Early Active Rehabilitation After Grip Reconstructive Surgery in Tetraplegia

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Abstract
Objective: To describe and evaluate the concept of early active rehabilitation after tendon transfer to restore grip function in tetraplegia.

Design: Retrospective cohort study.

Setting: Two nonprofit rehabilitation units in Sweden and Switzerland.

Participants: All patients with tetraplegia who underwent tendon transfer to restore grip ability during 2009 to 2013 (N = 49).

Intervention: Reconstructive tendon transfer surgery with early active rehabilitation to restore grip ability in tetraplegia.

Main Outcome Measures: Grip and pinch strength, grip ability test, and outcome of prioritized activities.

Results: In the 49 surgeries performed, postoperative complications included 2 patients with bleeding and 2 infections related to the surgery. There were no reported ruptures or lengthening of transferred tendons. Within 24 hours after surgery, all 47 patients (100%) with finger flexion reconstruction succeeded to activate their finger flexion. All but 1 patient with reconstructed thumb flexion successfully activated their thumb flexion (n = 40). Three weeks after surgery, all patients (100%) were able to perform basic activities of daily living, and instrumental activities of daily living were achieved by 74%. One year after surgery, the maximum grip strength in restored finger flexion was on average 6.9 kg (range, 1.5–15 kg; n = 29). The maximum pinch strength in restored thumb flexion was on average 3.7 kg (range, 1–20; n = 29). On average, grip ability improved from 33 to 101 (n = 19) according to the COPM. Prioritized activity limitations, as measured with the COPM, equated to an average of 3.5 steps (2.5 steps preoperatively to 6 steps postoperatively). Patients’ perceived satisfaction with this improvement was 4 steps (increasing from 2 steps preoperatively to 6 steps postoperatively).

Conclusions: Grip reconstructive surgery followed by early active rehabilitation can be considered a reliable procedure that leads to substantial improvements in grip and pinch strength and activity performance among patients with tetraplegia.

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approximately 10 times the force produced during active range of motion (ROM). As a consequence, the postoperative rehabilitation strategies must be adapted to optimize the result of the intervention.

The initiation of grip reconstructive surgery rehabilitation protocol in tetraplegia varies around the world. This article will focus on the concept of early active rehabilitation and the importance of activity-dependent muscle reeducation. In tetraplegia hand surgery in Sweden, early mobilization of transferred tendons has been performed since 1995, and the full early active rehabilitation protocol has been used since 2008. The aim of this article is to describe the concept of early active rehabilitation after tendon transfers to restore grip function in tetraplegia and its short and long-term clinical outcomes.

Methods

Early active rehabilitation protocol

Overview
A full grip reconstruction (alphabet procedure) may include up to 7 individual operations. Therefore, it is critical that the therapists are familiar with all of the surgical procedures and how they interact with one another in terms of training. Moreover, the patient must also understand the principles of the surgery and the postsurgical training in order to stay motivated and ensure that restrictions are followed. The therapists therefore play important roles in educating, supporting, and guiding the patient through the postsurgical training.

The early active rehabilitation protocol includes 2 parts: early mobilization of transferred tendons and a muscle reeducation rehabilitation program subsequently described.

Early mobilization after tendon surgery is a common treatment strategy in various types of hand surgery (eg, flexor tendon surgery) and has been used after grip reconstruction in tetraplegia since 1995. The benefits of early mobilization include reduced risk of adhesions, joint stiffness, muscular atrophy, and swelling. It also helps to maintain the neuromuscular and contractile function of transferred muscles, shorten postoperative rehabilitation periods, and improve outcomes.

The second cornerstone in early active rehabilitation is the muscle reeducation approach to promote active use of the transferred muscles. An activity-dependent approach enhances patient empowerment by letting them be actively engaged in their own rehabilitation and helps them to gain confidence in their ability to manage their everyday lives. Some patients hesitate to undergo surgery because of the decreased degree of independence that follows the postsurgical phase. In general, they have often worked hard to maximize their level of independence and regain roles in their families and are afraid to impair their acquired quality of life, even for a limited period of time. For these patients, minimal restrictions are critical in the process of deciding whether they will undergo surgery. Even if restrictions are imposed after surgery, patients are encouraged to be as active as possible in their daily lives. In this way, general fitness and independence are maintained to the greatest extent possible.

Preoperative preparation
Grip reconstruction is a combination of intricate procedures that requires the patients to be actively engaged in the rehabilitation process. Patient education is therefore a prioritized part of the early active rehabilitation concept. It also requires frequent communication between the surgeon and therapists. Therefore, rehabilitation planning starts prior to surgery. Patients need to be well informed about the surgical procedure and the postsurgery rehabilitation strategies to ensure they are prepared, focused, and actively engaged in the training. A slightly adopted version of the Canadian Occupational Performance Measure (COPM) is used to inform about patients’ expectations and serves as a guideline for postoperative activity training. It is also used as a patient rated activity outcome.

Preparations are made to address maintenance of important daily activities by means of environmental adaptations, changed techniques to facilitate for example transfers, altered technical aids, and temporary increased levels of assistance.

First days postsurgery
At this stage, the essential components of the rehabilitation program are edema control, protection of the transferred tendons, and controlled mobilization of the operated areas to prevent adherence of the healing tissue. The day after surgery, the surgical dressings are changed, and a smooth compression wrapping is applied with the aim to prevent edema without restricting active movement. A custom-made splint (subsequently described) holds the wrists and digits in a position that aims to unload the attachment sites and produces effective compression. Activation of the transferred muscles and passive movement of tenodesis functions are performed with careful instructions from the therapist several times per day, starting within 24 hours after surgery.

Splinting
The optimal position of the hand in the splint depends on the combination of surgical procedures used. The general aim is to position the structures in a relaxed but lightly stretched position to minimize stress to the transferred tendons. There is, however, no need to restrict elbow extension even if the brachioradialis (BR) (still working as an elbow flexor) is transferred. Studies have demonstrated that the attachment site of the sutured BR has a safety factor of at least 10 times the expected load resulting from active contraction, independent of the position of the elbow and wrist. To support the venous blood flow, the splint is applied on the volar side of the forearm with elastic bands over the dorsal aspects of the fingers, hand, and lower arm. This arrangement facilitates higher compression on the volar aspects of the hand, resulting in fluid being pressed dorsally, where most of the venous blood flow from the hand is located. At rest, and during periods of the day involving lower levels of activity, patients are encouraged to place the arm in an elevated position to control postsurgical edema. The splint is adapted to enable activities (eg, independently putting it on and removing it, driving a wheelchair, typing on a computer, assisting during catheterization) (fig 1).

List of abbreviations:

- ADL activities of daily living
- BR brachioradialis
- CMC1 first carpometacarpal joint
- COPM Canadian Occupational Performance Measure
- ROM range of motion
Training protocol for muscle reeducation

The initial postoperative training is mainly focused on 2 aspects: voluntary activation of the transferred muscle and maintaining the slide of tendon structures to avoid adhesions. Because the tendons are sutured using the side-to-side technique, the new tendon configuration is strong enough to be fully exercised immediately after surgery. It takes a force of 200N to load a tendon to failure, which provides a safety margin of approximately 10 times to perform active ROM training.3,4

Within the first 24 hours after surgery there is minimal resistance to the initial movements because the postoperative swelling has not yet fully developed. The aim is to facilitate motor relearning by exteroceptive stimuli (eg, sight, sensation) and using the proprioceptive input from muscle stretch. Because of consequences of the spinal cord injury, sensation and proprioceptive input are often limited or absent. Therefore, visual perception is important when learning how to activate the new functions.

To facilitate voluntary activation of a transferred tendon the patient is encouraged to focus on the motion that the transferred muscle had in its original functional position. For example, if the BR was transferred to replace the action of the flexor pollicis longus of the thumb, the patient is instructed to think about bending the elbow when trying to actively flex the thumb and then encouraged to visually observe and sense (when possible) the new movement produced.

Moreover, it is of the utmost importance to maintain the structures sliding, with the aim of preventing adhesions and maintaining muscle fitness. Here, active exercise of the transferred muscle in as large a ROM as possible is essential. To reestablish mobility and control of the transferred muscle-tendon units and maximize tendon gliding, isodynamic or light resistive ROM exercises are applied. External resistance has empirically been shown to increase muscle activation and makes it easier to achieve the full active ROM allowed. This is initially performed by applying some resistance to the transferred donor muscle’s original function. As in the previous example, applying resistance to elbow flexion when BR has been transferred to the tendon of flexor pollicis longus will facilitate voluntary activation of the BR in thumb flexion (pinch). If full active range of the new function cannot be achieved, the patient is encouraged to continue the movement passively, with assistance from the other hand, but still maintaining full activation of the transferred tendon. This is done to stimulate full sliding of the tendon.

To maintain the slide of tendon structures, passive movements are also performed. Passive movements typically intend to maximize the sliding between parallel tendon structures (eg, individual finger movements). It can also include active movements to exercise a passive tenodesis, produced by the surgery. An example is wrist extension and flexion, which can serve to exercise a tenodesis of thumb extension and flexion.

One advantage of early mobilization is to initiate the process to reestablish mobility and control of the transferred muscle-tendon units before resistance mediated by adhesions can limit the motion. The adhesion-mediated resistance is usually notable approximately 2 weeks postsurgery, when the myofibroblast in the wound starts to organize.12 It is important to inform the patient that the training might need to be slightly intensified at this time point. One additional rationale for early mobilization is based on the theoretical framework proposed by Sultana et al, that early mobilization leads to an early activation of the motor cortex and thereby improves the efficiency in attaining functional outcomes.7 In a similar study it was hypothesized that early mobilization of tendon transfer allows the brain to immediately use the activation of preexisting synergistic cortical finger movement programs, whereas immobilization may temporarily erase these neuronal networks.13 Additional studies have shown that the brain reorganizes rapidly, as soon as 48 hours after immobilization, demonstrated by a decrease in the cortical thickness in the primary motor and somatosensory areas.14,15

Training during the first few days postoperatively is performed 4 times over the course of the day, and exercises are carefully and gradually progressed. All restored movements are performed between 7 and 10 times per session. Multiple daily training sessions are important to prevent adhesions, but also for stimulating motor control and, we expect, to promote reorganization of the brain’s motor cortices. In case of restricted motion in structures after surgery, usually caused by edema or if the brain does not immediately adapt and reeducate itself, the number of repetitions is sometimes increased. On the other hand, if the transferred muscles were weak prior to surgery, or if the training enhances muscle fatigability in the transferred structures, the number of repetitions is sometimes reduced. A tailor-made and individually targeted training program is created; this includes images of the patient’s own arm and depictions of all exercises. The therapist thereafter teaches the patient to self-train, and after a few days the patient is able to take full responsibility, having learned how to perform the training program themselves or, if needed, with assistance.

Maintaining activities during the first weeks

Patients are instructed and encouraged to use the arm and hand as much as possible, as long as the splint is used. For example, starting the day after surgery, patients are encouraged to propel their manual wheelchair (if applicable). Adaptations and technical aids are customized to maintain individuals being as independent as possible, with the splint on. As previously mentioned, splint adjustments are also made so that the arm can be used as much as possible. The aim of the general active approach is to prevent edema by activating the muscle pump, avoiding pressure ulcers by moving in the wheelchair, maintaining general fitness, and most importantly, maintaining independence and control of their life.

Provided that arrangements in the patient’s home environment are in place, patients are generally discharged from the hospital 3 days after surgery. With guidance from an individually adjusted training program, they are encouraged to continue the training at home. If needed, telephone follow-up arrangements are made. However, some patients had to stay in hospital up to 10 weeks, because of environmental issues in their home.

Fig 1 Postoperative volar splint adapted to enable driving a wheelchair, putting the splint on and removing it independently, and typing on a computer.
Three weeks postsurgery

The patient returns to the clinic for a check-up and 5 days of intensive rehabilitation. The aim is to progress the training of functions, initiate activity training, and stimulate patients’ belief in their restored functions. Training is performed under the supervision of an occupational therapist and a physiotherapist, 4 to 5h/d.

Splints

From now on, the volar splint is only used during the night, until 3 months postsurgery. In case of a prominent edema, continued use of the volar splint is recommended some hours in the daytime, in combination with an elevated position during rest.

If a fusion of CMC1 was included in the grip reconstruction, a small custom-made splint to protect the fusion from high pressure was made. It is critical that the splint supports only CMC1 and lets the wrist and all 5 metacarpophalangeal joints move freely (fig 2). It is particularly important that the metacarpophalangeal joint of the thumb can move freely because movement in both the CMC1 and interphalangeal (IP) joints are restricted. The small CMC1 splint is adapted with rubber to enable to propel a manual wheelchair and is kept in use during the day until 10 weeks postsurgery. In case it restricts daily activities it may be temporarily removed, if the activity does not include high pressure on the CMC1.

Progression of muscle reeducation training

The training of functions now concentrates on trying to isolate the new movements and coordination and force regulation of the restored functions. As soon as the patient has achieved full ROM, without the need for external resistive force, dynamic exercises are commenced. Training is performed within active ROM, and no force is applied to increase ROM. If the surgical procedure included the combination of intrinsic and active finger flexion reconstruction, the initial 4-cm restriction of pulp-to-palm distance in finger flexion is phased out; that is, a gradually increased flexion is allowed during the next couple of weeks. In case the restored thumb flexion improves rapidly, protection of the interphalangeal joint thumb tenodesis is recommended for some additional weeks. As soon as the patient is able to use the regained functions in daily activities, the functional training is decreased.

Training in activities

After 3 weeks, patients are encouraged to use their restored functions in daily activities (fig 3). There are no general restrictions in terms of light or heavy activities. Postoperative swelling and limited ROM, and fear and pain, are usually factors that inhibit the activity-related training. It is important that the patients starts to use their hands in daily life and thereby achieves the important early benefits of using the hand in daily activities. Adaptations (eg, thickening grips, antislide attachments) are frequently used. It extends patients’ ability to function over a longer period of time. For example, antislide attachments attached on a fork can enable the grip to last for a whole meal, whereas a thickened grip on a hairbrush provides strength enough to brush the hair.

If possible, patients are trained in activities that were prioritized prior to surgery (in the COPM) to have them experience early desired benefits from surgery. Early benefits have shown to stimulate patients’ determination to achieve a higher level of independence, which is crucial for a successful rehabilitation outcome. Also, improved confidence in hand ability is a key element in the rehabilitation process. With these personal ingredients secured, the patient can establish hand control in daily life, challenge dependence, habits, and roles and finally reach the desired level of independence. In the early stages of the process, patients are more dependent on external input (eg, therapist guidance), but as confidence in ability increases, the need for external input decreases.

When a patient has learned how to activate a restored grip, some of the compensatory movements in the arm and shoulder are no longer needed. The rehabilitation therefore includes upper-extremity posture analyses, and in certain cases the therapist assists the patient in relearning more functional postures and ergonomic movement patterns.

However, despite early rehabilitation, limitations in ROM often restrict daily life activities 3 weeks after surgery. Restricted wrist extension also coincides with the ongoing healing process in the
fusion of CMC1. Therefore, transfers are often restricted until 8 to 12 weeks after surgery.

Three months postsurgery
Strength training of transferred tendons is now fully allowed and encouraged. There are no remaining restrictions in the use of the hand, except for when playing rugby, which has an additional 4 weeks of restrictions. At this stage, the therapist needs to investigate how well the patients use their hands in daily life. The process of achieving greater independence continues for at least a year after surgery. The therapists have important roles to ensure that patients continue to make progress in terms of self-confidence in their hand ability.

Study design
A retrospective design was used to evaluate the results from the early active rehabilitation concept. Data were collected from medical records after routine clinical follow-ups. The first evaluation is performed within the first 24 hours and thereafter at 3 weeks postsurgery. This evaluation only includes the Swedish population (n=41). The second evaluation is performed 1 year after surgery. The 1-year follow-up includes both the Swiss (n=8) and Swedish populations (n=41).

Participants
All patients with tetraplegia that underwent grip reconstruction and subsequent early active rehabilitation between 2009 and 2013 in Gothenburg, Sweden, and Nottwil, Switzerland, were included in this retrospective study. Eligibility criteria were geographic location of patient that enables the rehabilitation team to conduct a 1-year follow-up.

Grip reconstruction was defined as a surgery performed with the aim to improve grip ability with minimum 1 tendon transfer to restore grasp and/or pinch. Each surgery was individually designed based on the number of muscles available for transfer because of the spinal cord injury, together with patients’ needs and wishes.

Outcome measurements
To follow patients’ development during postoperative treatment and rehabilitation, evaluations were done within 24 hours and after 3 weeks. The outcome from surgery and rehabilitation were evaluated 1 year after surgery (table 1).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Preop</th>
<th>24h</th>
<th>3wk</th>
<th>1y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grip strength (grasp/pinch)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRT</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>COPM</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Volume of the hand (mL)</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Full activation of restored functions (y/n)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance of basic ADL (y/n)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Performance of instrumental ADL (y/n)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: GRT, grasp and release test; Preop, preoperative; y, yes.

In patients with reconstructed finger flexion, the ability to actively flex the fingers, within the allowed ROM, was evaluated (yes or no). Because of intrinsic reconstruction, the ROM in finger flexion was restricted to 4-cm pulp-to-palm distance. When thumb flexion was restored, the patients’ ability to flex the thumb fully against the index finger was evaluated (yes or no). Three weeks after surgery, the ability to use the restored functions in activities of daily living (ADL) was evaluated (yes or no). The results were divided into basic ADL (eg, self-care) and instrumental ADL (eg, household activities).

Evaluations 1 year postsurgery
Maximum grip strength was measured (kg) by the Jamar hand dynamometer. Maximum key pinch strength was measured (kg) by the Preston Pinch Gauge.

Grasp and release functions were evaluated using the grasp and release test. The grasp and release test is a pick-and-place test that requires the participant to unilaterally acquire, move, and release 6 objects varying in weight and size. The score is comprised of the total number of repetitions achieved in a 30-second trial for all 6 objects. The test was performed preoperatively and at the 1-year follow-up. The grasp and release test were added as an outcome measure in 2012.

Activity improvement was measured using a slightly adapted version of the COPM. The adaptation was made before surgery, when the patients were asked to specify which of the activity limitations, related to restricted hand function, would be most valuable for them to improve via the surgical procedure and postsurgical rehabilitation. The original COPM asked for activity limitations in general. Thereafter, the COPM was used as originally intended. Patients were asked to report up to 5 of the most relevant activity limitations. Patients were also asked to rate each performance level prior to surgery and the satisfaction with the same on a scale ranging from 1 to 10. The ratings were performed preoperatively and at 1-year follow-up.

Data analysis
Continuous data are presented using mean ± SD, whereas ordinal data are presented with median and range or as otherwise noted.
To evaluate the differences between pre- and postsurgery, paired r test was used for continuous data and Wilcoxon signed-rank test was used for ordinal data. The level of significance was set at P<.05.
Results

The follow-up data include 49 patients, among whom 41 patients had surgery in Gothenburg, Sweden, and 8 patients had surgery in Nottwil, Switzerland. Among these were 35 men and 14 women. The mean age was 42 years (range, 21–73y), and time after injury varied between 1 and 27 years (mean, 6y). Severity of injury was measured with International Classification of Hand Surgery for Tetraplegia.\(^{19}\) The International Classification of Hand Surgery for Tetraplegia specifies the number of innervated muscles below the elbow with muscle grade ≥4, which reflects the number of preserved muscles available for transfer (table 2).

Depending on the number of muscles available for transfer and patients’ needs and wishes, the surgeries included various procedures (table 3). Finger flexion (grasp) was restored in 43 hands, and thumb flexion (pinch grip) was restored in 39 hands. In 5 hands, active wrist extension in combination with passive thumb flexion and extension (tenodesis) to produce a tenodesis pinch were performed.

Complications

In the 49 surgeries performed, complications included 2 patients with hematoma and 2 patients with superficial wound infections postoperatively. However, neither of these complications affected the outcomes. There were no ruptures or lengthening of transferred tendons reported in the group, but some occasional lengthening in the interphalangeal tenodesis of the thumb and in the passive intrinsic reconstructions were noted. One patient with extensor carpi radialis longus transfer became weak in his wrist extension and is awaiting a reoperation to restore the function.

Outcome within the first 24 hours postsurgery

Within 24 hours after surgery, all 41 Swedish patients (100%) with restored active finger flexion were able to perform an active movement. Thirty-eight (97%) out of 39 patients who had a restored active key pinch were able to achieve an active pinch. The reason for the single patient not being able to activate the restored function was the pain experienced the first 24 hours. The subsequent day the patient successfully performed the restored movement. All patients, except the one with bleeding complications, were discharged home 3 days after surgery.

Outcome 3 weeks postsurgery

The 2 patients with postsurgical infection were excluded at this time point because they were not allowed to be active. Three weeks after surgery, 11 patients underwent volumetry of the hand.\(^{17}\) The results showed that the mean increase caused by swelling of the hand was 67±28mL (range, 25–100mL), which is equivalent to an average of 24%. Even though the swelling was considered substantial, it did not interfere significantly with the training. The ability to activate the restored functions in fully allowed ROM after 3 weeks was also recorded. Full thumb flexion was accomplished in 29 (74%) out of the 39 patients who had undergone restoration of active thumb flexion. Twenty-three (70%) out of 33 patients managed to reach the fully allowed active ROM in finger flexion at the 3 weeks follow-up (restricted to 4-cm pulp-to-palm distance until 3wk postsurgery because of intrinsic reconstruction).

All 39 patients (100%) were able to perform basic ADL 3 weeks after surgery (see fig 3). The ability to perform instrumental ADL was achieved by 29 of 39 patients (74%) 3 weeks after surgery (fig 4). Basic activities were typically fundamental self-care activities or driving a wheelchair, whereas instrumental ADL included kitchen activities or simple technical activities.

Outcome 1 year postsurgery

One year after surgery, the maximum grip strength in the restored finger flexors and maximum pinch strength in restored thumb flexors were on average 6.9 and 3.8kg, respectively. As measured

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**Table 2** Classification of preserved functions in the study group

<table>
<thead>
<tr>
<th>ICSHT</th>
<th>Preserved Muscles in the Forearm</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BR</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>BR, ECRL</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>BR, ECRL, ECRB</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>BR, ECRL, ECRB, PT</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>BR, ECRL, ECRB, PT, FCR</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>BR, ECRL, ECRB, PT, FCR, EDC</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>49</td>
</tr>
</tbody>
</table>

Abbreviations: ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; EDC, extensor digitorum communis; FCR, flexor carpi radialis; ICSHT, International Classification of Hand Surgery for Tetraplegia\(^ {19}\); PT, pronator teres.

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**Table 3** Surgery procedures included in the study population

<table>
<thead>
<tr>
<th>Restored Function</th>
<th>Active Tendon Transfer</th>
<th>n</th>
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<tbody>
<tr>
<td>Active finger flexion</td>
<td>ECRL to FDP</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>BR to FDP</td>
<td>5</td>
</tr>
<tr>
<td>Active thumb flexion</td>
<td>BR to FPL</td>
<td>39</td>
</tr>
<tr>
<td>Active wrist extension with passive thumb flexion</td>
<td>BR to ECRB</td>
<td>5</td>
</tr>
</tbody>
</table>

Abbreviations: ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; FDP, flexor digitorum profundus; FPL, flexor pollicis longus.

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Fig 4 Activity training (doing the dishes) 3 weeks postoperatively.
The early active rehabilitation concept aims to reduce patients’ hospitalization and postsurgical restrictions. All 39 Swedish patients in our study were able to perform basic daily activities 3 weeks after surgery, and all except 1 were discharged home 3 days after surgery. Because extended hospitalization and restrictions in daily life after surgery make some patients hesitate to undergo such procedures, these are important factors to consider. The early active rehabilitation concept actively enhances patient empowerment by enabling patients to be actively engaged in their own rehabilitation and helps them to gain control and confidence in their ability to manage their everyday lives. Perceived control is known to be associated with emotional well-being, reduced physiological effect of stressors, enhanced ability to cope with stress, improved performance, reduced pain, and a greater likelihood of being able to make difficult behavioral changes. The empowerment of patients, and making arrangements to maximize their activity level, is especially important during the period of restriction after surgery.

In a previous article from Wangdell et al., it was demonstrated that patients’ determination to achieve greater independence is what drives them throughout the rehabilitation process. Furthermore, it has been found that experiences of early benefits, and belief and confidence in their ability, is the key to establishing hand control in daily life, challenging dependence, habits, and roles and finally reaching the desired level of independence. By supporting, encouraging, and coaching individuals in their progress toward greater independence, the chances of achieving a good clinical outcome are optimized. Therefore, training of both function and activities is crucial in the rehabilitation after grip reconstruction. The results from surgery not only contribute to restored function, but also to well-integrated hand function in daily life. A successful rehabilitation has the potential to contribute to practical and social and psychological gains in the individual’s life.

Before the early active rehabilitation concept was established in 2008, postsurgical swelling was a frequent complication that greatly aggravated rehabilitation in our clinic. Patients who were treated according to the older and more restricted rehabilitation protocol were often shown to not achieve full active ROM in restored functions 4 weeks after surgery. In addition, at that time point, the remaining functional limitations in these patients commonly interfered with their activity-related training. The main objective of early active rehabilitation is to speed up the recovery process.

The results of this study show that grip reconstructive surgery followed by early active rehabilitation can be considered a safe procedure with a predictable and positive outcome. Most patients managed to activate the restored functions within 24 hours, and all patients were able to use their hands in daily activities 3 weeks after surgery. There were no ruptures or elongations of transferred tendons. The results 1 year postoperatively demonstrated substantial improvements in grip and pinch strengths and activity performance (fig 5).

Early mobilization protocols after tendon transfer surgery have been applied for almost 20 years, and the early active rehabilitation concept has been used for 6 years. The long-term results of early active rehabilitation seem to be promising compared with previously reported outcomes after grip reconstruction. In a systematic review of 23 articles by Hamou et al that includes 377 pinch reconstructions, the average restored pinch strength was 2.0 kg, compared with 3.7 kg in our study sample. However, because of the lack of previously published articles describing rehabilitation procedures in detail, comparisons are not possible. Differences in surgical techniques between centers may also complicate comparisons between rehabilitation strategies.

Discussion

The early active rehabilitation concept aims to reduce patients’ hospitalization and postsurgical restrictions. All 39 Swedish patients in our study were able to perform basic daily activities 3 weeks after surgery, and all except 1 were discharged home 3 days after surgery. Because extended hospitalization and restrictions in daily life after surgery make some patients hesitate to undergo such procedures, these are important factors to consider. The early active rehabilitation concept actively enhances patient empowerment by enabling patients to be actively engaged in their own rehabilitation and helps them to gain control and confidence in their ability to manage their everyday lives. Perceived control is known to be associated with emotional well-being, reduced physiological effect of stressors, enhanced ability to cope with stress, improved performance, reduced pain, and a greater likelihood of being able to make difficult behavioral changes. The empowerment of patients, and making arrangements to maximize their activity level, is especially important during the period of restriction after surgery.

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Fig 5 Presurgery writing performance, two-handed (A) compared to 3 weeks follow-up (B).

Table 4 Follow-up assessment data at 1-year follow-up

<table>
<thead>
<tr>
<th>Measure</th>
<th>n</th>
<th>Preop</th>
<th>1y Postop</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jamar grip strength (kg)</td>
<td>29</td>
<td>0.4±1.1</td>
<td>6.9±3.6</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Pinch (kg)</td>
<td>29</td>
<td>0.3±1.0</td>
<td>3.8±3.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>GRT</td>
<td>19</td>
<td>33±20</td>
<td>101±38</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>COPM performance</td>
<td>38</td>
<td>2.5±1 (1–8)</td>
<td>6.0 (1–10)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>COPM satisfaction</td>
<td>38</td>
<td>2.0±1 (1–8)</td>
<td>6.0 (1–10)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

NOTE. Values are mean ± SD, mean (range), or as otherwise indicated. Abbreviations: GRT, grasp and release test; Preop, preoperative; Postop, postoperative.
process to improve patients’ ability to perform tasks in their daily lives as efficient as possible. When the early active rehabilitation concept is applied, the postsurgical swelling may cause some functional limitations, but does not usually have a major effect on the training 3 weeks after surgery.

Early motor training appears to accelerate successful muscle reeducation. There is a growing body of evidence that senses and visual input can be used to modulate cortical plasticity. The use of sensory and visual feedback is therefore thought to be of particular importance in the early phase of the motor training.20 However, knowledge related to how the brain relearns after tendon transfer is limited. Plasticity within the primary motor cortex has been described in relation to recovery after acquired brain injuries (eg, stroke, brain trauma20,31). The plasticity associated with motor relearning after tendon transfer is still an underinvestigated field. Nevertheless, our patients start the relearning process immediately after surgery. After 3 weeks of training, patients have learned to voluntarily activate the transferred donor muscle in its new anatomic location and coordinate movements with new synergists during ADL. Our clinical experience is that patients find their restored functions relatively soon after surgery, without having to concentrate on the donor muscles’ previous functions. The fact that the patients succeeded in activating the restored functions soon after surgery may shed light on the brain’s capacity to adapt to peripheral changes. Investigations of the cerebral plasticity accompanying regained motor function after tendon transfer procedures have a great potential to improve our knowledge and thereby our rehabilitation strategies after tendon transfer surgeries.

Even when early and relatively aggressive mobilization strategies are used after surgery, tendon adhesions remain one of the most common complications. The remaining prevalence of adhesions, and the fact that no rupture has ever occurred after surgery, might indicate that the training could be even more progressive than suggested in this article. Future studies should address this question. A great deal remains when it comes to understanding the functional recovery and neuroplastic processes after tendon transfer, and further investigations are therefore required. Moreover, prospective studies comparing different rehabilitation strategies after tendon transfers are also warranted.

Study limitations
A limitation of this study is its retrospective design, which generated a high dropout rate at the 1-year follow-up. The reason for this is that the grasp and release test and volumetry were not included as outcome measurement until 2012; therefore, the results from these particular measurements cover only a subgroup. The other dropouts are mainly the result of the geographic spread of patients, which made long-term follow-up impossible. The high dropout rate needs to be considered when drawing conclusions from the results of this study.

Conclusions
Grip reconstructive surgery followed by early active rehabilitation can be considered a reliable procedure that leads to substantial functional improvements in grip and pinch strengths and activity performance in patients with tetraplegia. The early active rehabilitation protocol meets patients’ requirements to maintain independence and return early to daily activities.

Supplier
a. North Coast Medical.

Keywords
Quadriplegia; Reconstructive surgical procedures; Rehabilitation; Spinal cord injuries; Tendon transfer; Upper extremity

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References