Surgical rehabilitation of a tetraplegic hand: comparison of various methods of reconstructing an absent pinch and hook

Mukul Mohindra · Sukhbir Singh Sangwan ·
Zile Singh Kundu · Paritosh Gogna · Anurag Tiwari ·
Ankit Thora

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Abstract

Background Since complete functional restoration after spinal cord injury may not always be possible, the major focus in such cases has to be on rehabilitation. We performed surgery in such patients to reconstruct important absent hand functions viz. pinch and hook using various methods described in literature and compared their outcome.

Methods A total of 29 procedures were performed in ten patients (18 upper limbs) with tetraparesis consequent to cervical spine injury distal to C6 level who had at least grade 3 power of elbow extension but had not documented any significant improvement in hand function, at least 6 months post injury. Key pinch was reconstructed in 14 upper limbs using brachioradialis (BR) to flexor pollicis longus (FPL)

transfer in 11 and pronator teres (PT) to FPL transfer in three limbs. Hook was reconstructed in 15 upper limbs: PT to flexor digitorum profundus (FDP) ($n=7$), BR to FDP ($n=2$), and FDP tenodesis ($n=6$). The gains achieved were measured at intervals of 4 weeks, 3 months, and 6 months postoperatively and at a final possible follow-up of every patient, the average follow-up being 32 months. The functional outcome was assessed by the modified Lamb and Chan score.

Results For key pinch reconstruction, both BR and PT turned out to be equally efficacious donors, while for hook reconstruction, PT and BR transfer to FDP turned out to be superior to FDP tenodesis. The functional outcome as assessed by the modified Lamb and Chan score revealed good to fair outcome in 70 % of patients while poor in 30 %. Complications resulted from stretching of transfer, rupture of tenodesis, and maltensioning.

Conclusion Surgery can routinely be offered to suitable tetraplegics with deficient hand function in whom no useful recovery of any function is expected with at least 6 months elapsed post injury. Single-staged bilateral procedures enable maximal possible rehabilitation in minimal possible duration.

M. Mohindra · A. Tiwari
Department of Orthopaedics, Maulana Azad Medical College
and Associated Hospitals, New Delhi, India

A. Tiwari
e-mail: dranurag.tiwari@gmail.com

S. S. Sangwan · Z. S. Kundu · P. Gogna
Department of Orthopaedics, Paraplegia and Rehabilitation,
Pt BD Sharma PGIMS, Rohtak, Haryana, India 124001

S. S. Sangwan
e-mail: vicechancellor.uhsr@gmail.com

Z. S. Kundu
e-mail: zskundu2003@rediffmail.com

P. Gogna
e-mail: paritosh.gogna@gmail.com

A. Thora
Department of Orthopaedics, Maulana Azad Medical College
and Associated Hospitals, New Delhi, India
e-mail: dr.ankit20@gmail.com

M. Mohindra (✉)
630/18 Kundan Puri, Civil Lines, Ludhiana 141001, Punjab, India
e-mail: mukul_mohindra@hotmail.com

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Introduction

Spinal cord trauma is a devastating injury with up to 60 % involving injury to the cervical spine [15]. Since complete functional restoration after a cord injury may not always be possible, the major focus in these cases has to be on rehabilitation. Rehabilitation of such patients is a complex process that not only needs an orthopedic surgeon but also a team of dedicated medical and paramedical personnel. It not just involves nonsurgical measures viz. orthotic devices, wheel

Table 1 International classification (modified) for patients with tetraplegia [5, 11, 17]

International Classification	
0	No muscle functioning below elbow
1	Brachioradialis (BR)
2	Extensor carpi radialis longus (ECRL)
3	Extensor carpi radialis brevis (ECRB)
4	Pronator teres (PT)
5	Flexor carpi radialis (FCR)
6	Finger extensors—extensor digitorum communis (EDC)
7	Thumb extensors—extensor pollicis longus (EPL)
8	Partial digital flexors—flexor digitorum superficialis and profundus (FDS, FDP)
9	Lacks only intrinsic
X	Exceptions

chairs, and modifications to daily life equipment, but also has good scope for surgery, the role of which is highly under rated. Surgery in these cases is an important adjunct to nonsurgical measures and helps the tetraplegic in gaining even more independence [11, 20]. However, there has been a prevailing attitude against surgical reconstruction of the upper limb in tetraplegia, and even a review of some modern authoritative textbooks shows little reference to this topic [13]. Moreover, very little work has been done in this area especially in developing nations owing to limited resources and lack of patient motivation. As an attempt to reconstruct absent pinch and hook in tetraplegics, we carried out soft tissue procedures that included various tendon transfers and tenodesis. This article analyzes their objective as well as functional outcome and presents a comparison of the different methods we used for reconstruction.

Methods

This prospective study involved a total of 29 surgical procedures that were carried out in ten patients (18 upper limbs)

with tetraparesis. Inclusion criteria were elapse of >6 months since injury without expected recovery of any useful hand function with reasonably preserved elbow function, active wrist dorsiflexion of at least 45°, and a cervical spine injury at or distal to C6 spinal cord level. Patients with significant joint contractures were excluded from the study.

A detailed history was taken from each patient noting the mechanism of injury as well as the pre-injury job profile of the patient. A meticulous examination was performed and each upper limb of the patient was individually classified into the appropriate international classification (IC) group [5, 11, 17], depending upon the available functioning muscle groups (Table 1). Only those patients who had absent pinch and hook function in the hand but the upper limb categorization was IC-4 or higher were offered surgery, thereby implying functional wrist extensors, brachioradialis (BR), and pronator teres (PT). A donor was considered for transfer only if preoperative power assessment was >MRC grade 4. All patients underwent extensive preoperative physiotherapy to ensure supple joints as joint contractures severely jeopardize the results [17].

Surgical Technique

All surgeries were performed under general anesthesia and tourniquet control. Key pinch was reconstructed in a total of 14 upper limbs by empowering flexor pollicis longus (FPL). In 11 of these, BR was transferred (Fig. 1a), while in three upper limbs, PT was used as donor (Fig. 1b). Thumb interphalangeal joint was stabilized using the split FPL transfer (Fig. 2) method [5, 8, 17].

Hook was reconstructed in 15 upper limbs using the following procedures: transfer of PT to FDP (flexor digitorum profundus) in seven limbs (Fig. 3a, b), transfer of BR to FDP in two limbs, and tenodesis of FDP in six limbs. In two upper limbs to correct clawing thereby making the grasp more effective, simultaneous Zancolli lasso tenodesis was carried out by suturing the tendons of the flexor digitorum superficialis back onto themselves [1, 2, 13, 17].

Fig. 1 **a** Key pinch being reconstructed by transfer of BR to FPL (elbow should be in 90° flexion and wrist neutral and thumb pad should fall a little short of the contacting middle finger). **b** Key pinch being reconstructed by transfer of PT to FPL

Fig. 2 Split FPL transfer—radial half of FPL being taken back to be woven into the extensor pollicis longus tendon to stabilize thumb interphalangeal joint

In patients lacking both pinch and hook, both the above procedures were carried out in a single stage and those undergoing bilateral surgery had the procedures performed simultaneously by two separate surgical teams, each headed by a senior surgeon. The two senior surgeons operated all the patients in this study.

Postoperative Rehabilitation

Immediately after surgery, the operated limb was put in an above elbow plaster of paris cast for 4 weeks [11]. Sutures were removed at 2 weeks through a window in the cast. After cast removal, patients were subjected to an intensive physiotherapy protocol similar to the one described by Lo et al. [15].

Follow-up protocol included both objective and subjective assessment. Key pinch was measured using spring balance (Fig. 4a), and hook was recorded using a handheld dynamometer (Fig. 4b) in a position most comfortable to the patient. The record was taken at intervals of 4 weeks, 3 months, and 6 months postoperatively and at a final possible follow-up of every patient. The Lamb and Chan questionnaire (modified by Mohammed et al.) [13, 17, 19], based upon the activities of daily living, was provided to all patients after 6 months of

surgery. At the same time, a note was taken from each patient regarding his/her satisfaction from the result of the surgery.

Results

All ten patients included in our study belonged to a low socioeconomic strata with majority (60 %) having sustained injury after a fall from height. All of them were managed for the initial injury conservatively, with skeletal traction for 4 weeks followed by application of four post collar and thoroughly counseled to follow up at advised intervals for ensuring adequate quadriplegic care. There were nine males and one female with a mean age of 40.6 years (range 22–60 years). All the males except one, who was a graduate student, were employed prior to sustaining injury, but the female was a married housewife. The mean possible follow-up of our patients was 32 months (range 24–46 months). Eight patients agreed for bilateral surgeries, while two consented only for operating on the dominant limb.

The gains achieved from various procedures were measured precisely and tabulated for a detailed interpretation. The average value of key pinch (in kilograms) attained after 14 reconstructions was 1.45 kg at 4 weeks (range 0.7–2.8), 1.51 (range 0.8–2.8) at 3 months, 1.81 (range 0.8–2.6) at 6 months, and 1.77 (range 0.6–3.2) at the final follow-up. For 15 hook reconstructions, these values (in kilograms) were 2.32 at 4 weeks (range 0.4–3.2), 2.41 (range 0.6–3.4), 2.76 (range 1.2–4), and 2.58 (range 0.8–4), respectively. Table 2 gives a comprehensive tabulation of average gains achieved individually from each transfer.

On analyzing statistically, for key pinch reconstruction, both BR and PT were found to be equally efficacious donors (p value=0.2196), while for hook reconstruction, PT and BR transfers to FDP turned out to be equally efficacious (p value=0.9690) but superior to isolated FDP tenodesis (p value=0.001). Three upper limbs which had undergone FDP tenodesis demonstrated difficulty in finger straightening possibly owing to fibrosis occurring at surgery site limiting

Fig. 3 a PT being harvested along with a 10-cm strip of periosteum for hook reconstruction. b Hook reconstruction being done by empowering FDP with PT transfer (with wrist in 30° flexion, the pulp of fingers should be touching the palm)

Fig. 4 **a** Measurement of key pinch using a spring balance after reconstruction at 6 months postop. **b** Measurement of hook using a handheld dynamometer after reconstruction at 6 months postop

tendon excursion. Splints given to straighten fingers resulted in rupture of anastomosis leading to loss of gains achieved.

Figure 5 is depicting the trend over time in the average gains achieved for both pinch and hook reconstruction. It is quite evident from the graphs that there is an upward slope in the time interval between 4 weeks and 6 months after which the values plateau. This signifies the importance of postoperative physiotherapy and patient training. The short-term results at 3 months were compared with the results at mean follow-up of 32 months, and a statistically significant correlation was obtained (p value=0.0010 for pinch and p value=0.0015 for hook), strengthening the fact that gains achieved are maintained over a considerable period of time [19]. However, we must mention that no significant difference was observed in gains achieved on operating either the right or left upper limb (p value=0.3739 for pinch and p value=0.7400 for hook), implying the procedures on either side to be equally efficacious.

The functional outcome was assessed using the modified Lamb and Chan score [13, 17, 19]. Our results were good to fair in as many as 70 % of patients, while 30 % patients

reported poor functional outcome. However, no patient reported that his functional capacity had diminished in any way.

Discussion

Tetraplegia is a serious setback to the functional independence of the patient. Hence, it is quite obvious that even if minor benefits could be provided by reconstructive surgery of the upper limb to tetraplegics, it would not only make them more independent but also facilitate their development of personal interests, hobbies, sports, and recreational activities [20]. However, a high level of patient motivation, a proper patient selection, and appropriate surgical planning are key determinants to achieve this goal. Categorizing the upper limb into the respective international classification group greatly aids in the planning process. Patients with lesions above the C6 vertebrae are generally categorized in IC-0 and have no available donor muscle below the elbow. So operations to improve digital function are seldom indicated in this group [7]. In tetraplegics who have a lesion at the sixth or seventh cervical level, various

Table 2 Gains from individual reconstructive procedures

Aim	Transfer	No. of upper limbs	Average strength gained (kg)
Key pinch reconstruction	BR to FPL	11	1.69
	PT to FPL	3	2.27
Total		14	
Hook grasp reconstruction	FDP tenodesis	6	1.67
	PT to FDP	7	3.48
	BR to FDP	2	3.50
Total		15	

The values of average strength gained are at 6 months postoperatively
BR brachioradialis, PT pronator teres, FPL flexor pollicis longus, FDP flexor digitorum profundus

Fig. 5 Line graph depicting the trend over time in the average gains achieved for both pinch and hook reconstruction

Table 3 Comparison of pinch strength gained with other studies [6, 7, 9, 12, 14, 17, 22]

Study	No. of limbs reconstructed	Measurement (kg)
Freehafer et al. [1]	4	0.5
House et al. [9]	10	3
House and Shannon [10]	12	3.5
Kelly et al. [12]	24	1.47
Ejeskar and Dahllof [4]	50	0.7
Gansel et al. [7]	11	2.2
Vanden Berghe et al. [21]	14	0.7
Mohammed et al. [17]	57	2.1
Vastamaki [22]	10	1.1
Our series	18	1.81

Objective measurements of key pinch reported in other series

combinations of tenodesis, arthrodesis, and tendon transfer have been recommended. Generally, flexor carpi radialis (FCR), PT, BR, and extensor carpi radialis longus (ECRL) are the suitable motors available in such patients. FCR is generally not recommended as the patient may not have another wrist flexor available [11]. Active wrist extension of at least 45° is a prerequisite for the success of these procedures [7]. Although some surgeons have reported preliminary good results while employing extensor carpi radialis longus, we refrained from using this donor to avoid inadvertent compromise to active wrist extension and thereby the automatic grasp mechanism. Since PT is inserted in the middle of the radius and generally has to be harvested with a 10-cm strip of periosteum for gaining adequate length (Fig. 3a) to be attached to FPL in the distal forearm [7], the incision needs to be extended more proximally mandating more dissection. Hence, we preferred the transfer of the BR tendon to the FPL tendon for restoring lateral thumb pinch and used PT as the second donor to empower FDP for restoring hook. In cases where the strength of BR was unsuitable for transfer, we used PT for pinch reconstruction, and hook in these patients was simultaneously empowered by tenodesis of FDP tendons onto themselves. FDP tenodesis was also employed in patients where BR had been employed for pinch reconstruction, but this has

Table 4 Comparison of hook strength with other studies [9, 12, 17]

Study	No. of limbs reconstructed	Measurement (kg)
House et al. [9]	10	5.5
House and Shannon [10]	12	3.5
Kelly et al. [12]	24	2.81
Mohammed et al. [17]	57	2.1
Our series	18	2.76

Objective measurements of function reported in other series

Table 5 Subjective outcome of various studies [6, 7, 9, 13, 17]

Study	Year	No. of cases	Test	Positive results (%)
Hentz	1983	33	ADL	55
Lamb and Chan	1983	41	Lamb and Chan	83
Waters	1985	15	ADL	87
Riser	1986	9	Test of Jebsen	80
Ejeskar	1988	43	ADL	90
Gansel	1990	11	ADL	90
Vanden Berghe	1991	13	9 hand activities	100
Mohammed	1992	57	Lamb and Chan	75
House	1992	18	ADL	94
Paul	1994	9	ADL	77
Freehafer	1998	285	Not detailed	95
Our series	2011	18	ADL	70

ADL activities of daily living score

an inadequate strength of pronation of the forearm. We did not find complex grading involving sensory/ocular impairments to be of much use as did Lamb and Chan [13], and also, we recommend single-staged bilateral procedures to maximize rehabilitation which has been advocated by most authors [14, 17]. Although the procedures on both left- and right-sided upper limbs turned out to be equally efficacious, when consent was only for one side, we preferred operating on the dominant side. The experience of the surgeon is no doubt a crucial factor in determining the success of these procedures, as evidenced by the fact that we had better results with the patients operated in the latter half of the study, and an important part of treatment remains good planning and appropriate patient selection. Patients must be strongly motivated and cooperative enough to undergo a long postoperative rehabilitation regime [16]. We were lucky enough to have a separate rehabilitative unit in our hospital to ensure good supervision during patient rehabilitation. Considering the possibility of development of early joint contractures owing to the lack of health care facilities in most developing setups, we advise taking up patients even 6 months post injury if the surgeon feels any expected improvement is unlikely, rather than waiting for the routinely advised interval of 1 year [14, 17].

It is extremely difficult to assess and compare results after this type of surgery owing to the heterogeneity of neurological deficits and the functional demands exhibited by the patients. While subjective assessment assesses the patient's impressions of the overall results, objective results may correlate poorly with functional outcome [17, 18]. Tables 3, 4, and 5 give a comprehensive comparison of our objective and subjective outcomes as against the reports in literature, and the depiction shows us to be well within the approximation of the results attained by various other authors working on similar procedures.

Table 6 List of common complications of various studies [5, 17]

Common complications	Studies		
	Forner-Cordero et al. [5] Number	Mohammed et al. [17] Number	Our series Number
Wound infections	0	4	1
Ruptured anastomosis	0	5	3
Inadequate thumb IP joint stabilization	–	11	Nil
Thumb hyperflexion	2	–	3
Pain	1	–	–
Total no. of reconstructions	15	57	18

IP interphalangeal

We did confront a few notable complications which have been tabulated and compared with other authors in Table 6. In Fig. 6, 16.6 % upper limbs developed the problem of thumb hyperflexion. In these cases, the thumb hyperflexed into the palm prematurely when the wrist was dorsiflexed, thus making key pinch ineffective apart from obstructing finger flexion. Rupture of extensor pollicis longus (EPL) tenodesis to the distal radius was projected to be the culprit although there is a possibility of inappropriate tension being set while transferring BR to FPL. To tackle the problem, the patients were told to hold the thumb out against the side of a table or a wheelchair while fingers were being flexed, then bringing the thumb against the side of the index finger [13]. Arthrodesis of the metacarpo-phalangeal joint was fortunately not required. Intraoperatively, we recommend that such a complication can be prevented by ensuring that the donor muscle is attached to

FPL with elbow in 90° flexion, wrist in neutral position, and the thumb pad just falling short of contacting the middle finger [11]. The only case of superficial wound infection responded adequately to antibiotics. We must highlight that we confronted no complications regarding the use of split FPL transfer to stabilize the thumb interphalangeal (IP) joint which is currently the most recommended method by all authors. The transfer equalizes the pull in the volar and dorsal aspects of the thumb IP joint, effectively stabilizing the thumb during flexion [5, 8, 17].

The most encouraging aspect of the study was that even though 30 % of our results were poor as per the modified Lamb and Chan score, none of the patients made a remark that his/her functional capability in any way had deteriorated after the operation. The poor results encountered were mainly in those cases where either the joints were not adequately supple or patient motivation was not good. Neither age, duration of tetraplegia, nor level of spinal cord lesion seems to bear any significance altering results under any circumstances. An independent remark was taken in the end from every subject regarding his/her satisfaction from the surgery. Analysis revealed a very surprising fact as shown in Fig. 7. Even though only four of our patients reported that they had gained power useful enough to benefit their everyday life, seven patients reported that they were satisfied. This clearly reflects the fact that even in cases where objective gains achieved are minimal,

Fig. 6 Complication of thumb hyperflexion that likely resulted from maltensioning **Fig. 7** The relation between patients' satisfaction and objective gains achieved from these procedures

that extra bit of independence provided ensures that the functional benefit is maximal. Hence, we strongly recommend that all patients must be clearly and cautiously explained that the gain expected after surgery might only be minimal, but the functional benefit would be maximal. The surgeon must refrain from being over optimistic while counseling the patient as this may make the subject to set false functional goals. But yes, one can be counseled that gaining independence would provide greater psychological stability which may lead to resolution of many chronic problems like we had two patients who showed healing of their bed sores after surgery. Although not all but a couple of our patients were able to find for themselves a suitable vocation. One of them is presently writing articles for a local newspaper and another one, a 22-year-old graduate student, is presently pursuing his higher studies.

The major limitation of our study was a small sample size due to lack of motivation among our patients, short survival of tetraplegics owing to lack of medical care facilities, limited patient resources and access to health care, and above all, lack of adequate and transparent knowledge among practitioners regarding results of these procedures, precluding them from making appropriate referrals and lack of information among patients regarding the outcome and benefits of this surgery, which has also been cited by other authors [3, 23]. This is based on their belief that objective gain expected is minimal. But unfortunately, objective assessment in these cases may not correlate with functional gain. Even with minimal objective benefit, a good subjective outcome may result [5, 17, 18].

To conclude, we would recall what Bunnel had stated long time ago, “To the patient who has nothing, a little becomes a lot.” Hence, reconstructive surgical procedures can be routinely offered to suitable tetraplegics with injury at or distal to C6 cervical cord level, with concerned upper limb falling in IC-4 category or higher, at least after 6 months of injury, who fit well into the selection criteria and are motivated enough to comply with the long postoperative regime, but only after thorough and cautious counseling in regard to the benefits expected from surgery. The general principles of tendon transfers are to be respected, but at times, one should be creative enough to bend some of the rules as per the situation requires. However, the surgeon must understand that surgery is only an aid and not a substitute to other rehabilitative measures. The complex process of rehabilitation actually requires a focused team approach with the patient’s family and the patient himself being an important part of the team.

Conflict of Interest Mukul Mohindra declares no conflict of interest. Sukhbir Singh Sangwan declares no conflict of interest. Zile Singh Kundu declares no conflict of interest. Paritosh Gogna declares no conflict of interest. Anurag Tiwari declares no conflict of interest. Ankit Thora declares no conflict of interest.

Statement of Human and Animal Rights All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent The study was performed after taking informed consent from all patients.

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