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CASE REPORT
Reconstructive

Limb Preservation and Functional Reconstruction after Complete Amputation and Replantation of the Upper Arm and Thigh

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Summary: A 26-year-old man was admitted to our hospital due to the replantation of the severed right upper arm and right thigh injury 6 days before. The patient received emergency treatment at a local hospital. He underwent amputation and replantation for the right upper arm and right thigh. After surgery, he experienced fever, limb swelling, and wound pain. At the time of admission to our hospital, the patient exhibited stable vital signs. An infection was found at the replanted wound, and the culture results showed *Pseudomonas aeruginosa*. After admission, the patient underwent symptomatic antiinflammatory treatment. In addition, he received fracture reduction and external fixation with a bracket, radial nerve exploration and release of the upper and lower limb external fixation with a bracket, upper femur osteotomy, and external fixation with a bracket. He also received reconstruction of elbow flexion functions with biceps femoris tendon transplantation; reconstruction of wrist joint fusion, finger extension function, and palm function; removal of the femoral external fixation with a bracket; and tibiofibular osteotomy and leg lengthening surgery. Moreover, the anterior tibial tendon was fixed to correct foot drop deformity, and the external fixation bracket was removed. Owing to these efforts, the patient achieved limb preservation with well-reconstructed functions.
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Limb detachment is mainly caused by external forces. High large limb detachment is a serious limb injury, and patients may present with symptoms such as limb detachment, fractures, bleeding, pain, and skin avulsion. Besides, infection, shock, and other complications may also be induced. Patient death may even occur under critical conditions.[1] Since the 1960s, the successful application of limb replantation has been a milestone in surgery. However, the reconstruction of high limb functions after replantation has always been a recognized challenge.[2] In addition, the final function of the replanted limb is close to or exceeds that of prosthetics, which has always been the goal pursued by clinical doctors. The simultaneous amputation of multiple limbs at a high level is rare in clinical practice, and it is highly challenging for multiple limbs to survive replantation and restore good function. In this case report, a patient received limb salvage and functional reconstruction after the replantation of a high-level amputation of the upper arm and thigh and achieved favorable outcomes.

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CASE REPORT

A 26-year-old man was admitted to our hospital due to the replantation of the severed right upper arm and right thigh injury 6 days before. The patient accidentally twisted his right upper arm and right thigh during work 6 days before and received emergency treatment at a local hospital. He was diagnosed with incomplete disconnection of the middle segment of the right upper arm, incomplete disconnection of the middle segment of the

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right thigh, and hemorrhagic shock (Fig. 1). [**See figure, Supplemental Digital Content 1,** which displays the right upper arm detached after accidental trauma (attached and dissected 3 cm to compress the skin during replantation), **http://links.lww.com/PRSGO/D446**.] He underwent amputation and replantation of the right upper arm and right thigh. After surgery, he developed fever, limb swelling, and wound pain. He was transferred to our hospital on the sixth day after the injury. At the time of admission to our hospital, the patient exhibited stable vital signs. An infection was found at the replanted wound, and the culture results showed *Pseudomonas aeruginosa*.

Treatment Process

After admission, the patient received antiinflammatory and symptomatic treatment. The incision was opened, decompressed, and sutured 10 days after the injury. The x-ray showed separation and displacement of the middle segment fracture of the right humerus, as well as separation and displacement of the comminuted fracture of the lower end of the right femur. Two weeks after injury, humeral fracture reduction and external fixation with an external fixator were performed. The right femur fracture was treated with reduction and external fixation with a bracket 3 weeks after the injury. After surgery, the right upper limb was shortened by about 5 cm, and the right lower limb was shortened by about 13 cm. After 5 months of replantation, the right upper limb had poor functional recovery. Hence, the patient underwent right radial nerve exploration, release, and adjustment of external fixators for the upper limb and lower limb. After 14 months of replantation, the right lower limb was shortened by 13 cm, seriously affecting functions. Therefore, right upper femur osteotomy, bone transport, and external fixation with a bracket were performed. The reconstruction of elbow flexion functions was performed by transplanting the biceps femoris tendon due to poor upper limb functions 15 months after replantation. The right wrist joint fusion, finger extension function, and palm function reconstruction were performed 17 months after replantation. As a result, the femur was extended by 7.5 cm, and the femoral external fixator was removed 10 months after limb extension. The replanted lower limb was shortened by 4.5 cm compared with the healthy side. Tibiofibular osteotomy and leg lengthening surgery were performed 25 months after the replantation, and the leg lengthening was initiated 1 week after the surgery. The tibia and fibula were extended by a total of 4.5 cm. After limb isometry, due to injury to the right common peroneal nerve, the foot droop deformity was corrected by fixing the right anterior tibial tendon 33 months after replantation. After 39 months of replantation, the external fixation bracket was removed, and all treatment procedures were completed.

Fig. 1. Thigh partially detached after accidental trauma (attached and dissected 3cm to compress the skin during replantation).

Treatment Outcomes

Owing to these efforts, the patient achieved limb preservation with well-reconstructed functions. [**See Video 1** (**online**), which displays good recovery of lower limb function.] [**See Video 2** (**online**), which displays good recovery of upper limb function.] The range of motion of the right elbow joint of this patient was 0–120 degrees. The right upper limb muscle strength achieved level 5 in elbow flexion and level 4 in elbow extension. This patient also realized level 4 in finger grip muscle strength after wrist fusion surgery and level 3 in deep finger muscle strength. The Chen's upper limb function score[3] was favorable. The DASH upper limb function score[4] was 46. The range of motion of the right lower limb knee joint was 0–100 degrees, and the right lower limb muscle strength was rated as level 5. The range of motion of the right ankle joint range of motion was 20 degrees. The foot and ankle output scores[5] were rated as follows: pain, 88.9; other symptoms, 82.1; function in daily living, 94.1; function in sports and recreation, 45; and quality of life, 50. The scores on the social functioning-36 quality of life scale[6] were rated as follows: physical functioning, 75; role physical, 0; bodily pain, 64; general health, 77; vitality, 90; social functioning, 100; role emotional, 33.3; and mental health, 80 (Fig. 2).

DISCUSSION

The high-level amputation of multiple limbs has been common since the first report,[7] but the limbs after

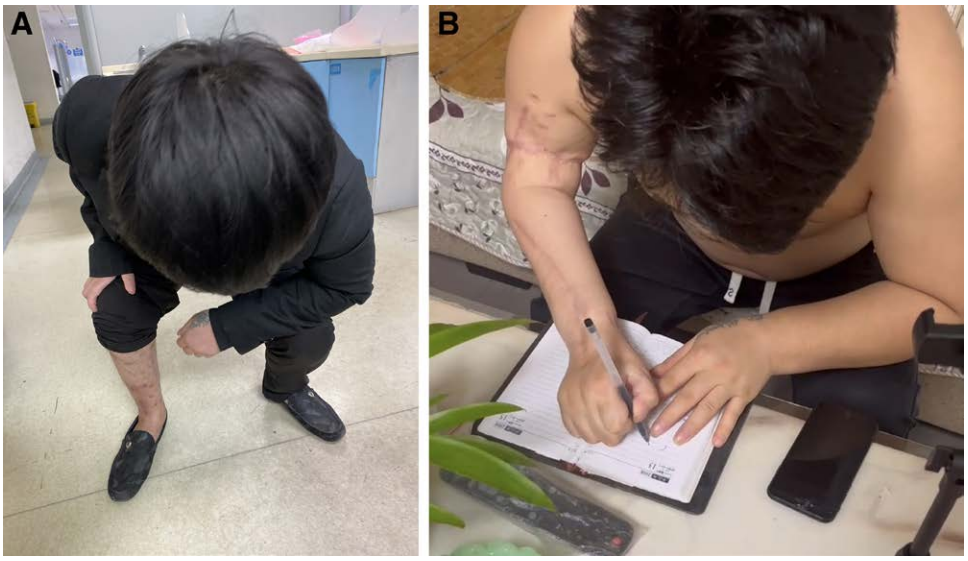

Fig. 2. The status of the patient after treatment. A, Recovery of lower limb function. B, Recovery of upper limb function.

replantation may have a risk of inactivation. Even if the limbs can survive, the incidence of poor functional recovery is high, leading to secondary amputation and poor outcomes. In this case report, a right-handed patient sustained a severed middle segment of the right upper arm. The three major nerves in the hand, namely the radial nerve, ulnar nerve, and median nerve, all needed to be sutured and repaired. Poor functional recovery occurred on the radial and median nerves in the later stage. After early nerve release, the ulnar nerve function partially recovered, and the elbow flexion function was restored through exploration and transplantation of the biceps brachii tendon. After radial nerve injury, the deformity in the hanging wrist and hanging finger did not achieve a favorable recovery after nerve release. Wrist joint fusion was performed to resolve the deformity of the hanging wrist, extensor tendon fixation was performed to improve finger functions, thumb carpometacarpal and interphalangeal joint fusion was performed to improve thumb opposition functions, and flexor tendon transposition of the index finger was performed to improve finger flexion functions. After a series of functional reconstruction procedures, the hand function of this patient was evaluated, with the DASH score being 46. It was assumed that the difficulty in improving the condition of this patient lay in the recovery of intrinsic muscle functions and the reconstruction of forearm pronation functions. The tendon transposition faced no alternative tendon transposition, and functional muscle transplantation faced no recipient site for neuromuscular branches to be anastomosed. Before surgery, it was necessary to identify whether applying new functional reconstruction techniques could further improve hand functions. It was also required to identify whether the use of intelligent hand exoskeletons[8] and intelligent prosthetic hands[9] after forearm amputation could bring a better hand function recovery. Moreover, the shortening of the upper arm was about 5 cm, and the appearance was unfavorable after high limb replantation. Hence, it was also necessary to identify whether implementing shortening and lengthening for the upper arm could improve the function and appearance of the limbs.

In this case report, some experience in designing a limb salvage reconstruction regimen for complex limbs can be obtained from the successful treatment of this patient. Firstly, it is necessary to establish the basic principle of giving priority to life before limb salvage. Secondly, the expected function of the limb after limb salvage treatment should be predicted. The biological prosthesis concept should be introduced in this process, which refers to limbs that undergo complex limb salvage and reconstruction after severe limb injury. The appearance and function of biological prostheses are significantly different from normal limbs. Given the strong willingness of this patient to salvage limbs, the function of such biological prostheses is similar to or even better than that of prostheses installed after amputation. Therefore, limb salvage and reconstruction are of great significance. This is also considered an indication for surgery. Moreover, such patients should undergo surgery in several stages. Specifically, the first stage involves limb salvage; namely, replantation, infection control, soft tissue coverage, and fracture management can be performed successively. The second stage involves limb reconstruction; namely, limb shortening and functional reconstruction of neurological dysfunction can be performed successively.

Of course, relevant lessons from the treatment of this patient were also summarized. The replantation of severed limbs is a systematic engineering project, including vascular anastomosis, which is a necessary condition for limb survival after replantation. In this case report, this patient did not receive thorough debridement during the first

replantation, resulting in infection within 5 days after surgery. Besides, the fracture was not accurately reduced and fixed, resulting in another surgical procedure for fracture reduction and fixation. Short-term fracture surgery after replantation can easily damage important structures, such as blood vessels and nerves, thus leading to such severe consequences as limb function damage and even necrosis, which poses enormous challenges to subsequent surgical procedures. Therefore, blood circulation should be restored within 6–8 hours of warm ischemia during emergency replantation. Under that premise, it is necessary to perform thorough debridement to reduce the risk of postoperative infection, accurately repair nerves and tendons to improve functional recovery, and effectively reduce and fix fractures while maintaining limb length as much as possible. Additionally, it is necessary to avoid secondary repair of fractures. As for limb shortening, secondary limb lengthening surgery can be performed. It is not necessary to prioritize preserving limb length for patients under this condition. As such patients often face defects in tendons, nerves, and blood vessels during replantation, shortening limbs is the fastest and most effective way to solve soft tissue defects. During the design of limb extension, it is advisable to perform in situ limb extension as much as possible, namely thigh extension surgery on the shortened thigh and calf extension surgery on the shortened calf. The non–in situ extension can be considered only when limb shortening exceeds the extension limit, which can result in bilateral joints not in the same horizontal plane. Of course, a thorough regimen is also required for limb lengthening. In this case report, if the patient underwent limb lengthening surgery on both the femur and tibia, the treatment cycle would be greatly shortened. Moreover, if a new generation of intramedullary nail limb extension systems can be applied, the satisfaction of patients will also be greatly improved.

In conclusion, high replanted limbs may recover favorably after limb salvage and reconstruction, and the recovery probability of lower limbs is larger than that of upper limbs. Our case report is the largest lower limb lengthening reported, which constitutes the innovation and inspiration from the successful treatment of this patient. Besides, severe shortening of severed replanted limbs can be solved through limb lengthening surgery. Nevertheless, the rate and limit of limb extension, as well as wearable exoskeletons and intelligent prostheses after partially preserving high-level amputated and replanted limbs, are worthy of further investigation.

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