Results of Free Functioning Gracilis Muscle Transfer in Severe Volkman's Ischemic Contracture of The Forearm in Children

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ABSTRACT
Background: Although free functioning muscle transfer can significantly enhance the function of the damaged upper extremity in cases of Volkmann's ischemic contracture (VIC), normal-functioning of the affected limb is not to be expected in the long-term.
Objective: To evaluate the results of using functioning free gracilis transfer for restoration of hand and wrist function in severe Volkman's ischemic contracture in children.
Subjects and Methods: In prospective interventional research that was carried out on twenty-four patients at the Hand and Reconstructive Microsurgery Unit, Assiut University Hospital (23 patients) and Department of Orthopedic Surgery Zagazig university hospitals (1 patient), free functioning gracilis muscle transfer was used for managing severe Volkman's ischemic contracture of the forearm in children.
Results: functional free muscle transfer (FFMT) proved to enhance post-operative passive range of movement (ROM), active ROM, active fingertip to palm crease, active thumb to palm crease and thumb opposition. Also, it improved power grade, pinch power and hand sensation. The earlier intervention resulted in better passive ROM. Functioning intrinsic muscles preoperatively gave better results as regard active ROM.
Conclusion: FFMT is the best solution in cases of severe VIC even if the best results can't be achieved.
Keywords: Free functioning, Gracilis muscle transfer, Volkman's ischemic contracture, Forearm.

INTRODUCTION

Muscle ischemia and necrosis lead to Volkmann's ischemic contracture if acute compartment syndrome is not treated promptly or sufficiently decompressed **(1)**. Ischemic muscular paralysis and contracture was initially described by Richard Von Volkmann in 1881. Instead of a neurologic damage, he blamed muscular necrosis after ischemia for this contracture **(2)**. Causes for this include, but are not limited to, distal radius fractures, crush injuries, tight dressings, and supracondylar humeral fractures **(3)**.

When acute compartment syndrome progresses to Volkmann's ischemic contracture in children, it is one of the most severe outcomes of a traumatic injury. It causes persistent impairment of the hand and wrist due to alterations in the muscles, nerves, and vascular endothelium. The flexor digitorum profundus (FDP) and the flexor pollicis longus are the most susceptible muscles in the deep flexor compartment of the forearm **(2)**.

During a free muscle transfer, the donor muscle is removed along with its vascular pedicle (artery and one or more veins), which is then transplanted to the recipient site and anastomosed to the recipient's existing blood arteries. A motor nerve is also present in addition to the vascular pedicle in transfers of functional muscle. The nerve is sutured to a supply of donor motor axons so that the patient can regain feeling and control over the newly-revived muscles **(4)**.

There are several free functional muscle transfer candidates, but the gracilis stands out for its many benefits. It has reliable anatomy, is easily replaced, and causes minimal morbidity in donors. Additionally, it can be collected concurrently during upper-extremity surgical procedures. In addition to having the potential to transport a skin paddle, it also has a highly respectable donor scar. Patients in this situation typically undergo neurolysis and muscle debridement before receiving a transplant of fully functional muscle. This rebuilding can be done in either a single stage or in two separate stages. Vascular assessment, neurolysis, and comprehensive debridement of necrotic muscle are crucial to the success of either surgical approach. For these patients, some surgeons favour a single-stage operation, while others favour a two-stage treatment **(3)**.

One benefit of importing a fully functional muscle is that it bypasses the ischemia insult that initially weakened the forearm **(6)**. In Volkmann's ischemic contracture, a free-functioning muscle transfer can significantly enhance the use of the afflicted upper extremity, but a full recovery to normal function is unlikely. Re-innervation of the transferred muscle takes a long time, which is another disadvantage **(5)**. Furthermore, not all patients qualify for a successful muscle transfer. They need to be self-driven enough to go through with the procedure, and financially stable enough to shoulder the massive recovery costs **(6)**.

Safe guarding feeling and a wide passive motion range are necessary conditions for effective muscle transfer **(3)**.

This research aimed for evaluation of the results of using functioning free gracilis transfer for restoration of hand and wrist function in severe Volkman's ischemic contracture in children.

SUBJECTS AND METHODS

This prospective interventional research was carried out on twenty four patients at the Hand and Reconstructive

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Microsurgery Unit, Assiut University Hospital (23 patients) and Department of Orthopedic Surgery Zagazig University Hospitals (1 patient), between 2016 and 2019, using the free functioning gracilis muscle transfer, for managing severe Volkman's ischemic contracture of the forearm in children.

Inclusion criteria: Children from 4-18 years old. Post traumatic Volkman's contracture (fracture, crush injuries or tight dressings). Severe degree of Volkman's contracture. Good passive range of motion in the affected hand. Surgically fit patients.

Exclusion criteria: Patients aged below 4 and above 18 years old. Post vascular repair Volkman's contracture. Mild to moderate degree of Volkman's contracture. Stiff hand. Surgically unfit patients. Infection of the forearm.

1- Preoperative evaluation:
Primary insult and time lag before operation, previous procedures, as well as expectations of patient guardians about the results and their motivations.

2- Clinical evaluation: Hand range of motion (Fingers passive ROM, fingers active ROM, active fingertip to palm crease, active thumb to palm crease and thumb apposition). Hand intrinsic muscles and hand power assessment, Functional assessment: Dash questionnaire (Disability of the Arm, Shoulder and Hand). Arabic quick Dash was used.

Surgical approach:
Surgical technique: One stage procedure was done in all cases; excision of all necrotic muscles, neurolysis and FFMT in the same stage.

Gracilis muscle harvesting: In our series the gracilis muscle was harvested as a myocutaneous flap with a skin monitor over its proximal third.

The laterality of the muscle: In all cases the muscle was harvested from the ipsilateral side to the affected limb for better neurovascular bundle orientations.

Technique:
Standard technique of the recipient site preparation, flap harvesting and in setting was used in all our patients.

(A) Proximal and distal dissection during harvesting of free gracilis. The distal incision was sutured

(B) the gracilis muscle was harvested through the whole incision

Figure (1): The gracilis muscle approach

Preparation of donor nerve:
The anterior interosseous nerve was the most frequently used motor nerve in our cases; used alone in 14 cases and augmented by direct implantation by branches of median nerve in the other 10 cases.

Neurolysis: All cases had neurolysis of the median and ulnar nerve and tenolysis as a part of the operative procedure. Nerve grafting was done for the ulnar and median nerves in one case by sural nerve graft as an adjuvant procedure. This was done before the transfer of the muscle to lessen the ischemia time.

Muscle inset: In all of our patients, the origin of the gracilis was fixed proximally to the medial epicondyle through transosseous sutures, and distally inset to FDP and FPL. In one case, the gracilis tendon was attached to FDP only.

Revascularization:
After insetting, the venous anastomoses is started with, we usually do one vein first. The arterial anastomosis then follows. Vascular clamps are then removed from both anastomoses at one time starting with the venous clamp. We do our best to anastomose the second vein after removal of the vascular clamps from the artery and the first vein. Blood engorging the second vein gives us an idea about the ongoing circulation in the transplanted muscle. In our cases the donor artery was the ulnar artery except in three cases; the anterior interosseus artery (branch from ulnar artery) in two cases and the radial artery in the other case. The gracilis veins are anastomosed to both superficial and deep veins in 14 cases, in 9 cases to deep veins only and to superficial vein only in one case (one vein anastomosis). All the vascular anastomoses are done through the operative microscope. All the arterial and venous anastomoses were done direct end to end anastomosis by 10/0 sutures without graft.

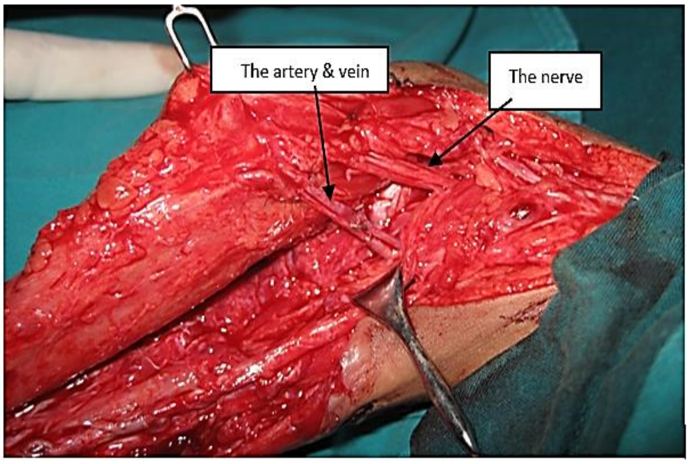

Figure (2): After microneurovascular anastomoses.

Neurotization:
The AIN is then sutured to that of the gracilis after the vascular anastomoses has been finished. All the microneural anastomoses in our cases were performed under operative microscope magnification and all were sutured using 10/0 sutures (no nerve glue was used). After finishing the anastomoses the final closure and dressing of the recipient wound is usually delayed for 20 to 30 minutes to allow the muscle to express its viability.

Follow-up period:
The mean follows up period was 24 ± 10.5 months (range 12 to 40 months). During the follow up period some patients needed 2ry surgeries to improve the function of the upper limb after FFMT.

Ethical consent:
This study was ethically approved by the Institutional Review Board of the Faculty of Medicine, Zagazig University and Assiut University. Written informed consent was taken from all participants. The study was conducted according to the Declaration of Helsinki.

Statistical analysis
The quantitative research was carried out using SPSS for Social Sciences, version 20 (SPSS).
The data were presented in the form of tables and charts. Means, medians, standard deviations, and confidence intervals were displayed with the numerical data. Data visualisations made use of numerical examples, such as frequency and %. The student's t test (T) is frequently used for analysing quantitative data with independent variables. Using Pearson's Chi-Square and Chi-Square for Linear Trend, we analysed data that was qualitatively different from one another (X^2). To be statistically significant, we determined that a P value of 0.05 or lower was necessary.

RESULTS
Mean age of studied group was 8.2 ± 2.1 years. 17 of them were males and 7 were females.
Affected hand was left hand in 62.5% of patients, 66.7% of them were type 1, 11 finger flexion cases and 46% had subsequent operative settings with 24 subsequent reconstructive procedures in following the functional free muscle transfer. Mean of passive ROM was 51.7^o ± 32.8, the mean of passive ROM % was 21.5 ± 13.4%, the mean of active ROM was 0.42^o ± 2, the mean of active ROM % was 0.21 ± 1, 70%. 8% of cases had preoperative power grade M0.

Table (1): Demographic and variable characteristics

Item	No=24	%=100
Age (Years)	Mean ± SD: 8.2 ± 2.1 Range: 5-12	
Sex: • **Males** • **Females**	 17 7	 71% 29%
Affected hand: **RT hand** **LT hand**	 9 15	 37.5% 62.5%
Variable	**No=24**	**%=100**
• **Type 1** • **Type 2**	16 8	66.7 33.3
Order of the FFMT	Frequency	Percent
1	13	54.2%
2	11	45.8 %
Total	24	100%
Variable	**No=24**	**%=100**
Power Grade: • **M0** • **M1**	 17 7	 70.8 29.2

Table (2) showed that the mean of operative time was 420.8 ± 123.1 and the mean of ischemia time was 100.2 ± 34.7 min.

Table (2): Operative time and ischemia time among studied group

Variable	Mean ± SD	Range
Operative time (min)	420.8 ± 123.1	240-720
Ischemia time (min)	100.2 ± 34.7	65-240

Table (3) showed that there was highly statistically significant difference between pre- and post-operative passive ROM and passive ROM % ($p < 0.001$). The passive ROM was significantly improved from 21.5 ± 13.4% preoperatively to 91.7 ± 12.8% postoperatively ($p < 0.001$).

Table (3): Comparison between pre- and post-operative passive ROM among studied group

Variable	Pre-operative	Post-operative	Paired t-test	P-value
Passive ROM: **Mean ± SD**	51.7 ± 32.8	220.6 ± 31	-22.8	**0.000* (HS)**
Passive ROM %: **Mean ± SD**	21.5 ± 13.4	91.7 ± 12.8	-22.9	**0.000* (HS)**

Table (4) showed that there was no statistically significant association between intrinsic muscles and late power grade among studied group ($p > 0.05$).

Table (4): Association between intrinsic muscles and late post OP power grade among studied group

Variable	Intrinsic muscles						$\chi 2$	P-value
	Intrinsic minus N=11		Intact intrinsic function N=1		Partial recovery N=12			
	N	%	N	%	N	%		
Power grade: **M4a** **M4b**	 0 11	 0 100	 0 1	 0 100	 1 11	 8.3 91.7	1	0.593

Table (5) showed that the mean of start of active motion was 3.6 ± 1.2.

Table (5): Start of nerve recovery

Item	Mean ± SD	Range
Start of active motion	3.6 ± 1.2	2-6

Table (6) showed that active range of motion (ROM) and ROM percent both increased significantly between pre- and post-operative treatment ($p<0.001$). The average arc of active ROM was significantly improved from 0.21 ± 1% preoperatively to 74.4 ± 18.9% postoperatively ($p< 0.001$).

Table (6): Comparison between pre and post-operative active ROM among studied group

Variable	Pre-operative	Post-operative	Paired t-test	P-value
Active ROM: **Mean ± SD**	0.42 ± 2	166.5 ± 54.1	-15.1	**0.000*** **(HS)**
Active ROM %: **Mean ± SD**	0.21 ± 1	74.4 ± 18.9	-19.3	**0.000*** **(HS)**

The distance from the tips of the fingers to the palm of the hand was significantly different before and after surgery ($p< 0.001$). There was statistically significant difference between pre- and post-operative active thumb to palm distance ($p< 0.05$) (Table 7).

Table (7): Comparison between pre- and post-operative active fingertip to palm distance among studied group

Variable	Pre- operative		Post- operative		$\chi 2$	P-value
	N	%	N	%		
Active fingertip to palm distance:					31	**0.000*** **(HS)**
• Touches the palm digital crease or within 10 mm	0	0	13	54.2		
• 10-30 mm	2	8.3	8	33.3		
• More than 30 mm	22	91.7	3	12.5		
Active Thumb to palm distance:					3.1	**0.045** **(S)**
• B/w 10mm & 30mm	2	8.3	3	12.5		
• More than 30 mm	22	91.7	6	25		
• Touches the palmodigital crease or within 10 mm	0	0	15	62.5		

In our cases, tenolysis was the most frequently done secondary operation after FFMT (seven operations of tenolysis**)**. The operation was not done unless one year has passed after the transfer (Table 8).

Table (8): Frequency of reconstructive procedures done after FFMT

Reconstructive procedure	Frequency
Flexor tenolysis	7
Wrist arthrodesis	6
Operation to enhance opposition (+/- TMC arthrodesis, +/- web plasty, +/- opponoplasty)	5
MP arthrolysis	2
Elbow arthrolysis	1
Derotation osteotomy of the radius	1
Dynamic tendon transfer to correct clawing	1
excision of unsightly scar at recipient site	1
Total	24

DISCUSSION

Clinical manifestations of Volkmann's ischemic contracture (VIC) are a spectrum resulting from the failure to diagnose or properly treat acute compartment syndrome. Ischemia causes damage to all tissues, from skin to bone, but muscles take the worst hit. Ischemic injury leads to muscular fibrosis, which worsens nerve damage and prevents distal motor recovery [(7)].

An established Volkmann's ischemic contracture requires careful and intricate management. The severity of their condition is a factor in how they are treated. Patients with extensive injuries that need sophisticated reconstruction were the primary focus of this study.

In the current study, 24 cases with severe VIC are included. They were managed by free functioning muscle transfer. The age range was 5-12 years old. They were 17 males and 7 females. Affected hand was RT hand in 9 patients and LT hand in 15 patients. Follow-up period range was 12-40 months. Direct nerve repair to AIN alone was done in 14 cases and adjuvant direct muscle neurotization was done in 10 cases. Our results showed no significant difference between these two groups regarding the late postoperative power grade and start of active motion. So, it is probably enough to neurotize the nerve to gracilis with the AIN without the need to further implant other motor branches of the median nerve.

The speed and extent of muscle recovery after re-innervation are dependent on neural factors and not muscular factors; the technical adequacy of the repair, the number of motor fascicles present in the donor nerve **[(8)],** and the distance between the nerve repair and the entrance of the recipient nerve into the muscle that should be kept ideally to two cm or less [(9)].

In our thesis, 6 months constituted the maximal time for the onset of contractions clinically. The mean time to onset of muscle contraction was three months and half with a minimum of two months. This result conforms to other studies where the onset of muscle contraction was reported to occur in the first two to four months **[(9)].**

Although supple joints are one of the prerequisites of free muscle transfer, it is accurately valid for non-traumatic (paralytic) conditions. But loss of function due to traumatic causes as in Volkmann’s ischaemia, there is always limitation of digital passive ROM. This limitation of motion is mostly due to a tenodesis effect of the contracted muscle bellies that is released before the application of the muscle **[(3)].** This agrees with our results as there was a highly significant improvement in the passive range of motion after FFMT in our Volkmann’s cases.

Some limitations however, were not solely due to tenodesis effect and we were sometimes faced with joint stiffness after excising the fibrotic muscle bellies. We could predict joint stiffness in such cases from the longer time elapsed since injury. The results were significantly better in the cases that had the surgery done within one year of injury. It is worth mentioning that 4 of cases needed dorsal capsulotomy of MP joint later to improve the range of motion. This observation was picked up by another author who mentioned that the preoperative stiffness in the fingers is sometimes because of inability to move about for an extended period of time and inadequate physiotherapy [(10)].

Regarding to the active range of motion of the fingers, there was highly statistically significant difference between pre- and post-operative active ROM in our thesis. The active ROM preoperatively was mostly zero due to absence of functioning flexor muscles. While after FFMT the active ROM was restored, as with increasing innervation comes an increasing range of muscle excursion. It should be expected that adequate muscle excursion is available after transplantation unless limited by postoperative adhesions. Tendon and muscle adhesions are the greatest obstacle to the function and so, early passive motion is recommended **[(8, 9)].**

The average arc of active finger flexion was significantly improved from 0.42 ± 2 (0.21 ± 1%) preoperatively to166.5 ± 54.1 (74.4 ± 18.9%) postoperatively. There was significant improvement in fingertip to palm and thumb to palm distance. Preoperatively, no one of the cases could touch the distal palmar crease or reach within 10 mm of it by any finger or thumb. Postoperatively, 54.2% of the cases were able to do that by fingers and 62.5% by thumb.

Harii *et al.* **[(8)]** reported that 9 of the 12 patients available for follow up after Volkmann’s ischaemia had full ROM in the fingers where they can fully flex and extend the fingers while the wrist is in neutral position. When compared to the findings of **Beaton *et al.*** **[(10)]**, who found that the gracilis muscle transfer in cases of Volkmann's ischemic contracture or the loss of flexor muscles of the fingers due to extensive debridements does not provide sufficient range of motion for complete digital flexion (i.e., zero percent full ROM), this is an excellent outcome**.**

Differences in thumb opposition before and after surgery were statistically significant. There was significant improvement in thumb opposition. Preoperatively, 8.3% of the cases could oppose and postoperatively, 58.3% of the cases were able to oppose the thumb. It is well known that a functioning muscle loses part of its power after the transfer. The strength in free functional muscle transfers is always diminished and the replanted muscle never regains 100% of its contractile capacity (G 5 according to MRC). It is not yet possible to restore normal strength for a given motion with this technique and a significant difference exists between the involved extremity and the normal control hand. Realistically, M4 strength is the best one can expect from this reconstructive procedure **[(8)]**. Nearly all authors consider a motor power grade of M3 or less to be as fair or poor, with M4a as good and M4b as excellent **[(8)]**. None of the patients of this thesis reached M5 muscle power grade according to the medical research council score, however, 100% reached M4 (95.8% of the patients reached M4b (excellent result) and 4.2% reached M4a (good result).

The failure to regain full function in FFMT has been attributed to two main factors; firstly, the necessity of a tenotomy (especially when being bipolar) like in tendon transfer operations (unipolar tenotomy) where the muscle must be of grade M5 to be useful for transfer because one grade of strength is lost after transfer on the medical research council score. The second factor is denervation and subsequent re-innervation by a different motor nerve [(11)].

Tendon and muscle adhesions are expected when the active range of motion of the transplanted muscle is less than the passive range available. There is a significant improvement of the ROM following tenolysis operation done after FFMT [(12)]. In our cases, tenolysis was the most frequently done secondary operation after FFMT (seven operations of tenolysis **)**. The operation was not done unless one year has passed after the transfer.

CONCLUSION

According to our results, FFMT significantly improved passive ROM, active ROM, active fingertip to palm crease, active thumb to palm crease and thumb opposition. Also, there is significant improvement in power grade.

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