored. This was expected because muscle imbalance was created in these severely paralysed patients who had insufficient tendons for transfer. This deformity was acceptable because it improved grasp and it posed no problems for any of the patients because the deformity was unilateral. However, if it were bilateral the patient would be unable to grasp large objects effectively. It should also be noted that finger flexion was motored in patients with poor automatic grasp or those whose proximal interphalangeal joints were fully extended and failed to flex by tenodesis action on wrist extension. Patients with flexion deformities of the fingers will probably develop serious flexion deformities if flexor digitorum profundus are motored as described.

Tenodeses of tendons was an effective means to improve grasp and release in these patients. Function, however, was never as good as it was when grasp was voluntary.

DISCUSSION

Cervical spinal cord injury patients have multiple problems. Prehension is only one of them but in a small number of patients tendon transfers are of value in restoring some useful function to an otherwise severely disabled patient. Even small amounts of improvement are worthwhile and help to further the goal of independence. Many of these patients are denied this unnecessarily or have undergone unwise or overenthusiastic reconstructive procedures which interfered with progress toward optimum independence.

Accurate assessment of the paralysed patient's status is essential. This cannot be done adequately until the patient has undergone a rehabilitation programme, the neurological examination is stable, spasticity is absent or minimal, sensation and motor power is adequate and the patient desires to improve himself. For these reasons tendon transfers done before one year has elapsed from the time of spinal cord injury may not produce optimum results and may actually cause more problems for these patients. The neurological status is frequently changing during the first year and may do so in some instances up to two years after onset of paralysis. A spinal cord injured patient in order to get from the wheel chair to the bed, toilet or car uses primarily his entire upper limbs in a way no normal person even thinks about. A knowledge of functional levels of quadriplegics with different neurological findings seen in spinal cord injury is essential (Garrett, Perry & Nickel, 1964). This serves as a basis for planning treatment.

Active wrist extension without contracture is the most important necessity of the severely paralysed spinal cord injured patient. He must use the heel of his hand for support, balance, push ups and locomotion. Active wrist extension usually effectively closes the fingers and thumb in useful grasp. Adding voluntary finger flexion and thumb opposition makes a stronger more effective grasp. To lose wrist extension makes grasp impossible and further handicaps the quadriplegic.

While the extensor carpi radialis longus can be used for transfer the surgeon must be confident that the extensor carpi radialis brevis alone will continue to extend the wrist. When the extensor carpi radialis brevis is weak or absent the extensor carpi radialis longus alone is a poor wrist extensor and usually pulls the wrist radially. Wrist fusion is never indicated because it eliminates automatic grasp and interferes with many activities performed by quadriplegics such as push ups, transfers, etc.

The approach used in this group of patients differs somewhat from that of others (Wilson, 1956; Zancolli, 1957, 1968; Lipscomb *et al.*, 1958; Nickel *et al.*, 1963; Masse *et al.*, 1968; Lamb & Landry, 1971, 1972). We have created thumb opposition instead of motoring the flexor pollicis longus. Occasionally palmar pinch is achieved but usually Key pinch results. The use of multiple and extensive surgical procedures should be avoided if at all possible. This of course is not always possible but when effective grasp can be accomplished with one procedure it is desired. Arthrodeses of multiple joints is undesirable because this usually interferes with important functions of the quadriplegic's hand, namely, support, lift and transfer. When severe deformities of thumb and finger joints do occur, however, arthrodeses may be the only solution.

It is impossible to restore the severely paralysed hand to normal. One can only hope to improve some function which might increase the patient's independence. Only patients with lower cervical injuries with weakness of opposition and those with partial paralysis can be expected to reach near normal results. In some instances restoration of grasp leads to flexion deformities of the proximal interphalangeal joints. This makes it impossible to grasp large objects and it is unwise to create this situation bilaterally. Transfers were done bilaterally, but only when the two upper limbs were indifferent groups or had different neurological levels. Increasing strength and effectiveness of grasp which often reduces ability to open the fingers will be a serious handicap if bilateral. Knowing that a muscle imbalance will occur when the finger flexors are motored bilaterally in paralysed hands only one hand should be done unless it can be determined with certainty that one hand will open sufficiently.

SUMMARY

Patients with cervical spinal cord injury can gain useful hand function from a good rehabilitation programme and non-operative hand care. Effective prehension can usually be achieved by proper positioning, exercises, and splinting but when grasp is poor, tendon transfers are very effective in furthering the goal of independence.

These patients have been reviewed extensively and classified into groups according to remaining neurological function.

Group I patients have weak elbow flexion and weak shoulder function or less. No tendon transfers were done.

Group II patients have shoulder control, elbow flexion and weak wrist extensors. Some of these patients can be improved by transferring the brachioradialis to the radial wrist extensor.

Group III patients have the above and good to normal brachioradialis and two radial wrist extensors. Transferring the brachioradialis to restore opposition

and the extensor carpi radialis longus to the flexor digitorum profundi provides strong and effective prehension.

Group IV patients have the above plus pronator teres and flexor carpi radialis which can be used for transfer. Opposition and finger flexion can be restored by a variety of transfers.

In groups III and IV tendon transfers were done only when automatic grasp was poor or absent. If finger grasp was good and thumb function ineffective only opponens transfers were done in order to achieve Key pinch.

Group V patients have all muscles functioning but with varying degrees of intrinsic weakness. Opponens transfer is useful for these patients.

Indications and contraindications to surgery are given.

All the patients have improved function and strength following their tendon transfers. No patient has regretted having had surgery.

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Discussion

DR. L. S. MICHAELIS (*G.B.*). I think we have all been impressed by Dr. Freehafer's paper. He is a real expert on hand surgery, and although he calls it simple-mindedness I would call it great judgement in operating as rarely as he does. In connection with what he has said, there are two questions which I think he did not touch on and to which I would like to have an answer. After what period following the accident does he decide on doing something to a hand in either a complete or incomplete tetraplegia? Secondly, after what period does he assess the final functional result? We had a discussion on this in connection with the remarkable operation done by Benassy some years ago in the nerve transfer. We all would like—if we want to operate at all—to operate as early as possible to prevent contractures, malformation etc. On the other hand, we feel we have to wait until a form of balanced judgement is possible on the function of the hand. If we operate too late, we deal with tendons which are already atrophic and which tend to stretch within the first two or three years following the operation. The first result which we proudly publish six months after operation may not be the final result. So, please, could I have these answers: how long between accident and decision to operate and how long between operation and assessment of result?

DR. P. STERN (*U.S.A.*). One is really between the devil and the deep blue sea in regards to making a decision, whether one should do nothing or should use a tenodesis splint as the one we have shown yesterday or advise reconstructive surgery. When you consider reconstructive surgery, of course, it's clear that you have to increase the web space, but recently I heard of a procedure which has not been mentioned whereby you use the extensor carpi radialis brevis and with a loop of the biceps. Thus when the patient flexes his elbow, at the same time he will get a supposedly tenodesis action. Referring to what Dr. Michaelis said, if you do that in a chronic patient where the tissues are atrophied your tendons will pull out or your tendons will break down and you will get the tenosinovitis. After two revisions of this surgery we went back to splinting and got a better result that way, so it is tricky.

DR. R. JACKSON (*Canada*). Dr. Freehafer, that was an excellent result of tendon-plasty that you were showing. I would ask if you would clarify some of the details of that, such as whether you stabilised the thumb.

DR. E. JACKSON (*U.S.A.*). Following the question about stabilisation of the thumb, I wonder if, as part of your final assessment particularly for C6 last reserved segment you include the ability to transfer rather uniform surgical attacks on hands in so far as this important function is concerned as we have experienced dismal results with this. It is also of great concern to us, say to convert a 20-year-old from an independent person to a dependent person requiring tender care.

DR. H. TALBOT (*U.S.A.*). Before Dr. Freehafer goes into the surgical technical procedures I would simply like to emphasise the fact that the important message he brought us this morning was the problem of evaluation and selection of patients. Being myself a conservative surgeon and convinced that most of my best surgical results came from patients where I refrained from operating, when I first knew Dr. Freehafer about ten years ago I thought he was one of these wild surgeons running around with a scalpel in his hand. I have learned since that he is a careful thinking surgeon—do not let him kid you, he is not really simple-minded—and I repeat that his main message this morning is not technical, it is a question of evaluation and selection. I think most of us who have been in this business for a quarter of a century or more, looking at the results of hand surgery both in our own and other clinics, have found to our great regret that more damage has been done than good over the long term. We hope that with careful selection within the next 25 years the reverse will be the case.

CHAIRMAN: SIR LUDWIG. I would like to endorse what Talbot and Michaelis have said. The most important points are, of course, *when* to make these plastic operations

and where and in which cases. I think Dr. Freehafer has given us a very detailed survey but I would also like to ask him exactly how long he waits before operating? You say one has to wait, send the man home, but for how long? I personally think—knowing that the adaptation of tetraplegics to their disability is quite remarkable in many cases—that one should wait at least one year if not longer. I do not fear the atrophy of the muscles, provided that the muscles are not overstretched during the waiting period. This is where the proper initial management in the hospital and afterwards by the patients themselves is so important, and no one has made any comments on the very interesting film shown by Wally Treanor. This is, of course, the crux in our treatment for tetraparesis with spasticity of the hands. Unfortunately, some 'dynamic' orthopaedic surgeons rush in with operation in these spastic lesions and Dr. Michaelis will remember the dreadful condition of the patient's hands after the operation. In fact, there is a man here at the games from Canada who has an incomplete cervical lesion and has had several plastic operations. His hands are so deformed and useless that although he has an incomplete lesion, we have to put him in the highest cervical class for sportive activities. This is clearly additional iatrogenic damage to an already severely disabled person. The next point is that I should like to endorse what Michaelis asked—how is the evaluation after operation done at a later period? I have been in various units where I have seen these patients and when I asked whether I could see them at work I was surprised to see that in some of the cases the patient worked with the unoperated hand instead of the so-called functionally improved operated one. This is where we still make mistakes and where we have to be more exact in our assessment of the final result, namely to watch the patient in his daily life, in particular at work.

DR. A. FREEHAFER (*U.S.A.*). Thank you very much for the kind remarks. I shall begin by answering Sir Ludwig, Dr. Talbot and Dr. Michaelis about the length of time from accident to surgery. I can tell you what we have done. The longest period has been 13 years. I think one should wait one and a half to two years, and this has to be based on a static neurological examination and the other factor I mentioned, somebody who has had an optimum rehabilitation programme. I do not think that hand surgery should be carried out on somebody who has had an inadequate or poor response to his disaster—he has to have adjusted considerably and has had to have a good programme and so on. As far as evaluating, it has been my practise to evaluate patients every time I see them. We have a follow-up clinic so I do see them frequently. We may not carry out all our tests every time we see them—they do not stray very far, and I think this is an important point because one does not want to evaluate them after two months or six months or even after one year and expect them to have maintained that progress. Now the hands that I showed you, I think must be seven years ago, and I guess that's been close to nine years, I do not have the statistics with me. I think those are important points.

Now, Dr. Stern mentioned wrist-driven hinge splint. It's my firm belief that the wrist-driven hinge splint is very valuable, and while it should be improved by the use of plastics and other materials, we use it and its an absolute requirement for all C6 and C7 tetraplegics. They have to learn to use it, I insist on it, and it depends on one's enthusiasm and vigour as to whether or not they are going to continue to use it in the long haul. In some patients you may think that it is not important whether they discontinue its use or not; push it as much as I push it. We have followed up our results and with the use of the wrist-driven splint, the majority do use them. I do not know the exact figures now. Maybe they use it for one specific task; for instance, one man uses it to help put his peruke on, some will just use it for eating, and someone else will just use it for brushing his teeth. Now, after they have learned to put it on and take it off within a reasonable period of time—and this is essential—they have to spend less than 60 seconds or they will not use it, then they can do what they like with it—I do not care whether they use it or not. A certain percentage will only use it on one side—I make them use it on both sides, perhaps I am too tough on them. As far as the biceps transfer,

this was recommended for restoring wrist extension. I suppose it could be used for other activities too, but I would be deathly afraid to transfer the biceps tendon because if you do then you would certainly lose the value of transfer.

In reference to Bob Jackson's question: no I have not carried out thumb stabilisation. But this is an important point to bring up because, whenever an opponens transfer is carried out this is recommended by some people and the approach is to, inasmuch as some people following opponens transfers develop a deformity in the thumb, then one has to correct it by perhaps a fusion around the joints. This has occurred in one of our patients: a woman patient who, following an opponens transfer, developed a hyperextension deformity of the m-p joint and we fused the m-p joint. Now, the method that we have used is to use the extensor pollicis brevis which is non-functioning and bring it across here and then take either the brachioradialis or the long wrist extensor and put it across the thumb. The morbidity following this is much greater, but sometimes this is the only way you can do it. This is the situation which produced the hyperextension deformity of the m-p joint as you can readily understand because of the function of that muscle.

Dr. Bob Jackson from the U.S.A. brought up an excellent point. They haven't been worse, the muscles that are used and the ones that are listed here I think are the safe muscles that you can transfer, except for the extensor carpi radialis brevis, which I don't think you should transfer.

DR. P. STERN (*U.S.A.*). I hope you all would try one thing, and that is if you have the hyperflexed fingers with a great deal of hyper-reflexia, just do a block of the meeting of the ulna nerve and the wrist to assess whether you get extra drive or not. The block should selectively spare the carpi radialis of course but this does not matter anyway because it is not that important. Bob Jackson asked the point about the brachioradialis transfer on the extensor carpi ulnaris. We have carried this out in nine patients selectively alone, and all those nine patients have full extension of the elbow. They have to be kept extended, but they do have full extension of the elbow.