Specific biomechanical consideration in trauma cases involving forearm and hand

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Abstract
The rescue of a severed or amputated limb and restoration of the its biomechanical unity after serious hand or forearm injuries is analysed and discussed with two case presentations. Methods of anatomy and surgery in these cases are not part of the everyday practice, the need for improvization during surgery is essential. Ischaemia-reperfusion time is also crucial when a limb has to be saved. The first case reports on the subtotal amputation of a young man's right hand and the successful revascularization and unorthodox restoration of the radiocarpal joint to full function. The second case is of a young woman with a conquassated left forearm. A special aspect in this case is the extremely long ischaemia-reperfusion time. Complete function was restored in this case too, however the patient's refusal of spongiosa-plasty resulted in the fatigue break of the fixation plate, that had to be replaced.

In traumatology it happens quite often, that serious decisions have to made by the operating table without the chance of consultation with colleagues and literature. The two presented cases might help to decide on treatment for those who meet similar cases in their practice.

Keywords: subtotal amputation; conquassation; ischaemia-reperfusion; revascularization; restoration of function

Introduction

Salvaging limbs injured as a consequence of the increasing number of industrial and traffic accidents is a real challenge for surgical teams (traumatologists, hand surgeons, plastic surgeons). Microsurgical skills and the knowledge of necessary techniques allow the revascularization of partly or totally amputated limbs and nerve repair, up to date and continuously improved surgical techniques provide the appropriate care of bones, muscles, tendons and skin defects.

Improvements in surgical technique

Successful revascularization and replantation was made possible by the development of adequate techniques and instruments. Nylen introduced the operating microscope for ear surgery in 1921. Mass production of such microscopes was started by Zeiss in 1953. In 1960 Jacobson and Suarez adapted the operating microscope to the construction still in use, providing better focus, magnification and movement in multiple planes.

The surgical team headed by Ronald Malt performed the first successful replantation in 1962 in Boston. There is a report on successful finger replantation on Rhesus monkeys in 1965, as well as a literature account of the successful blood vessel anastomosis in an avascularized thumb. The first finger replantation was performed by Japanese Komatsu and Tamai in the same year.

In the 1970s replantation centers and microsurgical laboratories were established, and a critical analysis of results was presented. Technique and replantation protocols were refined in the 1980s. At that time the previous practice of nerve and tendon repair months after skeletal stabilization and restoration of blood vessel continuation was stopped. This idea led to today's practice, during replantation each structure is repaired one other the another at the same time.

Surgical technique

Getting the patient into the operating theatre has the ultimate priority. It is beneficial to have two surgical teams. (There is usually no chance for it in domestic conditions.) The amputated body part should first be taken to the operating table, structures should be thoroughly prepared, vessels and nerves suitable for anastomosis should be marked. It is the time to examine the blood vessels to decide whether the replantation could be carried out or not. The next step is the preparation of flexor and extensor tendons.

General or regional anaesthesia is applied to the patient. General anaesthesia is often supplemented with regional, so that peripheral blood perfusion increases. It is important to protect the patient against hypothermia. Then the stump is prepared, blood vessels, nerves and tendons are marked, while the amputated part is kept cold.

Ostheosynthesis follows the thorough preparation and debridement. Kirschner-wires are often used, however in the forearm fixation plates or fixateur extern are recommended.

The next step is the suture of tendons, usually extensors precede flexors, then microvascular anastomoses follow on the artery and vein. During anastomosis it is important to frequently rinse the lumen of vessels with diluted heparin solution, to minimize the removal of adventitia, to carefully grip the proximal and distal ends of blood vessels, to choose appropriate size, non-absorbable, synthetic, monofilament suture and when it is necessary to apply a venous graft to avoid decreased flow rate of the blood. The sequence of unification depends basically on the anatomical situation, literature resources are not uniform on sequence. Nerve suture is last. Skin should be closed without tension.

When replanting burlier limbs unification of arteries takes priority in contrast with veins to decrease the amount of muscle necrosis and to remove toxic metabolites that would otherwise enter the patient's circulation. Extensive fasciotomy is also needed.

Due to the repeated, mindful preoperative and intraoperative reconsideration and the development of microvascular anastomosis techniques, the success rate of replantations improved significantly by now.

Postoperative care begins on the operating table. Anticoagulation is provided with dextran, heparin, LMWH, or thrombocyte aggregation suppressors. Replanted (revascularized) limbs should be bandaged with extreme caution to avoid compression. Similar indication has the fasciotomy at the end of surgery. Loose bandage has to be applied, only the distal part of fingers must be uncovered. It is the place to check the limb's circulation and oxygenization. The limb can not be moved. Sedatives are often given to minimize vasospasm caused by psychic distress. The reduction of pain with appropriate analgetics is also important. The skin color, turgor and temperature has to be checked continuously. The room temperature has to be controlled, too.

Case presentation 1

In 1994 an 18 years old young man subtotally amputeted his right hand with a disc saw *(Figure 1)*. The hand was only attached to the arm dorsally with a piece of skin approximately 3 cm wide. The saw mangled the proximal carpal bones, scaphoid, lunate and triquetral as well as the surface of the radiocarpal joint in the radius. The radial and ulnar arteries, the median, ulnar and radial nerves and the complete flexor and extensor apparatus were damaged. The ambulance crew provided fluids, analgesia, stabilised the arm and transported the patient with pneumatic compression to avoid severe blood loss into our hospital after notifying the accident and emergency department. The transport time was relatively short from the accident site 35 kms from the hospital.

The time of injury was around 10:00 in the morning. The patient arrived to the hospital at 10:45, got into the operating theatre at 11:00. The time of total reperfusion was 13:00, the operation finished at 16:00 after each structure was reconstructed *(Figure 2)*.

The reconstruction of the carpal joint caused some professional dilemma during surgery. In cases of similar severity operation usually starts

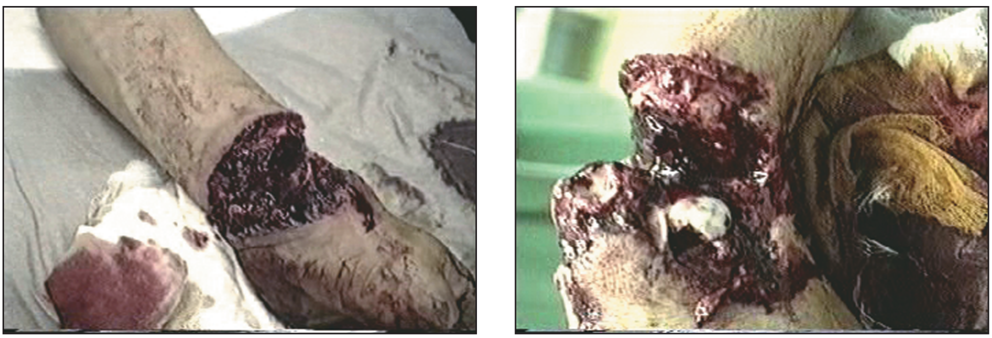

Figure 1. Images at the time of arrival to the hospital

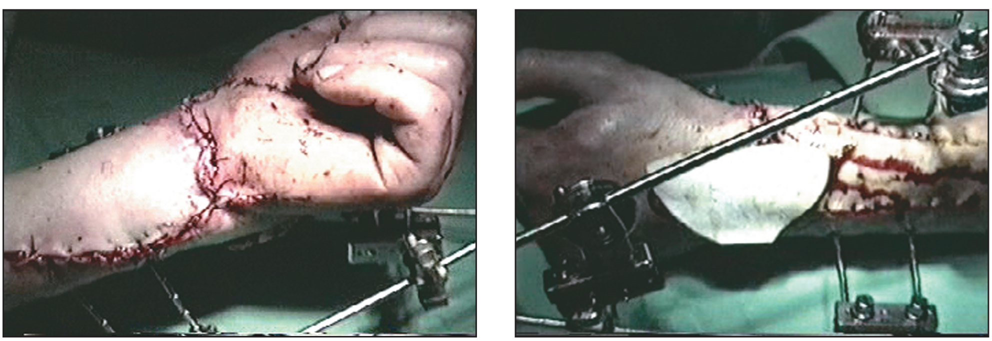

Figure 2. Postoperative images

with arthrodesis, as keeping the joint function is hardly possible. In this case an 18 years old young man was affected, whose wrist function we intended to reconstruct.

The distal carpal bones join the proximal row in an S-shaped arch which is convex proximally and concave distally, and its ulnar end is bulging towards distal, its middle part is domed intensely toward proximal according to the head of the capitate *(Figure 3)*. The joint capsule of the radiocarpal articulation is strengthened by a tight, strong system of ligaments (lig. radiocarpeum palmare et dorsale, lig. ulnocarpeum palmare) *(Figure 4)*.

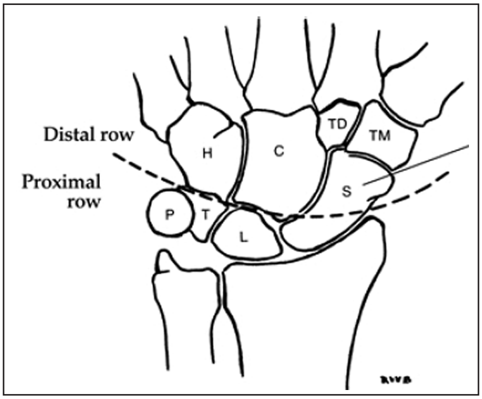

Figure 3. Bones of the radiocarpal joint[1]

The radiocarpal or wrist joint is an ellipsoid joint with two axes formed by the radius and the articular disk proximally and the proximal row of carpal bones distally. The complex movement of the minor articulations could best be observed under a fluoroscope. The splitting of such a structure can have serious consequences both statically and biomechanically. In this case the loss of the proximal row made reconstruction possible, as the disc saw injured major blood vessels, nerves, tendons and soft tissue with a loss of 1–1,5 cm. After a thorough debridement the defect of the joint surface of the radius was detected, as well as a distal piece of the scaphoid. It seemed obvious to use this piece of bone to form a „pin", that was inserted into the pit in the radius *(Figure 5)*. This „biological pinned joint" functions well even now and the hand regained its biomechanically important role *(Figure 6)*.

Considering the weak blood supply of the scaphoid we were afraid of a necrosis in the short run, not to mention the chance of early arthrosis. That is why a fixateur extern was applied at the end of surgery, however it was a technically more complicated fixation method. After restoring blood circulation the wrist stabilizers were cared for, it was possible to rein-

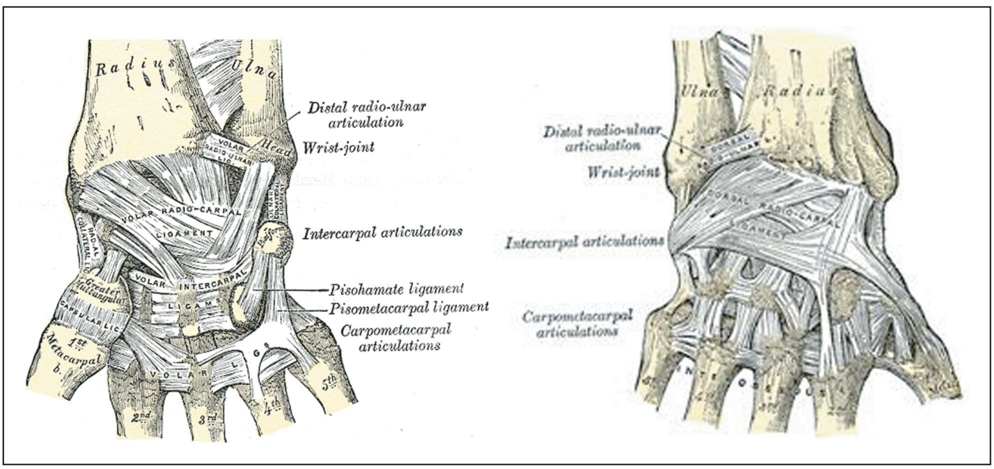

Figure 4. Ligaments of the radiocarpal joint[2]

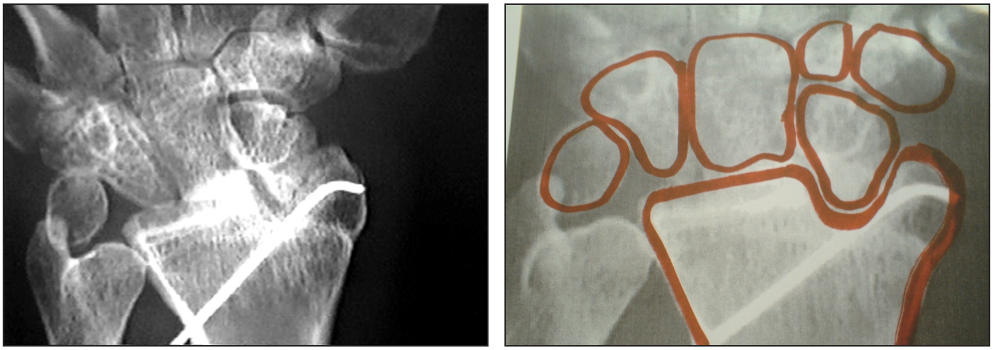

Figure 5. The scaphoid „pin" inserted into the radius

Figure 6. Early functional results

state musculus flexor carpi radialis and extensor carpi radialis longus by attaching them to the base of the 2nd metacarpal. All the other extensor and flexor tendons were systematically cared for and sutured. In this case nerve restoration and soft tissue correction were the final stage of surgery. Fortunately neither bone necrosis, nor early arthrosis did appear for as long as 15 years.

On the postoperative X-ray *(Figure 5)* it is apparent, that the distal carpal row fits well. Initially we had doubts about postoperative functional results because of the desorganization in the system of ligaments, still early physiotherapy began. Fortunately there was no septic complication. The wounds healed per primam. After early rehabilitation we were surprised how good the results were and how well the biomechanics of the hand returned *(Figure 6)*.

We were lucky enough to follow up the young man for many years, we were even able to control him 15 years after the injury in his home. The patient with the subtotally amputated

Figure 7. Late functional results

hand works now as a heavy machinery mechanic. Not just the quality of feeling and function returned, but he is able to lift heavy objects and perform hard physical labour *(Figure 7)*.

Case presentation 2

A 25 years old young woman had a road traffic accident, hit a crash barrier on the highway, the broken pieces of which conquassted her left forearm *(Figure 8)*. She was transported to the regional hospital, then to other institutions, everywhere amputation was recommended.

The diagnosis was as follows: conquassatio antebrachii sinistri, laesio arteriae radialis et ulnaris sinistrae, laesio nervi mediani, ulnaris et radialis rami muscularis sinistri, laesio musculi flexoris et extensoris digitorum antebrachii sinistri, defectus cutis antebrachii sinistri.

The accident happened at 19:40 2001-11-07, the patient arrived to our hospital the next day at 00:22, and about two further hours later reperfusion was ensured. The ischaemic duration was 6 hours 42 minutes. The extensive conquassated forearm injury involving skin and bones provided a professional challenge.

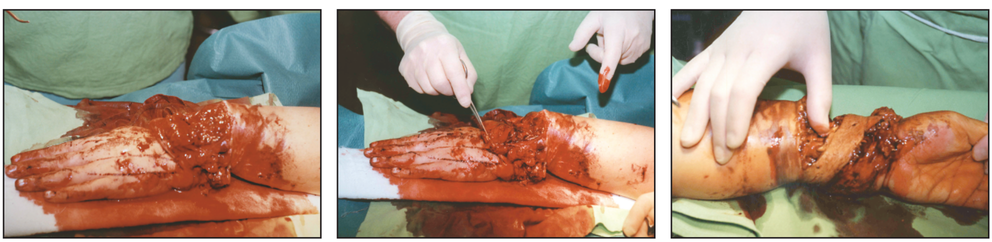

Figure 8. Preoperative images

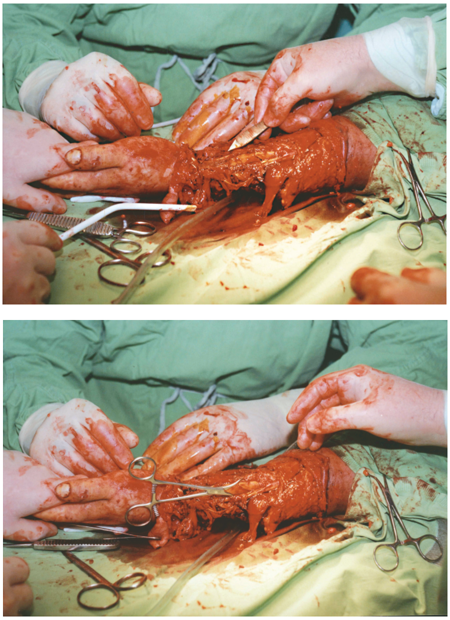

Figure 9. Intraoperative images after plate fixation

Because of the long ischaemic period we had to endeavor a quick solution, so that we could restore arterial circulation as soon as possible.

The extent of conquassation was such, that the identification of bones became very difficult. After fixation plate placement *(Figure 9)* the smaller and larger bone defects were clearly visible, but this problem had to be taken care of at a later date, because the restoration of arterial circulation had absolute priority.

In the postoperative period there was a – luckily superficial – septic complication, so after temporary debridements skin transplantation was performed using mesh-graft *(Figure 10)*.

Early spongiosa plastic surgery was planned to compansate for the bone deficit of the radius, however the patient rejected the operation based on her physical, psychic and familiar difficulties. After physiotherapy the hand's function was totally restored *(Figure 11)*.

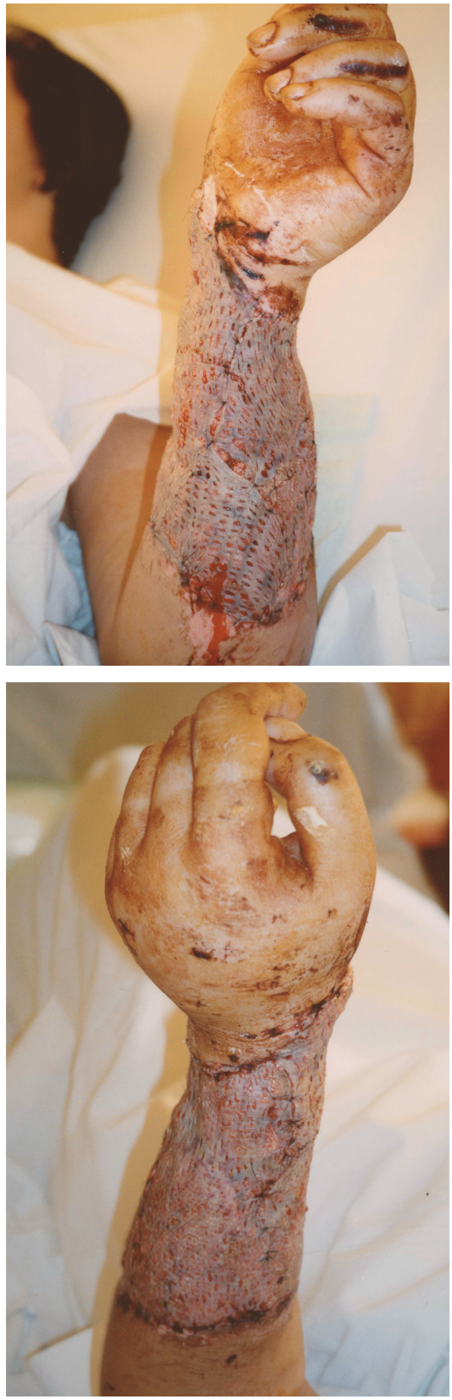

Figure 10. Mesh-graft

Figure 11. After physiotherapy the hand's function was totally restored

Based on the bone deficit the fixation plate's fatigue break was expected, and happened 7 years later *(Figure 12, on the left)*. Repeated reconstruction was also difficult, since the original fixation plate was placed atypically, so it was not possible to know the exact routes of blood vessels and nerves supplying the hand. Tightly and carefully following the metal we succeeded in changing the plate without further complications and spongiosa-plasty was also performed *(Figure 12, on the right)*.

After repeated rehabilitation and physiotherapy final results are almost complete function and a powerful hand, the young woman uses her left hand for everything in her everyday life, even for hard physical labour.

X-rays made in 2010 show the result of spongiosa plastic surgery, the pseudoarticulation disappeared, the radius became full *(Figure 13)*.

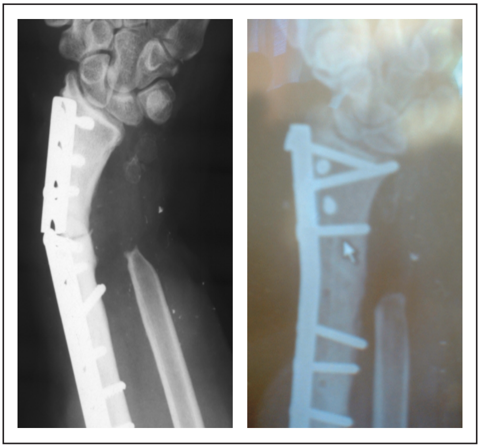

Figure 12. The broken and replaced fixation plates

Figure 13. X-rays made in 2010

Conclusion

Solutions at the operating table play an important role in majority of traumatological procedures, as in the two presented cases. There are no similar cases in textbooks, the surgeon has to improvise.

In the first case not even early surgical results were to be predicted, since quite a number of risks threatened the limb (thrombosis, septic complications, necrosis, suture insufficiency, etc.). Later on the necrosis of the scaphoid was to be expected, requiring early arthrodesis or resulting in early arthrosis, that did not happen. We were lucky with our atypical solution, that is why this method could be used in similar cases.

In our second case the gravest danger was the ischaemia-reperfusion time. The superficial septic complication is most probably a consequence of it, however the extreme contamination of the forearm might as well contributed. It was a mistake to go without spongiosaplasty, despite the fact that the patient kept on hoping that it will not be necessary. The fatigue fracture of the fixation plate was to be expected because of biomechanical reasons.

A surgeon thinks over and over a case and plans each treatment step in vain, if his original plan has to be changed later by the patient's will.

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