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Technical considerations and outcome of free functioning gracilis muscle transfer for finger flexion in patients with Volkmann's Ischemic Contracture

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ABSTRACT

Introduction: Severe Volkmann's Ischemic Contracture (VIC) is a reconstructive challenge for the surgeon because of the loss of entire flexor muscle mass and lack of powerful wrist extensors for restoration of finger flexion. In such cases, free functioning muscle transfer (FFMT) using gracilis is our choice. We herein summarize the technical considerations to achieve a successful outcome and report functional outcome achieved in our series.

Patients and Method: Between 2007-2018, 22 patients of VIC underwent gracilis FFMT for restoration of finger flexion. FFMT was done as a second stage following an initial stage of neurolysis/excision of fibrotic flexor muscles/contracture release/flap cover in these patients. Cases were retrospectively reviewed and their functional outcome at a minimum of one-year follow up was analyzed. Follow-up duration ranged from 2-13 years (average-4 years). At the final follow up, the motor and sensory recovery was evaluated using the Medical Research Council Grading and their function using Disabilities of the Arm, Shoulder, and Hand (DASH) score.

Results: The average age at surgery ranged from 3-45 years (average-18.4 years). All the transferred muscles survived. Secondary procedures to further improve the hand function were done in nine patients. The motor recovery for finger flexion was graded as M2 in two, M3 in nine and M4 in 11 cases. These 20/22 patients who recovered M3/M4 finger flexion expressed high satisfaction with the operation while other two also felt that they were better after the surgery. DASH score was available for 13 patients and it averaged 13.21 (Range-1.8-34.5). Grip strength was available for 10/22 patients and it averaged 10.5 kg (range-0-21kg) amounting to 24% of the normal side. The sensory recovery was graded as S4 in two, S3 in 17 and S2 in three cases.

Conclusion: Gracilis FFMT is a reliable option for restoration of finger flexion in patients with severe VIC. Outcome is better when done after an early preliminary stage of excision of fibrosed muscles and neurolysis which allows recovery of intrinsic function and sensation. FFMT is best carried out 3-6 months after the first stage with supple skin and good passive range of movement in the fingers.

Introduction

Volkmann's Ischemic Contracture (VIC) refers to a spectrum of clinical presentations which ensue as a sequelae to missed, or inadequately treated, acute compartment syndrome.[1,2] All the tissues from the skin to the bone are affected to varying level but muscles suffer the maximum in the ischemic insult. The muscle fibrosis that follows ischaemic injury aggravates nerve damage precluding distal motor recovery.

The severity of the muscle paralysis is variable (Table 1)[3], In mild cases, release or lengthening of the flexor muscles and in moderate cases, transfer of the extensor muscles to restore flexor function along with neurolysis are generally satisfactory. However, management of a patient with severe type of involvement is challenging because, the wrist extensors are not available for functional

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Table 1
Tsuge Grading for Volkmann's Ischemic Contracture of the hand and forearm.[3]

Types	Affected muscles	Neurological changes	Finger position
Mild [localized type]	Degeneration of part of the FDP muscle	There are hardly any neurological signs and when present, they are minimal	Contractures in only two or three fingers
Moderate	Degeneration of all or nearly all of the FDP and FPL, with partial degeneration of the superficial muscles as well.	The neurological signs are invariably present and generally the median nerve is more severely affected than the ulnar nerve	Contracture of all fingers, the thumb and often also the wrist
Severe	Degeneration of all the flexor muscles and varying degrees of degeneration of the extensor muscles.	The neurological signs are severe.	Claw hand

FDP- Flexor digitorum profundus; FPL – Flexor pollicis longus

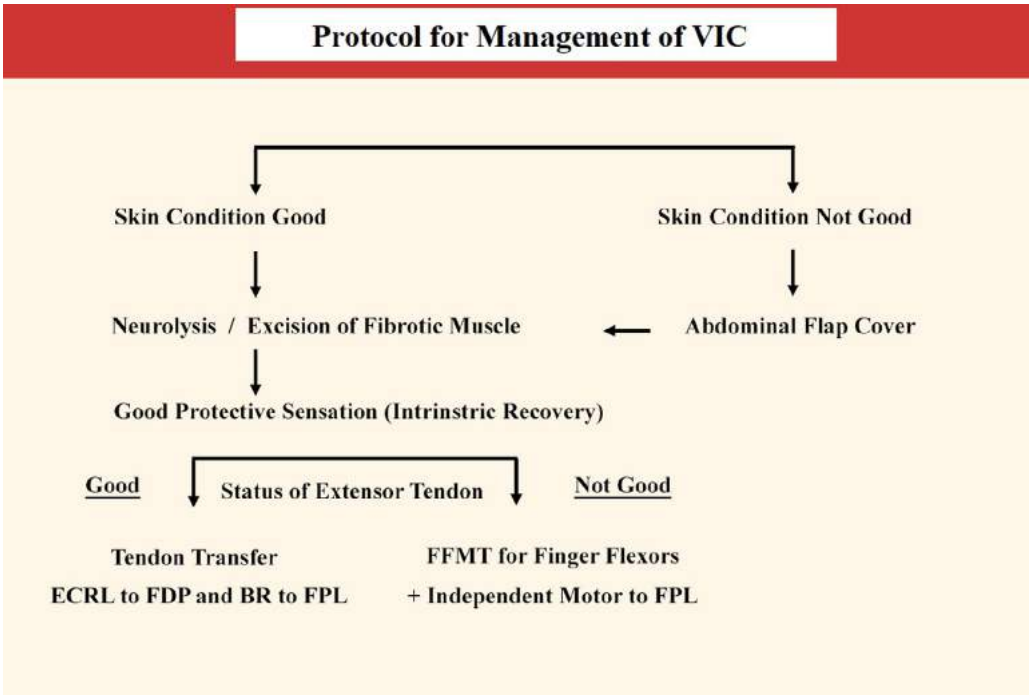

Fig. 1. Protocol for management of VIC- Patients are typically manged in two stages. First stage involves excision of the fibrotic muscle tissue, neurolysis, joint contracture release and addressing the soft tissue deficit if any. Restoration of the finger flexion is done at second stage, generally 3-6 months later, using either the functioning extensors or by a gracilis FFMT.

restoration. In such cases, free functioning muscle transfer (FFMT) plays the prime role. We report the functional outcome of using gracilis as FFMT in 22 patients and highlight the technical considerations necessary to achieve a successful outcome.

Materials and method

At Ganga Hospital, Coimbatore, India, during the period of 2007 to 2018, 22 patients of Volkmann ischemic contracture underwent gracilis FFMT for restoration of finger flexion. Of them 20 were graded as severe and two as moderate as per Tsuge classification (Table 1).[3] All patients had total loss of flexor muscles and the extensor carpi radialis longus (ECRL) was not powerful enough for transfer. FFMT was done as a second stage following an initial stage of neurolysis/excision of fibrotic flexor muscles/contracture release/flap cover in these patients (Fig. 1).

Clinical details of 22 patients were retrospectively reviewed and their functional outcome at a minimum of one year follow up was analysed. Follow-up duration ranged from 2 to 13 years (average 4 years). At the final follow up, the motor power of the finger flexion was evaluated using the British Medical Research Council (MRC) grading and sensory recovery was assessed using the MRC grading for sensory recovery modified by Mackinnon and Dellon.[4,5,6]. Patients were enquired about their use of the reconstructed hand and their function was documented using Disabilities of the Arm, Shoulder, and Hand (DASH) score (English or validated Tamil version of DASH Score).[7,8]

Results

The average age at the time of surgery ranged between 3 to 45 years (average- 18.4 years). There were 14 males and eight females; right side being involved in 10 patients and the left side in 12. The average follow up was 4 years (range 2 years to 13 years). All the patients had FFMT as the second stage procedure after the initial operation of excision of the necrosed flexor muscles, contracture release and neurolysis. Six of the 22 patients had undergone pedicled abdominal flap for resurfacing the scarred or skin grafted volar aspect of the forearm earlier to performing the FFMT. The duration between the first surgery and the FFMT ranged from 3 months to 72 months (average- 15 months); while the initial injury to the FFMT interval ranged from 5 months to 21 years (average- 42.68 months). Notably, one patient had the FFMT procedure at 21 years post initial injury and another at 18 years post injury. On excluding these two patients the average time between the initial injury and FFMT was 23.55 months (range 5 months to 8 years). In 18/22 cases neurolysis of the median and ulnar nerve was done during the initial operation. In four patients the severely

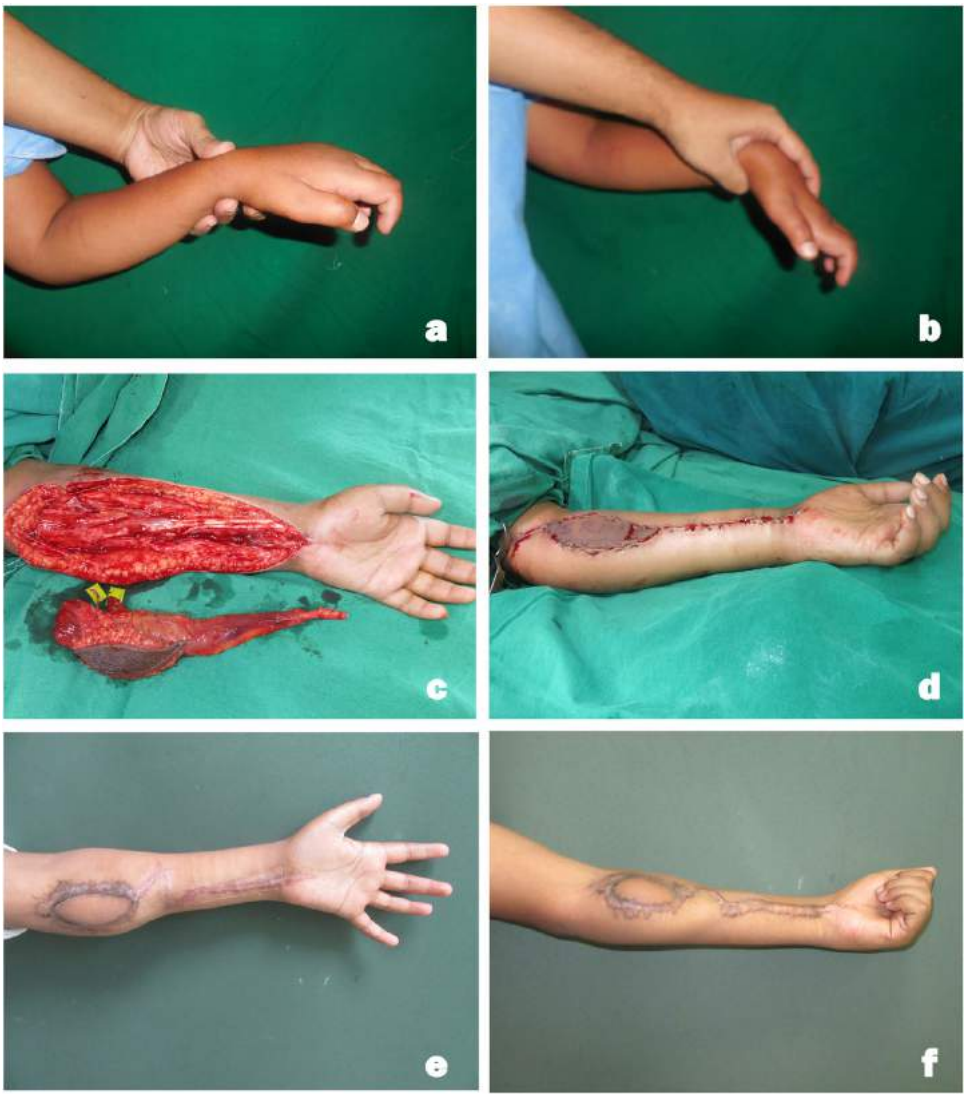

Fig. 2. Case series of an 8-years old child with severe VIC: a & b) - Preoperative picture showing the flexion contracture at the wrist and contracture of long flexors before the first stage of surgery. Patient underwent neurolysis and excision of the fibrotic flexor muscles. He showed good recovery of sensations and intrinsic recovery at 6 months. At second stage (c & d) he underwent FFMT to restore finger flexion. e & f)- Functional outcome at 5 years follow up. He achieved good finger flexion and was able to use his hand for all activities as a child. He reported a DASH score of 1.8.

Table 2
Details of the secondary procedures done after the FFMT.

Claw correction using ECRL and TFL graft – three cases.
FCU to ECRB and EIP opponensplasty – one case
Excision of hypertrophic scar, Z-plasty and closure -one case
MCP joint capsulotomy +/- MCP joint arthrodesis for thumb- two cases
Forearm contracture release and scar revision and release of median nerve adhesion – one case
Debridement of skin island of gracilis free flap and SSG to raw area to the volar aspect of forearm – one case
Adhesiolysis of flexor tendons – one case

ECRL- Extensor carpi radialis longus, TFL -Tensor fascia lata, FCU- Flexor carpi ulnaris, ECRB-Extensor carpi radialis brevis, MCP – Metacarpophalangeal

scarred nerves had to be excised during the initial operation and the median nerve was reconstructed with sural nerve grafts (average gap – 9 cm) at the time of performing FFMT.

All the 22 flaps survived. One patient had necrosis of the skin island and needed debridement and SSG cover. Secondary procedures to further improve the hand function were done in nine patients (Table 2).

The motor power recovery for finger flexion at a minimum of one year follow up was graded as M2 in two cases, M3 in nine and M4 in 11 cases. These 20/22 patients who recovered M3/M4 motor power for finger flexion expressed high satisfaction with the operation while other two also felt that they were better after the surgery. All patients were able to grasp objects and use their hands for day-to-day activities DASH score was available for 13 patients and it averaged 13.21, ranging from 1.8 to 34.5. Half of them had DASH score of <10 with one reporting her DASH score as $>$ 30 (34.5). Grip strength was available for 10/22 patients. The average

grip strength was 10.5 kg (range- 0-21kg) amounting to 24% of the normal side.

The sensory recovery at the follow up was graded as S4 in two, S3 in 17 and S2 in three cases. Four patients who underwent nerve grafting recovered S3 sensation in the respective nerve territory. Recovery of sensation after neurolysis was variable (S2-S4). The best sensory recovery was noted in the patients who underwent first stage of surgery within six months post injury.

Surgical Technique and Post-Operative Course

We prefer harvesting Gracilis with a skin island as it allows a tension free closure and facilitate gliding of the muscle on recovery. The skin island can also be used as the site for electrical stimulation of the muscle in the rehabilitation period.[9,10] Proximally, the gracilis was attached to the medial epicondyle and intermuscular septum in the lower third of the arm with strong 1-0 PDS sutures. Distally the FDP tendons were plicated together under appropriate tension to reproduce the cadence of the fingers on passive traction.[11,] The tendon of the gracilis was then attached to the FDPs of all the fingers with a Pulvertaft weave and sutured with 3-0 Prolene sutures. At completion of the repair, the fingers should be in a few degrees more flexion than the resting position.

The flexor pollicis longus (FPL) was not included in the distal attachment. A separate motor was provided for independent movement of the thumb, the donor being the brachioradialis in most cases. The FFMT can also be split and one part attached to FPL.[10] However we prefer not to use this option as adjusting the relative tension in the two repairs is crucial: either the thumb flexes early or too weakly resulting in poor grip and pinch.[12]

Gracilis muscle flap veins were repaired to the venae comitantes of the brachial artery and the artery anastomosed end to side to the brachial artery in all the cases. Average ischemia time was 42 minutes, being less than an hour in all cases.

Anterior interosseous branch of the median nerve was used as a donor nerve to innervate the gracilis muscle in 15/22 cases, in five cases, where this nerve was found to be severely scarred, a motor fascicle of median nerve was used for neurotisation and in two cases with more extensive involvement of median nerve, a fascicle of ulnar nerve was used to neurotise the gracilis. The nerve is sutured close to the muscle for early reinnervation.

The limb was immobilised in an above elbow slab with the elbow in 90 degrees of flexion, wrist in the neutral position and the Metacarpophalangeal (MCP) and Interphalangeal (IP) joints in the position of function. Passive finger flexion exercises are started the day after surgery.

The above elbow splint was kept for 6 weeks. At 6 weeks it was converted into a below elbow detachable dorsal splint. Intermittent Galvanic current stimulation was given to the muscle mostly through the skin island – 30 contractions twice a day, continued till perceptible active contraction of the muscle was felt, which usually occurred by 3 months. The muscle strengthening exercises were then started.

Discussion

FFMT is an effective and reliable method of restoring finger flexion in patients with VIC[12-22] It is most useful in patients in whom the wrist extensors are not strong enough for performing tendon transfer to restore finger flexion. The decision to choose FFMT is mostly clinical, based on the loss of the flexor muscles and donor muscle strength. Ultee and Hovius have suggested MRI as an important diagnostic tool to assess the status of the flexor muscles for deciding the need for FFMT.[18]

Our two-stage approach appears to be a reliable option for patients with severe VIC. The first stage is performed at 2-3 months post injury when the skin over the forearm has settled well after the initial swelling and blebs. First stage involves excision of the fibrotic muscle tissue, neurolysis, joint contracture release and addressing the soft tissue deficit if any.[23] Early neurolysis and excision of the fibrotic muscles allows better nerve recovery and restores sensation at the hand and provides best chance for recovery of the intrinsic muscles. Patients with extensive muscle involvement can be planned for FFMT at the second stage.

FFMT is undertaken 3-6 months after the initial stage, when the forearm skin is supple, ideally with good passive ranges of movement of the fingers and wrist joint and with recovery of the intrinsic muscles and sensations over the hand.

Functional restoration of finger flexion following VIC was the first clinical application of FFMT and it was performed at Sixth People's Hospital in Shanghai in 1973. Lateral part of Pectoralis major muscle was used as a free flap to reconstruct the flexor muscles of the forearm for a patient with VIC.[13] Subsequently, gracilis, latissimus dorsi (LD), rectus femoris and soleus have been used as FFMT. Over the years, gracilis has become the preferred muscle for this surgery due to minimal donor site morbidity, consistent neurovascular anatomy, ample muscle length (about 40 cm), good pedicle length (8-10 cm), and adequate excursion to match the finger flexors to provide a functional grasp.

Ercetin and Akinci reported the largest series of FFMT for finger flexion in 28 patients with VIC.[15] They used gracilis in 18 cases and LD in 12 cases. They preferred LD muscle transfer with its longer pedicle length in patients with brachial artery lesion whereas in other cases gracilis muscle flap was preferred. Krimmer et al. reported 15 cases of gracilis FFMT of which 13 were successful.[16] They preferred gracilis for its consistent anatomy and minimal donor site morbidity. Manktelow el al. reported 12 cases of FFMT to restore finger flexion, in 10 of them gracilis was used whereas pectoralis major was used in the other two patients.[12] All the 22 patients in our series underwent gracilis FFMT.

The power of a muscle depends upon the functional cross-sectional area while the amplitude of contraction depends upon the muscle fiber length. The Flexor Digitorum Superficialis (FDS) and Flexor Digitorum Profundus (FDP) individually have a cross sectional area of about 10 cm^2, while the gracilis has a functional cross-sectional area of 4 cm^2 and so the power generated by gracilis is relatively less. Though the maximal contracting force of gracilis is 17% of the flexor muscles, this deficiency can be compensated by muscle training.[13] Muscle like rectus femoris (cross section area - 26 cm^2) though structurally a better replacement for finger flexion in power and amplitude is not used because of inconsistent pedicle, multiple motor branches and significant donor site morbidity. The latissimus dorsi (cross section area- 8 cm^2) can provide more power but it does not have a suitable distal tendon for attachment like gracilis.[24] Though theoretically, LD could provide for better flexion power, Ercetin and Akinci found no significant difference in the strength provided by these two muscles. They based their choice, between gracilis and LD, on the length of the pedicle needed for anastomosis, preferring LD when a longer pedicle length was needed. Overall, they found the grip strength recovery to be 'disappointing' with most patients regaining 10-20 % of the normal grip strength.[15] Krimmer et al. also found the grip strength recovery to be lesser and found it to be worse when the patients had unstable wrist because of loss of the wrist motors.[16] They found that grip strength improved with wrist fusion in such patients. However, in spite of lesser grip strength the functional improvement noted in these patients was immense. Ercetin and Akinci found that 23/28 patients used their hands for daily activities and were satisfied with the functional outcome.[15] Krimmer et al. found that all the survived muscles regained some useful function.[16]

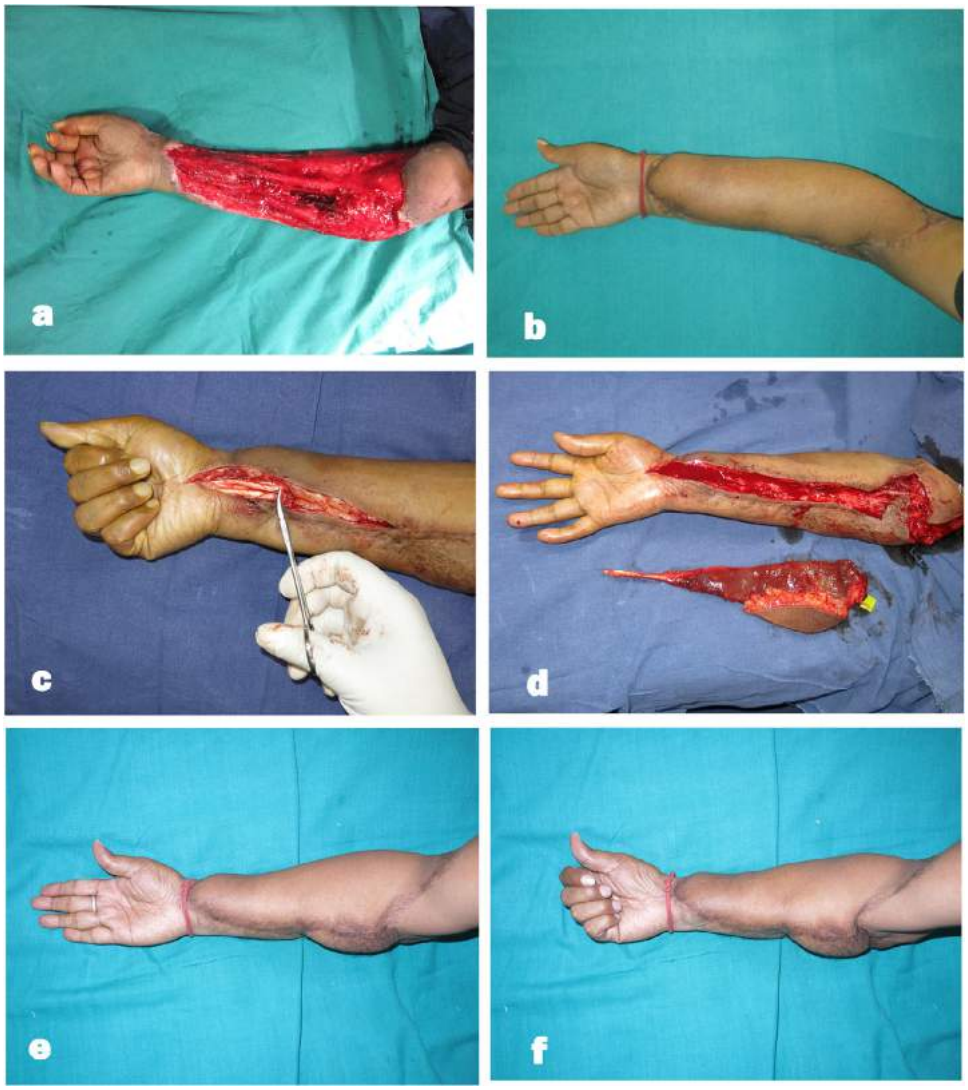

Fig. 3. Series of a patient with sever VIC and soft tissue scarring over the forearm. a)- At first stage she underwent excision of the scarred tissue over the volar aspect of the forearm, excision of the fibrotic flexor muscles and neurolysis of the median and ulnar nerves. b)- The flap settled well, and she recovered good sensations and intrinsic function at 4 months post-surgery. At second stage, gracilis FFMT was done to restore finger flexion (c & d). She had excellent recovery of finger flexion (e & f) and was able to perform all her household duties with ease. She reported a DASH score of 3.3.

As observed in previous studies, average grip strength achieved in our series also was not impressive, with average being 10.5 Kg. However, it did not parallel the subjective functional improvement achieved. All patients with motor power of over MRC grade 3 (20/22) gained satisfactory hand function. From zero movement at the fingers preoperatively they were able to hold things comfortably and actively use their hand for day-to-day activities. The average DASH score was found to be 13.21 which amounts to only mild disability. The DASH score improved over time with a patient reaching 1.8 at 5 years post FFMT (Fig. 2).

We observed that functional limitation was related to the stiffness of the finger joints limiting the range of finger flexion; presence of weak wrist extensors resulting in wrist instability during the action of FFMT; lack of intrinsic muscle function and poor sensation in the hand. Procedures to correct these deficits were needed in 10 of our patients [Table 2] and function improved in all of them after secondary procedures.

Sensory function of the hand is known to greatly influence the overall hand function. It was quite evident in our series. All the patients with best functional results had more than S3 or better sensations and intrinsic muscle function in the hand [Figs. 2 and 3]; further emphasizing the need for early intervention in the form of neurolysis and excision of the fibrotic muscles to prevent secondary nerve injury and supple soft tissue cover if needed (Fig. 3). Ercetin and Akinci noted improved sensory recovery once the nerves were covered with free muscle transfer and recommended early FFMT in patients with severe involvement.[15]

Conclusion

Free functioning Muscle Transfer with gracilis is a reliable option for restoration of finger flexion in VIC patients with severe involvement of muscles of the forearm. Outcome is better when done after an early preliminary stage of excision of fibrosed muscles and neurolysis which allows recovery of intrinsic function and sensation. FFMT is best carried out 3 to 6 months after the first stage with supple skin and good passive range of movement in the fingers. Secondary procedures can help to improve function in patients with poor nerve recovery.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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