KEY PRINCIPLES OF STAGED COMBINED RECONSTRUCTION OF FINGERS

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The aim of the investigation was to develop the technique of staged reconstruction of the lost fingers and repair of hand soft tissue defects using high-precision and standard surgical procedures.

Materials and Methods. We performed primary and secondary reconstruction of digits using a non-free flap plasty in combination with osteocutaneous grafting and their transposition by microvascular anastomosis in 41 patients with mechanical (29), thermal (8) and gunshot (4) hand injuries. Hand and forearm vessel examinations included clinical, radiological, biomechanical, reovasographic, anatomic and ultrasound investigations.

Results. Complete acceptance of osteocutaneous transplants was recorded in 92.8% patients. Lipocutaneous grafts were accepted in all patients. Handgrip was recovered in 75% patients, and hand function improvement was achieved in all patients. Radiological and morphological investigations revealed insignificant resorption in the distal segment of the bone graft, it being mostly expressed in cases of osteocutaneous radial flap grafting.

Conclusions. The developed technique ofreconstruction of fingers helps to recover an adequate handgrip function with minimal donor defects in patients with the most severe injuries as a result of mechanical, thermal or gunshot traumas.

Key words: finger reconstruction; lipocutaneous pedicle flap grafting; osteocutaneous flap transfer by microvascular anastomosis; the second toe transfer by microvascular anastomosis; transplantation of osteocutaneous radial flap.

Osteocutaneous complex transfer by microvascular anastomosis or its transfer from distal parts is the breakthrough of modern hand surgery. In case there are the defects of digits, soft tissues of the hand and forearm, the technique enables not only to perform one-stage digital reconstruction, but also recover adequate cutaneous covering of an upper extremity by transferring one or even several vascular pedicle flaps of the desired size . However, a single-stage grafting or the transfer of two or more tissue complexes are time-consuming, traumatic, present high risk of microvascular anastomosis thrombosing, and require high-cost technological support [1]. Moreover, grafting or transfer of large-sized complexes is frequently accompanied by a marked anatomical defect and functional changes not only in donor, but also in recipient parts, including “steal syndrome”, and the latter needs further treatment [2, 3]. These deficiencies warrant development of new treatment modalities for patients with digital stumps associated with the defects of the soft tissues of the hand and forearm [4]. The techniques based on the combined use of traditional lipocutaneous flap grafting and the digital bony frame reconstruction hold promise but this branch of reconstructive surgery is not well-developed.

The aim of the investigation was to develop the technique of staged reconstruction of the lost digits and repairment of hand soft tissue defects using high-precision and standard surgical procedures.

Materials and Methods. We developed the technique of sequential primary and secondary reconstruction of the lost digits based on the combined use of skin pedicle flap grafting and vascularized osteocutaneous grafting. The technique was first introduced in 1989 and it is based on the following main principles:

1. Primary or secondary plasty of the most part of the reconstructed digit, as well as the existing defects of the hand and forearm by ischemia-resistant lipocutaneous flaps on temporary pedicles.
2. The use of the primary and secondary digital reconstruction by blood supplied osteocutaneous graft alone, as well as the second toe transfer by microvascular anastomoses.
3. The formation of the working area of the reconstructed digit by means of the hypervascularized and reinnervated cutaneous island flap included in graft.
4. The use of no more than one magistral artery of the recipient part to mitigate the hand and forearm defects.
5. Primary suture of donor wounds.

These principles coupled with our considerable surgical experience in management of patients with lost fingers enabled to develop an efficient technique of digital

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reconstruction in patients with major hand and forearm deformities [4–10].

The digital and hand reconstruction using the developed approach was performed in 41 patients. Primary reconstruction was performed in 11 patients, and secondary reconstruction — in 30 patients. Mean age of the patients was 33.29±1.83 years. There were 37 male and 4 female patients. In most cases the hand defect was caused by mechanical injury (29 patients). Other injury causes included frostbite (7), gunshot wound (4) and electric burn (1). 23 patients had work injuries and 18 — injuries resulted from home accidents. 25 patients underwent the right hand reconstruction, 16 – the left hand reconstruction. The stump levels of the reconstructed digits varied within the carpal bone and condylus of proximal phalanges. There was a great variety of hand defects: 15 (36.6%) patients had the stump of I digit only, 11 (26.8%) patients — the stump of I digit and one or several triphalangeal digits, 9 (22.0%) patients – the stumps of all digits on different levels, and 6 (14.6%) patients — the stumps of several or all triphalangeal digits.

We performed the reconstruction of I (33), II (2), III (1) and IV digits (2), as well as ulnar margin of the hand in total absence of 2–5 radial bones (3).

For reconstruction of the digital soft frame (34 cases — 83.2%), replacement of hand tissue defects (6 — 2.46%), forearm defects (1 — 41%) we used a Filatov flap (16), doubled Converse-Blokhin graft (13), including that we had modified [5], a “sharp” flap (9), inguinal graft (2), and sequentially a Filatov flap and doubled Converse-Blokhin graft (1). Average dimensions of a defect were 53.88±6.74 cm^2.

“Sharp” flap and doubled Converse-Blokhin graft were predominantly used in acute trauma. A doubled graft was used more frequently to replace the tissue defects on the hand and a transferred toe, while a “sharp” bucket-handle – in primary or secondary osteocutaneous digital reconstruction. The chronic bucket-handle plasty was performed to treat injuries and building of forearm tissue defects, the flaps were formed in lateral part of the abdomen (38 cases — 92.7%), inguinal area (2 — 4.8%) and in the chest (1 — 2.4%). A Filatov flap was formed, as a rule, according to B.V. Parin technique, and a “sharp” bucket-handle — in accordance with V.V. Azolov technique. Training of the flap was performed according to the previously-developed method [6].

The reconstruction of the bony frame of the finger and the hand was performed using graft transfer by microvascular anastomosis of II metatarsal (15), II toe including that with the fragment of the corresponding metatarsal (9), fibular fragments (3), iliac crest (1) and the replacement of the radial bone fragment on a distal vascular pedicle (13). Bone grafts were taken by forming an island (“signal”) lipocutaneous flap 6.0×3.0 cm in size, muscular cuff/muff or an additional axial muscle flap [7]. When transferring the metatarsal fragment and replacing the radial flap, a “signal” flap was placed on digital working area and we performed its reinnervation by suturing a deep branch of fibular and surface branch of radial nerve included into flaps with a digital stump nerve. II toe was transferred with a small lipocutaneous flap on its dorsal surface [8].

The first stage consisted in the plasty of soft tissue defects of the hand and the forearm, formation of soft tissue digital frame [4, 8–10]. Depending on a graft used, and the condition of the tissues in the recipient area, bone grafting was performed as a single-step operation along with flap pedicle ablation [8, 9], or 2–3 months after the ablation [10]. A bone graft was transferred or replaced into the formed bed.

The anastomoses of the artery, vein and the nerve of the transferred or replaced osteocutaneous graft with similar structures of recipient area were frequently formed by the type “end-to-end” under a surgery microscope “Opton Universal S3” (Karl Zeiss, Germany) using microsurgical instruments and appropriate suture material. The artery of the vascular pedicle was joined with radial or ulnar artery, and veins — with cephalic veins of the forearm. Ultrasound Doppler of transferred and grafted complexes was performed on hardware and software system “Angiodin”, for duplex scanning we used HDJ ATL (USA), for the study of foot functioning — F-SCAN, F-SCAN Zite model, Version 3.623 (Tekscan Inc., USA). There were carried out histological studies of bone fragments taken from distal parts of grafts during the digital reconstruction proper and when performing corrective finger operations. The preparations were hematoxylin-eosin stained. In addition, we performed rheo-angiographic, electroneuromyographic investigations, polarographic determination of tissue oxygen tension, volumetric local blood flow by hydrogen clearance, and X-ray dosimetry of the reconstructed digital bony frame.

Clinical and laboratory findings were statistically processed using Wilcoxon–Mann–Whitney test and correlation analysis.

Complete acceptance of osteocutaneous transplants was recorded in 92.8% of cases. Lipocutaneous grafts were 100% accepted. Handgrip was recovered in 75% of cases, and hand function improvement was achieved in 100%.

Results and Discussion. The acceptance of the transferred and grafted tissue complexes using the technique we developed for the hand reconstruction was 92.8%. Total necrosis of the transferred tissue complex occurred in one case (2.43%), and partial necrosis — in two cases (4.8%). Only in one case (2.43%) there was observed marginal necrosis of lipocutaneous flap after its pedicle ablation. The wounds in donor and recipient areas healed by primary intention, despite the presence of extensive scar tissue changes. As our experience shows, tubed flaps are plastic, sliding and well corrected in early periods followed the previous surgery, since they have no lymphostasis peculiar to microvascular pedicle flaps. In contrast to axial flaps, the correction of non-free flaps is not accompanied by the development of ischemic disorders in them. Moreover, their correction presents less risk of the great vessel damage in the osteocutaneous complex with the bone blood supply disturbance. Therefore, in our view, non-free flaps are appropriate for soft tissue formation of the reconstructed finger, its side surface, thenar prominence area, and especially the first interdigital space in the presence of severe adduction contractures of I metacarpal.

We consider it unpractical to use additional grafting of the flaps with axial blood stream type. Moreover, the transfer of two tissue complexes (one — for soft tissue defect replacement, and another — for the reconstruction of the digit or its bony frame) by microanastomoses more frequently requires the anastomosis with two main arteries of the forearm, or two "end-to-side" anastomoses in one artery that results in exclusion of two main arteries from the hand blood supply, and significantly complicates the operative technique, makes it more traumatic, increases the risk of anastomosis thrombosis, as well as in some cases the development of the hand chronic ischemia in the form of "hand steal syndrome" [3]. Vascular complications can also occur after the transfer of two flaps on a peripheral vascular pedicle. The use of one tissue complex with a skin flap, the size of which is appropriate for the replacement of hand tissue defect, and the digital reconstruction, results in tissue defect formation in a donor area, and its repair can require the second flap plasty by microvascular anastomosis or a pedicle flap with similar consequences. Therefore, to eliminate the associated hand defects and form the most part of the skin covering of the reconstructed digit, it is reasonable to use non-free skin grafting.

As our experience shows the use of temporary pedicle grafts can eliminate the soft tissue defects of the hand and forearm of any length. Mechanical training of tube flaps leads to statistically significant increase of volumetric local blood flow and tissue free oxygen tension (up to 54.0±2.62 ml/min/100 g and 140.2±6.7% compared to the basic level) that promote their safe acceptance. Tissue complex grafting by microvascular anastomoses or its transfer are absolutely necessary only in the reconstruction of the digital bony frame and its working area, since avascular bone grafts undergo resorption with time [13]. Our approach enables to exclude from blood flow not more than one magistral artery due to the vascular pedicle transfer or one osteocutaneous complex grafting by microvascular anastomoses. The formation of the "end-to-side" anastomosis does not at all result in excluding a magistral artery from blood flow and the formation of vascular deformity with the development of the hand inadequate blood supply that is of particular importance in the treatment of patients with burns and electric burns due to the reduced regenerative resources of scar tissue changes and the deficiency of the vessels appropriate for anastomosis. None of our observations had the "hand steal syndrome" that was confirmed by clinical and instrumental investigations. Rheovasographic and ultrasound studies of the remained fingers recorded magistral blood flow, and its parameters after the reconstructive operation did not statistically significantly differ from initial ones (p=0.5).

The implementation of our approach results in the minimization of soft tissue donor defect, since a small-sized lipocutaneous flap is incorporated in a transferred or grafted tissue complex. It enables to close a donor wound by primary suture in all cases without using free cutaneous flaps or additional patchplasty. In case of II metatarsal fragment grafting, II toe is preserved and its appearance does not suffer any changes providing a cosmetic effect and no limitations concerning footwear in long-term postoperative periods. Donor wounds in the areas where skin pedicle flaps were taken were also closed by primary suture. They were normally in hidden part of patient's body. No corrective operative procedures in donor areas were required.

The feasibility of the developed technique is confirmed by biomechanical investigations as well. In case of foot tissue transfer, foot dysfunction manifestations were minimal. In short-term postoperative period, the foot contact time and maximum anterior push in II toe transfer were greater than after II metatarsal fragment transfer (p=0.064–0.049). The similar characteristics were found in intact feet as well. The mentioned parameters normalized within a year. Moreover, in follow-up period we revealed no statistically significant differences between biomechanical indices after II toe transfer and II metatarsal fragment grafting, and between the parameters of the operated and intact feet.

When applying our approach, the dimensions of the reinnervated island flap grafted or transferred together with bone graft are sufficient for covering the working (ulnar and end) surface of the reconstructed digit and providing its adequate sensitivity (10–15 mm according to Weber test). The sensitivity recovery of the digital working area alone did not discomfort patients in their professional activities. An innervated and hypervascularized flap with an axial blood flow is resistant to mechanical stress on the digital working area that provides safe prevention of trophic disturbances on the digital working area. The function of a double handgrip was improved in all cases with the accepted hand fragments.

Long-term treatment results were assessed according to A.E. Belousov technique (1984), which we improved. Long-term results were known in 24 patients, among them 2 patients (8.3%) had excellent results, 8 (33.3%) — good results, and 8 (33.3%) — satisfactory result, 6 patients (25.0%) had poor results. Poor results were observed mainly in patients with total defects of the first radial bone and complications of the surgeries. However, most of them demonstrated the improved function of the mutilated hand.

Let us consider a clinical example.

A 32-year-old patient S. was admitted to Nizhny Novgorod Research Institute of Traumatology and Orthopedics 4.5 months after getting injured (Fig. 1, a). He underwent the reconstruction of the ulnar margin of the hand resulted in segment consolidation. Double handgrip was recovered (Fig. 1, b–e). Two years later a bone graft fully preserves its structure and dimensions. Now the patient works within his specialty. Fig. 2, a–e shows the scheme of reconstruction stages.

In the formation of a tissue complex with a small lipocutaneous flap, the index of specific blood flow appears higher than in the dissection of a larger flap. It results in hyperperfusion and blood supply improvement of bone tissue, the most expressed in the transfer of a segment of II metatarsal or fibular bone, since the reduced volume of one of the flap constituents, and therefore, the total length of the perfused vessels is frequently accompanied by the increase of volumetric blood flow according to Hagen–Poiseuille's law [14]. Moreover, hyperperfusion is achieved due to the

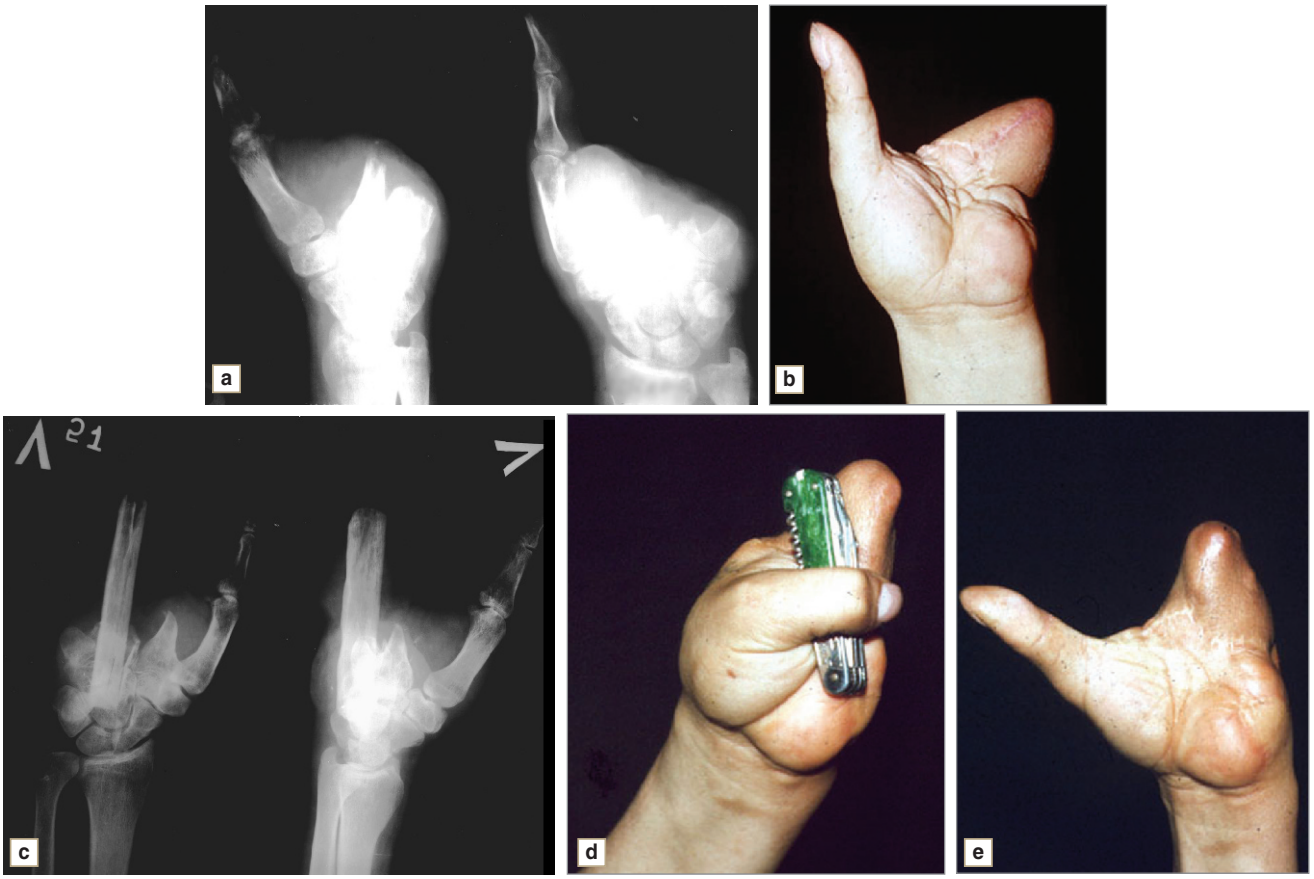

Fig. 1. The appearance and radiographs of a patient's S. hand: *a* – the hand radiograph before the operation; *b* — soft tissue frame of the ulnar margin of the hand formed from a tube flap; two years after the operation: *c* — the hand radiograph; *d* — the adduction function of the first digit to the ulnar branch; *e* — the adduction function of the first finger

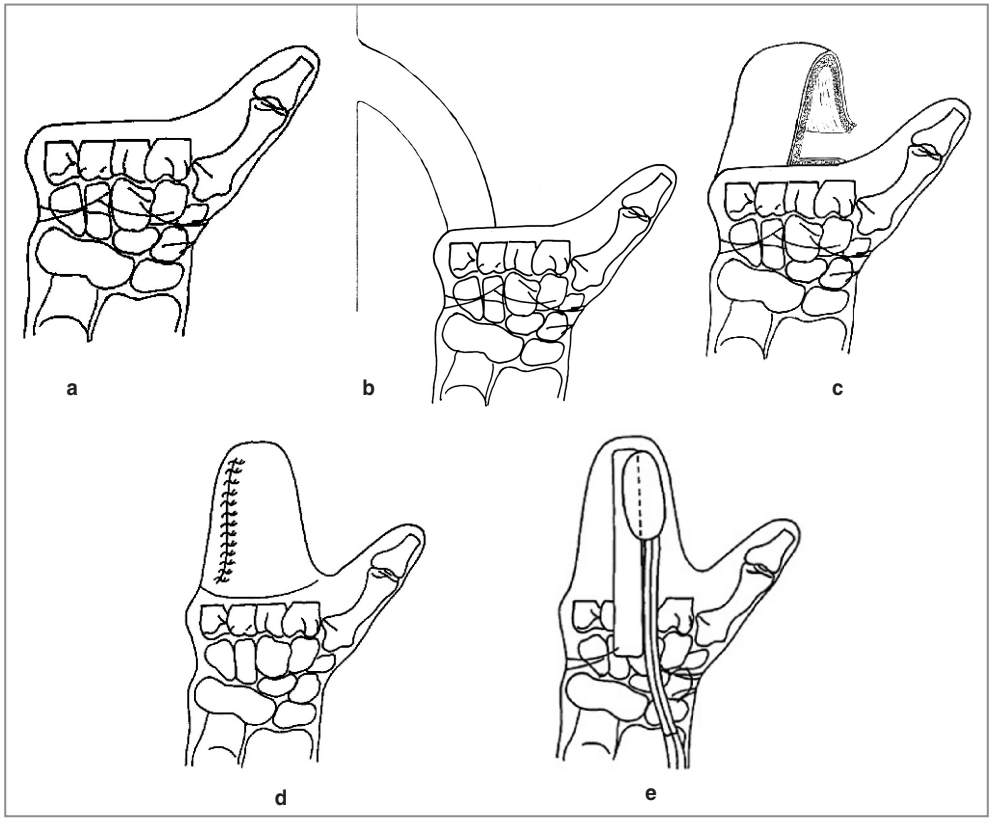

Fig. 2. The reconstruction scheme of the ulnar margin of the hand: *a* — the initial condition of the hand; *b*, *c*, *d* — the soft tissue formation of the ulnar margin of the hand by an one-pedicle tube flap; *e* — the recovery of the bony frame of the ulnar margin of the hand by fibular bone fragment transfer by microvascular anastomoses

blood passing in a relatively small bone fragment through a vascular pedicle by the formed anastomosis from a great magistral artery of the forearm providing blood supply of the entire hand or its most part under natural conditions. Constant and continuous blood supply of the bony frame of the reconstructed hand radial bone due to a magistral artery (most frequently, radial artery) prevents bone graft resorption; it preserves its length and adequate remodeling in a long-term postoperative period that is confirmed by the hand X-ray dosimetry examination. In addition, there were found the resorption of the distal ends of osteocutaneous grafts only; it was the most marked in radial bone fragment displacement (25.4±4.5 months after the operation the graft length was 91.1%, the width of a distal end — 79.4% compared to the initial values). When a metatarsal segment was used, the graft length 36.6±9.7 months after the operation was 93.3% compared to the initial values, the width of a distal end — 89.1%.

X-ray indices were found to correlate with morphological findings. Histological studies of the distal parts of the bony frame of the reconstructed digit showed atrophic and necrotic manifestations, to the maximum extent peculiar to the transferred radial bone fragments.

The use of non-free flap plasty is certainly to result in increased number of treatment stages compared to free flap plasty [1, 3]. However, such operations are more difficult to perform technically, twice as longer, and therefore, more traumatic than non-free plasty [1] that was clearly indicated by our findings. Thus, a staged hand reconstruction is reasonable, as it enables to reduce traumatism of the operation, and therefore, the complication risk. A sequential, staged reconstruction of the lost hand structures is easily endured by patients; therefore, it can be used in patients with contraindications to complex and long operative interventions.

Conclusion. In treatment of patients with severe posttraumatic hand and forearm defects accompanied by finger lost, it is reasonable to combine sequentially free grafting or transfer of a vascular pedicle lipocutaneous complex with traditional lipocutaneous grafting using the flap from distal parts. The developed digital reconstruction technique enables to recover an adequate double handgrip function with minimal donor defects including patients with severe burnsp.

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