Role of microsurgical techniques combined with Ilizarov techniques in limb salvage and functional reconstruction of thermal-crush injuries of the hand: A case report

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Abstract. The Ilizarov technology was proposed by Former Soviet orthopedic physician Ilizarov. It is a medical method to reconstruct missing tissues. Ilizarov technology combined with soft tissue stretching technology is of great significance in the treatment of common orthopedic problems like bone defects, finger absence, joint contracture and joint stiffness following thermal-crush injuries of the hand. In the present study a 25-year-old male patient sought for limb salvage treatment 1 month after sustaining thermal-crush injuries of the right hand and forearm. The patient had been treated by another hospital with multiple procedures of debridement, and recommended for forearm amputation. The patient was diagnosed with: i) Postoperative infection of thermal-crush injuries of the right hand and right forearm; ii) comminuted open fractures of the proximal and distal phalanges of the right thumb; iii) osteomyelitis; iv) palm skin defects with exposed tendons; and v) skin defects of the opisthenar and the forearm. After a series of treatments including debridement, removal of necrotic tissue, tissue transplantation, skin pedicle, bone lengthening, external shaping, tissue release, joint fusion, traction and rehabilitation exercises, the patient recovered some hand function. Overall, thermal-crush injuries of the hand are severe, complicated combined injuries composed of both heat burn and compression injury and their treatment is challenging. Overall, microsurgery combined with Ilizarov technology can effectively reconstruct the function of complex thermal-crush injuries of the hand.

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Introduction

Thermal-crush injuries belong to composite injuries caused by both thermal burns and mechanical compression, and they often accompany tissue damages of the skin, muscles, blood vessels and bones, with a high amputation rate of 13.3% (1,2). Thermal-crush injuries of the hand often occur in workplaces and fire accidents (3). Due to the complex condition and severe injury, functional recovery through limb preservation and reconstruction is challenging (4).

Treatment processes of thermal-crush injuries of the hand (1) are generally divided into three stages, namely limb salvage, functional reconstruction and functional rehabilitation. They are indispensable and important during the whole process of treatment. After designing a limb salvage reconstruction plan, bone and joint injuries often require an external fixation or simple internal fixation. Based on the general principles of burn treatment, an early and thorough debridement is necessary (5). Microsurgery and plastic surgery for soft tissue injuries are performed after the successful debridement. Thermal-crush injuries of the hand often involve severe composite injuries and defects of bones and soft tissues that require the bone and soft tissue reconstruction (6). Free tissues are usually used for reconstruction, especially free toe transplantation and free skin flap repair (7). Notably, an external fixation using Ilizarov external frame and bone transport technology is preferred to the reconstruction of bones and soft tissues in patients with thermal-crush injuries of the hand due to the fragile structure of the soft tissues of the hand (8).

A former soviet orthopedic physician, Ilizarov, hypothesized that human bones and soft tissues have great potential

for regeneration and plasticity. They are able to grow longer or shortened by medical methods to reconstruct damaged tissues. Since then, Ilizarov's external frame and bone handling techniques have been widely used in clinical practice to correct bone deformities (9). Ilizarov's technology combined with soft tissue stretching is of great significance in the treatment of common orthopedic problems like bone defects, finger absence, joint contracture and joint stiffness following thermal-crush injuries of the hand (10).

For challenging cases of thermal-crush injuries of the hand, a comprehensive hand microsurgical repair and reconstruction plan enhances the success rate of limb salvage (11). A further evaluation of limb salvage through mid-term and long-term follow-up is useful to provide references for an individualized therapeutic strategy of limb salvage and assessment of functional recovery (12).

Previously, we have treated similar cases in the upper, lower and hand regions. We used the Ilizarov technique for hand extension in 10 patients, traction correction in 5 patients with flexion contracture and limb extension in 5 patients after lower limb replantation or severe injury. Subsequently, 5 patients with limb extension after replantation or severe injury achieved successful surgery, restored limb length and plantar function and had no pain in the affected limb. In patients with flexion contracture and extension, the affected limbs had achieved improvement in range of motion, but due to the severity of flexion contracture and poor soft tissue conditions, they had not fully recovered their active and passive range of motion. We have extensive experience in applying Ilizarov treatment. Based on this, we successfully treated the current case. The present study reports a case of thermal-crush injuries of the hand treated with microsurgical technology combined with Ilizarov treatment for limb salvage and functional reconstruction.

Case report

A 25-year-old male patient sought for limb salvage treatment 1 month after sustaining thermal-crush injuries of the right hand and forearm. He had been treated with multiple procedures of debridement and was recommended for forearm amputation in another hospital. X-ray scans showed fractures of the proximal and distal segments of the thumb, and damage of the interphalangeal joint. After admission to Peking University Shenzhen Hospital (Shenzhen, China) in June 2018, the patient was treated with debridement procedures for skin defects of the whole palm, including palmar skin defects of the proximal phalanx of the index, middle, ring and pinkie fingers and exposures of the flexor tendon articular capsule and phalanges of the thumb. Only a small piece of dorsal skin of the thumb with 1.5 cm^2 in width remained. Other skin defects were present on the dorsal side of the hand and forearm, 10x3 cm^2 in width. Fortunately, the granulation tissues grew well without an exposure of deep tissues like tendons (Fig. 1A-C). The patient was therefore diagnosed with: i) Postoperative infection of thermal-crush injuries of the right hand and right forearm; ii) comminuted open fractures of the proximal and distal phalanges of the right thumb; iii) osteomyelitis; iv) palm skin defects with exposed tendons; and v) skin defects of the opisthenar and the forearm.

Treatment processes and follow-up. After admission, the patient was sequentially managed by debridement procedures, amputation of the distal phalange of the thumb and resections of the necrotic flexor tendon from the metacarpophalangeal joints of the thumb and index finger to the wrist joint [negative pressure wound therapy (NPWT) (13) technology was used].

At 5 weeks post-injury, a pedicled anterolateral thigh perforator flap was transplanted to repair skin defects on the palm, thumb and the palmar side of the index, middle, ring and pinkie fingers. The deep flexor tendon of the index finger and the flexor hallucis longus tendon were repaired by transplanting an autologous palmaris longus tendon. Full-thickness skin grafts were used to repair the skin defects of the opisthenar (Fig. 2).

The skin pedicle was severed at 3 weeks postoperation. At 3 months after the soft tissue repair, the patient was managed by minimally invasive osteotomy bone lengthening for the first metacarpal bone, and thinning and shaping of the palmar skin flap were performed.

At 1 week after the first metacarpal osteotomy (Fig. 3A-D), a 50-day thumb metacarpal lengthening for 2.5 cm was performed (Fig. 3E-G). At 3 months after the lengthening (Fig. 4A), an enlargement of the first web space, flexor tendon relaxation, fusion of the first carpometacarpal joint, capsular release of the index, middle, ring and pinkie fingers and Ilizarov external fixation of the right hand were performed (Fig. 4B and C).

At 1 week after the external fixation, the flexion contracture deformity was corrected by using an external frame to stretch the index, middle, ring and pinkie fingers. The thumb was slowly extended for the opening and extension of the first web space. The traction speed and frequency gradually increased to yield 5-10 times of a reciprocating motion of the stretching and flexibility, which were terminated 20 days after surgery. The outer frame was removed, followed by the intervention of rehabilitation exercises. After discharge, the patient received training with a rehabilitation therapist, wearing orthodontic braces throughout the early stages for fixation, and intermittently wearing braces after 4 weeks.

After the first skin flap surgery, the metacarpophalangeal joints of the index, middle, ring and little fingers were stiffened at 0˚, the proximal interphalangeal joint was stiffened at 90˚, the distal interphalangeal joint was flexed at 30˚ and the ROM was at 0˚. After the second Ilizarov stretch, the metacarpophalangeal joints of the index, middle, ring and little fingers moved at 30-60˚, the proximal interphalangeal joint moved at 40-70˚ and the distal interphalangeal joint flexed at 10-30˚ with ROM at 60˚. After follow-up for 1 year, hand function was recovered well with a QuickDASH (14) (Disabilities of Arm, Shoulder and Hand) score of 35 points, and Chen's criteria (15) of grade 2 (Fig. 5A-D).

Discussion

With the advancement of technologies and industry development, case numbers of thermal-crush injuries of the hand are gradually on the rise (16). Thermal-crush injuries of the hand are severe and complex due to the dual-injury of thermal burns and mechanical compression, as well as the anatomical characteristics of the hand. A timely transfer to medical institutions

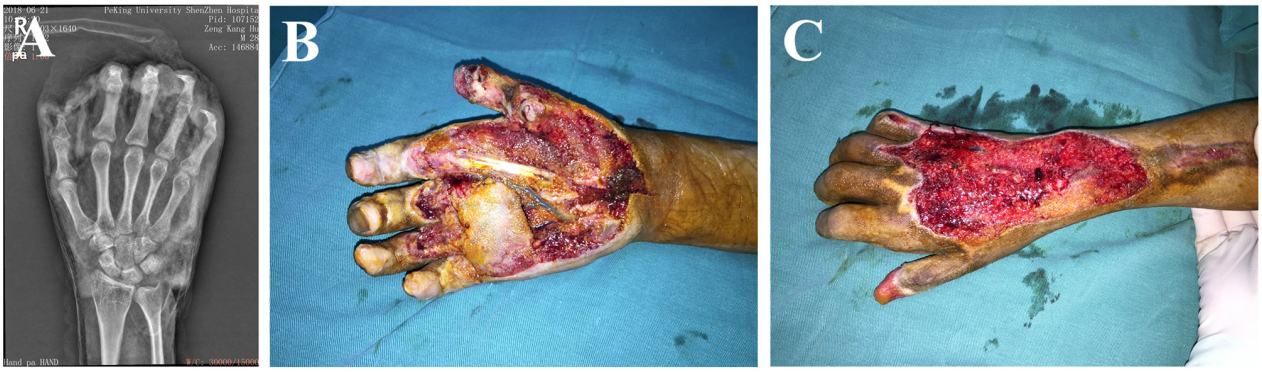

Figure 1. Disease condition at admission. (A) An X-ray scan showing a fracture of the distal phalanx of the thumb. (B) Necrosis of the palm skin, exposures of tendons, exposure of the metacarpophalangeal and interphalangeal joints of the thumb and bone exposure. (C) A skin defect of the opisthenar.

Figure 2. Treatment processes of the hand wound. A pedicled anterolateral thigh flap was designed to repair the palm wound and tendon transplantation was performed to repair the defect of the flexor tendon of the thumb and index finger.

with clinical experience of limb salvage and reconstruction is essential (17). In clinical practice, an accurate staging of thermal-crush injuries of the hand is necessary, and it usually requires an emergency X-ray or even CT based on the Mangled Extremity Severity Score (MESS) (18) and the Ganga Hospital Score (GHS) (19).

In the present case report, the patient was graded with 5 points and 10 points of MESS and GHS, respectively. An optimal treatment plan was comprehensively decided based on objective diagnostic scores and individualized conditions (20). Both individualized conditions of patients (21) and experiences of the medical institutions are two vital factors to influence the accurate clinical decision-making for limb salvage reconstruction (22). Amputation is an option for patients with thermal-crush injuries of the hand (23). The upper and lower limbs are flexible and highly needed in the daily life. Their functions usually cannot be replaced by the prosthetics. Therefore, great efforts have be made on limb salvage and limb reconstruction (24). Through the successful treatment of the present case, the current study suggested that the injured limb should be fully protected without violating existing medical treatment principles. Multidisciplinary consultations involving specialists of burn surgery, microsurgery, repair and reconstruction surgery and plastic surgery, and even multi-center remote consultations are recommended to reduce the amputation rate.

Principles of timely and thorough debridement in hand surgery (25) and early escharotomy in burn surgery (26) should be strictly conformed to during debridement procedures of thermal-crush injuries of the hand. A complete removal of obvious necrotic and inactivated tissues is required. A third-degree burn usually causes full-thickness skin necrosis, and the removal of the necrotic skin and soft tissues is necessary to reduce the risk of infection (27). NPWT is recommended for exposed wounds in order to regenerate the wound tissue in cases when there is a lack of effective soft tissue for reconstruction (28).

Soft tissue reconstruction is the major event of limb salvage for thermal-crush injuries of the hand (29). Following the general process of skin defect treatment in hand surgery (30), free skin grafting is often used to repair the wound surface in patients with well-growing granulation and lack of deep tissue exposure. Skin flap transplantation is the only choice for patients with a high demand for wear resistance and weight bearing, and those with a deep tissue exposure. In the present case, the pedicled anterolateral thigh flap (ALTP) was adopted for its high success rate of transplantation (31). Moreover, the impact of skin flap vascular anastomosis on the hand blood supply should be concerned due to the full hand injury, which can be preoperatively assessed by the angiography to localize the vascular recipient area, if necessary.

The Ilizarov treatment has been used clinically for a long time (32), and it was important in the reconstruction of hand function in the present case. The Ilizarov technique can effectively release and correct joint stiffness and flexion contractures without complex and dangerous release surgeries (33). At the same time, slow stretching of soft tissue can simultaneously correct defects in tendons, nerves, blood vessels and skin, avoiding complex micro repair and reconstruction surgeries (34). Additionally, the Ilizarov bone lengthening technique can correct thumb shortening without the need for complex toe transplantation and thumb reconstruction, without donor site damage (35).

However, its drawbacks are that Ilizarov technology requires specialized technical training and a longer learning curve for doctors. The cost of using an external frame is

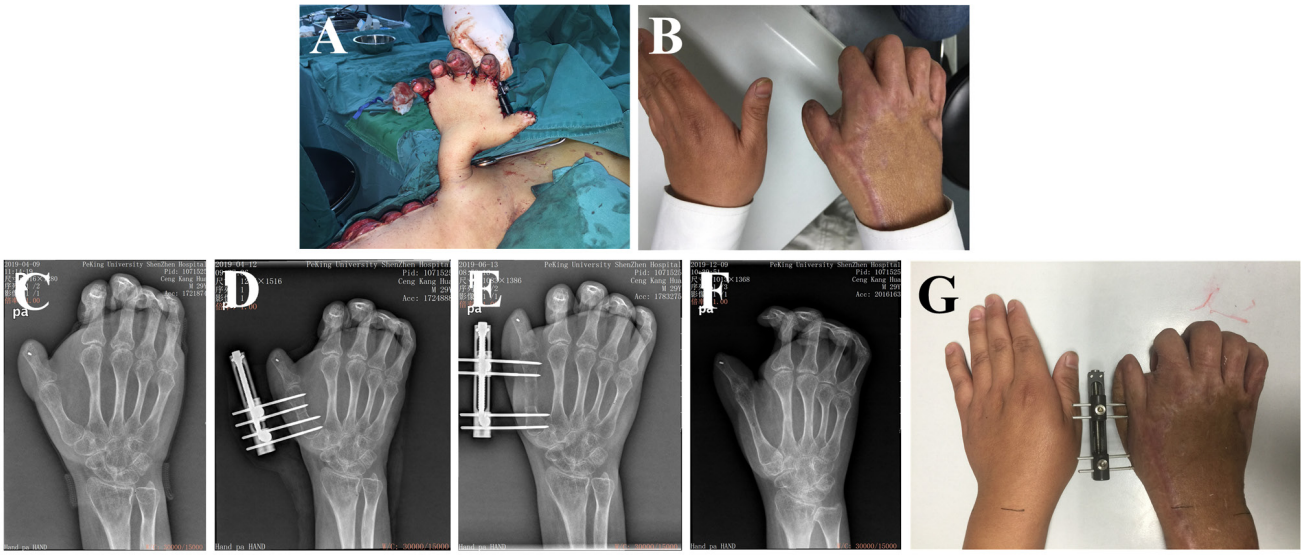

Figure 3. Treatment processes of the thumb. (A) The absence of the distal segment of the thumb repaired by the lengthening of the first metacarpal bone during surgery. (B) The postoperative hand shape. (C) An X-ray scan of the thumb before the repair. (D) An X-ray scan of the thumb before bone lengthening. (E) An X-ray scan during thumb lengthening. (F) An X-ray scan of thumb lengthening for a total of 2.5 cm. (G) A representative image of the hand after thumb lengthening.

Figure 4. Treatment processes of the index, middle, ring and pinkie fingers. (A) Flexion contracture of the index, middle, ring and pinkie fingers. (B) Fusion of the first carpometacarpal joint, and the flexion contracture release surgery of the index, middle, ring and pinkie fingers. (C) An Ilizarov ring frame was designed to perform opposition extension of the thumb and passive extension of the other four fingers.

relatively high, and there is a risk of nail path infection and joint stiffness when using an external frame. Patients may feel uncomfortable wearing an external frame compared with patients who do not use external frame for other treatment methods and it takes a longer time to wear it until the limb function is recovered. In addition, for patients with finger elongation, it is not possible to achieve good appearance and function after toe transplantation and reconstruction. For the correction of flexion contracture, the release effect for injured limbs of using Ilizarov technology is not as complete as patients using surgical release of soft tissue transfer coverage and there will be rebound after removing the external frame (36).

Some treatment innovations in the present case should be highlighted. First of all, the distal phalange of the thumb was amputated during the debridement procedures, resulting in a type 2 thumb defect. The patient refused a toe transplantation for finger reconstruction, and finally, a mini track bracket was used to perform a minimally invasive osteotomy plus bone lengthening for the middle phalanx of the first metacarpal bone. The thumb was ultimately lengthened by 2.5 cm, restoring its normal physiological length. Notably, severe soft tissue loss was repaired using the ALTP for the range of 2/3 of the circumference of the wound in the soft tissue defect. The successful finger lengthening indicated that the bone transport distraction osteogenesis via the Ilizarov method can still be applied to patients with severe finger injuries for limb reconstruction.

Although finger lengthening surgery is not the gold standard for finger reconstruction (37), the present study preferred not to create a functional thumb using the toe due to the poor overall condition of this patient. Secondly, a

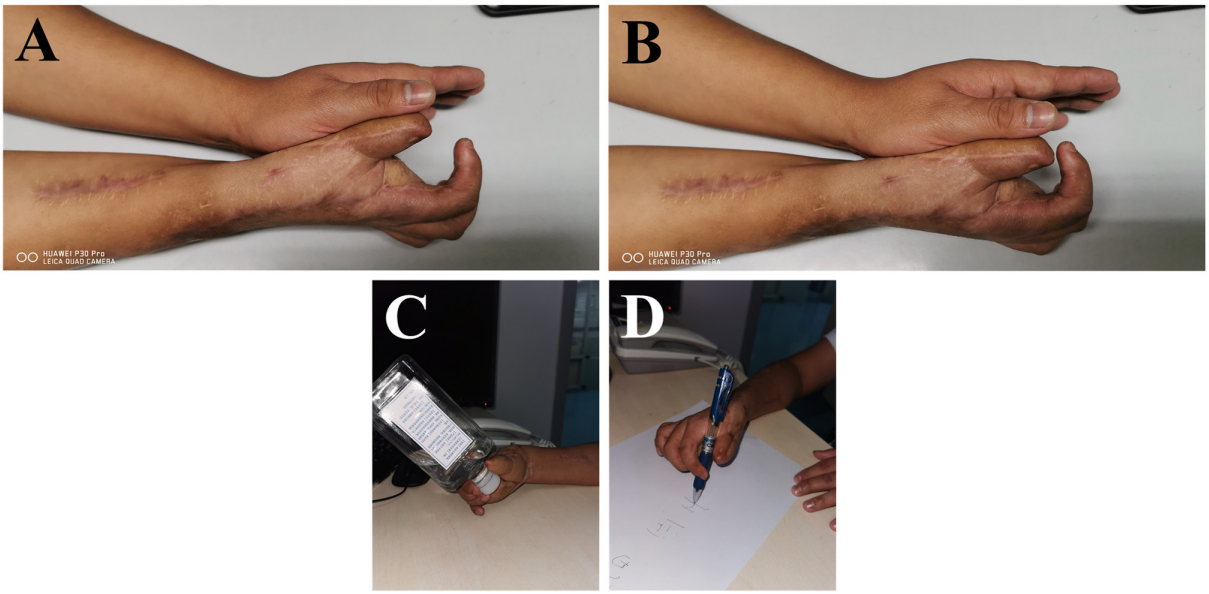

Figure 5. Recovery of hand function after 1 year of follow-up. (A and B) A comparison between the left and right hand. (C and D) Functional recovery of the right hand.

narrow first web space restricted active flexion and extension activities of the thumb after an initial treatment. Following the thumb lengthening, the present study performed an incisional release of subcutaneous scars in the first web space, installed a track-type external fixation frame between the first and second metacarpal bone and gently expanded the soft tissues in the first web space at 1 week postoperation (38). In addition, a gradual traction of the thumb to the palm opposition on the circular external fixator of the second to the fifth metacarpal bones and a fixation of the thumb to the palm opposition were performed to achieve the bony palmar opposition, which eventually yielded a successful reconstruction of thumb opposition.

Thirdly, the patient had scar hyperplasia after thermal-crush injuries of the hand. Although the index, middle, ring and pinkie fingers of the patient were able to be preserved, they were not functional. A conventional tendon release surgery requires extensive incisions (39), which inevitably causes defects in the palmar skin and soft tissues and damages the palmar nerve and vascular bundles of the fingers, leading to the high risk of finger necrosis (40). Using the Ilizarov method to achieve soft tissue traction, a traction device with the metacarpal ring as the fulcrum was designed to slowly stretch the index, middle and ring fingers, which successfully corrected flexion contracture deformities, restored finger pinching movements and reconstructed partial hand functions. Through the successful reconstruction of hand function in the present case of thermal-crush injuries using the Ilizarov external fixation method, the present study provided an alternative treatment plan of functional reconstruction for those with poor soft tissue conditions.

However, due to the small sample size, the treatment plan for the current case needs to be re-evaluated and optimized in future clinical applications. A long-term follow-up is also essential to assess the recovery condition. We hypothesize that for such patients, thumb extension can be performed after the wound treatment is completed. When flexion contracture occurs, stretching surgery can generally be considered when the scar softens 6 months after the last surgery. Attention should be paid to the hand function assessment during follow-up and the patient should be observed for secondary fractures and osteomyelitis.

We also gained experiences from the treatment processes of this case. Firstly, a more reasonable skin flap design (such as trying to reduce the amount of skin flaps taken from the donor area) is needed to avoid the pain and a long treatment cycle caused by pedicle skin flap transplantation. Free skin flap transplantation is recommended to achieve a better outcome through advanced microsurgical techniques. Secondly, doctors and materials science experts should aim to jointly design a multi-angle stretching device to achieve bone extension and a 10-15˚ recovery of the interphalangeal joint angle; thereafter improving hand appearance and function during thumb lengthening. Thirdly, the Ilizarov method and device can also be modified to achieve a simultaneous soft tissue stretching of the index, middle, ring and pinkie fingers during thumb extension, thus shortening the treatment cycle. An individual stretching of each finger may be useful to maximize the stretching effect and achieve a better functional reconstruction. Fourthly, the present study should strengthen the follow-up examinations and guidance for postoperative functional exercises throughout the entire treatment process. Their effective interventions after soft tissue reconstruction with the assistance of orthodontic fixed braces are expected to reduce or even avoid the flexion contracture deformities of the index, middle, ring and pinkie fingers.

In conclusion, microsurgery combined with Ilizarov technology can effectively reconstruct the function of complex thermal-crush injuries of the hand. Through the present successful treatment, we provide experience and strategies for clinical management for specialized doctors.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

JY, FY and ZZ confirm the authenticity of all the raw data. JY, FY and ZZ carried out conceptualization. FY acquired the funding. JY, LY, FM, JW, SW and YX carried out the investigation. FY and ZZ supervised the study. JY wrote the original draft. FY and ZZ reviewed and edited the draft. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This study was approved by the Research Ethics Committee of Peking University Shenzhen Hospital (Peking University Shenzhen Hospital Ethical Review (Research) (2023) no. 12).

Patient consent for publication

Written informed consent was obtained from the participant/s for the publication of this case report and any potentially identifiable images or data included in this article.

Competing interests

The authors declare they have no competing interests.

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