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COMPLICATIONS AFTER TOE-TO-HAND TRANSFERS IN CHILDREN WITH PATHOLOGIES OF THE HAND

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Background. Complications after microsurgical toe-to-hand transfer is a problem for which there is no common approach to treatment.
The aim of this study was to analyze the ischemic complications after microsurgical operations in children with pathologies of the hand to improve the quality of surgical treatment.
Materials and methods. From 2007 to 2016, we performed 210 microsurgical toe-to-hand transfers involving 306 transplants, 267 (87.3%) of which were performed in patients with congenital pathologies and 39 (12.7%) in patients with post-traumatic deformities of the hand. In total, 352 fingers were reconstructed.
Results. Blood supply disturbance following toe transplants occurred in 19 (6.2%) of the 306 transplants, most often in the early postoperative period (73.7%). The main cause of microcirculatory disorders was thrombosis of the venous or arterial trunks (8 cases). In 6 patients, the blood supply disturbance occurred because of thrombosis of autovenous grafts. Two patients underwent necrectomy at days 7 and 18 because conservative and operative treatments were not successful.
Conclusion. The treatment method of choice after the first appearance of signs of blood supply disturbance in a transferred toe is conservative therapy, which includes disaggregants, anticoagulants, and hirudotherapy. Conservative therapy should be performed within 3 hours from the beginning of ischemia; if ischemia is absent, the patient must undergo surgery. The operation includes soft tissue decompression, mechanical pumping across vascular anastomoses, and if necessary, excision of the abnormal vessel part with subsequent autoplasty.

Keywords: microsurgery; toe-to-hand transfer; complications.

ОСЛОЖНЕНИЯ ПРИ ИСПОЛЬЗОВАНИИ МИКРОХИРУРГИЧЕСКОЙ АУТОТРАНСПЛАНТАЦИИ ПАЛЬЦЕВ СТОПЫ У ДЕТЕЙ С ПАТОЛОГИЕЙ КИСТИ

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Актуальность. В настоящее время отсутствует единая тактика при возникновении сосудистых нарушений при микрохирургических аутотрансплантациях пальцев стопы в позицию пальцев кисти, что является актуальной проблемой.
Цель исследования — изучить и проанализировать ишемические осложнения при микрохирургических операциях у детей с патологией кисти для улучшения качества хирургического лечения с использованием данного метода.
Материалы и методы. За период с 2007 по 2016 г. в ФГБУ «НИДОИ им. Г.И. Турнера» Минздрава России выполнено 210 микрохирургических аутотрансплантаций пальцев стопы в позицию пальцев кисти. Перемещено 306 аутотрансплантатов. Из них 267 (87,3 %) при врожденной патологии кисти у детей и 39 (12,7 %) при приобретенных деформациях верхних конечностей. Всего проведена реконструкция 352 пальцев.
Результаты. По данным проведенного нами исследования, сосудистые осложнения в перемещенных аутотрансплантатах отмечены в 19 (6,2 %) случаях из 306. Большинство из них приходится на ранний послеоперационный период (73,7 %). Основной причиной нарушения кровообращения являлся тромбоз венозных или артериальных стволов (8 случаев). У 6 пациентов сосудистые нарушения возникли в результате тромбоза аутовенозных вставок. Компрессию сосудов из-за отека окружающих тканей или образовавшейся гематомы мы на-

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блюдали в трех клинических случаях. У двоих пациентов повторное вмешательство не выполнялось и попытки консервативного лечения нарушения кровообращения закончились некрэктомией на 7-е и 18-е сутки.
Выводы. Методом выбора при появлении первых признаков недостаточности микроциркуляции в аутотрансплантате является консервативная терапия, которая включает дезагреганты, антикоагулянты и гирудотерапию. В случае отсутствия эффекта от консервативной терапии повторное оперативное вмешательство необходимо проводить в течение 3 часов от момента начала ишемии.
В ходе оперативного вмешательства следует выполнить декомпрессию мягких тканей, механическое покачивание сосудистых анастомозов и при необходимости иссечение нефункциональных участков с последующей аутопластикой.

Ключевые слова: микрохирургия; аутотрансплантация пальцев стопы на кисть; осложнения.

Introduction

Microsurgical autografting of the toes to the fingers has been widely used for the reconstruction of hands with congenital defects and acquired deformities. Due to good functional and aesthetic results, microsurgical reconstruction of the hand in many challenging situations has been superior to traditional methods for orthopedic correction. Microsurgical autografting has been used for the treatment of children at the Turner Scientific and Research Institute for Children's Orthopedics since 1986. Microsurgical intervention requires maximum concentration, mastery of surgical and precision technology, excellent knowledge of topographic anatomy, and physical endurance, because the surgery often requires many hours for completion. According to international literature, the success rate of such surgeries in pediatric patients is 94%–96% [1–12]. Undoubtedly, the implementation of such complex and highly technological interventions, where the failure of the entire procedure may depend on one inaccurately placed suture, is impossible without complications. The main problem in the postoperative period is thrombosis of the venous or arterial trunks.

Studies have revealed that thrombus formation accompanies most angiorrhaphy procedures [6, 13]. Immediately after the removal of the clip on the transected and reanastomosed iliac artery of a rat, Acland et al. observed a microembolic flow moving away from the anastomosis zone to the distal bed on video microscopy with 100× amplification. The flow decreased in 10–20 min. The emboli settled on the bifurcations of the arterioles and capillaries and broke on them or drifted unchanged deep into the capillary bed. Sometimes, a large embolus closed the lumen, but after a few seconds, softening occurred, and it drifted away from the lumen. Fragments of the embolus elongated when they reached smaller vessels (diameter, 80–15 microns). After migrating into capillaries, the embolus occupied the entire lumen for 15–30 s and then drifted away, while decreasing in size. With a decrease in the flow rate, emboli accumulated in the zones of bifurcations with cessation of the distal blood flow for 1 h or longer. If the direct and collateral paths of microcirculation were blocked, ischemia of the entire zone occurred. Inoue also observed the formation of parietal thrombi on a reanastomosed rat artery in 50% of the cases 3–15 min after suturing. Thrombus formation was maximum after 7 min and dissipated after 30 min.

Studies have revealed that there is a quantitative limit of blood flow; the blood flow remains stable above this limit, but continues to decrease inevitably until stopping when below the limit [1–5]. This lower limit is the threshold below which the blood flow ceases to cope with the increased peripheral resistance due to partial embolization. Thus, according to impedance rheoplethysmography, this threshold is 7 mL/min/100 g soft tissue of the graft. The observations of Zdeblick [14] also demonstrated the development of an outflow block when the blood flow in the reimplanted paw of the rat was reduced by 40%. Thus, the following conclusions can be drawn:

1) Thrombus formation accompanies any application of anastomoses;
2) More massive embolization is observed with increasing number of anastomoses in the arterial pedicle of the graft;
3) There is a minimum threshold for the blood flow velocity below which the microcirculation block becomes irreversible. Decreased channel capacity and increased hemocoagulation may contribute to this condition;
4) Autovein, in addition to superfluous anastomosis, also indicates a decrease in the propulsive

pressure peak at the height of the systole. Any prosthesis extinguishes the pulse wave [5–8], especially with such a soft wall as that of a vein. This may also cause complications due to the added complexity of the microvascular stage [4].

According to research data, in addition to the state of the peripheral channel and local hemodynamics, the viscosity factor of blood is important. Transplantation ischemia is accompanied by extreme vasodilatation; therefore, the blood flow then entirely depends on the viscosity of the blood. Direct electromagnetic flowmetry on the axial vessels of the flaps [7, 8] showed an increase in the blood flow volume by 25%, with defibrillation. According to Dormandy [11], when the blood flow velocity decreases, the viscosity of the blood increases due to increased cellular aggregation [6].

An equally important function occurs due to metabolic changes in the graft during ischemia. It was found that tissues that underwent transplantation ischemia required enhanced perfusion to overcome metabolic and structural disorders [1, 4–6]. Kerrigan et al. [15, 16] found that the critical time for the occurrence of autograft ischemia was the time after the survival of 50% of grafts in the experiment, which was 13.1 h. In the next series of experiments, where the time of primary ischemia was the same (2 h; much less than the critical time), the duration of secondary ischemia of autografts with a blood supply for 12 h was induced. Its average critical time was almost half (7.2 h). They explained this difference by the fact that hypoxic tissue damage requires a certain time to eliminate metabolic shifts.

Banke mobilized the toes under a tourniquet, with one of the lowest proportions of failure (2.9%). In this center, before the transection of the arteries on the foot, the tourniquet is removed, restoring healthy blood flow. Next, the toe is removed completely. Thus, additional reperfusion of the graft is introduced. Mobilization with tourniquet ischemia is used in the clinical practice in all US microsurgical centers [1–3, 17, 18].

Based on the literature, we can conclude that the mechanism underlying the development of postoperative ischemia in grafts is complicated and exacerbated by the absence of unified approaches in treatment.

Aim. The study goals were to investigate and analyze ischemic complications in microsurgical interventions in pediatric patients with pathology of the hand to improve the quality of surgical treatment.

Materials and methods

From 2007 to 2016, 210 microsurgical autografts of the toes to fingers were performed at the Turner Scientific and Research Institute for Children's Orthopedics. A total of 306 autograft procedures were performed: 267 (87.3%) for congenital pathology of the hand and 39 (12.7%) for acquired deformities of the upper limbs. In total, 352 fingers were reconstructed. To reconstruct the fingers, the second toes of both the feet were used during one surgical intervention in 95 patients, second toe of one foot in 69, block of the second and third toes in 45 pediatric patients, and block of the second and third toes of one foot and second toe from the other foot in one.

Signed informed consent to participate in the study was obtained from all patients.

Results and discussion

All complications associated with microsurgical autografting of toes to the hand were characterized as immediate, early, and late [4–6].

Immediate complications arose during and 2 h after surgical intervention. Factors that contributed to the development of these complications included error in the surgical technique of vessel isolation during graft formation. Predictive factors for immediate complications included complex anatomical interrelations in the donor area, excessive exsanguination of the limb, misidentification of the vessels, atypical location of the vascular trunks, and young patient age.

Another predictive factor for immediate complications included severe vascular spasm causing microcirculation disorder in the autograft. Angiospasm may result from rough handling of vessels during isolation and coagulation of the vascular branches in the immediate vicinity of the main trunk.

A third predictive factor for immediate complications was the underestimation of magistral blood flow in the recipient area when displaced tissue complexes were larger than the size of the affected hand.

In general, early complications developed in the first 3 days after surgical intervention, most commonly at the end of day 2 or 3. The main cause was compression in the zone of vascular anastomoses due to edema of soft tissues caused by the large volume and trauma of the intervention. Hematoma caused by carelessly performed hemostasis may also cause compression.

Late complications included those that developed from postsurgical days 4–12. The causes included infectious processes leading to suppuration of the operated wound, vascular arrosion, and accidental injury to the hand in the postoperative period.

The management of complications in microsurgical autografting of the toes involves both preventive measures and repeat surgical interventions.

To avoid errors during surgical isolation of the vessels of the graft, the surgeon's focus and sound physical and psychological condition, exclusion of distractions, and operating room comfort are necessary. Exsanguination of the limbs should be moderate for good visualization of blood vessels. To prevent angiospasms, we performed blockade of peripheral nerves on the upper and lower limbs immediately before the surgery [3, 16]. Prolonged injection of anesthetics into the perineural catheter reduced the risk of angiospasm in the postoperative period. Isolation of arteries and veins was performed with utmost care and a small reserve of paravasal tissues to minimize the effect of angiospasm on the vessel adventitia. After graft mobilization and tourniquet ischemia, physical exertion on the vascular wall was achieved by wrapping the foot in napkins soaked in warm physiological saline.

After removal of the tourniquet from the lower extremity, transection of the vascular pedicle was performed 20–30 min after restoring the blood flow to the graft to reverse metabolic changes that may have occurred in the ischemic donor area.

We also attempted to use the feeding vessels of adequate or larger diameter than those of the recipient. With insufficient size of the arteries and veins at the hand and wrist joint, anastomosing was performed more proximally. The number of vascular anastomoses was reduced to a minimum. Autovenous grafting was used only in extreme cases.

To prevent thrombosis and increase blood viscosity during the surgical intervention, antiaggregants and anticoagulants were administered, and infusion therapy was performed. In the postoperative period, medication therapy was adjusted depending on clinical requirements and laboratory parameters as indicated by blood coagulation and thromboelastography analysis.

All microcirculatory disorders related to blood circulation in an autograft can be divided into three main types [5, 8]:

1. Venous: violation of venous outflow; the finger acquires a cyanotic hue.
2. Arterial: violation of blood inflow; the finger becomes pale.
3. Mixed: violation of venous outflow in combination with arterial insufficiency; the finger acquires a marble effect with alternating pale and cyanotic areas.

With the development of circulatory disorders in the graft in the postoperative period, additional approaches were determined by the type of disorder and postoperative duration.

If vascular graft complications were classified as immediate and number of postoperative days was <4, conservative treatment to eliminate venous stasis was initiated, including increasing the dosages of anticoagulants and antiaggregants. Local therapy included the use of hormonal ointments to reduce edema of the hand as well as medicinal leeches (*Hirudo medicinalis*), which were placed on the affected finger (Figures 1 and 2).

Within a specified time after hirudotherapy was initiated, the cyanotic quality of the skin deteriorated, sometimes until a pink shade and good capillary response were restored (Figures 3 and 4).

As an untimely diagnosis of this complication, the venous outflow disorder quickly ceased to be typical as an arterial inflow disorder developed. The finger that originally had a cyanotic hue became spotted, and purplish-violet areas alternated with the marbling.

In cases of expectant management, the cessation of the arterial blood supply with pronounced blanching of the finger and a sharp decrease in its temperature occurred within 1–2 h after development of the complication (Figures 5 and 6).

In this situation, repeat surgical intervention in the form of emergency revision of vascular anastomoses was the most expedient. During the intervention, the area of arterial and venous anastomoses was visualized. The vessels were decompressed, and the hematomas were removed. In addition, mechanical

Fig. 1. Microcirculation disorder of the venous type (hirudotherapy)

Fig. 2. Restoration of normal color and vascular response

Fig. 3. Microcirculation disorder of the arterial type

Fig. 4. Restoration of blood circulation in the graft after a series of conservative measures

Fig. 5. Microcirculation disorder of the mixed type

Fig. 6. Absence of vascular response after initiation of conservative treatment measures

pumping of the anastomoses was performed. In the absence of signs of restoration of circulation, several stitches were removed from the venous anastomosis, and local thrombolysis was performed with Actilyse solution. If the cause of the lack of blood flow was the presence of an anastomosis of the venous valve in the immediate vicinity, it was excised and repeat anastomosis was performed or a venous insert was used. The permeability of the artery was then restored. The blood flow was controlled by the appearance of venous blood. The veins were repeatedly sutured upon obtaining adequate perfusion of the graft.

If the artery was permeable to the site of entry into the graft but microcirculation was not observed, the Actilyse solution was also injected into the arterial bed of the displaced toe until sufficient perfusion was achieved. When obtaining stable blood flow in the graft, vessel reanastomosis was performed, and the stability of blood flow was evaluated for several minutes. Once stable perfusion in the autograft was achieved, surgical wounds were sutured. To reduce the tension on soft tissues, various types of skin grafting were used, both local and combined.

In our study, vascular complications in displaced autografts developed in 19 (6.2%) of 306 cases. In five cases, it was possible to eliminate circulatory disorders in the transplanted fingers with repeat surgical intervention. However, in 14 (4.6%) cases, attempts to restore blood circulation were unsuccessful (Figure 7).

On analyzing the complications that occurred over 10 years, we found that most (73.7%) were in the early postoperative period (Fig. 8). The primary cause of circulatory disorders was thrombosis of the venous or arterial trunks (8 cases). In six patients, vascular disorders occurred as a result of thrombosis of autovenous insertions. Compression of blood vessels due to edema of the surrounding tissues or hematoma was noted in three clinical observations. In two patients, repeat intervention was not performed, and conservative treatment of circulatory disorders resulted in necrectomy on days 7 and 18, respectively. These data are presented in Table 1.

Conclusions

1. To achieve successful results in the treatment of pediatric patients after microsurgical interventions with the use of toe autografts, prevention of both intra- and postoperative complications is necessary.

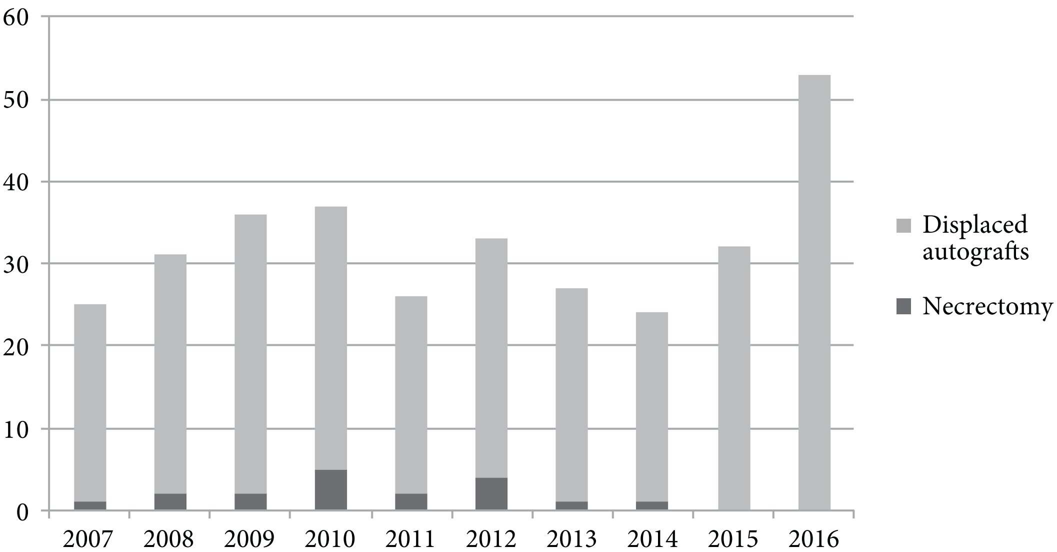

Fig. 7. Number of displaced autografts and necrectomy procedures

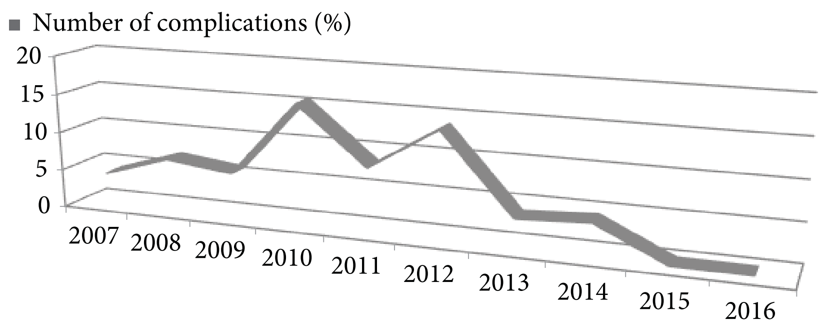

Fig. 8. Dynamics of complications over 10 years

Table 1

Description of complications

Cause	Complications		
	Immediate	Early	Late
Autovenous insertion thrombosis	1	5	–
Vessel compression	1	2	–
Thrombosis of arteries or veins	1	7	–
Unidentified	–	–	2
Total	3	14	2

2. The preferred treatment for the first signs of microcirculation deficiency in an autograft is conservative therapy, which includes antiaggregant and anticoagulant administration and hirudotherapy.
3. If conservative therapy does not produce a positive outcome, repeat surgery should be performed within 3 h of the onset of ischemia.
4. During surgical intervention, the decompression of soft tissues and mechanical swaying of vascular anastomoses should be performed. In the absence of a positive outcome, reanastomosing (with the administration of thrombolytics) should be performed, and if necessary, nonfunctional areas should be excised with subsequent autografting.

Despite efforts to prevent and eliminate complications, treatment outcomes may be unsatisfactory. Nevertheless, the data on successful results of surgical intervention obtained in our study correspond to international findings. The advantages of surgical intervention for severe deformities of the hand in pediatric patients justify the risks of potential complications.

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