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Research Article

Transposition of Hand Segments in Children with Traumatic Loss of First Radius

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Abstract

Introduction: This study investigates the possibilities of reconstructing amputated fingers in children by various methods of hand segment transposition.

Materials and Methodology: We have carried out a retrospective study analyzing the outcomes of reconstructive surgery of thumbs and fingers performed on injured hands by way of segment transposition in 28 children. The defect origins included mechanical injuries (10), gunshot wounds (11), burns (6), and a frostbite (1). In total, 29 fingers were reconstructed by transferring intact (3) and mutilated (2) fingers, finger stumps (13), and metacarpal stumps (11). The surgeries were performed using traditional (14) and non-traditional (15) techniques. In 25 cases, segment transposition required skin grafting with donor material harvested from remote sites. We have developed new approaches that allow to transfer a mutilated finger or any stump of a proximal phalanx or a metacarpal bone regardless of their location, amputation level, nature of hand defect, degree of soft tissue scarring and blood flow impairment, and allow also to ensure adequate prevention of ischemic complications.

Results: All the transposed segments healed, including segments with total tissue scarring and vessel damage. According to the long-term outcome analysis, hand grip was restored in 23 cases. Transposition of intact fingers resulted in the best outcomes. The use of non-salvageable segments (otherwise discarded) allowed to restore bilateral grip with minimal donor defect. Two-point discrimination results were 2 mm after finger transfers, 4.5 mm after finger stump transfers, and 6.5 - 7.4 mm after metacarpal stump transfers.

Conclusion: Transposition of the segments of an injured hand in children to reconstruct the thumb yields acceptable functional and anatomical results. This method can be used in finger reconstruction on a par with other techniques. Our new approaches to technique and treatment tactics make it possible to broaden the criteria of segment viability and the indications for this procedure.

Keywords: *Hand Finger Stumps; Children; Pollicization; Transposition of Finger and Metacarpal Stumps; Indications for surgery; Treatment Outcomes*

Introduction

Today pollicization of the second finger has taken root as the most effective method of thumb reconstruction in cases of its total congenital absence and this procedure is often performed in early childhood [1,2]. This procedure is therefore the method of choice in cases of 4 - 5 degree thumb hypoplasia. Similarly, there is no doubt that transposition of hand segments on pedicles is one of the most effective techniques of reconstructing lost digits in cases of hand injury and its consequences in adults [3]. Modern reconstructive surgery has gained detailed knowledge of utilizing distraction in order to extend finger and metacarpal stumps with the Ilizarov method in cases of such pathologies in children [4]. This approach can be applied to stumps of sufficient length. However, there is only limited research on the possibilities of thumb reconstruction when treating this cohort of patients by transferring segments of mutilated hands. The few available publications are based on isolated case studies of applying this technique after mechanical injury and electrical burns [3,5,6]. Many surgeons hold the view that using a well preserved and functional finger to reconstruct another digit, including a thumb, is unjustified, although for some cases they might consider it reasonable to transfer a defect or an intact finger, usually the latter [7-9]. Many techniques and tactical aspects of hand segment transposition in cases of hand injury and its consequences in children need further investigation and improvement. Furthermore, there is no definite indications for choosing to transfer a specific segment over another depending on its type, location, nature of hand defect, and amputation level of the digit to be reconstructed. As a surgical technique, pedicled hand segment transposition has essentially remained unchanged for over a century [7,8]. As a rule, some segments adjacent to the reconstructed digit (usually the thumb) are chosen for transposition only when dealing with a very narrow set of finger defect types and loss levels, which constrains tactical approaches to the choice and limits the method's potential [9]. The options for transposition of finger and metacarpal stumps in children with post-traumatic hand deformities are described in single-case studies [4,10,11]. Just a few surgeons have experience in transferring fingers, other than the second finger, in cases of both congenital and acquired pathologies [8,12-14]. Therefore, the lack of proper data calls for researching this issue, defining indications for the use of this method, and developing new approaches that should expand the range of applicability of the technique.

This study investigates the possibilities of reconstructing amputated thumbs in children by various methods of hand segment transposition.

Materials and Methodology

29 thumbs were reconstructed on 29 hands in 28 children from 6 to 18 years. Mean age was 13.71 ± 0.66years. Time after injury before operation was 25.57 ± 4.87 months. Most of the patients were male (25). Right hand was injured in 15 cases, left hand in 12 cases, and both hands in one case. The defects included 10 mechanical injuries, 11 gunshot wounds, 3 thermal burns, 3 electrical burns, and 1 frostbite. Post-traumatic hand deformities were characterized by extensive variability, irregularity and marked individuality. There were 4 patients with isolated thumb loss, 9 patients with loss of the thumb and a finger, 11 patients with loss of the thumb and two or three fingers, 5 patients with loss of all five digits. Most cases (27), especially after burns, presented soft tissue scarring with lesion of various degree of severity, length, depth, and localization. The scarring gave rise to adduction contractures of the first metacarpal, diverse deformities in the preserved fingers, and wrist joint contractures of various severity, which significantly complicated treating this patient group. Reconstructions were carried out on the thumb with stumps at the levels of the proximal third of the proximal phalanx (1), the base of proximal phalanx (9), the head (10), distal third (3), medial third (4) of the metacarpal, and wrist bones (2). Different hand segments served as donor material, including intact fingers (3), mutilated fingers (2), finger stumps (14) and metacarpal stumps (11). The transferred fingers included intact fourth (1) and second (2) fingers and mutilated second (2) fingers. The finger and metacarpal stumps were transposed using the traditional technique (9), which allows to transfer a longer stump onto a shorter one and using own non-traditional techniques (15) (Inventor's certificates No.1560160, No.1775883, RF Patents No.2069545, No.2152184, No.2093092, No.2072807, No.21458120, No.2120246, No2391930, No.2460487). In principle, the proposed two-stage approach is specifically designed for having incomplete

anatomical hand structures develop a higher resilience to localized surgical trauma. Higher resilience is achieved through controlled mechanical stress applied by a transosseous apparatus and through extension of tissue pedicles. First, the soft skeleton of a mutilated hand segment is preliminarily reconstructed by grafting, if necessary (Figure 1a). After that, the first stage involves two sequential procedures: mobilization to surgically train the segment to be transferred on a pedicle followed by distracting the segment by means of applying the transosseous apparatus (Figure 1b). The second stage involves removal of the transosseous apparatus after 6 - 8 weeks, re-mobilization of the preformed segment, and its transfer on one or two distracted pedicles onto the receiving amputation site of a digit or a metacarpal (Figure 1c). The distraction was performed by an Ilizarov apparatus or similar adaptable devices made of titanium. The external fixation apparatus was based on the Transosseous osteosynthesis component kit for the Ilizarov technique (Russian state registration of medical devices certificate No.81/823-53). Each apparatus was assembled and mounted individually depending on the nature of deformity, however all the transferred hand segments were distracted by an L-shaped wire with intramedullary access (Figure 1b). The distraction started 7 - 10 days after setting up the external fixation. Distraction rate was 0.5 - 1.0 mm at a time daily, the distraction period varied from 3 to 6 weeks depending on the desired extension of the pedicles.

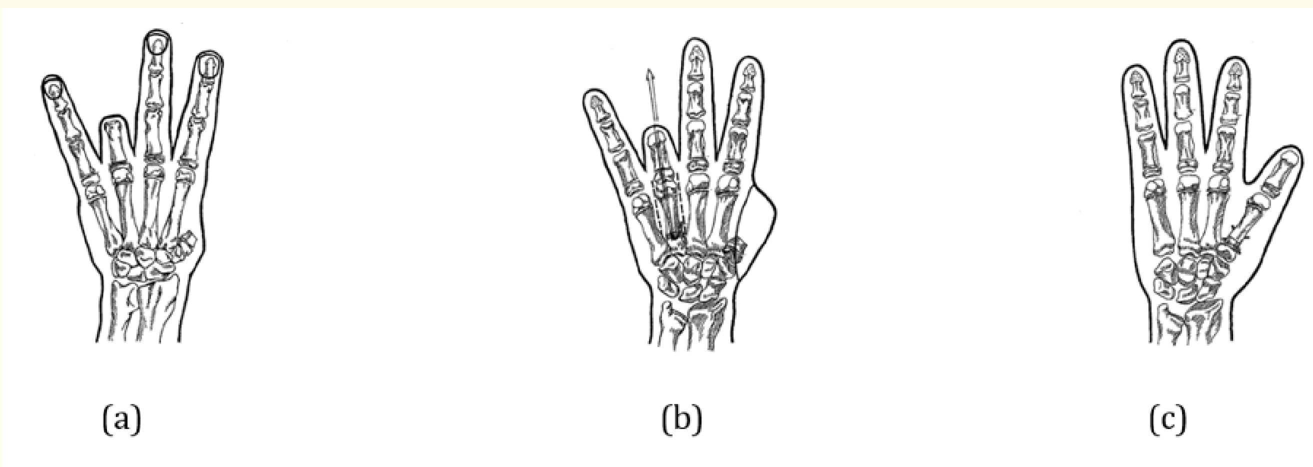

Figure 1: *Procedure chart for hand segment transfer: a - Appearance of the hand before surgery; b - Soft tissues formed in the thenar area, osteotomy of the transferred segment performed, distracting wire inserted intramedullary, skin incision arrangement for a dermo-vascular pedicle and distraction direction indicated; c - Metacarpophalangeal segment transferred onto the thumb site.*

We have developed an approach to the procedures that not only ensures the surgical viability of transferring any pathologically affected hand segment regardless of its size, location relative to the donor stump, and prospective reduction of digit deformity, but an approach that also provides adequate prevention of ischemic complications by means of achieving proper neo-angiogenesis, neo-cytogenesis, and neo-fibrillogenesis in the pedicles as well as in the transposed anatomical structures (Figure 2a-2d). Under distraction all the structural elements of the scar, both preexisting and newly formed, orderly align with the field vector of the mechanical stress induced by the transosseous apparatus, which serves as a structural base for scarry tissue de-retraction, elimination of contractures, and extension of pedicles (Figure 2b-2d).

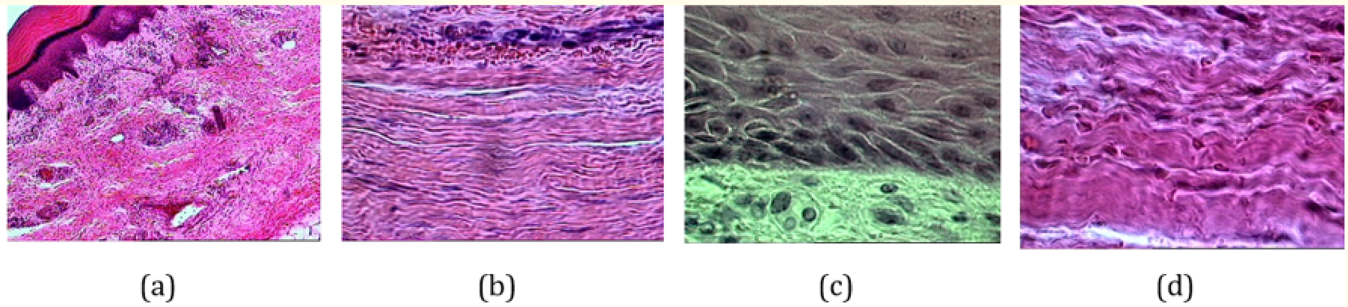

Figure 2: *Tissue histomorphology of a distracted dermo-vascular pedicle: a - Numerous newly formed vessels of various diameters in the surface layers of the distracted scar. Stain: haematoxylin-eosin x10; b - Longitudinal orientation of weak collagen fibers. Stain: haematoxylin-eosin x40; c - Tilt of basal-layer cells of scar epidermis. Stain: haematoxylin-eosin x100; d - Fibroblasts adjacent to collagen fibers of various diameters in longitudinal orientation. Stain: haematoxylin-eosin x100.*

Moreover, the extension of pedicles makes it possible to transfer any finger stump regardless of the ratio between the amputation levels of the donor and receiving stumps. The segment is transposed on one or two pedicles depending on the blood flow state. The traditional technique was used to transfer stumps of proximal phalanx of the second (3) and third (1) fingers, and the second metacarpal (6) at the level of the head and distal third. The approaches we have developed allow to transfer stumps of the second (3), third (3), fourth (3) and fifth (1) fingers, predominantly at proximal levels of the proximal phalanx together with a fragment of the corresponding metacarpal. We also performed transfers of distracted stumps of the second (1), third (4) metacarpals at the levels of the head and medial third (Table 1).

Transferred segment type	Transferred stump amputation levels									Total
	Inter. ph. base	Hd. prox. ph.	Dist/3 prox. ph	Med/3 prox. ph.	Prox/3 prox. ph.	Prox. ph. base	Met. bone. hd	Dist/3 met. bone	Med/3 met. bone	
Finger stump traditional				1	1	1				3
Metacarpal stump traditional							5	1		6
Finger stump distracted	1	1	3			5				10
Metacarpal stump distracted							4		1	5
Total:	1	1	3	1	1	6	9	1	1	24

Table 1: *Amputation levels of the transposed finger and metacarpal stumps depending on the segment type and operation technique.*

Different methods were used to form pedicles depending on the nature of hand defect, as well as the tissue and blood flow state of the segment. Permanent dermo-vascular pedicles were used in most cases (Table 2). The pedicle comprised a skin strip of 1.0 - 1.5 cm wide, including in cases of severe scarring.

Transfer techniques and methods of pedicle harvesting	Transferred segments					Total	
	Intact finger (3)	Defect finger (3)	Finger stump, traditional (3)	Metacarpal stump, traditional (6)	Distracted finger stump (10)	Distracted metacarpal stump(5)	
Hilgenfeldt technique	1		3	4			8
Azolov technique	2	1					3
Two dermo-vascular pedicles		1					1
Palmar distracted dermo-vascular pedicle					5	5	10
Dorsal and palmar distracted dermo-vascular pedicles					5		5
W/o harvesting pedicles, digitization				2			2
Total:	3	2	3	6	10	5	29

Table 2: *Hand segment transfer techniques.*

Transposition on two dermo-vascular or fasciocutaneous pedicles was carried out in cases of extensive tissue scarring and damage of major vessels.

When transferring segments with tissue scarring or using metacarpal stumps and finger stumps with a fragment of the corresponding metacarpal bone, various grafting techniques were required due to preexisting or newly formed tissue defects. Local skin grafts were applied in 7 cases. Skin flap grafting, including the use of microvascular anastomosis, was carried out in 5 cases due to newly formed or preexisting tissue defects on the radial and ulnar aspects of the reconstructed thumb, in the first interdigital space, and on the radial-aspect surface adjacent to the donor segment of the metacarpal. We used free full-thickness grafts and thick dermatome grafts in cases of defects on the radial (3) and ulnar (4) aspects of the repaired thumb, the ulnar aspects of the thumb and radial aspect of the adjacent metacarpal (3), the radial and ulnar aspects of the thumb (3), the palmar and radial aspects of the thumb (2), the radial aspects of the thumb and the adjacent metacarpal (1), the ulnar aspect of the thumb and the first interdigital space (1), the ulnar aspect of the thumb, the radial aspect of the adjacent metacarpal and the first interdigital space (1), the radial aspect of the metacarpal adjacent to the repaired thumb and the ulnar aspect of the metacarpal adjacent to the donor segment (1). The number of free skin grafts used alone and together with local flaps was 19 in total. The method of the osteosynthesis of bone fragments involved insertion of the fragments after machining them with a cylinder-shaped bone cutter or after implementation of crossed wires. When transferring finger and metacarpophalangeal segments, sutures were applied to the extensor tendon of the digit. Flexor tendons were invariably included into the composition of the pedicle with some cases requiring shortening them in order to achieve muscle stabilization in the formed thumb. Scarred segments and segments with poor vascularization were distracted after preliminary replacing the scarry tissue with a cutaneous-adipoid flap, surgically training the segment, forming two pedicles and reducing the length of a single distraction exposure. A new movement pattern was developed in the repaired thumb in the early postoperative period using devices with EMG feedback. This study relies on clinical, radiological, biophysical, biomechanical, morphological and statistical methods. All the patients were examined and operated on after receiving voluntary informed consent from their parents or guardian for the child to be part of the study and undergo surgical treatment.

Results

The analysis of the immediate treatment outcomes showed that wounds healed by primary intention in all patients, all the transposed segments healed as well as all the flaps and free grafts, including in cases of severe tissue scarring. These facts indicate an adequate blood supply to the transferred segments. The literature describes long-term pollicization results in children in cases of a congenital pathology only. For this reason, we used a modified version of the Belousov methodology (1984) to study long-term results in 2 hands. Alongside the aggregate active range of motion in finger joints and two-point discrimination in the repaired digit, we also evaluated abduction, adduction, and opposition. The absolute values of these parameters of thumb function were recorded as scores and then integrated into a single score for overall hand function recovery. The nature of hand defect (isolated loss of the thumb, loss of the thumb and several fingers, loss of all digits) and the type of reconstruction (primary, secondary) determined the designation of the main parameters of grip function and assigning weights to their values in the aggregate integrated score. The evaluated cases presented 5 optimal, 7 good, 8 satisfactory, and 3 poor outcomes. Poor outcomes correlated to traditional techniques of transferring metacarpal bones and could be accounted for primarily by insufficient length of the repaired thumb. Functional results were good in 1 case, satisfactory in 21 cases, poor in 1 case. Our methodology allows to recognize a positive result as optimal only in case of full recovery of ROM in the joints and achieving functional opposition of the thumb to all fingers. Despite a high number of poor outcomes, an insufficient outcome was observed only in one case where the patient had had a severe hand burn. This indicates that after such interventions hand muscles respond with an adaptive reaction. All examinations showed consolidation of the transposed bone fragments and no resorption. Even in cases with severe pathological tissue change, the skeleton of the transferred non-salvageable segments demonstrated resilience to resorption, which indicates an adequate blood supply. In cases where segments had been transferred before closure of the growth plates of the phalanx or metacarpal, the repaired thumb grew by 0.4-3.0 cm, depending on the child's age and follow-up duration. An intramedullary inserted wire, used for distraction, did not lead to premature growth plate closures in the transposed segments. Two-point discrimination of the repaired thumb was 2 mm after intact or defect finger transfer, 4.5 mm after finger stump transfer, 6.5 mm after traditional-technique transfer of the metacarpal. After transferring finger stumps on distracted pedicles, the two-point discrimination of the repaired thumb was 4.4 ± 0.4 mm, and 7.4 ± 1,12 mm for metacarpal stumps. The best results were registered after intact finger transfers: active ROM in the transposed joints was 90 degrees, which corresponds to outcomes in adults, see references [14,15]. The results of transferring finger and metacarpal stumps were roughly similar for traditional ($P = 0.708$) and distracted ($P = 0.79$) pedicles. The values of hand grip recovery after transferring these segments were compared with a chi-square test.

Case Study

Patient I.C., female, 11 years, case sheet No. 166690, admitted with stumps of the thumb and the fifth finger at the level of the proximal phalanx, and scarry flexion contractures in fingers 2, 3, 4 on her left hand (Figure 3a and 3b). According to her past medical history, 5 years prior to admission the patient grabbed a live high-voltage wire, which resulted in an electrical trauma, a 3 - 4 degree electrical burn of the left hand. The two-point discrimination of the fifth finger stump was 5 mm, and 4 mm on the proximal phalanx of the healthy hand. The patient complains of a cosmetic defect in the hand. We decided to reconstruct her thumb by transferring the most damaged segment of the hand, namely the fifth finger stump. Due to the distance between the donor and receiving sites and the identical size of the first and fifth finger stumps, we performed a two-stage transfer of the fifth finger stump together with the distal segment of its metacarpal. The first stage involved osteotomy of the fifth metacarpal and pedicled mobilization of its distal fragment with the finger stump. For distraction, an axial wire was inserted intramedullary through the stump and the distal metacarpal segment. The wire was then fixed to a screw drive on an Ilizarov ring fitted around the forearm (Figure 3c). Following this procedure, the segment was gradually distracted at a rate of 1 mm per day. The bony fragments were set apart 3 cm, after 41 days the structure composed of the stump and the metacarpophalangeal joint was transferred on a distracted palmar dermo-vascular pedicle (Figure 3d and 3e). The pedicle was necessary to ensure adequate blood supply to the segment. The postoperative period presented no complications. The transposed stump fully healed, the wounds healed by primary intention. The free skin graft transplanted onto the radial aspect of the transferred segment healed 100%. Taken with the metacarpal, the effective length of the repaired thumb was 7 cm, growing to 8 cm at 3 year follow-up. Thumb abduction and opposition to all other fingers was achieved (Figure 3f-3h). The ROM of the transferred metacarpophalangeal joint was 30 degrees. The two-point discrimination of the transferred stump was 5 mm. The patient notes an improvement in the cosmetic aspect of the hand. The X-rays clearly showed proximal and distal growth plates in the repaired thumb (Figure 3e).

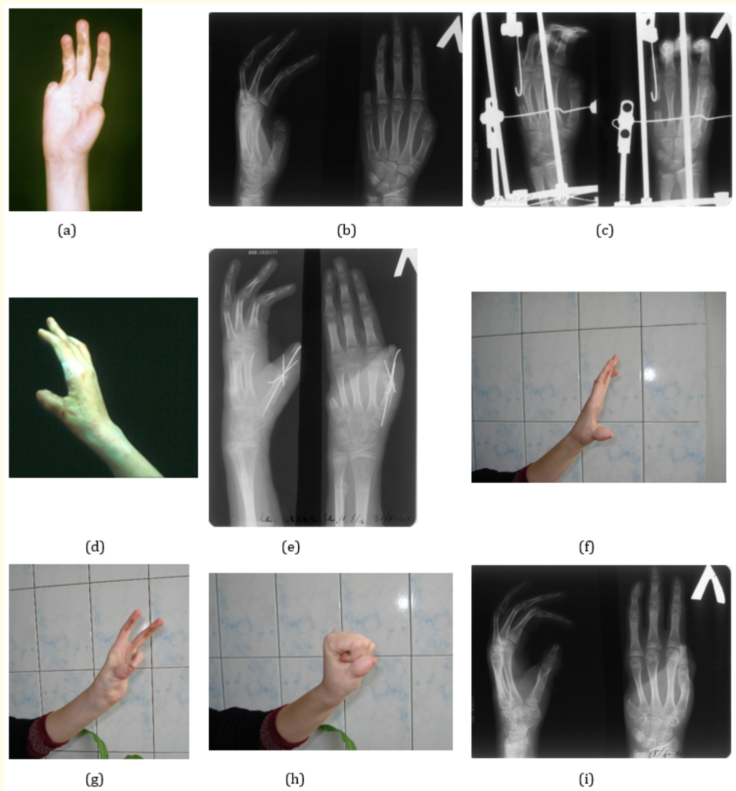

Figure 3: *Patient I.C., female, 11 y.o. Hand deformity resulting from a burn: a - Appearance of the hand before surgery; b - X-rays before surgery; c - X-rays after the second stage of the surgery, osteotomy performed on the fifth metacarpal, wire with a hooked base inserted intramedullary through the stump and the distal metacarpal segment for distraction, the other end of the wire attached to the Ilizarov apparatus, bony fragments partially set apart; d - Appearance of the hand after transferring the segment onto the thumb stump; e - X-rays after thumb reconstruction; f - Treatment outcome at 3 year follow-up, thumb abduction; g - Treatment outcome at 3 year follow-up, thumb opposition to the fourth finger achieved; h - Treatment outcome at 3 year follow-up, power grip; i - X-rays at 1 year follow-up.*

Discussion

The formation mechanisms of traumatic hand deformities are based on common fibrosis of the soft and bony framework in the injured hand with major disruptions to macro- and microcirculation and tissue retraction [18,19]. This drives the incidence of ischemic complications, more often-venous, after surgical interventions, reaching 10 - 15% [16]. The incidence increases dramatically when pathologically impacted segments are chosen for transfer. The differences in the formation patterns of congenital and traumatically acquired hand deformities in children necessitate development of qualitatively different algorithms for their treatment [17-19]. In cases of congenital pathology, where as a rule there is no tissue fibrosis in the hand, surgery is usually carried out under standard conditions, i.e. aplasia of thumb and its metacarpal bone, and underdeveloped second finger. This situation is rare among traumatic deformities, which makes necessary further investigation of applicability of the technique for other defect configurations with the goal to be able to transfer other segments, from other locations and types, and not just the second finger or its stump which are often the segment of choice [12]. The use of pedicle is central to this technique as it ensures sufficient blood supply to the donor tissues. Most surgeons today make transpositions on a palmar neurovascular pedicle in cases of both congenital and traumatic hand pathologies [12,13]. Only few cases are treated with the Hilgenfeldt-Shushkov technique whereby a dermo-vascular pedicle is harvested [3,5,8]. Techniques of transferring lateral and transverse segments of metacarpal bones on two (dorsal and palmar) neurovascular bundles were designed to make this method more reliable [4]. If the segment has any intact subcutaneous veins, these are preserved or restored by precision surgery [20]. However, these techniques are not applicable in cases of damage to neurovascular bundles, soft tissues or hand skeleton, or vein obliteration, and in cases of marked tissue scarring (palmar and dorsal), which makes the differentiation of vessels harder-ultimately meaning that such procedures carry high risks of iatrogenic damage of the remaining intact vessels. Our study has shown that conventional segment transposition techniques are only applicable in 37.9% of cases with hand lesions (11 out of 29). The go-to technique of transferring hand segments to restore a defect on the radial side is not universally feasible due to the natural anatomical constraint on pedicle length. It can be used for transfer of any finger to the thumb metacarpal stump of any length. However, the power of the conventional approach is significantly limited when it comes to transfer of proximal finger stumps and even more so transfer of metacarpal bone stumps. It is limited to transposing a stump of the second metacarpal bone to a shorter stump of the first metacarpal bone. This is the reason behind the need to make the transfer technique of hand segments universally applicable. The newly developed methods of finger reconstruction enable expansion of the range of transferable hand segments regardless of their type, location, severity of scarring or disruption of blood circulation. These advantages make it possible to use previously non-salvageable hand segments for reconstruction, thus minimizing the donor defect by preserving fingers and their longest stumps. This means that the most damaged three-phalange fingers should be transferred only if there are no stumps available. We believe that in cases of trauma the use of the Hilgenfeldt-Shushkov technique should become more widespread. The proposed methods are in principle less traumatic, which is extremely important for extending the function of bone growth plates and minimizing postoperative edema and scarring. Depending on the severity of soft tissue scarring, the nature of the hand defect, the amputation level of the stump and its blood supply, the technique of choice can be the conventional approach or the newly developed technique based on pedicle tissue distribution. Any intact finger can be transferred only provided that thumb defect is isolated and there is no defective finger or finger stump; this can only be done with a notarized written consent by the parents or their legal guardian. In cases of different levels of the first metacarpal stump and thumb stump, any segment can be translated within the proximal third of the main phalanx. Full acceptance of the transferred segment can be achieved, even in cases of massive scarring, by means of differentiated use of techniques for different pedicle types. The preferred option in such situations is a dermo-vascular pedicle, built without isolation of neurovascular bundles, which minimizes surgical damage and prevents any damage to lymphatic vessels, that are very rare in scarred tissue. In cases of disrupted major vessels and obliteration of dorsal subcutaneous veins, the transfer of a finger, a finger or metacarpal stump should be transferred on two (dorsal and palmar) dermo-vascular or fasciocutaneous pedicles, including distracted pedicles to ensure adequate venous and arterial blood supply to the segment by streamlining the blood flow. Such surgical preconditions make it absolutely necessary to use different techniques of skin plastics, including flap grafting, in order to offset for pre-existing or emerging tissue defects and prevent adduction contractures in the thumb metacarpal or its stump. With the above provisions it is possible to restore bilateral grip even in the most severe cases of hand deformity, disruption of blood circulation or soft tissue scarring. Note that bilateral grip function in children can be restored by transfer of any of the hand segments: finger, finger or metacarpal stump. Consistent functional improvements are observed after such transfers and are reliably not dependent on the nature of the transferred segment. Note separately that longer-term follow-up has revealed that there is an elasticity increase in the transferred scarred tissues, which is probably enabled by active functional use of the transformed segment, improvement of blood and lymph circulation, and activation of elastogenesis. In cases where an intact finger is used, it enables restoration of movement in the thumb joints and metacarpal, with no detriment to the length of the transposed finger.

Ethics Approval and Consent to Participate

Ethical approval was granted by the Federal State Budgetary Educational Institution of Higher Education "Privolzhsky Research Medical University" of the Ministry of Health of the Russian Federation with Registration Number: No. 166690.

Consent for Publication

Written informed consent was obtained from the participant and their parents for publication of their individual details in this manuscript.

Availability of Data and Materials

All data and questionnaires are available on your request.

Competing Interests

There are no competing interests.

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