A 16-year-old right-hand-dominant boy sustained a crushing right hand injury following an ATV accident, resulting in loss of the dorsal skin and extensor digitorum tendons of the little, ring, and middle fingers at extensor zones 4–6 along with the disruption of lumbricals and dorsal interossei muscles. Initial X-rays showed oblique fractures of the second and third metacarpal bones, with open joint capsules and a defect soft tissue area covering 10 × 9 cm. Radial and ulnar pulses were palpable, and Allen’s test was satisfactory. Sensory neurological examination and two-point discrimination were normal for areas innervated by the radial, ulnar, and median nerves. Primary surgery performed on the day of the injury involved fixation of aforementioned fractures utilizing K-wires along with superficial circumflex iliac artery flap coverage for the raw areas post debridement. Following this, primary extensor tendon reconstruction was performed using silicon Hunter rod implants and autologous tendon grafts via a two-stage approach. Over a 2-year postoperative period, the patient demonstrated active functional extension of all four fingers with some limitations to range of motion. This case report supports the hypothesis that the pseudo-synovial sheaths created by silicone rod implants assist the easy gliding motion of tendon grafts in the second stage of reconstruction, reducing the risk of tendon adhesions, shortening, and extension lag. (Plast Reconstr Surg Glob Open 2021;9:e3858; doi: 10.1097/GOX.000000000003858; Published online 14 October 2021.)

**FIRST-STAGE EXTENSOR TENDON RECONSTRUCTION**

The first stage of the extensor tendon reconstruction was performed 4 months after the primary injury. An incision was made in the proximal end of the superficial circumflex iliac artery flap that covered the dorsum of the hand and the medial aspect of the right dorsal forearm, to expose the extensor retinaculum. Another incision was made in the little ring and middle fingers to expose the extensor surface of the three digits. Three tunnels were created beneath the extensor expansion, connecting the distal cut ends of the extensor tendons of the ulnar fingers to the forearm. Three hunter rods third of the second and third metacarpal fractures, and a transverse K-wire to prevent malrotation (Fig. 2). This was followed by hand casting and physiotherapy. The patient followed up in the outpatient department, and a two-stage extensor tendon reconstruction plan was devised.

**Summary:** The extensor system of the hand is an intricate complex component that involves a working balance between the extrinsic and intrinsic muscles of extension. Injuries to the extensor tendons are typically repaired primarily or by tendon transfers or grafts at a second stage. A 16-year-old boy sustained a right hand crush injury following an all-terrain vehicle accident, resulting in the loss of dorsal skin and extensor tendons of digits 3, 4, and 5 involving extensor zones 4–6, and oblique fractures in the second and third metacarpal bones. Primary surgery involved fixation of aforementioned fractures utilizing K-wires along with superficial circumflex iliac artery flap coverage for the raw areas post debridement. Following this, primary extensor tendon reconstruction was performed using silicon Hunter rod implants and autologous tendon grafts via a two-stage approach. Over a 2-year postoperative period, the patient demonstrated active functional extension of all four fingers with some limitations to range of motion. This case report supports the hypothesis that the pseudo-synovial sheaths created by silicone rod implants assist the easy gliding motion of tendon grafts in the second stage of reconstruction, reducing the risk of tendon adhesions, shortening, and extension lag. (Plast Reconstr Surg Glob Open 2021;9:e3858; doi: 10.1097/GOX.000000000003858; Published online 14 October 2021.)
were inserted into the tunnels guided by loose loop prolene sutures to allow rod movement. The distal cut ends of the extensor expansion of the three ulnar fingers were sutured to the Hunter rods at the beginning of the proximal phalanx (zone 4). The proximal ends of the Hunter rods were sutured to the fascia of the forearm extensor compartment (Fig. 3). Closure was performed and a hand splint applied. Passive movements in flexion and extension were initiated 10 days postoperatively, and short active flexion and extension movements were initiated 2 weeks postoperatively.

The patient was discharged with a physiotherapy plan. X-rays were performed with lateral flexion and extension to assess “buckling” and implant positioning after a passive range of motion was restored. He demonstrated almost full passive extension before second-stage reconstruction, which was performed 3 months later.

SECOND-STAGE EXTENSOR TENDON RECONSTRUCTION

Second-stage reconstruction was performed 3 months after the first-stage procedure with autologous tendon grafts. The right palmaris longus and right plantaris tendon were harvested. A highly vascularized pseudo synovial sheath had formed around each rod. Autologous tendons were fashioned to the proper length and then sutured to the distal end of Hunter rods, which were extracted proximally for placement of tendon grafts within the pseudo synovial sheaths. The proximal ends of the tendon grafts were sutured to the extensor digitorum muscle belly. (See Video [online], which displays conveying of extensor function after tendon graft is sutured.) Successful reconstruction of the lost segments is crucial for maintaining adequate hand function. Finally, a splint was applied in a functional position (wrist extension at 30 degrees and full finger extension at the IP joints). Passive range of motion exercises were started 10 days postoperatively, short-arc extension and flexion were introduced 2 weeks postoperatively, with resistance exercises added 6 weeks postoperatively.

During the 6 month postoperative period, the patient demonstrated active functional extension of all four fingers with the ability to hold a pen and write. The DIP and PIP joints had no limitations in their movement. Unfortunately, follow-up physiotherapy was not sufficient to maintain, and 2 years postoperatively the patient demonstrated a decrease in metacarpophalangeal (MCP) joint flexion of only 10 degrees, with an extension lag of approximately 10 degrees. However, the patient experienced no disruption to daily function and finished his high school education without difficulty.
DISCUSSION

Two-stage extensor tendon reconstruction is not a preferred method in literature guidelines.\textsuperscript{1–3} In contrast, it is often applied in complex or neglected flexor tendon reconstructions. The reason for this is the absence of the fibroosseous sheath with synovial lining that enables smooth finger extension action, which involves the coordinated action of both the extrinsic and intrinsic extensor muscles. The trauma imposed on our patient disrupted both these sets of muscles; however, the range of motion at the MCP joint demonstrated by the patient would not have been possible without adequate extensor tendon reconstruction.

One of main constituents of the extensor structures is the extensor digitorum tendon communis, which is joined at the level of the MCP joint with the sagittal bands. These sagittal bands originate from the volar plate of the MCP joint. They serve to stabilize the extensor tendon and to help in extension at the level of the proximal interphalangeal joint. The ECD tendon continues distally to the MCP joint as a central slip that inserts at the base of the middle phalanx to assist in proximal interphalangeal joint extension. Two lateral slips originate from the central slip and from a part of the conjoined bands, which insert at the base of the distal phalanx and assist in the distal interphalangeal joint extension.\textsuperscript{4} There is an established nomenclature for classifying extensor tendon injuries based on anatomical areas, with odd numbers given overlying the joints (Fig. 4).

Complex dorsal hand skin, soft tissue, and tendon injuries have been successfully reconstructed with free flaps that contain completely or partially vascularized tendon grafts, in centers suitably equipped for microscopic reconstruction.\textsuperscript{5} However, only a limited number of cases have reported the use of silicon rods for extensor tendon reconstruction.\textsuperscript{3} In the present case, due to the severity of soft tissue injury and the extent of extensor tendon damage, including the lumbricals and dorsal interossei muscles, two-stage reconstruction of the tendons was selected, as it allows fast re-mobilization of the digits in both stages with restoration of the extensor mechanism to allow functional use of the fingers. The use of silicone rods helps minimize the risk of adhesions that result from fibrosis in the healing process that follows immediate tendon transfer with open contaminated soft tissue defects, allowing the creation of a highly vascularized pseudo-synovial sheath that maintains a tunnel between the forearm and fingers.\textsuperscript{1,3,6,7} The pseudo-synovial sheath is formed of three layers: an intima, media, and adventitia, forming an excellent gliding surface for tendon grafts. The intima secretes glycosaminoglycan substances, while the media is made of collagen and provides structural and vascular support and the adventitia is a highly vascularized structure composed of loose fibrous tissue.\textsuperscript{3} Moreover, two-stage reconstruction has been reported as an alternative to immediate tendon transfers at the time of the trauma when the tendon injury is associated with complex bone injury, requiring immobilization of the hand, with silicon rods utilized to maintain the tendon route while grafting is performed at a later stage.\textsuperscript{6}

Soft tissue coverage was performed using a superficial circumflex iliac artery flap, due to the extensive dorsal surface damage, overcoming the limited resources at the primary hospital where microsurgery was not viable, and avoiding the need for the patient to be optimized before reconstruction with flaps containing tendons. The use of free flaps with vascularized tendon grafts for complicated extensor tendon injuries in well-equipped microsurgical centers enables faster healing time and earlier rehabilitation initiation; the rationale explaining this is that tendons are harvested with their sheaths, which derive their blood supply from the tissues underlying the flap.\textsuperscript{5} However, tendon defects that were treated with single-stage reconstruction by tendon grafts reported unsatisfactory range of motion at MCP joint in six of 14 patients in a study by Sundine et al, and donor site morbidity is a considerable issue.\textsuperscript{5,9} In this case, the extent of soft tissue damage and contamination from zones 4 to 6, which is from the proximal phalanxes to the area overlying the metacarpal bones.\textsuperscript{10} This would indicate that one-stage reconstruction could have resulted in diffused adhesions and fibrosis due to the healing process, affecting functional extensor tendon recovery, potentially.\textsuperscript{9,10}

In comparison with similar cases done by Al-Qattan, our patient’s hand dynamics were similar with three of six cases having an almost comparable active range of motion.

Fig. 4. Extensor zones are displayed.
in the middle and little finger, at around 10–80 degrees. Another reported outcome showed a case with extension lag of 10 degrees, comparable to our case. Moreover, the resultant outcome in this patient’s range of motion lies within the daily functioning range of flexion more than 70 degrees and extension lag less than 30 degrees.

Even with optimum physiotherapy, a degree of stiffness is expected in the MCP joint, especially following extensive injury to the extensor tendon areas, although with later surgery it is possible to retune the tension of implanted tendons for improved function.

CONCLUSIONS

This case supports the hypothesis that pseudo synovial sheaths created by silicone rod implants assist the easy gliding motion of tendon grafts in the second stage of reconstruction. This reduces the risks of tendon adhesions, shortening, and rupture, which are often reported in cases of extensive soft tissue trauma to the dorsum of the hand, accompanied with extensor tendon loss.

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