Arch Orthop Trauma Surg (2012) 132:1797–1805
DOI 10.1007/s00402-012-1590-8

HANDSURGERY

Macroreplantations of the upper extremity: a series of 11 patients

Franck Marie Leclère · Lukas Mathys · Bettina Juon · Torsten Franz · Frank Unglaub · Esther Vögelin

Received: 9 May 2012 / Published online: 11 August 2012

Abstract

Introduction Micro- or macroreplantation is classified depending on the level of amputation, distal or proximal to the wrist. This study was performed to review our experience in macroreplantation of the upper extremity with special attention to technical considerations and outcomes.

Materials and methods Between January 1990 and December 2010, 11 patients with a complete amputation of the upper extremity proximal to the wrist were referred for replantations to our department. The patients, one woman and ten men, had a mean age of 43.4 ± 18.2 years (range 19–76 years). There were two elbow, two proximal forearm, four mid-forearm, and three distal forearm amputations. The mechanism of injury was crush in four, crush-avulsion in five and guillotine amputation in two patients. The Chen classification was used to assess the postoperative outcomes. The mean follow-up after macroreplantation was 7.5 ± 6.3 years (range 2–21 years).

Results All but one were successfully replanted and regained limb function: Chen I in four cases (36 %), Chen II in three cases (27 %), Chen III in two cases (18 %), and Chen IV in one patient (9 %). We discuss the steps of the macroreplantation technique, the need to minimize ischemic time and the risk of ischemia reperfusion injuries.

Conclusion Thanks to improvements in technique, the indications for limb preservation after amputation can be expanded. However, because of their rarity, replantations should be performed at specialist replantation centers.

Level of evidence: Level IV

Keywords Amputation · Macroamputation · Replantation · Macroreplantation · Upper extremity · Microsurgery

Introduction

Micro- or macroreplantation is classified depending on the level of amputation, distal or proximal to the wrist. Annually, despite efforts in preventing such injuries [1], between 1 and 10 upper extremity amputations occur for every 100,000 people [2]. The decision to replant is based on the evidence that the function and overall wellbeing of the patient will be better than with a prosthetic device. Once the decision to replant has been made, patient safety becomes the prime concern. All indications for replantation must take into account the patient's general state of health, the ischemia time and the level, type and extent of tissue damage [3–6]. It should also be kept in mind that replantation is costly and requires prolonged operative time, long recovery periods, multiple procedures, and motivated patients to achieve optimal outcomes [7].

The literature is full of series dealing with digital and mid-hand replantations and revascularizations. However, there are only a few reports about traumatic complete amputations proximal to the wrist [8]. In 1990, our center reported its 10-year experience in severe complex injuries of the upper extremity [9]. In a series of 29 patients, limb survival rate was 93 % despite the severity of the injuries. All patients regained some hand function, with 76 % attaining a group I or group II functional result using the Chen scale [10]. This

F. M. Leclère (✉) · L. Mathys · B. Juon · T. Franz · E. Vögelin
Department of Plastic and Hand Surgery, University of Bern, Inselspital Bern, Freiburgstrasse, 3010 Bern, Switzerland
e-mail: franckleclere@yahoo.fr; franck.leclere@inserm.fr; franck.leclere@insel.ch

F. Unglaub
Department of Hand Surgery, Medical Faculty Mannheim, Vulpius Klinik, Bad Rappenau, Germany

additional study was performed to review our experience within macroreplantations with attention to both technical considerations and outcomes. Furthermore, this report revisits the different technical steps resulting in possible successful macroreplantation and emphasizes the importance of referring all patients with severe injuries of the upper extremity to microsurgically trained hand centers. Finally, it highlights the technical progress in management of the ischemia and ischemia–reperfusion injuries.

Materials and methods

Patients

Eleven patients with macroamputation who underwent macroreplantation of the upper extremity in our institution between 1990 and 2010 were controlled. The mean age was 43.4 ± 18.2 years (range 19–76 years). There were two elbow, two proximal forearm, four mid-forearm, and three distal forearm amputations. The mechanism of injury was crush in four, crush-avulsion in five and guillotine amputation in two patients. Age of the patients, level of amputation, mechanism of injury, technique of bone fixation, extent of bone shortening, details of vessels and nerves repaired, ischemia time, follow-up period and secondary procedures were reviewed.

Functional outcome assessment

The functional outcomes were assessed using the Chen scale [10] (Table 1). Two patients had died due to a cause not related to their trauma, 3 and 4 years after replantation. They were evaluated on the basis of their last follow-up visit. The mean follow-up after macroreplantation was 7.5 ± 6.3 years (range 2–21 years).

Surgical technique of the replantation

Ischemia time management

In Switzerland, replantation centers are accredited on the basis of the presence of trained personnel and organization facilities: helicopter area, 24 h services, intensive care unit. In our guidelines (Table 2), the first surgical team examines the patient while the second surgical team examines the amputated part. This allows for an efficient management of the extremity. When the amputation is largely monotraumatic, continuous brachial plexus anesthesia is given by the anesthesiologist before replantation commences, to benefit from sympathicolysis and pain relief afterwards.

Debridement and identification of structures

Debridement is performed on the severed extremity and the amputated part. To avoid confusion, all the structures are systematically tagged. Additional debridements are mandatory both before and after the restoration of circulation. Moreover, supplementary debridements are also performed during the early period after replantation to minimize the risk of infection.

Bone fixation

Bone shortening is a prerequisite for successful macroreplantation. It not only facilitates proper debridement but also enables primary repair of vessels and nerves and potentially avoids the need for grafts. Usually, bone shortening of the forearm by 5–8 cm is well tolerated. Bone stabilization is preferentially done by plate fixation or with Kirschner wire [4] depending on the localization of osteotomies. Intra-operative X-ray control is used to check the osteosynthesis. Particularly after shortening of the forearm bones, adequate bone length, rotation and congruency of the distal or proximal radioulnar joint has to be ensured to avoid restriction of forearm rotation.

Vessel repair

In case of long ischemia time or crush amputation injury it is helpful to re-vascularize by preliminary arterial shunting [11]. Our guidelines meet those of Sabapathy et al. [12, 13] in which the sequence of artery and vein repairs is directly influenced by the amount of involved muscle mass in the injured zone and by the ischemia time (Table 2). All but at least two major arteries are possibly repaired. As many

Table 1 Chen's criteria for the evaluation of function after extremity replantation [10]

Grade	Function
I	Able to resume previously held employment; range of motion exceeds 60 % of normal; complete or nearly complete recovery of sensibility muscle power of grades 4 and 5
II	Able to resume professional activities; ROM exceeds 40 % of normal; nearly complete sensibility; muscle power of grades 3 and 4
III	Able to lead normal daily life; ROM exceeds 30 % of normal; partial recovery of sensibility; muscle power of grade 3
IV	Almost no useable function in survived limb

Table 2 Technical guidelines in macroreplantations (adapted from Sabapathy et al. [12])

Level of amputation	Injury time to arrival at hospital (h)	Technical guidelines
Proximal to mid-arm level	3	Debride; fix bone; do artery, vein, and nerve repair; and then release clamps (regular sequence)
	3–4	Debride, fix bone, do artery repair first, release artery clamp to perfuse for 5–10 min, clamp artery, repair other structures, and then release clamps
	4–5	Use preliminary arterial shunting on arrival and then do the sequence as in (3–4 h). If any delay occurs during procedure, the artery clamp can be released once every 30 min for 5 min
	5–6	Gray zone for replanting. Replant only if fingers are freely passively mobile/replant and do a proximal below elbow amputation to gain length for prosthesis fitting
	>6	Difficult to replant
Lower third of arm and proximal forearm	4	Regular sequence
	4–7	Elbow arthrodesis enables more muscle debridement. Do artery repair first after bone fixation, release clamp for perfusion for 5 to 10 min, clamp artery, and then repair other structures. Then release arterial clamps
	>7	Difficult to replant
Mid-forearm to wrist level	6	Regular sequence. Ensure excision of muscles attached to tendons in the amputated part
	6–8	Debride, fix bone, do artery repair first, release clamp, allow perfusion for 5–10 min, clamp artery, and then repair other structures
	>8	Difficult to replant

veins as possible are repaired to avoid bleeding after clamp release. The commitant veins are repaired whenever possible because they transport a large amount of blood.

Fasciotomies

Afterwards, fasciotomies are routinely performed if cold and warm ischemia time is over 6 h or a crush injury has occurred.

Muscle repairs

Tendon injuries are primarily repaired whenever feasible. This includes epimysial repair of the muscle belly lesions. Large defects are reconstructed primarily or secondarily with grafts, tendon transfers or free muscle flaps.

Nerve repairs

All three main nerves are immediately repaired and whenever possible without nerve grafts: bone shortening is performed to avoid nerve grafts entirely or to keep them as short as possible.

Skin defect

After debridement, skin defects depend on the type of trauma and the extent of bone reduction. In the presence of a good muscle bed and no exposed vessels, tendons, bones or plates, a simple meshed split thickness skin graft can be performed. A vacuum-assisted device (low vacuum <70 mm mercury or no vacuum nearby anastomoses) can be used and final skin or soft tissue closure with, for example, free flaps can be delayed.

Postoperative management

Monitoring of the replanted limb is essential because revision surgery is required in the event of early arterial or venous thrombosis. It can be performed with either temperature probes or transcutaneous sensors. Evaluation of the perfusion with laser doppler flowmetry (Aimago®, Lausanne, Switzerland) has been mostly performed in the laboratory [14] and represents an alternative that has been proven to be useful in replanted patients in our department. The monitoring is based on the Doppler principle and is a measure of blood flux within the skin. The diagnostic value of this non-invasive technology lies in its ability to continuously detect instantaneous changes within the microcirculation of the skin. Large prospective comparative studies are currently being carried out to confirm its possible superiority over other techniques of monitoring in macroreplantations. Antibiotics are continued and anticoagulants (low molecular heparin) as well as weight adapted IV fluid substitution are systematically prescribed for 5 days. Vascularization of the revascularized part is checked on a regular basis for 5 days. Aspirin is given routinely for 1 month.

Secondary procedures include correction of soft tissue contracture, joint stiffness and malunion or non-union of bones. Function-enhancing procedures include failed primary tendon and nerve repairs, tendon transfers, selective arthrodeses or soft tissue augmentation and scar corrections with/without microvascular flaps. During the immobilization phase, nerve regeneration, soft tissue contracture and joint stiffness have to be treated by correct adaptation and regular monitoring of the splint and passive mobilisation under physiotherapy. The timing of secondary corrections relies on the progress of rehabilitation and regeneration, the trophic condition of the skin and soft tissue and the general health of the patient or other necessary procedures.

Measured parameters

The retrospective study includes 11 patients. All the parameters measured are reported in Tables 3 and 4. Regarding age of the patients and follow-up, statistics were done using XL Stat program (Addinsoft). Data are presented as mean ± standard deviation of the mean.

Results

Eleven patients with macroamputation were operated on in a 21-year period (Table 3). All but one was successfully replanted (Figs. 1, 2). In this particular instance, ischemia time was more than 7 h and revascularization after 20 min by preliminary arterial shunting was unsuccessful, whereupon an amputation was performed. Age of the patients, level of amputation, mechanism of injury, technique of bone fixation, extent of bone shortening, details of vessels and nerves repaired, ischemia time and secondary procedures are reported in Table 4.

Complications

Despite several debridements performed after replantation in each case (Table 4), two cases of deep infection occurred. The first case occurred 2 weeks after replantation and was saved through aggressive debridement and local flap coverage. The second case occurred 3 months after replantation and debridement and partial metal removal were performed to save the replantation (Patient 2 and 3 of the series). Two cases (18 %) of significant non-septic soft-tissue necrosis occurred because of inadequate primary debridement. These required free flap coverage after 1 and 10 months, respectively (Patient 4 and 7 of the series). All free flaps were viable and solved the problem. One patient developed a complex regional pain syndrome (CRPS II). This patient had severe neurological deficits from a brain injury (Patient 8 of the series). Despite aggressive occupational therapy, his hand function remained mediocre and this patient had the worst results in the replantation series.

Secondary procedures and functional results

According to Chen's table, functional results were Chen I in 4 cases (36 %), Chen II in 3 cases (27 %), Chen III in 2 cases (18 %) and Chen IV in one patient (9 %) (Table 3). Avulsion injuries required multiple secondary procedures to improve functional results, mainly nerve grafts, tenolysis and tendon transfers.

Discussion

As early as 1903, upper extremity replantation was being performed experimentally by vascular surgeons in the laboratory using animals [15]. Sixty years later, the first

Table 3 Functional outcome in relation to level of amputation and mechanism of injury

Patient	Level of amputation	Side	Types of trauma	Mechanism of injury	Follow-up (years)	Chen's grade
1	Proximal forearm	L	Polytrauma	Crush	21	I
2	Elbow	R	Monotrauma	Guillotine	13	I
3	Distal forearm	L	Monotrauma	Guillotine	13	II
4	Proximal forearm	R	Polytrauma	Crush -Avulsion	8	II
5	Mid-forearm	L	Polytrauma	Crush	5	II
6	Distal forearm	R	Monotrauma	Crush	Death 4 years after replantation	III
7	Mid-forearm	R	Polytrauma	Crush -Avulsion	Death 3 years after replantation	III
8	Mid-forearm	R	Polytrauma	Crush	4	IV
9	Mid-forearm	L	Monotrauma	Crush -Avulsion	2	I
10	Distal forearm	L	Monotrauma	Crush -Avulsion	2	I
11	Elbow	L	Monotrauma	Crush -Avulsion	–	Amputation

Table 4 Our series of 11 macroreplantations

N	Age	Sex	Level of amputation	Mechanism of injury	Bone fixation	Bone shortening (cm)	Vessels repaired	Nerves repaired	Total ischemia time (h)	Early secondary procedures	Late secondary procedures
1	19	M	Proximal forearm	Crush	Two plates	5	Ulnar artery Radial artery Three veins	Median nerve Ulnar nerve	4	Two debridements	Tenolysis Tendon transfer
2	21	M	Elbow	Guillotine	Two small plates	0	Ulnar artery reconstruction (with great saphenous vein) Radial artery Three veins	Median nerve Ulnar nerve Deep branch of radial nerve	4	Two debridements and partial metal removal due to infection	Tendon transfer
3	61	M	Distal forearm	Guillotine	Arthrodesis plate	0.5	Ulnar artery Radial artery Three veins	Median nerve Superficial branch of the ulnar nerve	7	Debridement and local flap due to infection	Twice tenolysis MCP and PIP capsulotomy index, middle, ring, little finger
4	35	M	Proximal forearm	Crush-avulsion	Two plates	5	Ulnar artery, Radial artery Three veins	Median nerve (with superficial radial nerve graft) Ulnar nerve	6	Two debridements and skin-mesh-graft/anterolateral thigh free flap due to significant non-septic soft-tissue necrosis	Sural nerve graft for Median nerve reconstruction (7 cm) Thrice tenolysis Thrice tendon transfer
5	76	M	Mid-forearm	Crush	Two plates	4	Ulnar artery Radial artery Anterior interosseous artery Three veins	Median nerve Ulnar nerve Superficial branch of the ulnar nerve Posterior interosseus nerve	4	Two debridements Skin-mesh-graft	Tendon transfer
6	48	M	Distal forearm	Crush	Two plates	4	Ulnar artery Radial artery Three veins	Ulnar nerve Median nerve	7.5	VAC Seven debridements Skin-mesh-graft	Free vascularized sural nerve graft for median nerve reconstruction Thrice tenolysis Twice tendon transfer Ulnar nerve neurolysis twice Ulnar head excision Ulnar head prosthesis

Table 4 continued

N	Age	Sex	Level of amputation	Mechanism of injury	Bone fixation	Bone shortening (cm)	Vessels repaired	Nerves repaired	Total ischemia time (h)	Early secondary procedures	Late secondary procedures
7	56	M	Mid-forearm	Crush-avulsion	Two plates	5	Ulnar artery Radial artery Three veins	Median nerve Ulnar nerve Superficial branch of radial nerve	4	Two debridements and Scapular Free Flap due to significant non-septic soft-tissue necrosis	Twice tenolysis Corrective osteotomy of the radius and ulna
8	56	M	Mid-forearm	Crush	Two plates	7	Ulnar artery Radial artery Two veins	Median nerve Ulnar nerve	7.5	Five debridements Skin-mesh-graft	None
9	44	M	Mid-forearm	Crush-avulsion	Two plates	6	Ulnar artery Radial artery Two veins	Median nerve Ulnar nerve Medial antebrachial cutaneous nerve	6	One debridement	Tenolysis Scar correction
10	37	M	Distal forearm	Crush-avulsion	Two plates	6	Ulnar artery Radial artery One vein	Median nerve Deep branch of the ulnar nerve	4.5	VAC Five debridements Skin-mesh-graft	Rotation flap Twice tendon transfer
11	24	F	Elbow	Crush-avulsion	–	–	–	–	No reflow after shunting		–

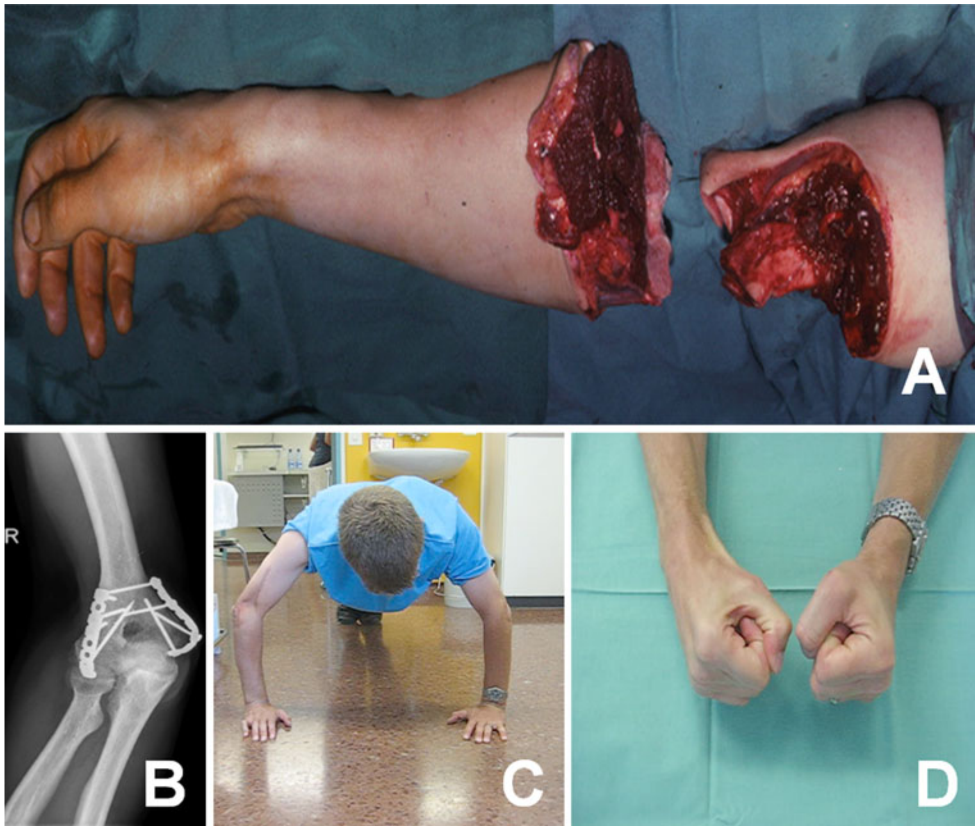

Fig. 1 Patient 2 of the series. **a** Macroamputation at the elbow level. **b** Postoperative X-ray after bone consolidation. **c**, **d** Chen 1 functional results 13 years after macroreplantation

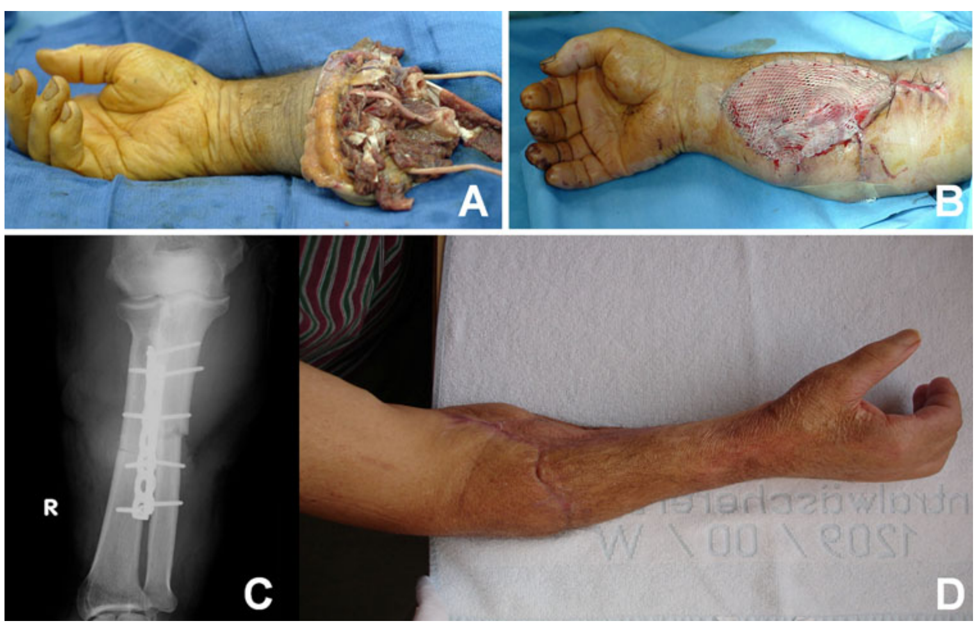

Fig. 2 Patient 8 of the series. **a** Macroamputation at the mid-forearm level. **c** Post-operative X-ray (5 cm-bone shortening, osteosynthesis with two plates). **b**, **d** Chen 4 poor functional results 4 years after macroreplantation despite good aesthetic results

successful replantation of a severed limb in a 12-year-old boy was carried out by Malt in Boston [16]. Since this early report, replantation of the upper limb has been steadily on the rise. For pioneers in microsurgery, tissue survival with functional failure was acceptable. Today, functional recovery after replantation has become the ultimate goal, requiring restoration of skeletal stability, joint mobility, muscle power and sensitivity. Such results can only be achieved by experienced surgeons who are aware of all relevant factors such as the patient's general state of health ("life before limb" concept [17]), the risks involved in replantation, the technical possibility and feasibility for replantation, the possible complications and the potential need for secondary surgery. Due to the rarity of these replantations, they should be performed at specialized replantation centers where surgeons can adapt quickly to all possible cases [18]. In this context, Ozçelik et al. [19] and Liang et al. [20] have recently underlined the possible indication for cross-extremity replantation when the patient suffers from bilateral total amputation at different levels and orthotopic replantation is impossible. In 1990, we stressed the lack of large series in literature and the need for clear guidelines [9]. This additional study presents the outcomes of 11 patients who presented to our university hospital with macroamputation since this first report. All but one were successfully replanted and regained limb function: Chen I in 4 cases (36 %), Chen II in 3 cases (27 %), Chen III in 2 cases (18 %), and Chen IV in one patient (9 %). These results could be obtained because of high priority to reduce ischemic time and the risk of ischemia reperfusion injuries.

Time is essential because ischemic muscles without oxygen will irreversibly deteriorate within hours. In order to reduce the time of ischemia, the storage and preparation of the amputated part and the reception of the patient on the arrival must be appropriately managed. Recently, Lloyd et al. [21] introduced their A-M-P-U-T-A-T-E concept. This sequence emphasizes the major role of perfusion of the amputated part, its conditions of transport and its photographic documentation. Digital pictures can be sent to the replantation unit for quick information ahead of the reception of the limb [21–23]. They also prevent repeated manipulation of the injured segment by all actors of the replanting chain.

Limb ischemia can be drastically reduced by adapted reception of the patient on arrival (two surgical teams are mandatory for a major limb replantation). Pre- and intra-operative cooling of the amputated part using ice packs and ice water in filled surgical gloves minimizes warm ischemia. When the amputation is more or less monotraumatic, a temporary shunting is usually performed to quickly revascularize the extremity [4, 24]. If resuscitation of the patient makes a long replantation procedure unfeasible, temporary ectopic implantation of the amputated part to a healthy recipient, e.g. the groin, can be an alternative to salvage the severed extremity in rare difficult clinical situations [25]. A simple alternative to ectopic implantation is simply to perfuse the amputated part [26]: Different fluids and artificial oxygen carriers (fluosol and fluorocarbon) [27] have been proposed to ensure early tissue oxygenation. Recently, Constantinescu et al. [27] have shown that continuous perfusion with oxygenated blood may offer an alternative solution (1) by maintaining the survival of the whole limb and (2) with extracorporeal whole blood perfusion over 12 h and different ischemia times using a pediatric heart–lung machine. Their ex vivo studies in a porcine model have proven effective in preservation of muscle function. This therapy has crossed the gap between bench and bedside and will now be integrated to our macroreplantation protocols. In case of part muscle ischemia inspite of intensive care during preoperative management, aggressive debridement should be performed. Additional debridements are always repeated after revascularization and during the early replantation follow-up. In this context, it is important to mention that in our series, infections occurred in two patients, which was probably due to inadequate primary debridement.

Ischemia–reperfusion is a subject of interest to hand surgeons involved in replantations as it can cause more tissue damage than ischemia alone. Reperfusion elicits rapid production of reactive oxygen species in the mitochondria and initiates tissue injuries. Over the past 5 years, numerous substances have been examined in an attempt to minimize these injuries. These include recombinant human BCL2 protein, hydrogen sulfide, ketamine, recombinant human VEGF165, low-level laser therapy and Wisconsin solution [28]. However, none of these agents has shown consistently promising results. Wang et al. [28] reviewed the recent progress of therapeutic options to reduce ischemia–reperfusion injuries. They highlighted the maneuver of postconditioning (brief alternative episode of nonocclusion/reocclusion of the feeding artery) or remote postconditioning (brief alternative episode of ischemia and reperfusion of the contralateral non operated side) as effective therapies in amputation injuries applied at the onset of reperfusion. These favorable results in the field of organ transplantion must now be replicated in composite tissue replantation or transplantation.

The success of first series of macroreplantations was largely due to the advent of microsurgery. Progress will now come from the laboratory with the understanding of the phenomenon of ischemia and reperfusion injuries at the cellular level to extend the survival and functional outcome of amputated (especially crushed) limbs. With the emergence of many programs for transplantation [29] of the upper limb, this research is currently experiencing a boom resulting in great benefits to both replantation and transplantation programs.

Conclusion

As a result of technical progress, the indications for limb salvage after amputation can be expanded. However, due to the rarity of these replantations, they should be performed at specialized replantation centers.

Conflict of interest The authors declare no conflict of interest.

References

1. Lindfors N, Raatikainen T (2010) Incidence, epidemiology, and operative outcome of replantation or revascularisation of injury to the upper extremity. Scand J Plast Reconstr Surg Hand Surg 44:44–49
2. Lerman OZ, Haddock N, Elliott RM, Foroohar A, Levin LS (2011) Microsurgery of the upper extremity. J Hand Surg [Am] 36:1092–1103
3. Ball CG, Rozycki GS, Feliciano DV (2009) Upper extremity amputations after motor vehicle rollovers. J Trauma 67:410–412
4. The Hoang N, Hai LH, Staudenmaier R, Hoehnke C (2009) Complete middle forearm amputations after avulsion injuries-microsurgical replantation results in Vietnamese patients. J Trauma 66:1167–1172
5. D'Addato M, Pedrini L, Bertoni M et al (1989) Traumatic amputation of the upper limb: replantation of the arm. J Trauma 29:876–879
6. Zuker RM, Stevenson JH (1988) Proximal upper limb replantation in children. J Trauma 28:544–547
7. Friedrich JB, Poppler LH, Mack CD, Rivara FP, Levin LS, Klein MB (2011) Epidemiology of upper extremity replantation surgery in the United States. J Hand Surg [Am] 36:1835–1840
8. Gulgonen A, Ozer K (2012) Long-term results of major upper extremity replantations. J Hand Surg 37:225–232
9. Axelrod TS, Buchler U (1991) Severe complex injuries to the upper extremity: revascularization and replantation. J Hand Surg [Am] 16:574–584
10. Chen ZW, Yu HL (1987) Current procedures in China on replantation of severed limbs and digits. Clin Orthop 215: 15–23
11. Weinstein MH, Golding AL (1975) Temporary external shunt bypass in the traumatically amputated upper extremity. J Trauma 15:912–915
12. Sabapathy SR, Venkatramani H, Bharathi RR, Bhardwaj P (2011) Replantation surgery. J Hand Surg [Am] 36:1104–1110
13. Sabapathy SR, Venkatramani H, Bharathi RR, Dheenadhayalan J, Bhat VR, Rajasekaran S (2007) Technical considerations and functional outcome of 22 major replantations (The BSSH Douglas Lamb Lecture, 2005). J Hand Surg [Eur] 32:488–501
14. Fischer JC, Parker PM, Shaw WW (1986) Waveform analysis applied to laser Doppler flowmetry. Microsurgery 7:67–71
15. Höfner E (1903) Ueber Gefaessnaht, Gefaesstransplantation und Reimplantation von Amputierten Extremitaeten. Arch Klein Chir 70:417
16. Malt RA, Mekhann CF (1964) Replantation of severed arms. JAMA 189:716
17. Pho RWH, Kiat TS (1988) Reimplantation surgery—major upper limb replantation. In: Pho RWH (ed) Microsurgical techniques in orthopaedics. London: Butterworths, pp 20–26
18. Beris AE, Lykissas MG, Korompilias AV, Mitsionis GI, Vekris MD, Kostas-Agnantis IP (2010) Digit and hand replantation. Arch Orthop Trauma Surg 130:1141–1147
19. Ozçelik IB, Mersa B, Kabaka F, Saçak B, Kuvat SV (2011) Crossover replantation as a salvage procedure following bilateral transhumeral upper limb amputation: a case report. Arch Orthop Trauma Surg 131:567–572
20. Liang K, Zhong G, Yin J, Xiang Z, Cen S, Huang F (2011) Cross-arm replantation for traumatic bilateral upper extremity amputations: a case report. Arch Orthop Trauma Surg 131:157–161
21. Lloyd MS, Teo TC, Pickford MA, Arnstein PM (2005) Preoperative management of the amputated limb. Emerg Med J. 22:478–480
22. Hsieh CH, Jeng SF, Chen CY et al (2005) Teleconsultation with the mobile camera-phone in remote evaluation of replantation potential. J Trauma 58:1208–1212
23. Buntic RF, Siko PP, Buncke GM, Ruebeck D, Kind GM, Buncke HJ (1997) Using the internet for rapid exchange of photographs and X-ray images to evaluate potential extremity replantation candidates. J Trauma 43:342–344
24. Lee YC, Pan SC, Shieh SJ (2011) Temporary femoral–radial arterial shunting for arm replantation. J Trauma 70:1002–1004
25. Higgins JP (2011) Ectopic banking of amputated parts: a clinical review. J Hand Surg [Am] 36:1868–1876
26. Hicks TE, Boswick JA Jr, Solomons CC (1980) The effects of perfusion on an amputated extremity. J Trauma 20:632–648
27. Constantinescu MA, Knall E, Xu X, Kiermeir DM, Jenni H, Gygax E, Rieben R, Banič A, Vögelin E (2011) Preservation of amputated extremities by extracorporeal blood perfusion; a feasibility study in a porcine model. J Surg Res 171:291–299
28. Wang WZ, Baynosa RC, Zamboni WA (2011) Update on ischemia–reperfusion injury for the plastic surgeon: 2011. Plast Reconstr Surg 128:685–692
29. Vögelin E (2011) Hand transplantation—fiction or reality? Ther Umsch 68:730–734