Spinal Cord (2002) 40, 574–580

www.nature.com/sc

Original Article

Improvements in activities of daily living following functional hand surgery for treatment of lesions to the cervical spinal cord: Self-assessment by patients

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Study design: Tetraplegic patients were tested for hand strength before and after hand surgery. They also answered questions about how they rated the results of surgery.
Objectives: Presentation of the efficacy of reconstruction of hand raising, lateral grip, and cylindrical grip in the tetraplegic hand.
Setting: The study was conducted in the Werner Wicker Clinic, Bad Wildungen, Germany, from 1991 to 1998.
Methods: The results of reconstruction surgery performed on 23 tetraplegic hands, as reflected in lifting the hand ($n=3$), lateral grip ($n=21$), and cylindrical grip ($n=14$), are presented. In a follow-up study in 22 patients, their management of activities of daily living 34.1 months (9–51 months) after the surgery is compared with the preoperative situation. Subjective satisfaction levels were elicited for each of the 22 patients by means of a questionnaire.
Results: The gain in force corresponded to 893 g (150–1500 g) for cyclindrical grip and 488 g (100–1200 g) for lateral grip, while they were able to develop grade 4 force for lifting the hand. After the operation 28 aids/appliances that patients had formerly used regularly were no longer necessary. There were 75 separate activities listed in the questionnaire, and on average the 22 patients were able to perform 8.7 (0–20) more of these. Most patients (19) said they would advise others to have the operation and 18, that they would have the operation again. There were 12 complications in nine patients.
Conclusion: Reconstructive surgery on the hands of tetraplegic patients leads to gains in both cylindrical grip and lateral grip force and to increased manual dexterity. Patient satisfaction with the procedure is high.
Spinal Cord (2002) **40,** 574–580. doi:10.1038/sj.sc.3101384

Keywords: tetraplegia; surgical in upper extremities; activities of daily living

Introduction

Injury to the cervical spinal cord leads to complete dependence immediately after the causal event. This makes it all the more impressive when an individual patient who has access to help from a multidisciplinary team in a specialist department for the treatment of tetraplegia is able to rise above such a catastrophe. Numerous tricks can be used to compensate for the disability, and individually adapted aids are available, but the everyday functioning of the hands and their typical use in communication remain severely restricted. Numerous papers have described surgical techniques designed to improve dexterity in such patients, the most novel being those for implantation of neuroprostheses.[1–15] It is rare, however, for authors to give any details on how such measures affect activities of daily living (ADL) or how patients themselves feel about the results.[2,5,9] The papers on the efficacy of implanted neuroprostheses[12–15] were the first to give any detailed information on ADL and patient satisfaction levels. The object of the present study is to illustrate the efficacy of this functional surgery in the upper extremities of tetraplegic patients by reporting what ADL patients were able to complete without help from others before and after such surgery and how the patients themselves assess the results.

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Table 1 Self-assessment questionnaire

		Yes	*No*
1	*Personal care (12)*		
	Wash and dry face and hands		
	Wash and dry front to waist		
	Wash and dry back to waist		
	Wash and dry front from waist down		
	Wash and dry bottom		
	Wash and dry legs and feet		
	Check skin with mirror		
	Get toothbrush ready		
	Clean teeth		
	Wash hair		
	Brush/comb hair		
	Shave/apply make-up		
2	*Bladder and bowel care (8)*		
	Apply urinal		
	Assemble urinal		
	Empty urinal		
	Catheterize self		
	Stimulate rectum		
	Evacuate rectum		
	Insert suppository		
	Cleaning after toileting		
3	*Eating and drinking (11)*		
	Use spoon		
	Use fork		
	Spread bread		
	Cut with knife		
	Lift drinking vessel to mouth		
	Beaker		
	Glass		
	Pour from jug or glass		
	Open bottle		
	Screw cap		
	Crown cork		
	Manage kitchen appliances		
	Prepare meals		
4	*Dressing (22)*		
	Pullover		
	Put on		
	Take off		
	T-Shirt		
	Put on		
	Take off		
	Vest		
	Put on		
	Take off		
	Buttons		
	Fasten		
	Undo		
	Trousers		
	Put on		
	Take off		
	In the toilet		
	Take clothes off/down/unfasten		
	Rearrange clothing		
	Socks/stockings		
	Put on		
	Take off		
	Support socks/stockings		
	Put on		
	Take off		
	Shoes		
	Put on		
	Take off		
	Jacket/coat		
	Put on		
	Take off		
	Wheelchair gloves		
	Put on		
	Take off		
5	*Transfers (11)*		
	Wheelchair to bed		
	Bed to wheelchair		
	Electric wheelchair to bed		
	Bed to electric wheelchair		
	Shower wheelchair to bed		
	Bed to shower wheelchair		
	Wheelchair to toilet		
	Toilet to wheelchair		
	Wheelchair to car		
	Car to wheelchair		
	Loading wheelchair in car		
6	*In bed (5)*		
	Turn over in bed		
	Position self		
	Sit up		
	Change setting of bed		
	Cover self up		
7	*Other (6)*		
	Use telephone		
	Use typewriter/computer		
	Insert/take out paper		
	Type		
	Handle post		
	Insert/take out CD/cassette		

Materials and methods

From 1991 to 1998, a total of 24 tetraplegic patients (three female and 21 male patients: 25 hands in all) underwent hand surgery in the Werner Wicker Clinic. All had sustained spinal cord injuries as the result of accidents. Complete data sets were ascertained for 22 of these patients. One patient had died of pneumonia unconnected with the operation at the time of the study. One patient living outside Germany could not be enrolled in the study. The average age was 37.5 years (range 21–57 years). On average, 8 years (range 21–28 years) had passed between the accident and the operation.

Data relating to ADL in 22 patients (surgery performed on 23 hands in all) were ascertained preoperatively and a mean of 34.1 months (range 9–59 months) postoperatively.

Figure 1 Lateral grasp measurement with plastic plate and weights

Figure 2 Cylinder grasp measurement with wooden cylinders and weights

Before the operation the data were collected with the aid of an independence in ADL questionnaire listing 75 separate ADL (Table 1). The list is based largely on the Quadriplegia Index of Function (QIF).[16] The individual activities were assessed by the patient together with the occupational therapist (OT), and each question was answered with 'Yes' or 'No'. In the case of a Yes answer, any aids used in getting to grips with the task concerned were noted. A Yes answer means that the task under scrutiny is performed by the patient with no help from any other person or persons.

After the operation each patient was requested to fill out the same questionnaire again as had been used to ascertain the preoperative data. Again, aids used in managing the individual tasks were also asked about. The rules for when to answer with Yes and when with No were also the same as before the operation. In addition, the questions displayed in Table 2 were inserted this time, to elicit the patients' subjective level of satisfaction with the results of the operation. This was evaluated by comparing the preoperative and postoperative situations.

The key grip and lateral grip force were measured before and a mean of 114 days (range 59–293 days) after the surgery. The final postoperative measurements of grip force were done at the time of discharge from hospital. The duration of treatment for any complications is included in the time noted for duration of hospital stay in each case.

We felt that the dynamometer and pinchmeter conventionally used to measure manual strength were hardly suitable for the measurement of key grip and lateral grip force in our tetraplegic patients (Figures 1 and 2). These are instruments that tetraplegic patients are frequently unable to grip and use without

Table 2 Questions posed at follow-up after surgery ($n=22$)

Question	*Answer (n)* *Yes*	*No*
Would you recommend the operation to others?	19	3
Would you have the operation again?	18	4
Do the scars influence how you feel about your appearance	1	21
Has the operation had a positive influence on your life at work?	2	20

assistance. We therefore decided on measuring instruments especially adapted for the gripping action of tetraplegics. These are a plastic disc allowing measurement of the level of force developed in 50 g increments for lateral grip and wooden cylinders to which weights can be added in increments of 50 g for cylindrical grip. There is no restriction on total weight. The weights are attached in increasing order, and each is held only once.

The aim of the operative treatment was to achieve active dorsal extension of the wrist, active or passive lateral grip and active or passive cylindrical grip. At the same time, the possibility of surgical reconstruction to allow extension of the elbow was investigated. Each patient was informed of this option. The neurological function still present despite the tetraplegia was classified according to the Giens system[17] in each case (Table 3).

The preoperative treatment and the whole of the postoperative treatment were carried out in a specialist center for the treatment of spinal cord injuries. The patients were admitted after being seen in the outpatient clinic. A preoperative analysis made by the attendant surgeon, occupational therapist (OT) and physical therapist was used as the basis of the operative protocol, which was drawn up once the aims of surgery had been agreed with the patient. Contraindications to surgery were decubitus ulcers, spastic paralysis of the upper extremities causing impaired function, infection of the respiratory tract and urinary tract infection, double incontinence, and unrealistic objectives. Any patient in whom neuropsychological deficits were suspected was referred for psychological assessment.

Up to 1994 the surgery was followed by immobilization of the arm in a plaster cast for 6 weeks, with the elbow flexed at 90° and the wrist in a neutral position.

With time, we had the impression that this long period of immobilization was leading to later problems when it was time for the wrist and the small joints of the fingers to be remobilized; with effect from 1995, we therefore decided to reduce the period of immobilization to 3 weeks. After removal of the plaster cast, a thermoplastic support is applied. Progress is assessed in weekly team meetings involving the surgeon, the OT and the physical therapist. In the first 3 weeks after removal of the plaster cast isometric exercises of both the transplanted muscles and all other muscles remaining are carried out. Careful exercise incorporating ADL without weightbearing is carried out in the first 3 weeks. The scar tissue is massaged. Translatory mobilization of the finger joints and the wrist is carried out. In addition, exercises designed to mobilize the shoulder joint are done daily, and biofeedback and functional electrical therapy are also applied daily.

From the sixth week onward, elbow extension is no longer restricted, ADL including those involving weightbearing are carried out with biofeedback, functional electrical therapy is continued, and patients also perform regular exercises to strengthen their muscles. They use their manual wheelchairs again. Transfers and weightbearing are allowed with increasing frequency.

Up to 1994, 13 patients had been treated for a mean of 128 days (range 68–293 days); from 1995 to 1998 we treated nine patients in a total of 10 periods in hospital, each lasting a mean of 96 days (range 59–178 days).

The lack of any adequate outpatient provision means that the postoperative treatment is also carried out in the Spinal Cord Center.

In the 20 patients finally enrolled in the study, active or passive lateral grip was reconstructed in 21 hands, active or passive cylindrical grip in 14, and active dorsal extension of the wrist in three. The operative procedures are summarized in Table 4. In three cases radial osteotomy was carried out to correct supination contracture of the lower arm, and in one case each, capsulodesis from digits II to V to correct hyperextension in the metacarpal phalangeal joints and lengthening of the finger flexors to correct contractures in the long figures. The hand that had been the nondominant one before the accident was operated on in nine cases and in 14 cases, the dominant hand. Only two patients accepted the offered reconstruction of elbow extension, and in neither was it on the same side as the hand operation.

Table 3 Giens[12] functional-neurological classification in 23 tetraplegic patients (Cu cutaneous, O ocular)

O1	4
O2	3
O Cu 2	9
O Cu 3	1
O Cu 4	6

Results

In the case of lateral grip, the gain in force made it possible for patients to lift 488 g (mean; range 100–1200 g) more with each of the 21 hands treated. Reconstruction of the cylindrical grip (14 hands) made it possible for patients to lift a mean of 893 g (range 150–1500 g) more than before surgery. In the three wrists in which dorsal extension was restored, grade 4 muscle strength was achieved. A detailed breakdown of the gains in lateral and cylindrical grip force by neurological function group is shown in Table 5. On average, a gain of 238 g was measured for group O1, 445 g for group O/OCu 2, and 693 g for groups OCu 3 and 4 together. In the case of cylindrical grip an average gain of 1213 g was measured for group O/OCu 2, but only 467 g for group OCu 3/4; in this group there were four patients in whom transposition of the flexor carpi radialis muscle onto the flexor digitorum profundus muscle was followed by gains in force corresponding to no more than 500 g, while in group

Table 4 Operative procedures

Dorsal extension (n=3)		*Brachioradialis muscle→Extensor radialis brevis muscle*
Lateral grip (*n*=22)	Tenodesis	Flexor pollicis longus muscle (*n*=6)
		Extensor pollicis brevis muscle (*n*=1)
		Abductor pollicis longus muscle (*n*=3)
		Extensor pollicis longus (*n*=19)
	Transposition	Brachioradialis muscle→Flexor pollicis longus muscle (*n*=15)
		Flexor carpi radialis muscle→Flexor pollicis longus muscle (*n*=4)
		Flexor carpi radialis muscle→Extensor pollicis longus muscle (*n*=1)
	Arthrodesis	Interphalangeal (*n*=18)
		Metacarpophalangeal (*n*=1)
		Carpometacarpal (*n*=2)
	Capsulodesis	Carpometacarpal (*n*=2)
Cylindrical grip (*n*=14)	Transposition	Extensor carpi radialis longus muscle → Flexor digitorum profundus muscle (*n*=5)
		Brachioradialis muscle → Flexor digitorum profundus muscle (*n*=5)
		Flexor carpi radialis muscle → Flexor digitorum profundus muscle (*n*=4)
	Tenodesis	Zancolli lasso (*n*=13)
		Flexor digitorum profundus muscle (*n*=1)

Table 5 Gains in grip force

Giens grade	*Lateral grip*	*Cylindrical grip*
O1	238 g (200–300 g) (*n*=4)	
O/OCu 2	445 g (100–1200 g) (*n*=10)	1213 g (150–1500 g) (*n*=8)
OCu 3/4	693 g (250–1100 g) (*n*=7)	467 g (150–1000 g) (*n*=6)

Table 7 Numbers of aids/appliances used postoperatively relative to before surgery

O1	+1/−1
O/OCu 2	+1/−12
OCu 3/4	−15

Table 6 ADL gain after surgery

Giens grade	*Personal care (bladder/bowel) (20 items)*	*Eating and drinking (11 items)*	*Dressing and undressing (22 items)*	*Transfers and bedtime (16 items)*	*Other (6 items)*
O1	1.5 (0–5)	2 (0–4)	0.5 (0–2)	0.3 (0–1)	2.8 (0–4)
O/OCu	0.9 (2–5)	2.5 (0–5)	3.3 (2–11)	2 (0–6)	0.8 (0–2)
OCu 3/4	1 (0–3)	2.9 (0–5)	2.7 (0–6)	1.3 (0–4)	0.9 (0–4)

O/OCu 2 the extensor carpi radialis longus muscle was transposed onto the flexor digitorum profundus muscle with subsequent gains in force of between 150 and 1500 g. There was only one patient who had a very slight result in terms of gain in cylindrical grip force, with 150 g.

Twenty-two patients, that is to say all those who were enrolled in the study, responded to the questionnaire on self-assessment of ADL. The average improvement experienced after surgery is shown in Table 6, broken down by neurological function group and by ADL category. In all three neurological function groups there is a striking gain of 2–2.9 items per patient in the domain of eating and drinking. Quite a large gain is also seen for dressing and undressing in groups O/OCu 2 and OCu 3/4. Considering the small number of items, the largest relative gain is that experienced by group 01 patients for the category 'Other'. Two patients each reported losing the ability to perform some of the tasks among the ADL listed. Overall, however, enhanced capabilities were determined in all domains of daily life in this study. After surgery, patients were able to dispense with a total of 28 aids (Table 7). Groups O/OCu 2 and OCu 3/4 benefited most in this respect. Their improved functional situation made it possible for two patients to use adapted aids allowing them to eat and drink without help from other people.

The results in the only patient who underwent bilateral surgery were positive but not above average. In this patient the primary indications for surgery were supination contracture and the desire for an improved external appearance of the upper limbs, but he also experienced the benefit of improved active lateral grip in both hands.

Table 8 Complications ($n = 12$)

Complication	*n*
Infection	3
Loosening of Kirschner wires	6
Loss of tension on tenodesis/transposition	2
Contracture	1

Neither of the two patients who had surgery to replace the triceps muscle had exceptionally good results in terms of greater hand grip force or increased capability in ADL compared with the preoperative status.

When asked, 19 patients said they would recommend the operation to other tetraplegic patients, and 18 said they would have the operation again. Only one patient felt inhibited because of the appearance of the scars. In two patients the improved manual function had a positive influence on their professional work. However, only seven of the 22 patients were actually holding down jobs (Table 2).

There were a total of 12 complications in nine patients (Table 8). Loosening of the Kirschner wires used for the interphalangeal arthrodeses was common. (In one case the patient pulled out a wire himself with his teeth). In another patient a distal phalanx became infected, with involvement of the joint. Resection of the joint was necessary in this case, leading to a loss of tension in lateral grip, and therefore a loss of force. One infection led to loosening of the transposed brachioradialis muscle. Once the infection was eradicated the brachioradialis muscle was again transposed to the radial wrist extensors, this time with the aid of an interposed fascia lata implant. In one case a superficial infection cleared up with no loss of function after wound revision. A tenodesis of the extensor pollicis longus muscle worked loose postoperatively and had to be redone. In one woman patient all the long fingers became stiff after cylindrical grip reconstruction. In this case the functional result remained poor despite mobilization under anesthesia and adhesiolysis.

Discussion

As long ago as 1978 and 1983, respectively, Moberg[1] and Hentz[7] drew attention to the problems of determining objective results following reconstructions in tetraplegic hands. The gain in strength available for raising the hand and for both cylindrical and lateral grip does not mean an automatic improvement in ADL. Vanden Berghe's group made a detailed comparison of how ADL were managed before and after surgery. In particular, this group draws attention to a gain in the capacity to handle quite small objects and to patients' ability to dispense with aids/appliances.[5] In our study, the patients' self-assessments of the separate ADL reflect gains mainly in the category of eating and drinking and, specifically in neurological function group 01, in the handling of small objects used in everyday life, for which the lateral grip is preferentially used (Table 6). Lamb and Chan[2] and Mohammed's group[9] emphasize the large number of capabilities restored to their patients and the high level of patient satisfaction revealed by the postoperative information on ADL. This is in keeping with our own results, but it must be mentioned that after surgery two of our patients reported no longer being able to manage all the activities they had earlier.

Assessment of the situation with aids/appliances revealed striking benefits, especially for patients in group OCu 3/4, who found a total of 15 aids were no longer needed, and in group O/OCu 2, for whom 12 aids they had needed before surgery were not unnecessary. This suggests that increasing functionality makes aids and appliances unnecessary.

In keeping with the results of other studies,[2,4–7,9–15] the gains in lateral grip and cylindrical grip force were significant in all neurological function groups. The method we used means our results cannot be directly compared with measurements taken with dynamometers or pinchmeters, but nonetheless we recorded a decisive gain in the force developed for the lateral grip in the different groups. However, the gain in cylindrical grip force is conspicuously small in group OCu 3/4. We attribute this disappointing result to the transposition of the flexor carpi radialis muscle onto the deep flexor of the finger, a procedure we no longer practice.

The introduction of neuroprosthetic surgery into functional hand surgery makes it worthwhile reconsidering the indications for conventional muscle transposition and tenodesis in view of the results in terms of ADL and grip force in group 01 and in some of the patients in group O/OCu 2. The convincing papers published by Mulcahey *et al*[14] and Peckham *et al*[15] lead us to believe that whenever conditions are suitable neuroprostheses should be implanted. Our own preliminary experience with a total of four patients indicates that neuroprostheses give superior results.

In all studies in which complications are reported in detail, the complication rate of reconstructive surgery on the tetraplegic hand is very high. Lamb and Chan[2] report 27 complications in a series of 41 patients, Mohammed *et al*,[9] 27 complications in 57 patients, and Vanden Berghe,[5] seven complications in 13 patients. In the present study too, 12 complications were observed in nine of the 22 patients.

Surigcal operations for correction of spastic contractures following brain injuries are of a similar level of sophistication, but a relatively low rate of complications is reported for such operations.[18] The only explanation we can suggest for this difference is the differing complexity of the two kinds of operations.

All this makes the consistently high level of patient satisfaction with the results even more amazing, though Mohammed *et al*[9] are so far the only team to have reported on patient surveys in any detail. The overwhelmingly positive attitude of our own patients

(Table 2) is in keeping with the observations published by Mohammed's group.

None of the reports published so far comment on the duration of treatment, which we find very strange. Regardless of whether the operation is done as an inpatient procedure or as day surgery, readiness to undergo it is a measure of a patient's commitment to achieving an improvement. Our patients were treated in hospital as inpatients for a mean of 114 days (range 59–293 days). Shortening the postoperative period of immobilization did lead to shorter stays in hospital, but this has had no influence on the complication rate. The long period of inpatient treatment was necessary because there were no adequate outpatient facilities for tetraplegic postoperative patients. Another factor in the long period of hospitalization is our own learning curve during the establishment of the treatment team. After some attempts in the 1960s and 1970s, function-enhancing operations on the upper extremities of tetraplegics had been abandoned in Germany.

The question of bilateral interventions[6,9] also cannot be settled with reference to the available data. It remains for future studies to determine whether bilateral operative treatment will yield functional enhancement that will be reflected in increased independence in ADL and development of greater force.

Despite the small number of operated cases, we can say in summary that operative interventions on the tetraplegic hand bring about a definite gain in the force that is developed, which can be exploited in cylindrical and lateral grip, and an improvement in ADL. The subjective acceptance among patients is high; at present, unfortunately, the complication rate is also high and a long duration of treatment is necessary.

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