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FINGER RECONSTRUCTION IN CHILDREN BY THE TRANSFER OF HAND SEGMENTS

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Aim. We aimed to evaluate the possibility of reconstruction of amputated fingers using various methods of hand segment transfer in children.
Materials and methods. A retrospective analysis of the reconstruction of the first and triphalangeal fingers of an injured hand using a segment transfer method in 31 children was performed. Eleven patients had a mechanical injury; 12, a gunshot injury; 7, a burn injury; and 1, a freezing injury. The reconstruction of 32 fingers was performed by the transfer of an intact triphalangeal finger (3), defective finger (3), finger stump (14), and a metacarpal (12). The surgery was performed using traditional (16) and original (16) methods. In 26 cases, skin grafting using donor resources from remote areas was required for segment transfer. Newly developed approaches enable the transfer of the defective finger and any stump of the main finger phalanges and metacarpals, irrespective of their location, amputation level, hand defect character, level of cicatrical changes of the soft tissues, and impaired circulation, while adequately preventing ischemic complications.
Results. Survival of all the transferred segments, including those with total cicatrical tissue changes and vascular disruptions, was achieved. The analysis of results showed that handgrip was restored in 31 hands. The best results were achieved in the transfer of intact fingers. Transfer of the utile segments enabled the reconstruction of the double-sided grip with minimum donor retrieval. Two-point discrimination was 2 mm for finger transfer, 4.5 mm for finger stump, and 6.5–7.4 mm for the metacarpal stump.
Conclusion. The transfer of injured hand segments in children for finger reconstruction provides acceptable functional and anatomical results. This method can be used in combination with other finger reconstruction methods. Advanced technical and tactical approaches have widened the criteria of segment suitability and indications for the use of this method.

Keywords: finger stumps, children, pollicization, transfer of finger stump and metacarpal, indications for surgery, treatment results.

ПЕРЕМЕЩЕНИЕ СЕГМЕНТОВ КИСТИ У ДЕТЕЙ С ПОСТТРАВМАТИЧЕСКИМИ КУЛЬТЯМИ ПАЛЬЦЕВ

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Цель — изучить возможности реконструкции ампутированных пальцев кисти различными методами перемещения ее сегментов у детей.
Материалы и методы. Проведен ретроспективный анализ реконструкции первого и трехфалангового пальцев травмированной кисти методом перемещения ее сегментов у 31 ребенка. Механическая травма отмечена у 11, огнестрельная — у 12, ожоговая — у 7, отморожение — у одного больного. Выполнена реконструкция 32 пальцев путем перемещения интактного трехфалангового (3), дефектного (3) пальцев, культи пальца (14) и пястной кости (12). Операции проведены с применением традиционных (16) и оригинальных (16) способов.

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В 26 случаях при перемещении сегмента потребовалась кожная пластика с использованием донорских ресурсов из отдаленных областей. Разработанные подходы позволяют переместить дефектный палец, а также любую из культей основных фаланг пальцев и пястных костей независимо от их расположения, уровня ампутации, характера дефекта кисти, степени рубцовых изменений мягких тканей и нарушений кровообращения, а также обеспечить адекватную профилактику ишемических осложнений.

Результаты. Достигнуто приживление всех перемещенных сегментов, в том числе с тотальными рубцовыми изменениями тканей и повреждениями сосудов. Анализ результатов показал, что схват кисти восстановлен на 31 кисти. Лучшие результаты достигнуты при перемещении интактных пальцев. Перемещение утильных сегментов позволило восстановить двусторонний схват с минимальным донорским изъяном. Дискриминационная чувствительность в случае перемещения пальца составила 2 мм, культи пальца — 4,5 мм, а культи пястной кости — 6,5–7,4 мм.

Заключение. Перемещение сегментов травмированной кисти у детей с целью реконструкции пальца обеспечивает приемлемые функциональные и анатомические результаты. Метод может быть применен наряду с другими для реконструкции пальцев. Разработанные технические и тактические подходы позволяют расширить критерии пригодности сегмента и показания к применению метода.

Ключевые слова: культи пальцев кисти, дети, поллицизация, перемещение культи пальца и пястной кости, показания к операции, результаты лечения.

Introduction

Currently, pollicization of the second finger has become the most effective method of reconstruction of the first finger in case of its congenital total absence. This technique is commonly used in early childhood [1, 2]. For this reason, surgery serves as a method of choice in the case of hypoplasia of the first finger of 4°–5°. Consequently, there is no doubt that the displacement of hand segments on the pedicles is one of the most effective methods of reconstructing lost fingers in hand injuries and their consequences in adults [3]. At the present stage of development of reconstructive and restorative surgery in childhood, Ilizarov [4] discussed in detail the distraction elongation of the finger stumps and metacarpal bones in a patient with similar pathology. Such an approach can be implemented if the stumps have sufficient length. The possibilities of reconstructing the first finger when treating this cohort of patients by transposing the segments of the injured hand have not been adequately studied. Few studies based their single observations on the application of this method with the consequences of mechanical trauma and electrical burns [3, 5, 6]. Many specialists believe that the use of a fully preserved and functioning finger for the reconstruction of another, including the first one, is unjustified. In some cases, they displace both the defective finger and the intact finger, more often the second finger [7-9]. Many techniques and tactical aspects of displacement of the hand segments in injuries and their consequences in children need to be further studied and improved. In addition, the indications for displacement of a certain segment depending on its type, location, nature of the hand defect, and level of amputation of the finger to be restored have not yet been determined. The surgical technique of transposing hand segments on pedicles has not significantly changed during the last 100 years [7, 8]. As a general rule, some segments adjacent to the restored finger, in most cases the first finger, are displaced in the case of only a few types of hand defects and finger loss levels, limiting tactical approaches to the choice of a segment and the potential of the method [9]. The possibilities of transposition of the finger stumps and metacarpal bones in children in the case of post-traumatic hand deformities are described in several studies [4, 10, 11]. Only a few specialists have experience of transposing fingers other than the second finger in both congenital and acquired pathology [8, 12-14]. Thus, current available data in the literature serve as a basis for studying this problem, developing new approaches that extend the range of implementation of the method, and determining the indications for its application.

The present study aims to investigate the possibilities of reconstruction of amputated fingers of the hand using various methods of transposition of its segments in children.

Materials and methods

A total of 32 fingers in 32 hands were reconstructed in 31 pediatric patients (aged 5–18 years). The average age of the patients was 13.52 ± 0.67 years. The first (30 patients), third

(1 patient), and fifth (1 patient) fingers were restored. Secondary reconstruction of a finger (31 patients) was mainly performed. Primary reconstruction in only one patient was performed 4 h after a gunshot injury. The period from injury to surgery was 24.49 ± 5.24 months. The majority of patients were males (28 patients). The right hand was injured in 18 patients and the left hand was damaged in 12. Bilateral pathology occurred in only one patient. Mechanical injury was observed in 11 patients, gunshot injury in 12, flame burns in 3, electrical burns in 4, and frostbite in 1. Post-traumatic deformities of the hands were characterized by great variety and individuality (non-standard). Isolated absence of the first finger in four patients, absence of the first and one of the three phalanx fingers in two, absence of the first and two or three phalanx fingers in 12, absence of all fingers in five, and absence of all three phalanx fingers in one was observed. In most cases (29 patients) on the hand and forearm, especially in cases of burns, there were scar changes in the soft tissues and their defects of different degrees of severity, extent, depth of lesion, and localization. Scar changes in the tissues caused the formation of adduction contractures of the stump of the first metacarpal bone, multiple deformities of the preserved fingers, and contractures of the wrist joint of varying severity, which significantly complicated the treatment of this cohort of patients.

Reconstruction of the first or one of the three phalanx fingers was performed with their stumps at the level of the middle third of the middle phalanx (1 patient), head of the proximal phalanx (1), proximal third of the proximal phalanx (1), base of the proximal phalanx (9), head of the proximal phalanx (11), distal third (3), middle third of the metacarpal bone (4), and wrist bones (2). Various segments of the hand were used as donor material, such as an intact three phalanx finger (3 patients), a defective three phalanx finger (3), a finger stump (14), and a metacarpal bone stump (12). The intact fourth (1) and second (2) fingers and defective fourth (1) and second (2) fingers were displaced. The displacement of the finger stumps and metacarpal bones was performed using the traditional technique (10), which allows movement of the longer stump to the short one, and the original (16) techniques (author certificate nos. 1560160 and 1775883; RF patent nos. 2069545, 2152184, 2093092, 2072807, 21458120, 2120246, 2391930, and 2460487). In general, the proposed two-stage technological approach to segment displacement consists of purposeful development of increased resistance of the inferior anatomical structures of the hand to local surgical trauma with the use of controlled mechanical tension created by transosseous devices and lengthening of tissue pedicles. In the first stage, after preliminary reconstruction of the soft core of the defective segment of the hand using flap grafting (if necessary) (Fig. 1*a*), two consecutive techniques are performed: surgical training in the form of

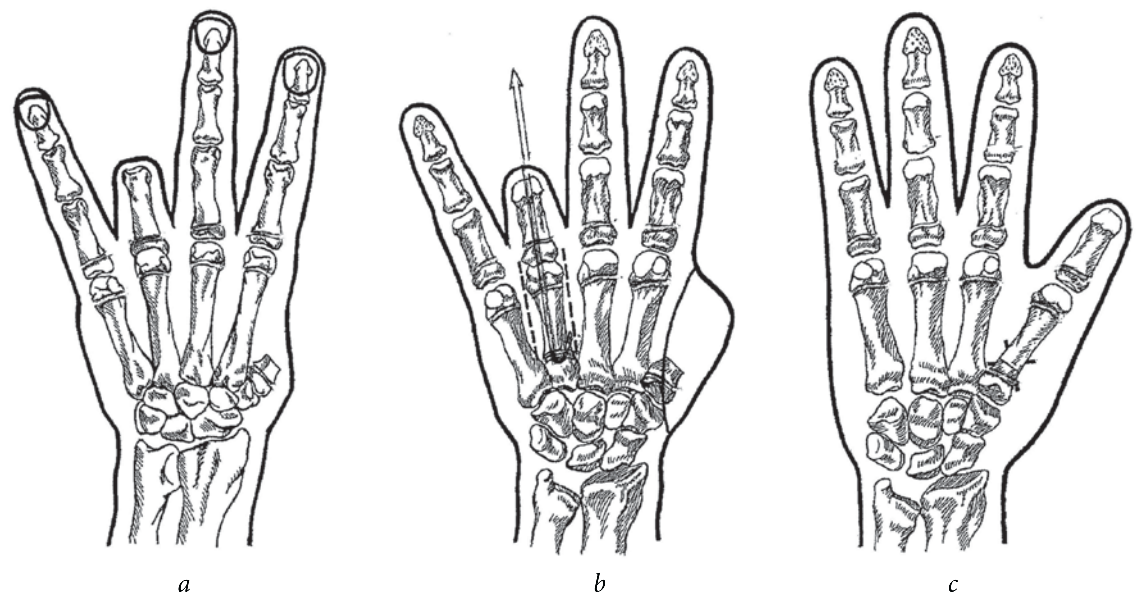

Fig. 1. Scheme of displacement of a hand segment. (*a*) Hand before the surgery. (*b*) Soft tissues in the thenar area are formed. Osteotomy of the segment displaced is performed. Intramedullary distraction pin is inserted. A scheme of the skin incisions for the formation of the skin-vascular pedicle and the direction of distraction are presented. (*c*) The phalanx-metacarpal segment is displaced to the position of the first finger

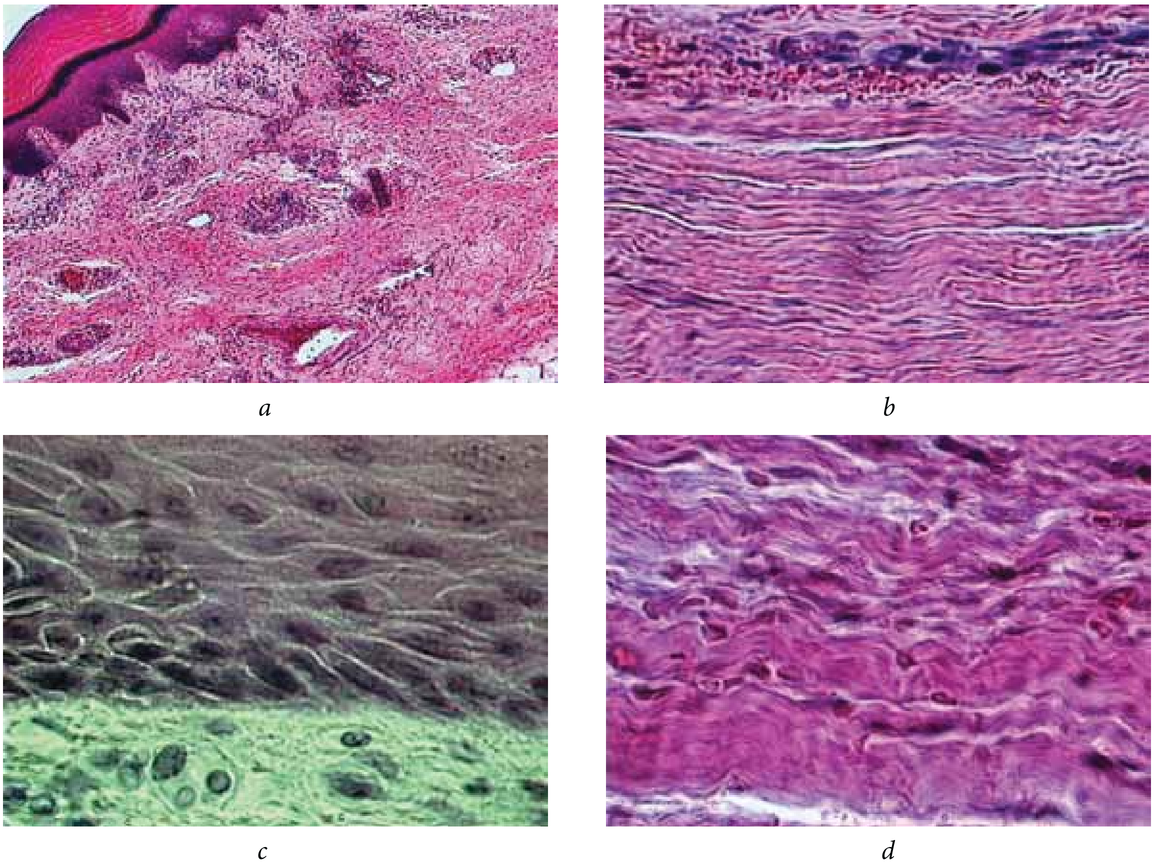

Fig. 2. Histomorphology of the tissues of the distracted skin–vascular pedicle. (*a*) Plurality of newly formed different caliber vessels in the surface layers of the distracted scar. Staining with hematoxylin and eosin, ×10. (*b*) Longitudinal orientation of low fibrous collagen fibers. Staining with hematoxylin and eosin, ×40. (*c*) Inclination of the basal cells of the scar epidermis. Staining with hematoxylin and eosin, ×100. (*d*) Cells of the fibroblastic series, conjugated with longitudinally oriented different caliber collagen fibers. Staining with hematoxylin and eosin, ×100

mobilization of the displaced hand segment on pedicles and subsequent distraction with the use of a transosseous device (Fig. 1*b*). In the second stage, the transosseous device is removed after 6–8 weeks, and repeated mobilization of the preformed segment of the hand is performed, as well as its displacement on one or two pedicles to the existing amputation defect of the finger or metacarpal bone (Fig. 1*c*). The Ilizarov apparatus or similar universal devices made of titanium were utilized for distraction. The transosseous osteosynthesis method proposed by Ilizarov was used for the assembly of the external fixation device (registered in the State Register of Medical Devices no. 81/823-53). The apparatus was individually assembled, depending on the nature of the deformity, but in all patients, the displaced hand segment was distracted with the use of an L-shaped pin, which was inserted intramedullary (see Fig. 1*b*). Distraction started 7–10 days after the transosseous device was applied. The rate of distraction was 0.5–1.0 mm once per day. The duration of distraction varied from 3 to 6 weeks, depending on the size of the required extension of the pedicles.

The developed universal technological approach provides not only the surgical ability to displace any pathologically altered segment of a hand irrespective of its size, location on the hand relative to the donor stump, and elimination of the deformities of the fingers but also the adequate prevention of ischemic complications due to optimization of neoangiogenesis, neocytogenesis, and neofibrilogenesis in both pedicles and displacing anatomical structures (Fig. 2*a*-*d*). All structural elements of the pre-existing and newly formed scars in distraction are ordered according to the vector of the mechanical stress field created by the transosseous device, which is a structural basis for deretraction of the scar tissue, removal of the contractures, and lengthening of the pedicles (Fig. 2*b*-*d*).

Furthermore, the elongation of pedicles ensures the displacement of any of the stumps of the three phalanx fingers, regardless of the ratio of the amputation levels of the donor and the receiving stumps. The segment was displaced on one or two pedicles depending on the state of blood circulation. The stump of the proximal phalanx of the second (3) and third (1) fingers, second (6) metacarpal bone at the head level, and distal third was displaced using the traditional technique. The developed approaches allowed transposition of the stumps of the second (3), third (3), fourth (3), and fifth (1) fingers mainly at the proximal levels of the proximal phalanx together with a fragment of the corresponding metacarpal bone. In addition, the distracted stump of the second (1), third (4), and fifth (1) metacarpal bones was transposed at the level of the head and middle third (Table 1).

Different techniques were used to form the pedicles according to the nature of the hand defect, state of the tissues, and blood supply to the segment. In most cases, the segments were transposed on permanent skin-vascular pedicles (Table 2). The pedicle included a strip of skin of 1.0–1.5 cm wide, including its severe scar changes.

Table 1

Levels of amputation of the transposed finger stumps and metacarpal bones, depending on the nature of the segment and the method of surgery

Nature of transposed segments	Levels of amputation of transposed stumps									Total
	Base of middle phalanx	Proximal phalanx head	Distal third of the proximal phalanx	Middle third of the main phalanx	Proximal third of the proximal phalanx	Base of proximal phalanx	Head of metacarpal bone	Distal third of metacarpal bone	Middle third of metacarpal bone	
Finger stump, typical		1		1	1	1				4
Stump of the metacarpal bone, typical							5	1		6
Stump of the finger after distraction	1	1	3			5				10
Stump of the metacarpal bone after distraction							5		1	6
Total	1	2	3	1	1	6	10	1	1	26

Table 2

Techniques for transposing a hand segment

Techniques of transposition and forming pedicles	Transposed segments						Total
	Intact finger (3)	Defective finger (3)	Finger stump, typical (4)	Stump of the metacarpal bone, typical (6)	Stump of the finger after distraction (10)	Stump of the metacarpal bone after distraction (6)	
According to Hilgenfeldt	1		3	4			8
According to V.V. Azolov	2	1					3
On two skin–vascular pedicles		1					1
On the palmar distraction skin-vascular pedicles					5	5	10
On the dorsal and palmar distraction skin-vascular pedicles					5		5
On an atypical dorsal-radial pedicle			1				1
On a tubed temporal pedicle		1					1
Without formation of pedicles by digitization				2			2
After distraction without formation of pedicle						1	1
Total	3	3	4	6	10	6	32

Displacement on two skin-vascular or fascio-cutaneous pedicles was performed with extensive scar changes of tissues and damage to the major vessels.

In the case of transposition of segments under conditions of scar changes of tissues, as well as the use of metacarpal bone and finger stumps with a fragment of the corresponding metacarpal bones, various methods of skin grafting were necessary because of the presence of pre-existing or newly formed tissue defects. Local skin grafting was applied in seven cases. Flap skin grafting, including in the case of microvascular anastomoses, was used in five cases because of the fact that tissue defects were formed or pre-existed on the radial and ulnar surfaces of the restored first finger, first interdigital space, and radial surface adjacent to the donor segment of the metacarpal bone. Free full flap and thick dermatomal skin grafts were applied in the presence of defects on the radial (3) and ulnar (5) surfaces of the formed first finger; ulnar surface of the first finger and radial surface of the adjacent metacarpal bone (3); radial and ulnar surfaces of the first finger (3); palmar and radial surfaces of the first finger (2); radial surface of the first finger and adjacent metacarpal bone (1); ulnar surface of the first finger and the first interdigital space (1); ulnar surface of the first finger, radial surface of the adjacent metacarpal bone, and first interdigital space (1); and radial surface adjacent to the restored first finger of the metacarpal bone and ulnar surface adjacent to the donor segment of the metacarpal bone (1). Free skin grafts alone and in combination with local grafts were used in a total of 20 cases. Osteosynthesis of bone fragments was introduced after treatment using cylindrical mills or crossed pins. The suture of the extensor tendon of the finger was overcast in the case of transposition of the finger and phalanx-metacarpal segments. The flexor tendons of the segment were always included in the pedicle, and in some cases, their shortening was required for the muscular stabilization of the formed finger. Distraction of the scar and poorly vascularized segment was performed after preliminary replacement of scars with adipodermal flap, surgical training of the segment, formation of two pedicles, and reduction of the value of a single distraction. A new motor stereotype of the formed finger was employed with the help of devices with electromyographic feedback in the early postoperative period. Clinical, radiographic, biophysical, biomechanical, morphological, and statistical methods were used in the work. All pediatric patients were examined and underwent surgery after their parents or official representatives signed a voluntary informed consent to participate in the study and undergo surgical treatment.

Results

The analysis of the short-term treatment results showed that wound healing by primary intention occurred in all patients; all the displaced segments were engrafted, as well as transplanted grafts and free skin grafts, including severe tissue scarring. These facts confirm the adequate blood supply to the segment. The long-term results of pollicization in pediatric patients are described only in the study for congenital pathology. For this reason, the long-term results on 25 hands were studied using the 1984 A.E. Belousov technique as improved by us. We evaluated not only the total volume of active movements in the finger joints and two-point discrimination on the restored finger but also the function of its abduction, adduction, and opposition. The absolute values of the parameters of the first finger function are expressed in points and included in the total integral recovery index of the hand function. The basic parameters of the hand gripping function were determined, as well as their significance in points in the total integrated index depending on the hand defect type (isolated absence of the first finger, absence of the first and several three phalanx fingers, and absence of all fingers) and nature (primary and secondary) of reconstruction. Excellent anatomical results were obtained in five cases, good results in eight, satisfactory results in nine, and poor results in three. Poor results were observed with the use of traditional techniques for transposition of the metacarpal bone stumps and are primarily due to the insufficient length of the formed finger. Functional results were distributed as follows: good results were noted in two, satisfactory results in 22, and poor results in one. The developed technique assesses the positive functional results as excellent only when restoring the full volume of motion in the joints and the possibility of opposing the first finger to all three phalanx fingers. Despite a significant number of unsatisfactory anatomical results, an insufficient functional result was obtained in only one case in a patient with the consequences of a severe burn of the hand. This suggests the development of adaptive reactions of the hand muscles after such interventions. Consolidation of displaced bone fragments and the absence of their resorption in all observations were achieved. The bone skeleton of the displaced waste segments proved to be resistant to the processes of resorption even under conditions of severe pathological changes in the tissues, indicating the sufficiency of its blood supply. The growth of the recovered finger up to 0.4–3.0 cm was noted in the case of segment displacement before the closure of the growth zones of the phalanx or metacarpal bone, depending on the child's age and period of follow-up. The use of an intramedullary distraction pin did not lead to premature closure of the growth zones of the segment transposed. Two-point discrimination in the reconstructed finger in the case of displacement of an intact or defective finger was 2 mm, that in the finger stump was 4.5 mm, and that in the metacarpal bone stump using a typical procedure was 6.5 mm. Under conditions of displacement of the finger stump on the distracted pedicles, the two-point discrimination of the formed finger was 4.4 ± 0.4 mm and that of the metacarpal bone stump was 7.4 ± 1.12 mm. The best outcomes were observed in displacement of intact fingers when the volume of active movements in displaced joints was 90°, corresponding to data in previous studies and that obtained in adults [14, 15]. The results of displacement of the stumps of the fingers and metacarpal bones were approximately identical when using both typical ($p = 0.708$) and distracted ($p = 0.79$) pedicles. The recovery rates of grip after displacement of these segments were compared using the chi-square test.

Clinical case. An 11-year-old female patient (case history no. 166690) presented to the clinic with stumps of the first and fifth fingers at the level of the proximal phalanges and scar flexion contractures of the second, third, and fourth fingers of the left hand (Fig. 3*a*, *b*). Regarding the case history, the patient grasped a high-voltage wire 5 years ago, resulting in an electrical injury and a third-to-fourth degree electrical burn of the left hand. Two-point discrimination on the stump of the fifth finger was 5 mm and that of the proximal phalanx of the healthy hand was 4 mm. Reconstruction of the first finger was performed due because of displacement of most of the waste segment of the hand, the stump of the fifth finger. A two-stage displacement of the stump of the fifth finger with a distal fragment of the homonymous metacarpal bone was performed because of its remoteness from the recipient area and the equability of the stumps of the first and fifth fingers. At the first stage, the osteotomy of the fifth metacarpal bone and mobilization of its distal fragment together with the stump of the homonymous finger on the pedicles were performed. Through the stump of the finger and the distal fragment of the metacarpal bone, an intramedullary axial distraction pin was inserted, which was fixed to the screw thrust of the Ilizarov apparatus mounted on the forearm (Fig. 3*c*). A gradual distraction of the segment of 1 mm per day was performed postoperatively. Bone fragment spreading by 3 cm was performed, after which the actual displacement of the stump of the fifth finger with the metacarpophalangeal joint to the stump of the first metacarpal bone was performed on the distracted palmar cutaneous-vascular pedicle after 41 days (Fig. 3*d*, *e*), providing adequate blood supply to the segment. The postoperative period proceeded without complications. The transposed stump fully engrafted, and the wounds healed with primary intention. The free skin graft transplanted to the radial surface of the displaced segment engrafted by 100%. The length of the first finger together with the metacarpal bone was 7 cm, and it was 8 cm 3 years postoperatively. The adduction and opposition of the first finger to all the other fingers was achieved (Fig. 3*f-h*). Movements in the displaced metacarpophalangeal joint were feasible in a volume of 30°. The two-point discrimination on the transposed stump is 5 mm. The proximal and distal growth zones of the restored first finger are clearly traced on the radiograph (Fig. 3*i*).

Discussion

The stochastic character mapping of sustaining damages, their variability, and specificity determine the extreme polymorphism of variants for the formation of post-traumatic deformities, exceptional complexity of their systematization, and fundamental differences in the pathogenesis of the development of congenital and acquired deformities of the hand [17-19]. The pathogenesis of deformities is determined by the etiological features of destruction

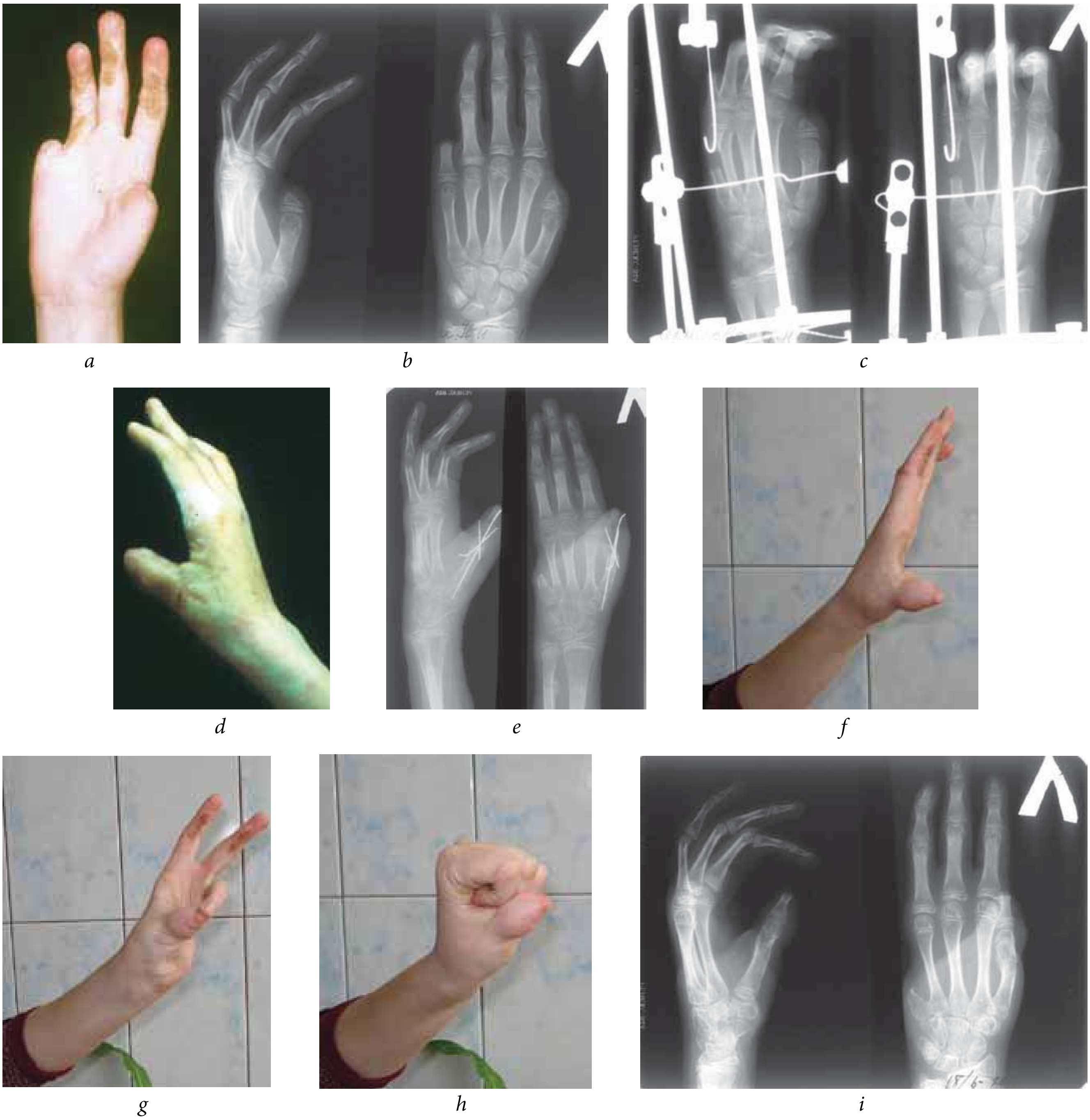

Fig. 3. An 11-year-old female patient with an after-burn deformity of the hand. (*a*) The appearance of the hand preoperatively. (*b*) Radiograph taken preoperatively. (*c*) Radiograph taken after the first stage of surgery. Osteotomy of the fifth metacarpal bone is implemented through its distal fragment, and in the stump of the fifth finger, a distracting bulb-tipped pin in the form of a hook is inserted intramedullary. The second end of the pin is fixed using the Ilizarov apparatus. Partial spreading of the bone fragments is done. (*d*) The appearance of the hand after transposition of the segment to the stump of the first finger. (*e*) Radiograph after reconstruction of the first finger. (*f*) The result of treatment 3 years after the reconstruction, abduction of the first finger. (*g*) The result of treatment 3 years after the reconstruction, the opposition of the first finger to the fourth. (*h*) The result of treatment 3 years after the reconstruction, fist grip. (*i*) Radiograph taken 1 year after the reconstruction

and reparative regeneration of different tissues. The main components of post-traumatic deformities of the hand most often are the absence of the fingers, a non-systemic combination of finger stumps with the remaining scar contractures, and the presence of soft tissue defects and their scar changes of different severity. Pathology is aggravated by damage to the blood vessels and nerves in a number of cases. In this case, the transposed segment can have different lengths, taking all possible positions on the hand relative to the stump of the restored finger. In the case of congenital pathology, surgery is usually performed in a standard situation in the absence of the first finger with the corresponding metacarpal bone and the presence of an incomplete second finger. In the structure of post-traumatic hand defects, such a combination is rare, making it necessary to study the possibility of using the method for other defects to move different segments and not just the second finger, which is often the segment of choice [12]. In the pathogenesis of acquired deformities of the hand, the leading role is played by changes in tissues caused by the development of scar transformations and their consequences, presence of defects of various structures, and primary or secondary disorders of macro- and microcirculation [18, 19]. The incidence of ischemic complications after such interventions reaches 10%-15% [16] and significantly increases with the displacement of scar segments. For this reason, new pathogenetically feasible approaches should be developed to improve the relocatability of scar segments, the elimination of soft tissue defects, and the prevention of abduction and circulatory disorders of scar and ischemic tissues in the case of acquired deformities [18].

The main element of the transposition technique of the segment is the formation of its pedicle, which provides sufficient blood supply to donor tissues. Currently, most specialists displace the segment on the vascular nerve pedicle with both congenital and acquired pathology of the hand [12, 13]. In only a few cases, the Hilgenfeldt–Shushkov method is used, which involves the formation of a skin-vascular pedicle [3, 5, 8]. To improve the reliability of the technique, a method for transposition of the longitudinal and transverse segments of the metacarpal bone on two (dorsal and palmar) neurovascular bundles was developed [4]. However, with damage to the neurovascular bundles and marked scar changes in the palmar surface tissues of the hand, these techniques cannot be used in principle because they do not provide adequate blood supply to the segment and are accompanied by a high risk of iatrogenic vascular damage. Under such conditions, it is advisable to displace the segment on one or two (palmar and dorsal) scar skin-vascular pedicles formed as one block, without isolating vessels, significantly reducing the risk of damage and the development of ischemic complications. In the presence of preserved dorsal subcutaneous veins of the segment, they should be preserved or restored using precision techniques [20].

In such cases when the finger arteries of the segment displaced are damaged, their microsurgical restoration can be performed in the absence of gross scar changes in the tissues and obligatorily during the primary transposition. Research studies and our experience show that the possibilities of transposition of the stumps of the metacarpal bones and fingers at the proximal levels are limited by the length of the pedicle. The preliminary distraction of the remote and/or short segment, as well as the formed skin-vascular and fasciocutaneous palmar and dorsal pedicles (in the case of damage to the digital arteries), provides their elongation and increase in the distance of segment transposition. Furthermore, the mechanisms of deretraction of scars also start to operate. The approaches we developed provide adequate prevention of ischemic complications due to neoangiogenesis, axialization of blood flow in the distracted tissues of the pedicle, and development of mechanisms for compensating vascular insufficiency and metabolic disorders in scar tissues as a result of surgical training. In addition, distraction enables the use of an additional dorsal pedicle of the segment, regardless of its location and the state of the preserved fingers, which ensures adequate blood circulation of the segment even under ischemic conditions caused by extensive and total scar tissue changes and vascular damage.

These surgical techniques provide 100% engraftment of the segment even under such extremely unfavorable conditions. Our results showed, with the implementation of the developed method, that the stumps of any of the three phalanx fingers can be displaced at the level of the proximal half of the proximal phalanx, including the corresponding metacarpal bones, metacarpal bone head, and its middle and proximal third. Anatomical and morphological features of post-traumatic deformities of the hand also require the performance of combined or flap skin grafting, which is more frequent than congenital pathology, including on the formed finger. This is in part due to the presence of pre-existing defects and scar changes in the hand tissues, adduction contracture of the first metacarpal bone, and expansion of applicability of distracted segments of the metacarpal bones, including the metacarpophalangeal joint, which inevitably cause skin defects on the lateral surfaces after the displacement. In addition, the inclusion of strips of the scar skin in the pedicle and the use of two such pedicles lead to the need for skin grafting when displacement of the other segments, especially in the case of scar tissue, is regenerated. The results of application of different variants of skin grafting were positive in all cases, although some were accompanied by prolongation of treatment. The use of rational variants of skin grafting significantly increased the ability to displace the waste segments of the injured hand, forming adequate soft tissues of the finger and providing revascularization of its bone skeleton.

The main objection to the surgeries of pollicization on the injured hand is the absence of a formal increase in the number of the fingers on it and unwillingness of the specialists to sacrifice one of the fingers to restore another, including the risk of irreversible ischemic complications. The study of the effectiveness of restoration of the hand grip and its donor defect with the use of clinical, radiographic, and biomechanical methods revealed the advantages and disadvantages of transposition of each of the hand segments. The variety of hand deformities determines the necessity of distribution of donor segments according to their priority use. Displacement of any of the segments ensured restoration of the hand grip. The donor defect was inversely proportional to the degree of the defect of the segment.

In addition, the donor defect after the displacement of the segment in some cases was leveled because of the elimination of deformities and the improvement of the function of the preserved fingers. The efficiency of the displacement of the metacarpal stump was better than the outcome of the displacement of the other segments taking into account the ratio of the functional result/donor defect. For this reason, with the ratio of the functional result/donor defect, the donor segments should be ranked according to the principle of priority use and maximum usability, such as the metacarpal stump, finger stump, defective finger, and intact finger. The study revealed that the ratio of effectiveness/donor defect correlates with the serial number of the segment in this series. Each successive segment in this ranked series can only be transposed if there is no previous one on the hand, which enables to preserve the fingers and their stumps of sufficient length (at distal levels), thereby minimizing the donor defect and improving the appearance of the hand. The use of this ranked series facilitates the choice of the donor segment and the variant of finger reconstruction. The donor segment and the technique of its displacement should be considered taking into account the type of defect, the levels of amputation of the donor and perceiving stumps, the degree of deformity of the three phalanx fingers, and the scar changes in the soft tissues of the hand. The displacement of the intact finger (second, third, fourth, or fifth) is indicated only when the first finger is isolated. The defective finger should be transposed regardless of its location in the absence of the first one and not more than one of the three phalanx fingers or their stumps at the distal levels. In the case of fewer preserved fingers, surgery is not indicated, as this leads to a sharp deterioration in the appearance of the hand, although it enables to restore grip. The transposition of the defective finger should be individually approached in each case, taking into account the prospects of restoring the function in the joints while in their position. If there are no such prospects, then it is better to transpose this segment to the position of the first finger, and its mobility will be implemented by the first carpometacarpal and preserved metacarpophalangeal joint of the stump of the restored finger. The functionality of this segment will also depend on the residual mobility in its joints. Indications for the displacement of such a segment are absolute, including in the presence of a metacarpal stump if it disrupts the function of adjacent fingers and stumps because of an irreversible defect position in the metacarpophalangeal joint. The stump of the finger or metacarpal bone is displaced in both the absence of all the fingers and when one or more three phalanges (intact or defective) are retained. The defective finger should be transposed in the presence of a defective finger and intact fingers. If there are several defective fingers, the most defective finger should be displaced if there is no stump of the finger or metacarpal bone. In cases wherein there are several stumps of the fingers and metacarpal bones, the shortest finger should be displaced if its length is not less than 2 cm.

Absolute indication for the displacement of an intact finger can only be in the absence of the first finger along with the metacarpal bone because in this case, it is possible to restore the first finger that has mobility in the interphalangeal, metacarpophalangeal, and carpometacarpal joints. An objection to the displacement of such a segment at other levels of amputation is the inevitable loss of its full metacarpophalangeal joint. In the case of displacement of a defective, limited-functioning finger, the loss of the metacarpophalangeal joint is not so significant, especially in the presence of its pathology. For this reason, we consider it expedient to transpose such a segment when the first finger is amputated at different levels of the proximal third of the proximal phalanx, metacarpal bone, and its complete absence. In the latter case, the radial anti-abutment branch is formed with the remaining three phalanx fingers, which also ensures the restoration of the gripping function. The stump of the finger or metacarpal bone is transposed at similar levels of amputation of the recovered finger. In transposition of a short stump of the metacarpal bone, the missing length of the formed finger is restored using the interposed nonvascular bone graft that is located between the displaced and the recipient stumps. Inclusion of the metacarpophalangeal joint in the complex of tissues or displacement of the metacarpal segment to the preserved fragment of the proximal phalanx or metacarpal bone allows the formation of the first and/or three phalanx finger that have mobility in the interphalangeal, metacarpophalangeal, and/or carpometacarpal joints.

Using the developed methods of finger reconstruction and rational variants of skin grafting expands the spectrum of segments suitable for transposition by including the stumps of any of the three phalanx fingers and metacarpal bones, fingers with different kinds, degree of deformities and scar changes, and circulatory disorders. In many cases, these segments are waste, and they are often amputated to improve the function and appearance of the hand. Original methods allow the maximum implementation of the principles of conservative surgery and use these segments while preserving their innervation and blood supply with a minimal donor defect. The application of the developed paradigm of selecting the donor segment of hand provides restoration of the hand grip with a minimal donor defect.

Conclusion

Reconstruction of the fingers of an injured hand by transposition of its segments in pediatric patients provides acceptable functional results. The developed methods are pathogenetically substantiated. They enable safe displacement of the waste segments, irrespective of their location on the hand and the degree of scar changes with guaranteed prevention of ischemic complications, with minimal damage to the donor area, and can be used in a variety of post-traumatic deformities of the hand and scar changes in its tissues, including in of the case of burns. The use of new approaches expands the boundaries of the applicability of the method and the indications for its implementation.

Information about the contribution of each author

N.M. Aleksandrov – concept and study design, data collection and processing of materials, data analysis, writing the text.

S.V. Petrov – concept and design of the study.

O.I. Uglev – collection and processing of materials.

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References

1. Buck-Gramcko D. Pollicisation de l'index en cas d'aplasie et d'hypoplasie du pouce. Methodes et results. *J Rev Chir*. 1971;57(1):35-48.
2. Soildado F, Zlotolow DA, Kozin SH. Thumb hypoplasia. *J Hand Surg Am*. 2013;38(7):1435-1444. doi: 10.1016/j.jhsa.2013.03.021.
3. Шведовченко И.В., Каспаров Б.С., Кольцов А.А. Операция поллицизации как вариант восстановления двухстороннего схвата у пациентов с приобретенной патологией 1-го луча кисти // Вестник Российской военно-медицинской академии. – 2014. – Т. 46. – № 2. – С. 77–80. [Shvedovchenko IV, Kasparov BS, Kol'cov AA. Operacija pollicizacii kak variant vosstanovlenija dvuhstoronnego shvata u pacientov s priobretennoj patologiej 1-go lucha kisti. *Vestnik Rossijskoj voenno-medicinskoj akademii.* 2014;46(2):77-80. (In Russ.)]
4. Корюков А.А. Реабилитация детей с дефектами пальцев кисти. – СПб.: Гиппократ, 2010. [Korjukov AA. Reabilitacija detej s defektami pal'cev kisti. Saint Petersburg: Gippokrat; 2010. (In Russ.)]
5. Шведовченко И.В., Каспаров Б.С., Кольцов А.А. Операция поллицизации как метод восстановле-

ния двухстороннего схвата кисти при врожденной и приобретенной патологии верхней конечности // Гений ортопедии. – 2014. – № 2. – С. 11–16. [Shvedovchenko IV, Kasparov BS, Kol'cov AA. Operacija pollicizacii kak metod vosstanovlenija dvuhstoronnego shvata kisti pri vrozhdennoj i priobretennoj patologii verhnej konechnosti. *Genij Ortopedii.* 2014;(2):11-16. (In Russ.)]

6. Агранович О.Е. Ортопедическое лечение последствий контактных электроожогов верхних конечностей у детей: Дис. … канд. мед. наук. – СПб., 2000. [Agranovich OE. Ortopedicheskoe lechenie posledstvij kontaktnyh jelektroozhogov verhnih konechnostej u detej [dissertation]. Saint Petersburg; 2000. (In Russ.)]
7. Kozin SH. Pollicization the concept technical details and outcome. *Ciin Orthop Surg.* 2012;4(1):18-35. doi: 10.4055/cios.2012.4.1.18.
8. Hilgenfeldt O. Operativer Daumenersatz und Beseitigung von Greifstörungen bei Fingerverlusten. Stuttgart: Ferdinand Enke Verlag; 1950.
9. Ishida O, Taniguchi Y, Sunagawa T, et al. Pollicization of the index finger for traumatic thumb amputation. *Plast Reconstr Surg.* 2006;117(3):909-914. doi: 10.1097/01.prs.0000200627.74575.15.
10. Weinzweig N, Chen L, Chen ZW. Pollicization of the mutilated hand by transposition of middle and ring finger remnants. *Ann Plast Surg.* 1995;34(5):523-529. doi: 10.1097/00000637-199505000-00012.
11. Ionescu G, Popovici A, Cohn H, Ciornei G. La reconstruction du pouce ampute par la pollicisation des doigts restants chez les enfants. *Acta Orthop Belg.* 1975;41(1):38-44.
12. Buck-Gramcko D. Thumb reconstruction by digital transposition. *Orthop Clin North Am.* 1977;8(2):329-342.
13. Finseth F, Krizek TJ. Pollicization. *Yale J Biol Med.* 1977;50(2):199-206.
14. Schoofs M, Leps P. The value of pollicization in the reconstruction of thumb injuries in adults. Observations apropos of 15 cases. *Ann Chir Main.* 1992;11(1):19-26.
15. Dijkstra R, Ros KE. Functional results of thumb reconstruction. *J Hand.* 1982;14(2):120-128. doi: 10.1016/s0072-968x(82)80002-8.
16. Goldfarb CA, Monroe E, Steffen J, et al. Incidence and treatment of complications suboptimal outcomes and functional deficiencies after pollicization. *J Hand Surg Am.* 2009;34(7):1291-1297. doi: 10.1016/j.jhsa.2009.04.001.
17. Тяжелков А.П. Реконструктивно-восстановительное лечение сложных пороков развития кисти у детей: Автореф. дис. … д-ра мед. наук. – Иркутск, 1993. [Tjazhelkov AP. Rekonstruktivno-vosstanovitel'noe lechenie slozhnyh porokov razvitija kisti u detej [dissertation]. Irkutsk; 1993. (In Russ.)]
18. Петров С.В., Вазина И.Р. Клинико-морфологический анализ послеожоговых рубцов и возможности их использования при реконструктивных операциях // Международный конгресс «Комбустиология на рубеже веков». – М., 2000. – С. 206–207. [Petrov SV, Vazina IR. Kliniko-morfologicheskij analiz posleozhogovyh rubcov i vozmozhnosti ih ispol'zovanija pri rekonstruktivnyh operacijah. In: Mezhdunarodnyj kongress "Kombustiologija na rubezhe vekov". Moscow, 2000. P. 206-207. (In Russ.)]
19. Филиппова О.В., Красногорский И.В. Структурные изменения в рубцовой ткани у детей на различных этапах созревания рубца и на фоне коллагенолитической терапии // Клиническая дерматология и венерология. – 2013. – № 1. – С. 22–29. [Fillipova OV, Krasnogorskij IV. Strukturnye izmenenija v rubcovoj tkani u detej na razlichnyh jetapah sozrevanija rubca i na fone kollagenoliticheskoj terapii. *Klinicheskaja dermatologija i venerologija.* 2013;(1):22-29. (In Russ.).
20. Операция поллицизации у детей с врожденной и приобретенной патологией кисти: метод. рекомендации / сост. И.В. Шведовченко, Е.М. Беляев. – СПб., 2000. [Shwedovchenko IV, Beliaev EM, sost. Operatsiia pollitsizatii u detei s vrohdennoi i priobretennoi patologiei kisti: metod. rekomendatsii. Saint Petersburg; 2000. (In Russ.)]

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