

Reconstruction of the hip stump

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ABSTRACT

The formation of a functional limb stump after combat injuries with extensive soft tissue damage is challenging. After amputations or revision surgeries, long femoral stumps may remain. Although functionally inferior to tibial stumps, they can still provide satisfactory movement and performance. However, prolonged prosthesis use or poor-quality muscle grafting can lead to complications, such as skin breakdown, trophic issues, and inability to continue prosthetic use. These problems are partly due to the mismatch between the area of the bone stump end and the applied body weight.

Ilizarov compression-distraction osteosynthesis, radiographic assessment, and gait analysis before and after treatment using the GaitRite system.

We describe a case of femoral stump reconstruction following a mine-blast injury. Prosthetic fitting was complicated by massive scars covering the bone fragments. A method was developed to expand the distal end of the femoral stump via distraction osteogenesis using the Ilizarov apparatus. This approach created a stable platform with a significantly larger bearing surface. For the first time, the bearing surface area was increased twofold, reducing soft tissue trauma and enhancing the load-bearing capacity of the prosthesis.

The proposed reconstruction method significantly enlarges the distal femoral stump area, creates a mushroom-shaped end, decreases load per unit area, ensures even pressure distribution within the prosthetic socket, and improves the patient's functional outcome.

KEY WORDS: prosthetics, Ilizarov technique, bearing surface, distraction method, hip amputation, increase in bearing surface area

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INTRODUCTION

The main requirements for good prosthetics are maximum lever strength and pressure on the end of the cushion, which brings walking in the process closer to natural walking by transmitting information through the sensory nervous system. In addition, stump support is the most effective counteraction to the development of osteoporosis [1].

Transfemoral amputation is one of the most extensive types of amputation during war and peace. In the immediate and long term, it dramatically affects the quality of life, including phantom and local pain, leg and joint pain [2-5]. Existing studies on amputation surgery are more concerned with transtibial amputations [6,7]. They pay special attention to bone synostosis to reduce the pressure in the receiving sleeve, eliminate pain syndrome, and maximize the load of the distal part for the purpose of force closure between the stump and the receiving sleeve [7,8]. By increasing the bearing surface, a more even pressure distribution in the contact surface of the prosthesis can be achieved.

According to [9,10], prosthetic comfort depends on the pressure distribution at the interface between the prosthetic socket and the residual limb end. Uneven pressure distribution on the residual limb causes residual limb end pain, damage to the dermofibrous lining, and decreased motivation to use the prosthesis. The rejection rate due to high residual limb pressure is 60 [11]. These data indicate the need to find ways to increase the support surface of the femoral stump end.

There is no information in the literature about the prospects of improving the functional qualities of the residual limb in transfemoral diaphyseal amputation.

CASE REPORT

PATIENT AND STUDY DESIGN

A 27-year-old male combatant, previously in good health, with no associated diseases, received multiple wounds to the right shin, foot and knee joint as a result of a mine explosion. During the evacuation stages,



Fig. 1. Radiograph of the hip stump before surgery
Picture taken by the authors

the lower third of the thigh was amputated. Due to extensive suppuration a month later, reamputation was performed at the border of the lower and middle thirds of the thigh. (Fig. 1). The wound healed with secondary healing. After 4.5 months, primary prosthetics was performed. At first he used crutches, and after 34 days he started walking with a cane. Periodically the scar surface of the residual limb became inflamed due to penetration by the end of the residual limb into the bone. Walking in the prosthesis was accompanied by pain and inflammation.

Written informed consent was obtained from the patient for the case details and images to be published.

METHODS

Complete blood count, urine test, calcium, albumin, phosphorus, magnesium, parathyroid hormone, vi-

tamin D, X-ray of the stump upon admission, during reconstruction and at specific intervals, ultrasound to determine the area of the support surface, assessment of gait parameters in the prosthesis on the Gaitrite biomechanical track (UK) before surgery and in the long term. Osteotomy of the stump bone, application of the Ilizarov apparatus (compression, distraction, fixation), anaesthetic for 2 days after surgery and for 8-9 days after the start of distraction, calcium, vitamin D.

CASE PRESENTATION

After preparing the surgical field, two cross pins were inserted into the proximal femoral metaepiphysis perpendicular to the limb axis, taking into account the anatomy of the sciatic nerve. 4 cm below the pins in the sagittal plane, a 3.5 mm diameter self-tapping rod was inserted perpendicular to the femur. The pins and rod are fixed in two rings of the device. The rings are connected to each other by threaded rods. The femur was isolated by a flap incision of the skin, subcutaneous tissue and fascia. Scar tissue was removed. The pointed bone was rounded and shortened by 1 cm. After perineural injection of 1% novocaine solution, the sciatic, saphenous and posterior femoral nerves were shortened. In the cortical layer, 4 linear periosteum incisions were made proximally from the end of the bone stump in accordance with the directions of the planned corticotomies. Three bone and periosteum plates measuring 2.5 x 0.5 cm and 1.5 mm thick were formed. Two oblique corticotomies of the femur were made from the end of the stump in the proximal direction at an angle of 45° to the outer and inner cortical layer with an oscillating saw. The latter were broken with a bit. 2 bone and periosteum fragments in the form of triangles 2.5 cm long and 0.9 cm wide were formed. The resulting bone and periosteum plates were placed on the mother bed and temporarily fixed with a bone holder. Under the control of an electron-optical transducer, 2 parallel pins with stop pads 10 mm apart were passed through the proximal parts of the formed grafts and the mother bone in the frontal plane, without reaching the bone with 4 mm of stop pads. A cannulated drill with a diameter of 3 mm was used to make channels in both grafts and the mother bone along the pins. The pins with stop pads were pulled to the bone and fixed in threaded brackets. In this way, the proximal parts of the grafts are fixed, which will prevent their axial displacement during distraction. Two pins with stop pads were passed through the distal parts of the formed grafts at an angle of 30° to the bone axis. Proximally, the pins are fixed in the tension rods and to the overlying apparatus with the help of attachments and brackets. Distally, the pins are

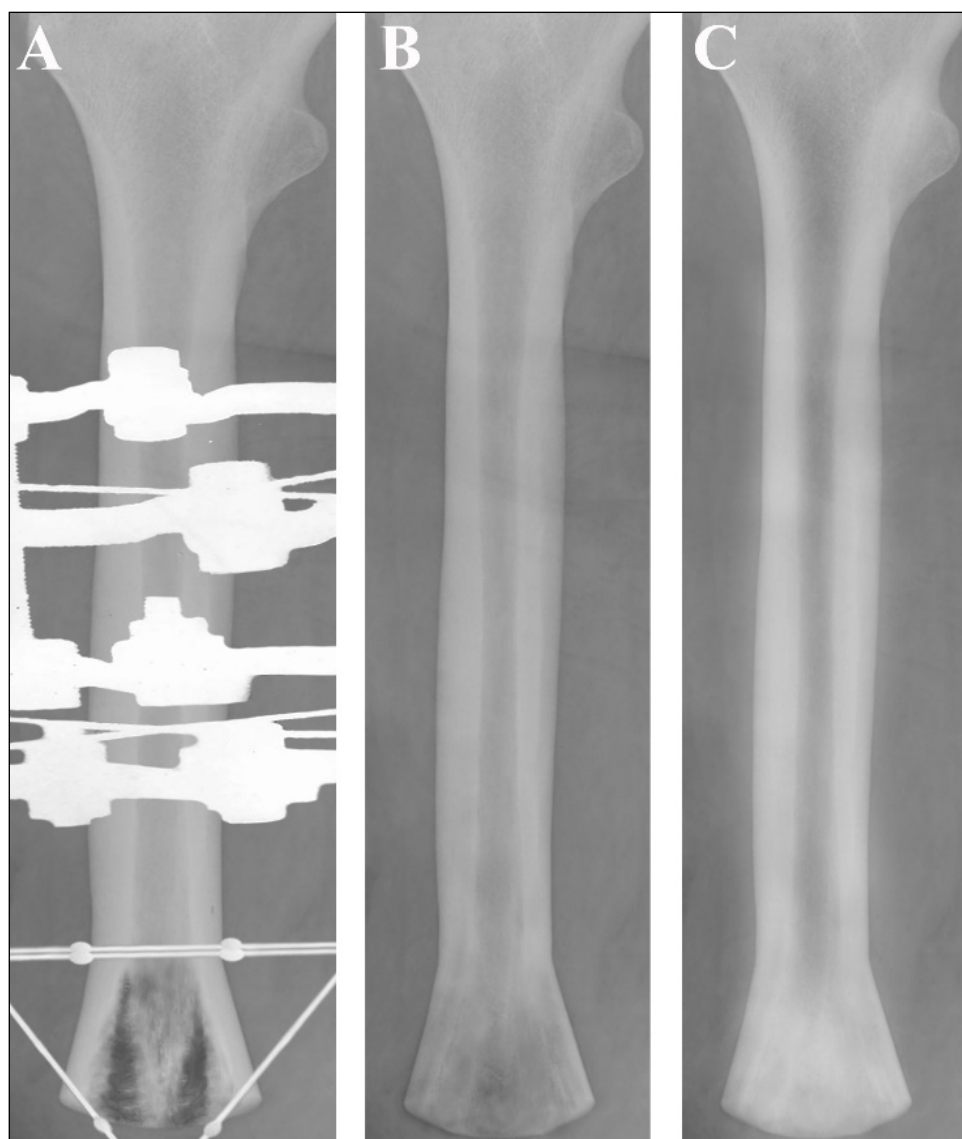


Fig. 2. Radiographs of the hip stump: A) during distraction, B) 1 year after surgery, C) 4 years after surgery
Picture taken by the authors

fixed to the anterior half-ring of the apparatus with the help of pins clamps (not quite rigidly, so that the pins can easily slip into the clamp during future distraction). The half-ring is rigidly connected to the above rings using threaded brackets (Fig. 2A).

The postoperative wound is closed. Classically, according to Ilizarov, the distraction rate should correspond to 1 mm per day, which in most cases allows to obtain a regenerate. In this case, since 2 oblique osteotomies were performed, distraction was performed in fractions of 0.25 mm 4 times a day for 30 days. As a result, endosteal-periosteal regenerates are formed due to abundant vascularization. Vascularization is carried out due to the vascular network of soft tissues, periosteum and medullary vessels, including a nutritia.

After 7 days the one-hour dosovana distraction of both grafts was started on the string-pulls for 30 days. Then the apparatus was set for fixation until full mineralization of the regenerates. After 65 days the apparatus was removed.

Radiography was performed once every 12 days during the distraction period and once a month during the fixation period. The magnitude of diastasis and the nature of the course of osteogenesis were determined.

At X-ray examination after 12 days, signs of periosteal callus with cloud-like shadows were detected at the point of contact along the edges of the grafts. After 30 days of distraction (day 37 after surgery), cloud-like shadows of medium intensity were detected over the entire area of the distraction regenerate. After one month of fixation (2 months after surgery), the regenerate was filled with a homogeneous shadow of high intensity. By the end of fixation (3 months after surgery), fusion of bone trabeculae was observed. A cortical-diaphyseal layer was formed along the edges of the regenerates, which indicated the maturity of the distraction regenerates. The bone stump acquired the appearance of a fungus. The area of the supporting surface of the femur before the operation was 4.0 cm², and after the operation – 10.9 cm².

Table 1. Patient's walking parameters before and after treatment according to the GaitRite system.

	Before treatment			After 1 year			After 4 year		
	healthy	prosthetics	Dif	healthy	prosthetics	Dif	healthy	prosthetics	Dif
Step Time (sec)	1.34	1.19	0.15	0.66	0.71	0.05	0.61	0.59	0.02
Cycle Time (sec)	1.32	1.93	0.61	1.19	1.36	0.17	1.12	1.09	0.03
Step Length (cm)	34.71	14.36	20.35	51.91	45.74	6.17	55.78	50.9	4.88
Stride Length (cm)	82.23	74.95		86.47	80.18		104.31	103.65	
Single Support (%GC)	73.1	25.8		39.6	33.2		41.4	39.7	
Double Support (%GC)	44.2	97.8		36.8	40.3		24.3	26.1	
Mean Normalized Velocity		0.57			0.83			1.06	
FAP Scope		53			88			91	

Source: compiled by the authors of this study

BEFORE SURGERY

On admission to the clinic, the presence of an amputation stump at the border of the middle and lower thirds was noted. On the end surface of the residual limb there is an extensive scar with an area of 14.2 cm² fused to the bone fillet penetrating the tissue. The muscles on the lateral and anteroposterior surfaces are fused to the scar, tightened proximally so that the residual limb has acquired a cone-shape. During active and passive movements in the hip joint, pain syndrome occurs in the stump of the sciatic nerve and the scar tissue on the end of the stump. On radiographs, the femoral stump shows moderate osteoporosis.

AFTER SURGERY

An educational and training prosthesis and then a permanent prosthesis were made.

The patient was examined one year (Fig. 2B) and 4 years (Fig. 2C) after surgery. After 4 years, the femoral stump is moderately conical in shape. The skin is normal in color. Uses a prosthesis with a rigid receiving cavity with a contact bottom. The entire surface of the residual limb, including its end, is in direct contact with the rigid walls and the bottom of the receiving sleeve. When standing on "both legs", he loads the prosthesis like a healthy leg, feeling stability and no pain. Gait is rhythmic and stable. The stride size of the healthy and prosthetic limbs is almost identical. Walking on level

and uneven surfaces, on inclines, climbing stairs is performed without restrictions. The patient can withstand direct loading while standing on the residual limb without the prosthetic socket. The turn of the prosthetic foot corresponds to the position of the foot of the healthy limb. Radiologically, the shape of the bone stump end is preserved. The remodeling of the bone tissue of the residual limb is complete. The area of the supporting surface of the residual limb is 10.9 cm².

The patient's walking parameters were measured using the GaitRite system. The examination was performed when the patient came to the clinic (before surgery) and during control examinations after 1 and 4 years. The results of the patient's walking parameters before and after treatment are shown in Table 1.

Prior to treatment, the patient had a significant limp, which was confirmed by a significant asymmetry of the time and geometric parameters of the steps.

The difference in foot support time (Step Time) was 0.15 s with a noticeable decrease in the duration of support on the prosthesis base. The difference in the duration of steps (Cycle Time) was 0.61 s, with a clear increase in the duration of the prosthetic limb step. The largest difference of 20.35 cm was in the Step Length, with the prosthetic limb's step being only 14.36 cm.

The time of support (Single Support) on the foot of the prosthetic limb was 2.8 times shorter (25.8%) than on the opposite foot (73.1%), the same proportion differed in the index of double support (Double Support), that



Fig. 3. Patient with prosthesis
Picture taken by the authors

is, when the healthy limb was the support, the duration of support increased by 2.2 times (97.8%). According to the study, the average normalized speed was 0.57. The FAP Scope functional capacity index was 53 points.

Such a pronounced asymmetry of the patient's walking was caused by the presence of pain at the end of the stump.

In 1 year after the reconstruction of the stump, a significant improvement in the quality of walking was noted. The time of support decreased by half to 0.66 s for the healthy and 0.71 s for the prosthetic limb with a difference of 0.05 s. The step duration also normalized due to a decrease in the parameter of the prosthetic limb to 1.36 seconds and became more symmetrical. The length of steps decreased, but still remained noticeable – 6.17 cm. The length of the short step increased to 51.91 cm for the healthy and 45.74 cm for the prosthetic limb, the length of the long step also increased, although not as noticeably, by an average of 5 cm. The proportional indicators of single and double support became more symmetrical

compared to the pre-treatment data. The overall FAP Scope score was 80 points.

After 4 years, the walking performance for both limbs became almost symmetrical. The length of steps and the duration of support became the same, the difference was 0.02 and 0.03, respectively. A slight difference of 4.88 cm remained in the length of the short step, but the length of the long step became the same and increased significantly to 103.65 cm. The percentages of the stride parameters - single and double support - have equalized. The speed of movement almost doubled. At the end of the rehabilitation period, the functional capacity index FAP was 91 points, which corresponds to the indicators of healthy people. The results obtained indicate the formation of a stable walking pattern and the feasibility of performing such operations.

The positive dynamics of walking recovery was obtained, due to the elimination of pain and a significant increase in the area of the bearing surface.

The patient works as a security guard. He walks 12-13 km per day (Fig. 3).

When determining the indications for lower limb prosthetics, one of the most important factors is the mental and physical condition of the patient. A healthy psyche, positive attitude and motivation contribute to a speedy prosthesis and recovery. Somatic conditions (cardiovascular disorders, paralysis, urinary and fecal incontinence) require an individualized approach and sometimes even refusal of prosthetics. In the absence of mental and physical impediments, the most important factor for successful prosthetics is the suitability of the residual limb for prosthetics.

Formerly painful scars are caused by secondary wound healing when the underlying tissues are involved in the inflammatory process. They are easily traumatized and ulcerated when using prostheses. In cases where the residual limb is of sufficient length and painful scars are combined with other pathologies (neuroma, high muscle location, osteophyte), reamputation is indicated. Retraction of muscles and their attachment to the skin scar occurs due to insufficient attention to the muscle suture. The muscles truncated during amputation or reamputation contract and fuse with the scar, thus obtaining a false point of attachment. As a result, muscle strength decreases and the residual limb loses functionality. The muscles fused with the scar do not perform their inherent functions. The energy of their contraction is spent unproductively.

Knee disarticulation stands apart. On the one hand, it has disadvantages due to the fear of complications with wound healing and problems with prosthetics due to the club-like shape [12,13]. On the other hand, the high energy efficiency of such a residual limb is very attractive. The residual limb after disarticulation allows direct load transfer, which is a physiologic method of weight bearing, and has a larger surface area than a diaphyseal residual limb [14]. In order to reduce clubbing, it has been proposed to reduce the volume of the residual limb by trimming the medial, lateral, and posterior outgrowths and removing the patella cup, which somewhat simplifies prosthetics.

Unfortunately, in military settings, localization of the wound does not always allow for knee disarticulation.

In addition, after unilateral disarticulation in the knee joint, it is not possible to position the center of rotation of the knee joint of the prosthesis in accordance with the center of rotation of the same joint of the healthy leg, so it is necessary to prescribe heavy low-functional prostheses with superimposed splints.

The suitability of the residual limb is understood as painlessness, moderately conical shape, the condition of the adjacent muscles, the ability to enter into proper interaction of the prosthesis with full contact of the residual limb over the entire surface of the socket. The

most valuable qualities are leverage strength and the ability to fully load the end of the residual limb. Transfemoral diaphyseal amputations are performed in 78%.

In modern prostheses, it is the end surface of the residual limb that requires close contact and maximum support, which makes prosthetics closer to natural walking. Attempts to relieve the end surface by transferring the support to the area above the residual limb result in impaired venous and lymphatic outflow. At the same time, the bearing capacity of the end surface is the only way to counteract the development of osteoporosis and to maximize walking in the prosthesis.

To a certain extent, the amount of loading depends on the soft tissue at the residual limb end and the quality of the prosthetic socket. The surgeon's task is to perform muscle grafting for both function and soft tissue framing of the end bone surface. In addition to closing the residual limb, muscle plasty involves volume reduction, contour correction, and preservation of antagonist agonist muscle tone [14-16].

In total-contact prosthetics, preserving the ability to perceive the limb requires their tension to be at least 61% [16].

The advantage of the proposed method is to reduce the load in the prosthesis on the distal fossa and to compensate for the loss of mechanical load. Certainly, this can be achieved after disarticulation when bearing capacity is preserved or with femoral shortening osteotomy. Unfortunately, the researchers did not study the effect of prosthetics on the nature of clinical and functional problems, although they note that the patient's mobility index was significantly higher after knee disarticulation compared to transfemoral amputation.

The use of the proposed method of reconstruction of the diaphyseal femoral stump is based on the creation of compression-distraction forces in the places of contacts of the formed grafts with the parent bone and dosed displacement of bone fragments in the frontal plane.

At the stage of compression the creation of permanent immobility at the junction of the grafts with the maternal bed is a necessary condition for the formation of bone fusion due to proliferating skeletogenic tissue. Distraction begins in the period of the greatest reparative reaction before the beginning of ossification of the interlayer. Fractional dilatation of the device subsystems by 0.5 mm per day on each side leads to stretching of connective tissue bridges formed during the compression period. During the distraction period (40 days), the new formation of transversely oriented bone beams continues at the border between the bone sections of the regenerate and the connective tissue layer. This leads to the formation of large-filament spongy bone

with a lamellar structure. Periosteal bone formation due to osteoperiosteal plates plays a definite positive role in this process [6]. The maturation of fibrous structures and their replacement by newly formed bone (ossification) increases. Completion of ossification, sufficient volume and density of the regenerate allow removing the Ilizarov apparatus and starting functional rehabilitation. It continues until the reorganization processes ensure the formation of an organotypic structure of the newly formed end of the bone stump capable of providing the possibility of functional loading.

All forces of a static or dynamic nature between the patient and the prosthesis are transferred through the socket-stump contact surface [7,8]. Theoretically, the pressure can be minimized by increasing the surface area of the residual limb end - creating a maximum support surface, since pressure (P) equals force/area ($P=F/A$). The task of the surgeon and prosthetist is to achieve a uniform pressure distribution in the contact surface of the prosthesis [7,8]. The possibility of full contact increases the hydrostatic pressure in the receiving sleeve and improves the distribution of body weight on the prosthesis. The more intensively the distal part of the residual limb is loaded, the more reliable is the "force closure" between the residual limb and the prosthesis socket, the more painless is walking on the prosthesis. A study of walking dynamics has shown that reducing pressure at the end of the residual limb promotes symmetry of joint moments, which approximates the walking behavior of humans without amputation [18]. According to [19] the skin and soft tissues of the residual limb form an important contact with the socket of the prosthesis, and the shape of the bone residual limb end plays a leading role. Therefore, it is important to perform muscle plasty with miodesis. In order to close potentially important areas for prosthetics, it is necessary to preserve the tone of the agonist-antagonist muscles. Such tensioning is only possible with total-contact prosthetics, which was seen in this case.

A well-formed, painless, moderately conical stump with an enlarged oval bone end was an indication for the fabrication of a rigid socket. The rational shape of the receiving sleeve must meet certain clinical and biomechanical requirements: 1) not to allow concentrated pressure on some parts of the residual limb and not to leave others unloaded, 2) to provide conditions for the functioning of the residual limb muscles, not to compress vessels and nerves, 3) to prevent the formation of soft tissue roll in the area of the adductor muscles and perineum, not to allow venous stasis, chafing, naminas. 4) limit displacement of the femur in the soft tissues of the residual limb, reduce piston-like movements and phenomena of external-internal instability, 5) prevent

rotation of the sleeve relative to the residual limb, especially in the rolling phase, and do not impede normal sitting.

One of the advantages of the proposed method is that it eases the load on the distal sulcus and provides a faster walk [17]. The distribution of force over a larger surface area protects against soft tissue destruction. We agree with the statement [17] that the preservation of muscle strength plays an important role after transfemoral amputation, which allows for gait with minimal deviations. An increase in the area of the bone bearing surface on the receiving sleeve compensates for the loss of mechanical load transfer by 30% [20,21].

The functional difference of the proposed method is the development of a rollback force during a fast walk.

The technique can be used in reconstructive interventions after traumatic and oncological amputations in young and middle-aged people who want to lead an active lifestyle associated with a profession that requires prolonged movement during the day. In the case of vascular diseases and in the older age group, such interventions are risky. In the postoperative period, infectious complications are possible - inflammation of the tissues near the studs. In this case, the staple is removed and another staple is performed in healthy tissues. In this observation, there were no complications.

The criteria for restrictions before surgery are: stumps after amputation due to thrombobliterative vascular diseases, stump osteomyelitis, pustular skin inflammation, insufficient mastery of the external fixation device, the need for skin treatment around the stump, purulent-inflammatory skin diseases, diabetes mellitus, taking glucocorticosteroids, bisphosphonates within the last 3 months, chronic kidney disease, hyperthyroidism and hypothyroidism, chronic heart failure, tuberculosis, systemic diseases.

Potential limitations are associated with prolonged use of external fixation devices. This is the risk of infection and inflammation of the soft tissues around the spikes, their eruption and delayed union, which depends on the nature of the bone structure, its vascularization, and the selected distraction speed.

CONCLUSIONS

Thus, the use of the developed method of reconstruction of the distal part of the femoral stump will allow to significantly increase its area, create a mushroom-like shape of the end of the stump, reduce the load per unit area, achieve a uniform distribution of pressure in the prosthesis sleeve, and increase the patient's functional capabilities.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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