REVIEW

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Management of Volkmann Ischemic Wrist Contracture: A Literature and Case-Based Review of Treatment Modalities with a Focus on Ilizarov Circular Frames

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ABSTRACT

Volkmann's ischemic contracture is a disabling consequence of compartment syndrome, characterized by irreversible muscle and nerve damage leading to joint deformities and functional impairment. Traditional surgical approaches such as tendon lengthening, neurolysis, and free muscle transfer are often limited in severe cases, especially when soft tissue is compromised. This article reviews current treatment options, focusing on the Ilizarov circular frame as a minimally invasive alternative for managing complex wrist contractures.

A narrative review of the literature was conducted to assess treatment modalities for Volkmann's contracture, with emphasis on the Ilizarov method based on distraction histogenesis. Two clinical cases of post-traumatic Grade III wrist flexion contractures were included to illustrate the technique. Diagnostic workup included clinical examination, electromyography (EMG), and MRI. Both patients underwent gradual correction using customized three-ring Ilizarov external fixators. Frame setup, hinge positioning, and postoperative rehabilitation were documented in detail.

Review of treatment options for Volkmann's contracture highlights gradual correction as a less invasive, effective alternative. Both patients achieved functional wrist alignment without complications. The technique preserved neurovascular structures and soft tissues, with no skin necrosis, nerve injury, or recurrence observed. These findings support the method's safety and adaptability in complex contractures.

The Ilizarov circular frame offers a safe and effective treatment for severe Volkmann's wrist contractures, particularly when conventional surgery is contraindicated. These cases support broader application of circular external fixation in upper limb deformities and highlight the need for further clinical investigation.

Keywords: Volkmann's ischemic contracture, Ilizarov circular frame, Distraction histogenesis, Wrist deformity.

INTRODUCTION

Permanent damage to muscles, tendons or skin in the hand, regardless of the cause, often leads to deformities that reduce functionality and significantly impact a patient's quality of life. Volkmann's ischemic contracture is an example, where muscle ischemia due to compartment syndrome causes muscle fibrosis and results in deformity[1-3]. This type of contracture involves hand flexors and extensors, which leads to a deformity of the wrist joint. Similar deformities can be caused from burns, neurological injuries or congenital abnormalities.

To address these conditions, many surgical treatment methods have been applied, including tendon lengthening, Z-plasty, and skin grafting that often provide limited results in severe contractures. On the other hand, Ilizarov circular frame offers a less invasive option to correct deformities and restore motion that is based on distraction histogenesis.

Volkmann contracture develops when prolonged ischemia causes muscle necrosis and progressive fibrosis of the flexor compartments, often accompanied by nerve dysfunction. Several grading systems exist, most notably those of Seddon and Tsuge, which classify contracture severity based on muscular involvement

and neurological impairment. In its severe form (Grade III), deformity becomes rigid and disabling, limiting surgical options due to compromised soft tissue quality.

Although Ilizarov circular frames have gained wide use in limb deformity correction, their application to wrist Volkmann contracture remains non-reported. This article presents two severe wrist cases treated successfully using Ilizarov principles – filling the therapeutic gap[1,4].

MATERIALS AND METHODS

A structured literature search was conducted in PubMed, Scopus and Embase from inception to June 2025. Search terms reflected three core domains: (1) the condition - "Volkmann contracture", "ischemic contracture", "compartment syndrome", (2) anatomical region – upper limb, wrist, forearm, and (3) treatment modality - "Ilizarov frame", "external fixation", "circular fixator", "distraction histogenesis". Boolean operators were applied to combine domains: ((Volkmann contracture) OR (ischemic contracture) OR (compartment syndrome)) AND ((Ilizarov frame) OR (external fixation) OR (circular fixator) OR (distraction histogenesis)) AND ((wrist) OR (forearm) OR (upper limb)). Whenever available, controlled vocabulary was incorporated (e.g., Volkmann Contracture, Wrist Joint, Ilizarov Technique, External Fixators). Reference lists of eligible articles and cited reports were screened manually to ensure completeness.

Additionally, two clinical cases of severe post-traumatic wrist contracture treated with Ilizarov frames are presented to illustrate the technique. The first case involved a 26-year-old male with a post-compartment syndrome deformity, and the second involved a 25-year-old male with contracture following a bi-osseous fracture. Surgeries were performed under general anesthesia on a radiolucent hand table. Detailed descriptions of both patient histories and treatment protocols are provided in the Addendum. Ring, wire, and Schanz screw locations were documented using MUDEF notation. MUDEF notation communicates wire orientation relative to anatomical quadrants. For example, "K-wire III (ulna, pronation) 10-4" describes placement from a 10-o'clock to 4-o'clock when forearm is in pronation position.

RESULTS

The initial search returned 141 articles. After title and abstract screening, 35 articles discussed upper limb contractures, and only 7 [25,26,29,30,31,32,35] described Ilizarov-based correction in upper limb. No reports described severe Grade III wrist deformity managed with circular fixation, reflecting a clinical evidence gap addressed by our cases.

Regarding the two clinical cases presented in this study, both patients achieved successful mechanical correction of the deformity. In Case 1, the wrist was corrected to a neutral position, allowing for the initiation of physical therapy. The Musculoskeletal Tumor Society Score (MTSS) improved from 9/30 preoperatively to 16/30 postoperatively. In Case 2, all joint deformities were corrected and remained stable, with the MTSS score improving from 11/30 to 15/30. While anatomical alignment was restored in both cases without significant pain or soft tissue complications, functional manual dexterity remained limited due to the severity of the initial nerve damage.

DISCUSSION

Volkmann's ischemic contracture is still one of the most complex deformities of the upper limb. Despite well-described pathophysiology and variety of surgical strategies, treatment of severe multiplanar wrist deformities with compromised soft tissue poses significant challenges. Conventional approaches such as muscle slides, tendon transfers, and free muscle flaps often require multiple stages and carry high complication due to dense fibrosis or neurovascular involvement.

Overview of Current Treatment Modalities

Conventional Treatments

The management of Volkmann's contracture depends on its severity (Table I), with specific for mild and moderate cases. Early identification and intervention are critical in order to achieve good clinical and functional outcome.

In mild contractures, the primary focus is on preserving joint mobility and strengthening non-necrotic muscle function. Early therapy includes dynamic splinting(to prevent fibrosis and permanent contracture) and active muscle use. Passive joint motion exercises are essential for maintaining muscle length and flexibility[5-12]. Surgery is typically considered after three months if conservative measures fail. In isolated deformities without other congenital abnormalities, options such as limited flexor origin slide or distal tendon release with tenodesis can restore function. If multiple muscles are involved, a muscle sliding operation is generally more effective than isolated tendon lengthening or wrist resections[10,13].

Moderate contractures require surgery due to more extensive muscle and nerve involvement. Lengthening at the flexor myotendinous junction or flexor-pronator slide can correct joint deformities while preserving strength. Median and ulnar nerve neurolysis is often required, and fibrotic muscle tissue is excised. When flexor function is lost, volar tendon transfers using wrist extensors (e.g., brachioradialis to flexor pollicis longus, or extensor carpi radialis longus to flexor digitorum profundus) may be performed[14-16]. In Grade III cases with severe neurological injury, free functional muscle transfer with nerve reconstruction results with best functional restoration.

For surgical planning, MRI and angiography are critical for assessment of muscle damage, perfusion, and potential donor/recipient vessels[7,10-13].

Advanced Treatments

Severe contractures require complex (often staged) treatment involving debridement of necrotic tissue, nerve decompression, and vascular evaluation[2,14,15]. While some authors recommend early intervention (within three weeks), others advocate waiting three months to one year after the ischemic insult[14-16].

In cases of complete muscle loss, free innervated muscle transfer—most commonly using the gracilis—is preferred for restoring finger flexion. Latissimus dorsi or medial gastrocnemius can be used when soft tissue coverage is also needed[16-20]. Two-stage protocols may be used: initial debridement and neurolysis, followed by muscle transfer once sensation and intrinsic hand function return. If extensors are also affected, double muscle transfers may be necessary. Sural nerve autografts are typically used for concurrent median nerve reconstruction.

Postoperative rehabilitation—including muscle re-education, joint mobilization, and splinting—is essential for optimizing recovery and long-term function[19-23].

Role of Ilizarov Circular Frames

Introduction to Ilizarov Circular Frame

The management of Volkmann's contractures is often challenging due to the complex triad of soft tissue damage, bone involvement and the need for functional recovery. As mentioned before, not all patients are suitable for invasive interventions and cannot be treated with conventional therapeutical methods. For this group of patients, Ilizarov technique offers a minimally invasive, effective alternative. Ilizarov circular frames' application has extended to correcting joint deformities and contractures, making it a valuable tool in both early and advanced stages of Volkmann's contracture, especially when soft tissue integrity or is compromised or when neurological deficit is present[24-26].

Principles of Ilizarov Frame and Application to Wrist Contractures

The Ilizarov method is based on the principle of distraction histogenesis, in which gradual, controlled distraction stimulates regeneration of soft tissues (including muscles, tendons, nerves and skin) without requiring extensive surgical incisions. This can be particularly advantageous in the treatment of Volkmann's contracture with compromised soft tissue. The external-circular frame allows progressive correction of wrist and finger deformities while maintaining structural stability. Correct hinge placement, acting as both the center of rotation and correction, is essential to avoid joint subluxation during distraction. The distraction rate is calculated using pre-operative radiographs and the "rule-of-triangle". Ilizarov method also reduces the risk of the "rebound phenomenon" (the recurrence of deformity commonly seen with other techniques) and can be used either as a standalone intervention or as a preparatory stage before definitive procedures such as tendon transfers or arthrodesis. Post-frame removal, splinting and aggressive rehabilitation are crucial to maintain long-term correction[2,25,26].

In severe (Grade III) wrist Volkmann's contractures the Ilizarov frame offers a unique advantage over conventional surgeries, which often require extensive dissection, tendon lengthening, and may lead to complications such as wound breakdown or graft failure. In contrast, the Ilizarov system gradually corrects flexion deformities while preserving surrounding soft tissues. It is especially beneficial in cases with fractures, as it allows simultaneous fracture stabilization and soft tissue lengthening. In mild to moderate-Grade II contractures, the Ilizarov frame may serve as an alternative to tendon release, facilitating mechanical lengthening and enabling early physiotherapy due to minimal tissue damage. In more complicated deformities, it may be the first stage in a multi-step strategy, creating neutral alignment prior to procedures like arthrodesis or free muscle transfer.

Patient-based frame construction is critical. Preoperative imaging (radiographs and CT scans) individualizes treatment planning. Hinge placement should correspond with the joint's axis of rotation—either at the joint level (to correct angular deformity) or distal to it (to enable joint distraction). The modular

nature of the Ilizarov system allows for flexibility in addressing a wide range of deformities and functional needs[2,25,26].

Outcomes in Literature

Volkmann's ischemic contracture remains a relatively uncommon yet complex condition. As a result, there is a gap in the literature regarding the utilization of the Ilizarov frame for its treatment. Available literature on Volkmann's contracture focuses on conventional-traumatic surgical interventions. The principles of the Ilizarov method that rely on distraction histogenesis—make it theoretically suitable for managing the flexion deformities seen in Volkmann's contracture. Our cases prove this theory and present two successful applications of Ilizarov frame in Volkmann's wrist contracture. Similar contractures affecting the wrist, hand, or lower limb due to burns, cerebral palsy, hemophilia, congenital disorders or trauma have been successfully managed with this technique[27-36]. Given the shared pathophysiological features (fibrosis, joint stiffness, and compromised neurovascular structures), we can extrapolate these outcomes to the treatment of Volkmann's contracture.

In contrast, the Ilizarov circular frame offers a minimally invasive alternative, utilizing the principle of distraction histogenesis to achieve gradual, controlled correction without soft tissue dissection[40–43]. Our cases demonstrate the successful application of the Ilizarov technique in chronic, Grade III Volkmann's contractures, highlighting its potential as both a definitive and preparatory treatment. With calculated hinge placement and gradual distraction, we achieved neutral (or slightly hyperextended) wrist alignment without soft tissue undermining, therefore avoiding common complications such as flap necrosis or iatrogenic nerve injury. Our results align with prior Ilizarov applications in burn-related, congenital, or neurologic contractures, where controlled correction promotes both mechanical alignment and tissue regeneration.

Distraction histogenesis promotes neoangiogenesis, collagen remodeling, and adaptive lengthening of tendons and nerves, which is particularly valuable in ischemic contractures, where healing is often compromised by hypovascularity. Importantly, this approach preserves native tissues and enables early rehabilitation, making it suitable for complex/staged reconstructions. Given the rarity of severe Volkmann's contractures, particularly involving the wrist, clinical evidence supporting Ilizarov use is absent[1–3]. These cases contribute novel data to the literature, supporting circular external fixation as a versatile, tissue-preserving modality in the management of advanced ischemic deformities.

CONCLUSION

The treatment of severe Volkmann's ischemic contracture of the wrist remains a surgical challenge, particularly when soft tissue is compromised. This article highlights the importance of the Ilizarov circular frame as a valuable, minimally invasive alternative that fills a significant gap in the current literature. By utilizing the principles of distraction histogenesis, the Ilizarov method allows for the gradual correction of complex deformities while preserving neurovascular integrity and minimizing the risk of recurrence. While further research is needed, our findings suggest that this technique is an effective preparatory or definitive tool for restoring mechanical alignment and facilitating functional rehabilitation in these complex cases.

ADDENDUM

Case Report 1

Presentation

A 26-year-old male presented with Volkmann deformity following compartment syndrome that he had two years ago after stabbing injury. The wrist was locked in a 90-degree flexion with no passive or active extension (Figure 1a). The patient reported minimal finger flexion.

Compartment syndrome was treated with fasciotomy and wound debridement by plastic surgeon and patient was discharged. An MRI of the left upper extremity conducted during his initial hospitalization revealed no brachial plexus injury but did show soft tissue and muscle damage.

Clinical Findings & Diagnostic Assessment

During our examination, significant muscle atrophy was observed in the left forearm, and the wrist was completely stiff, with severe pain on attempted passive extension. Electromyography (EMG) studies that were conducted twice indicated severe axonal neuropathy of the median and radial nerves, which aligned with a diagnosis of Volkmann contracture. Preoperative X-rays showed no significant bone deformities or evidence of old fractures.

Revised Musculoskeletal Tumor Society Score (MTSS)[38] was used to score patients' functional status. The MTSS score prior to intervention was 9/30.

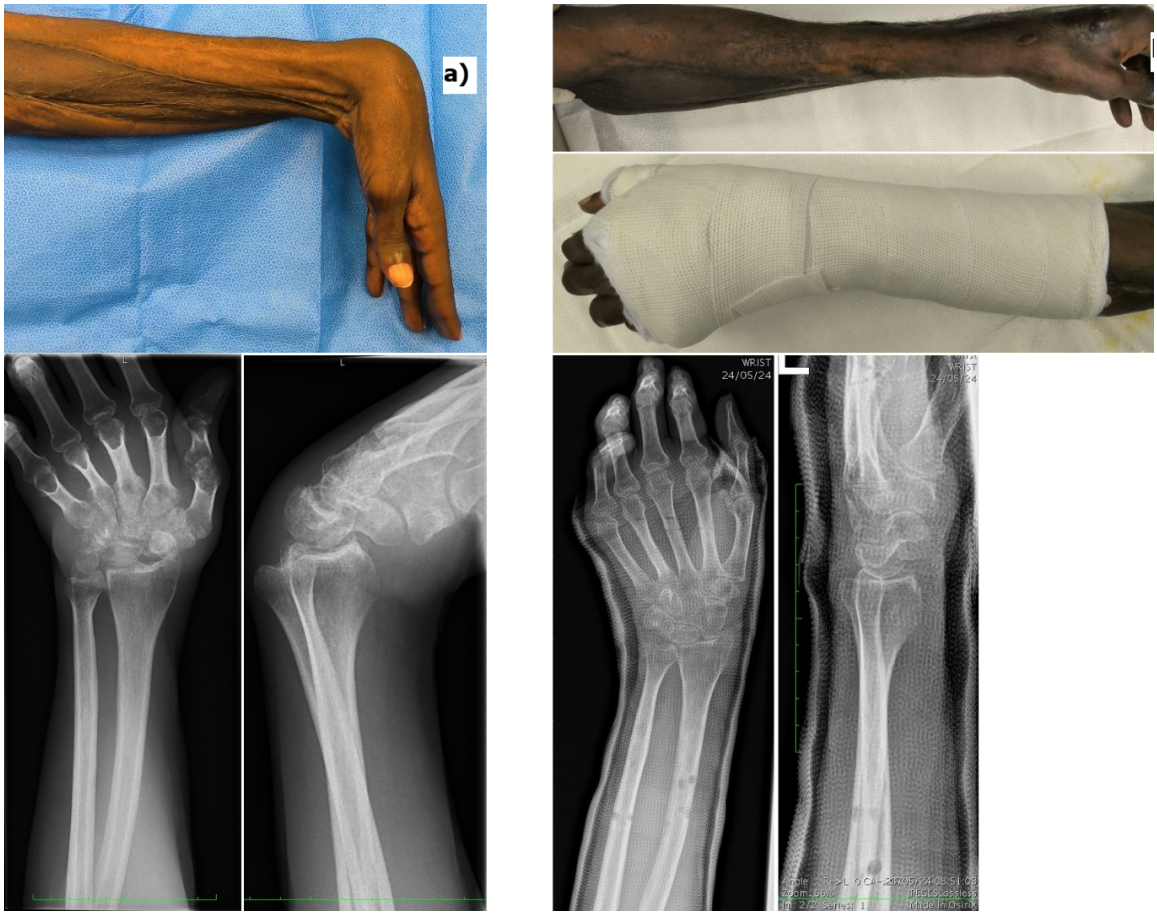

Fig. 1

The sub-scores were:

- Pain = 5/5 (5 = No pain; 0 = Severe disabling)
- Function = 0/5 (5 = No restriction; 0 = Total restriction)
- Emotional = 0/5 (5 = Enthused; 0 = Dislikes)
- Hand positioning = 4/5 (5 = Unlimited; 0 = None)
- Manual dexterity = 0/5 (5 = Unlimited; 0 = Cannot grasp)
- Lifting ability = 0/5 (5 = Normal load; 0 = Cannot help)

Therapeutic Intervention

Our therapeutic goal was to achieve a neutral position of the wrist to enable the patient to begin physical therapy, with the potential for a future wrist arthroplasty to improve range of motion and hand function. We chose to manage the contracture using a three-ring circular Ilizarov frame and perform gradual correction.

Surgery was performed under general anesthesia, patient was placed in supine position on a radiolucent table. The patent's left hand was extended and placed on a C-Thru Surgical Hand Table.

The ring, Kirschner Wires (K-wires) and Schanz screws positions are described using the Method of Unified Designation of External Fixation (MUDEF) as per Solomin[39]. A two-module construction was used, based on three full-rings. Two rings were placed on the forearm and one on the hand.

The proximal forearm ring was placed on level III and distal forearm ring on level VI. Proximal forearm full-ring was secured with one 2.0mm tensioned K-Wire: III(ulna,pronation),10-4, and one Schanz screw: III(ulna,pronation),6,90. Distal forearm full-ring was secured with one 2.0mm tensioned K-Wire: VI(radius,pronation)8-2 ,and one Schanz screw: VI(ulna,pronation),6,90. Both rings were connected between them with 4 threaded rods (anterior, posterior, medial and lateral).

Hand full-ring was placed on level of metacarpal heads. The ring was secured with two non-tensioned 1.8mm K-Wires. One K-Wire passed through 2nd and 3rd metacarpal bones and other K-Wire passed through 4th and 5th metacarpal bones. The metacarpal wires are not tensioned in order to avoid excessive compression of the cancellous metacarpal bones, to

preserve vascular integrity and to avoid the risk of subluxation. After that the hand module and forearm module were connected on the medial and lateral side with 4 rods attached to complete hinges. After, the hand ring and the distal forearm ring were connected posteriorly with the system of 3 hinges, first hinge on the hand ring, second hinge on the level of the wrist joint and third hinge on the distal forearm ring. First hinge is locked in a 90-degree angle and third hinge is connected to a motor that creates rotational force and corrects angular deformity(Figure 2 b). No osteotomy has been performed.

The treatment involved the gradual extension of the wrist at a rate of 1mm per day. On the 48th postoperative day(Figure 2 c), a second motor was added anteriorly, connecting the hand full ring with the distal forearm full ring, in order to achieve overcorrection, specifically increasing wrist dorsiflexion to ensure that a neutral position could be maintained after the frame's removal. By the 60th postoperative day, the desired correction was achieved(Figure 2 d), and the Ilizarov frame was subsequently removed on the 120th day post-surgery. Following frame removal, a circular forearm cast was applied to maintain the wrist position(Figure 1 b).

Follow-Up And Outcomes

Successful correction of the wrist to a neutral position, enabling the patient to initiate physical therapy. Correction assessment and dressing changes were done during weekly outpatient visits. No significant pain was reported during therapy and patient remained stable.

At the most recent follow-up, the patient continued to experience limitations in hand function due to the existing nerve damage.

Post-operative MTSS score was 16/30 (+6/30 = + 25%). Sub-scores were:

- Pain = 5/5
- Function = 1/5
- Emotional = 5/5
- Hand positioning = 5/5
- Manual dexterity = 0/5
- Lifting ability = 0/5

Moving forward, the patient may require a wrist arthroplasty to improve the range of motion and enhance functional use of the hand.

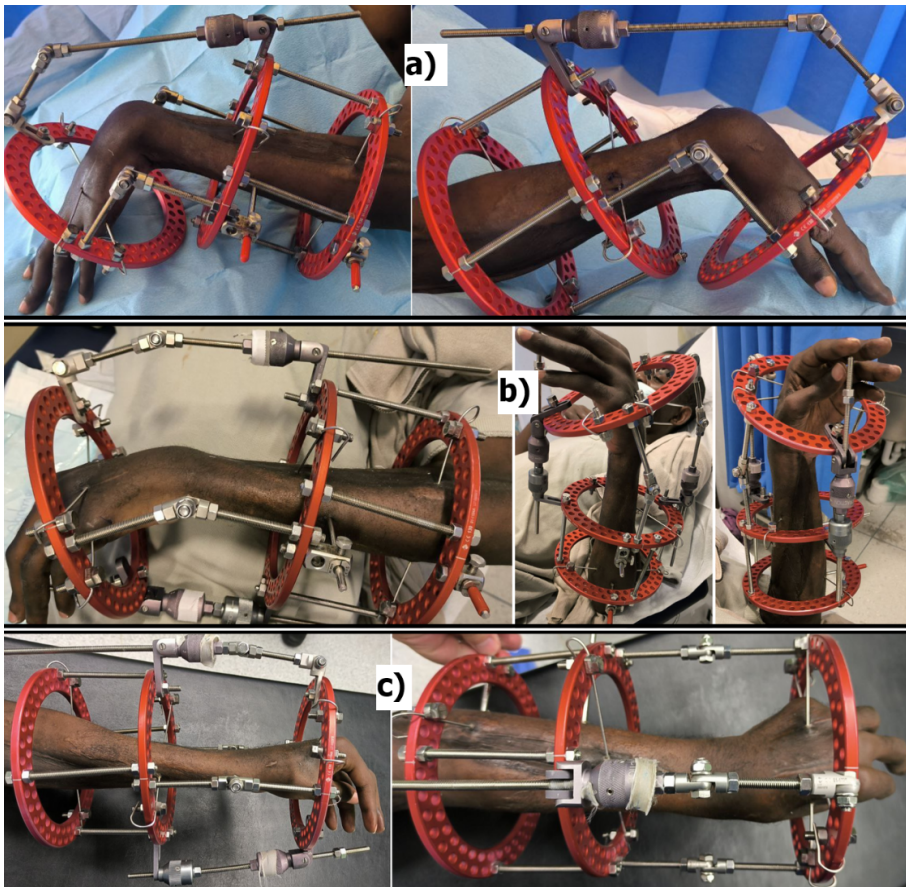

Fig. 2

Case Report 2

Presentation

A 25-year-old male presented with a Volkmann contracture of the left forearm, which developed following bi-osseous fracture of the left forearm, which was initially managed non-operatively with a long plaster cast due to poor general condition and unsuitability for surgical intervention (Figure 3 a). The patient also had multiple facial and abdominal injuries.

Twenty days after plaster application, a bas smell from the cast was noted. Upon removal, examination revealed significant muscle atrophy, claw-hand deformity, a skin ulcer (Figure 3 b) and a rigid deformity of the forearm with no active pronation or supination (Figure 3 c). Flexor retraction seen in Volkmann contracture was noted (Figure 3 d). Open Reduction and Internal fixation with plates for the ulnar and radial fractures was performed (Figure 4 a).

Clinical Findings

On examination, the patient exhibited a fixed flexion contracture of the wrist, worsened by scarring over the volar aspect from prior surgery. There was an extension contracture of the metacarpophalangeal joints (MCP), flexion contractures of the proximal and distal interphalangeal joints (PIP and DIP) and an abduction contracture of the thumb (Figure 4 b).
Pre-operative MTSS totaled to 11/30. The sub-scores were:

- Pain = 5/5
- Function = 0/5
- Emotional = 1/5
- Hand positioning = 5/5
- Manual dexterity = 0/5
- Lifting ability = 0/5

Therapeutic Intervention

The patient was treated under general anesthesia. After the ulnar and radial plates removal, a custom-made hybrid Ilizarov-Truelok frame was applied (Figure 4 c, d). A two-module construction was used, based on two full-rings and one half-ring. Two full-rings were placed on the forearm and one half-ring on the hand. The proximal forearm ring was placed on level III and distal forearm ring on level VII. Proximal forearm full-ring was secured with one 2.0mm tensioned K-Wire: III(radius,pronation),12-6 ,and one Schanz screw: III(radius,pronation),9,120. Distal forearm full-ring was secured with three 2.0mm tensioned K-Wires: VII(radius,pronation)1-7, VII(radius,pronation)2-8, VII(radius,pronation)3-9. Both rings were connected between them with 4 threaded rods (anterior, posterior, medial and lateral).

Hand half-ring was placed on level of metacarpal bones' base. The ring was secured with two non-tensioned 1.8mm Olive-Wires. One Olive-Wire passed through 2nd and 3rd metacarpal bones and other Olive-Wire passed through 4th and 5th metacarpal bones. After that the hand module and forearm module were connected on the anterior side with 4 rods attached to complete hinges (mono-planar). After, the hand ring and the distal forearm ring were connected medially and laterally with 2 rods and 2 extension plates attached to mono-planar hinges.

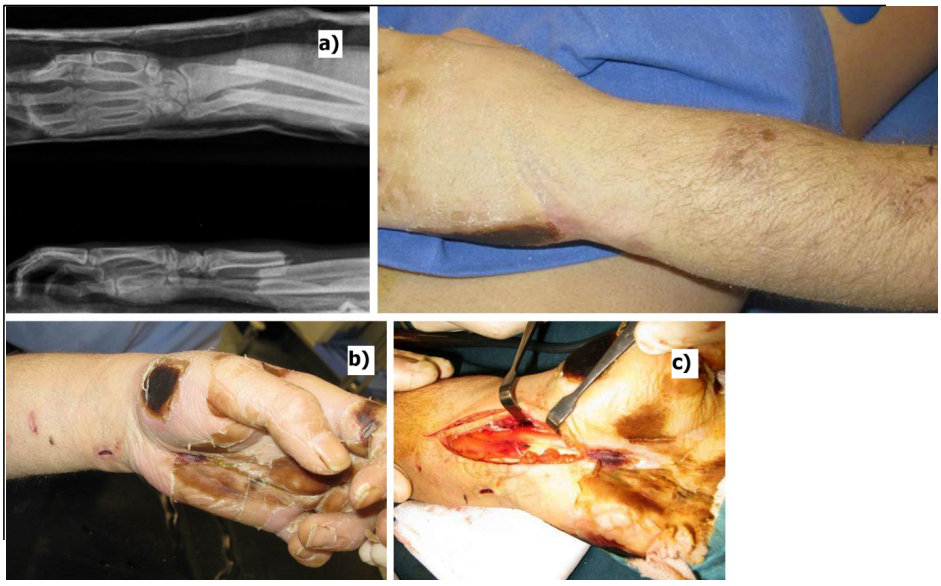

Fig. 3

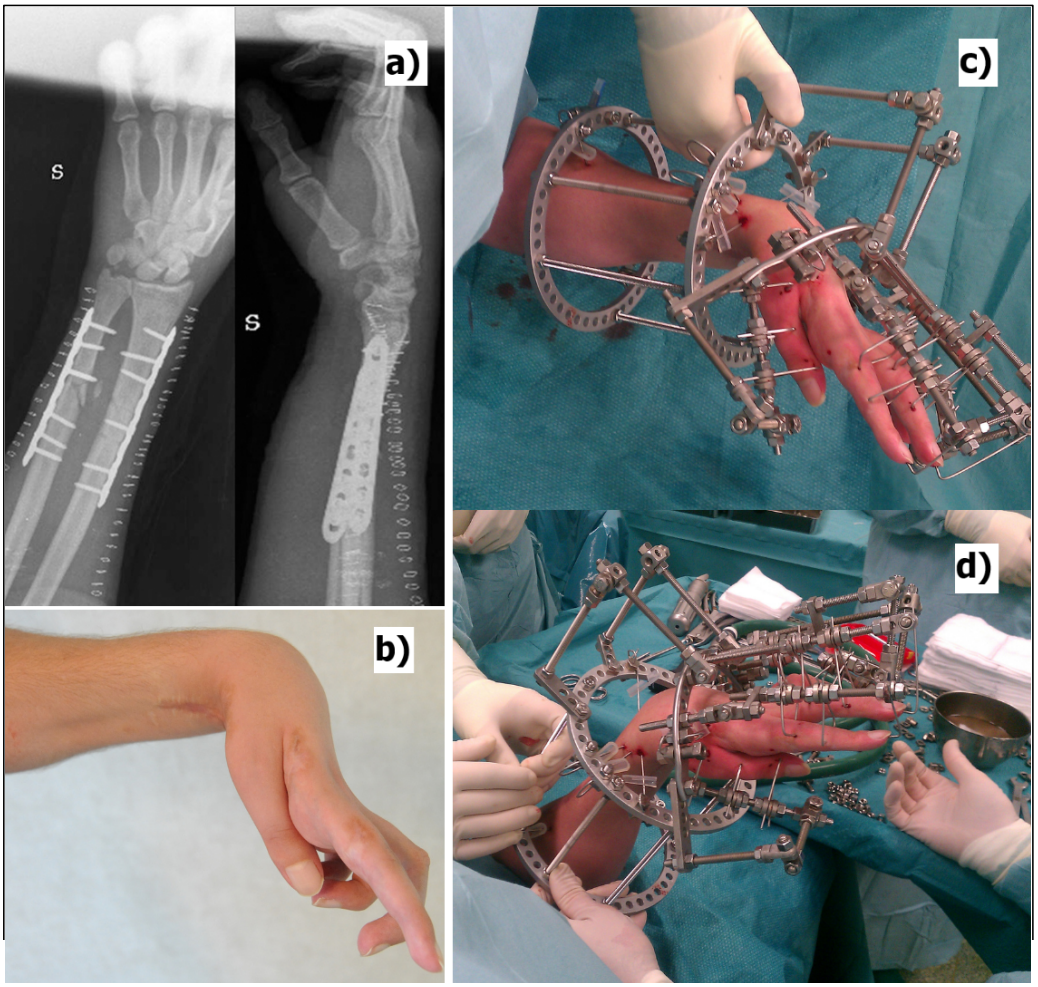

Fig. 4

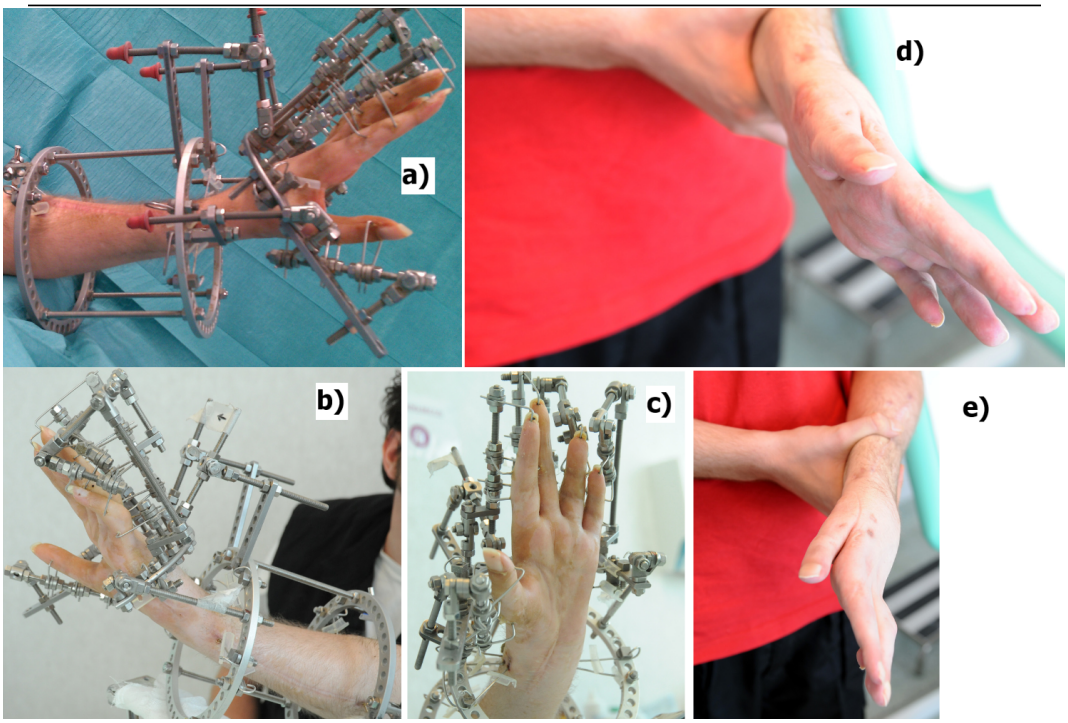

Fig. 5

2nd to 5th fingers were fixed by one transverse Kirschner wire through the proximal phalange, one transverse Kirschner wire through the middle phalange and one longitudinal Kirschner wire through the distal, the middle and the proximal phalanges.

The first finger was fixed by transverse Kirschner wires only through proximal and distal phalanx.

First, fourth and fifth fingers were connected with rods and hinges to the hand ring as they required extension. Second and third fingers were connected to the hand ring with rods.

No osteotomy has been performed.

Postoperative Course and Correction Protocol

Postoperative pain was managed with morphine, NSAIDs and acetaminophen. Patient was discharged on 4th postoperative day.

Correction began on postoperative day 5 at a rate of 1 mm/day using the rods connecting the distal forearm ring to the hand half-ring. Follow-ups were conducted biweekly to change dressings and monitor joint alignment (Figure 5 a, b, c).

On 25 post-op week frame was removed and a circular cast was applied to maintain correction. The patient intermittently removed the cast during the day to attend supervised physiotherapy, focusing on passive wrist and finger mobilization.

Follow-Up and Outcomes

At 43 weeks postoperatively (18 weeks after frame removal), the MTSS score improved modestly to 15/30(+13.33%). Sub-scores were:

- Pain = 5/5
- Function = 0/5
- Emotional = 5/5 (+80% improvement)
- Hand positioning = 5/5
- Manual dexterity = 0/5
- Lifting ability = 0/5

At the last follow-up (Figure 5 d, e), all joint deformities were corrected and remained stable without any pain. However, overall functional improvement of the hand and wrist remained limited and comparable to preoperative status.

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Ethics Statement and Informed Consent: Approval was obtained from the ethics committees of General Hospital of Nicosia and Humanitas Hospital. Both patients provided informed consent for the publication of clinical data and figures 1–5. No personal identifying information will be disclosed, and all personal data will be protected. The study adhered to the principles of the Declaration of Helsinki.

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REFERENCES

1. Mubarak, S. J., & Carroll, N. C. (1979). Volkmann's contracture in children: aetiology and prevention. The Journal of Bone & Joint Surgery British Volume, 61(3), 285-293.
2. Azar, F. M., Canale, S. T., & Beaty, J. H. (2020). Campbell's Operative Orthopaedics, E-Book. Elsevier Health Sciences.
3. Seddon, H. J. (1956). Volkman's Contracture: Treatment by Excision of the Infarct. Plastic and Reconstructive Surgery, 18(6), 494.
4. Geissler, J., Westberg, J., & Stevanovic, M. (2018). Pseudo-Volkmann contracture: a case report and review of the current literature. JAAOS Global Research & Reviews, 2(11), e031.
5. Mirza, T. M., & Taqi, M. (2020). Volkmann contracture.
6. Ikuta, Y., Tsuge, K., & Kubo, T. (1976). Free muscle transfers by neurovascular anastomosis using microsurgical techniques—clinical case. Plast Reconstr Surg, 58, 407.
7. Griffart, A., Gauthier, E., Vaiss, L., Williams, T., Mallard, F., & Le Nen, D. (2019). Functional and socioprofessional outcome of surgery for Volkmann's contracture. Orthopaedics & Traumatology: Surgery & Research, 105(3), 423-427.
8. Meena, D. K., Thalanki, S., Patni, P., Meena, R. K., Bairawa, D., & Bhatia, C. (2016). Results of neurolysis in established upper limb Volkmann's ischemic contracture. Indian journal of orthopaedics, 50(6), 602–609.
9. Tsuge K. (1975). Treatment of established Volkmann's contracture. The Journal of bone and joint surgery. American volume, 57(7), 925–929.
10. Neri, I., Magnano, M., Pini, A., Ricci, L., Patrizi, A., & Balestri, R. (2014). Congenital Volkmann syndrome and aplasia cutis of the forearm: a challenging differential diagnosis. JAMA dermatology, 150(9), 978-980.
11. Oishi, S. N., & Ezaki, M. (2010). Free gracilis transfer to restore finger flexion in Volkmann ischemic contracture. Techniques in Hand & Upper Extremity Surgery, 14(2), 104-107.
12. Stevanovic, M., & Sharpe, F. (2006). Management of established Volkmann's contracture of the forearm in children. Hand clinics, 22(1), 99-111.
13. Chuang, D. C., Carver, N., & Wei, F. C. (1996). A new strategy to prevent the sequelae of severe Volkmann's ischemia. Plastic and reconstructive surgery, 98(6), 1023-1031.
14. Stevanovic, M., & Sharpe, F. E. (2024). Refinements in the treatment of Volkmann ischemic contracture of the forearm: A thematic review. Plastic and Reconstructive Surgery–Global Open, 12(2), e5532.
15. PAGE, C. M. (1923). An operation for the relief of flexion-contracture in the forearm. JBJS, 5(2), 233-234.
16. Tsuge, K. (1967). Treatment of established Volkmann's contracture of the forearm. Nihon Seikeigeka Gakkai zasshi, 40(13), 1569-1584.
17. Seddon, H. (1964). Volkmann's ischaemia. British Medical Journal, 1(5398), 1587.
18. Nisbet, N. W. (1952). Volkmann's ischaemic contracture benefited by muscle slide operation: report of a case. The Journal of Bone & Joint Surgery British Volume, 34(2), 245-247.
19. Zuker, R. M., Egerszegi, E. P., Manktelow, R. T., McLeod, A., & Candlish, S. (1991). Volkmann's ischemic contracture in children: the results of free vascularized muscle transplantation. Microsurgery, 12(5), 341-345.
20. Chidester, J. R., Leland, H. A., Navo, P., Minneti, M., Ghiassi, A., & Stevanovic, M. (2018). Redefining the anatomic

boundaries for safe dissection of the skin paddle in a gracilis myofasciocutaneous free flap: an indocyanine green cadaveric injection study. Plastic and Reconstructive Surgery–Global Open, 6(12), e1994.
21. Stevanovic, M., & Sharpe, F. (2014). Functional free muscle transfer for upper extremity reconstruction. Plastic and reconstructive surgery, 134(2), 257e-274e.
22. Zuker, R. M., & Manktelow, R. T. (2007). Functioning free muscle transfers. Hand Clinics, 23(1), 57-72.
23. Manktelow, R. T., & Zuker, R. M. (1989). The principles of functioning muscle transplantation: applications to the upper arm. Annals of plastic surgery, 22(4), 275-282.
24. Landi, A., Caserta, G., Giorgini, A., Sartini, S., & Oishi, S. (2023). Compartment Syndromes (CS) and Volkmann's and Upper Limb Vascular Pathology in the Peri-and Neonatal Period. In Pediatric Hand Surgery (pp. 391-414). Cham: Springer International Publishing.
25. Uysal, M. (2018). The Treatment of Complications in Ilizarov Technique. In Basic Techniques for Extremity Reconstruction: External Fixator Applications According to Ilizarov Principles (pp. 691-699). Cham: Springer International Publishing.
26. Vishnu, Y. S., Raman, G., Puneetpal, K., Sitaram, Y. V., & Akanksha, O. (2024). Soft-tissue origin joint contractures treated with the Ilizarov fixation method. Гений ортопедии, 30(2), 255-262.
27. Solignac, N., Vialle, R., Thévenin-Lemoine, C., & Damsin, J. P. (2009). Popliteal pterygium knee contracture: treatment with the Ilizarov technique. Orthopaedics & Traumatology: Surgery & Research, 95(3), 196-201.
28. Zhai, J., Weng, X., Zhang, B., Peng, H., & Bian, Y. (2019). Management of knee flexion contracture in haemophilia with the Ilizarov technique. The Knee, 26(1), 201-206.
29. Ullmann, Y., Fodor, L., Soudry, M., & Lerner, A. (2007). The Ilizarov technique in joint contractures and dislocations. Acta orthopaedica belgica, 73(1), 77.
30. Niall, D. M., Murphy, P. G., Fogarty, E. E., Dowling, F. E., & Moore, D. P. (1998). Correction of soft tissue contractures of the wrist using the Ilizarov technique. Journal of Hand Surgery, 23(4), 442-444.
31. Madhuri, V., & Dhanraj, P. (1998). Correction of post burns contracture of wrist with Ilizarov method. Burns, 24(6), 576-578.
32. Tsumura, T., Matsumoto, T., Matsushita, M., Kishimoto, K., Shiode, H., & Murakami, H. (2022). Severe hand contracture treated by external fixation after proximal row carpectomy and awake tenolysis after general anesthesia: A case report. Chinese Journal of Traumatology, 25(01), 54-58.
33. Tsumura, T., Matsumoto, T., Matsushita, M., Kishimoto, K., Shiode, H., & Murakami, H. (2022). Severe hand contracture treated by external fixation after proximal row carpectomy and awake tenolysis after general anesthesia: A case report. Chinese Journal of Traumatology, 25(01), 54-58.
34. Yang, J., Yu, L., Meng, F., Wen, J., Xiao, Y., Wan, S., Yu, F., & Zhou, Z. (2024). Role of microsurgical techniques combined with Ilizarov techniques in limb salvage and functional reconstruction of thermal crush injuries of the hand: A case report. Experimental and therapeutic medicine, 28(1), 291.
35. Hou, N., Zhang, H., Bai, M., Chen, H., Song, W., & Wang, L. (2020). The old supracondylar fracture of femur treated by gradual deformity correction using the ilizarov technique followed by the second-stage internal fixation in an elderly patient with osteoporosis. Geriatric Orthopaedic Surgery & Rehabilitation, 11, 2151459320931673.
36. Leonchuk, S. S., Novikov, K. I., Subramanyam, K. N., Shikhaleva, N. G., Pliev, M. K., & Mundargi, A. V. (2020). Management of severe congenital flexion deformity of the knee using Ilizarov method. Journal of Pediatric Orthopaedics B, 29(1), 47-52.
37. Gaurav, K., & Vilas, J. (2010). A new approach to the management of fixed flexion deformity of the knee using Ilizarov's principle of distraction histogenesis: a preliminary communication. The International Journal of Lower Extremity Wounds, 9(2), 70-73.
38. ENNEKING, W. F., Dunham, W. I. L. L. I. A. M., GEBHARDT, M. C., Malawar, M. A. R. T. I. N., & PRITCHARD, D. J. (1993). A system for the functional evaluation of reconstructive procedures after surgical treatment of tumors of the musculoskeletal system. Clinical Orthopaedics and Related Research (1976-2007), 286, 241-246.
39. Solomin, L.N. (2012). Method of Unified Designation of External Fixation (MUDEF). In: Solomin, L. (eds) The Basic Principles of External Skeletal Fixation Using the Ilizarov and Other Devices. Springer, Milano. https://doi.org/10.1007/978-88-470-2619-3_4
40. Cham, P. M. H., Drolet, B. A., Segura, A. D., & Esterly, N. B. (2004). Congenital Volkmann ischaemic contracture: a case report and review. British Journal of Dermatology, 150(2), 357-363.
41. Raimer, L., McCarthy, R. A., Raimer, D., & Colome-Grimmer, M. (2008). Congenital Volkmann ischemic contracture: a case report. Pediatric dermatology, 25(3), 352-354.
42. Silfen, R., Amir, A., Sirota, L., & Hauben, D. J. (2000). Congenital Volkmann-Lesser ischemic contracture of the upper limb. Annals of plastic surgery, 45(3), 313-317.
43. Blakemore, L. C., Cooperman, D. R., Thompson, G. H., Wathey, C., & Ballock, R. T. (2000). Compartment syndrome in ipsilateral humerus and forearm fractures in children. Clinical Orthopaedics and Related Research (1976-2007), 376, 32-38.