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CASE REPORT

Reconstruction of the Tibial Stump After Fibulectomy

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Abstract: The formation of a functional tibial stump after combat injuries with extensive tissue damage is sometimes difficult. We describe a case of reconstruction of the tibial stump after a mine-blast injury. In this case, the fibula was completely removed as a result of fracture, and the tibia was amputated at the border of the upper and middle thirds. To create a stable platform with a larger bearing surface area and reduce the load on the distal fossa, the Ilizarov method was used. For the first time, the area of the bearing surface of the tibia stump was increased by more than 2 times in the case of the removed fibula. Thanks to the original surgery technique, the mushroom shape of the stump end was also obtained for the first time. In the process of prosthetics, this geometry actually increases the bearing surface area and has advantages over the Ertl technique, where the cylindrical end of the stump due to muscle atrophy and thinning of the fibro-skin lining can lead to bursitis and even ulcers. The spherical shape of the stump end causes less soft tissue trauma, increases the load-bearing capacity and durability of the results. According to the data of the GaitRite system, the walking performance in the long-term period practically corresponded to that of a healthy person. The technique of the operation is described in detail, including petal decortication, two oblique corticotomies of the tibia, formation of bone and periosteum fragments, distraction. The result is a highly functional stump with the possibility of using end support and full prosthetics. The proposed technique can be used in reconstructive operations on the tibia and femur stumps.

Keywords: reamputation, distraction, absence of the fibula, increase in the area of the end of the stump, Ilizarov method

Introduction

Improvement of the consequences of transtibial amputation after combat injuries of the limbs in young people is an urgent task. The use of Burgess and Ertl techniques in most cases allows to obtain highly functional stumps with the possibility of full prosthetics.[1–9] In some cases, the presence of extensive scars adherent to the skin, significant bone shortening, inflammation in the soft tissues and bone, valgus deviation of the fibula, surgeons are forced to perform various atypical reconstructive interventions.

Fibulectomy is contraindicated in primary amputations.[10] In repeated operations, the issue of removing the remaining fibula is controversial.[6,8,11] A number of authors[10,12] consider its removal necessary to avoid later problems of hypersensitivity, wound closure with a skin defect, excessive mobility, or protrusion under the skin. The surgery is attractive because it allows for easy fitting of the prosthesis. However, in a few years, as the muscles atrophy, the outer surface of the tibia protrudes. The skin is pressed against the bone by the prosthesis wall, quickly thinning and atrophying. The end of the stump becomes conical. Bursitis and abrasions occur.[10] Especially often in children, unfavorable long-term results of fibula removal are observed. Severe recurvature of the knee joint and deformity of the remaining tibia develop in a few years. Prosthetics after that is sharply complicated, mobility is difficult.

Nowadays, defibulation is performed as an exception in reconstructive surgeries only in case of a particularly short stump and a sharp valgus deviation of the residual fibula, which make prosthetics difficult.

In contrast to fibulectomy, Ertl's operation allows to obtain a bridge between the bones of the tibia. In primary amputation, it prevents, and in reamputation, it eliminates balloting of the fibula and increases the area of support. This operation has evolved from the creation of a periosteal tube between the tibiae,[1,9] the use of a graft from the fibula[3] and tibia,[13] to proprietary

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bone grafting by forming a distraction regenerate.[14–16] Proponents of the method, along with the elimination of pain, note the major positive impact of the increased support surface area in prosthetics. However, the Ertl operation is not feasible in case of fibula removal. According to the data,[17] comfort and fit of the residual limb in the prosthesis socket are the main factors affecting prosthetic quality. The distal end of the residual limb is the most sensitive area to external loading and due to its enlargement, the rate of pressure increase in this area was the highest, sensitive and vulnerable.[17] Prosthetics after fibulectomy will result in even greater stress on the residual limb end due to the absence of the fibula head, which is the site of pressure application of the prosthesis socket. Studies[18,19] have shown that prosthetic comfort depends on the pressure distribution at the interface between the socket and the residual limb. Uneven pressure distribution on the residual limb can cause pain, skin damage along with underlying tissues, altered walking patterns, decreased motivation to use the prosthesis and lead to reoperation. The rejection rate due to high residual limb pressure and poor fit of the prosthesis socket is 60.[20] These data indicate the need to search for methods to increase the support surface area of the tibial stump end during fibulectomy. There is no data in the literature about the prospects and possibilities of improving the functional qualities of the tibial stump with the removed fibula. The impetus for the development of the method of tibial stump reconstruction was the operation of lengthening and creating a bone block using the distraction method.[14–16]

Case Presentation

A man, a soldier, aged 24, previously healthy, with no associated diseases, received multiple shrapnel wounds to his lower extremities from a mine explosion. Soft tissues of the right limb were damaged by shrapnel. Due to significant injuries, the left lower limb was amputated at the level of the middle and lower third. Later, due to extensive suppuration of tissues on the outer surface of the residual limb, defibulation was performed. The wound healed secondarily. After 3 months primary prosthetics was carried out. At first he walked with the help of crutches, and then with a cane. Periodically he noted inflammation of the scars. Walking was painful and lately impossible due to pain on the external and end surfaces of the residual limb.

On admission to the clinic, the presence of an amputation stump of the left tibia on the border of the middle and lower third was noted. Knee joint movements are in full volume. The tibial crest was not spilt, fused with an extensive scar running from the end surface along the outer surface to the knee joint. The muscles of the lateral and posterior groups are excessive in length, soldered to the scar. Palpatorily there is pain on the external and posterior surfaces of the residual limb. On radiographs, tibial stump with pointed end. Moderate osteoporosis.

The patient's written consent for surgery was obtained.

Consent for publication: Informed consent from the patient for the publication of identifying information/images in an online open-access publication was taken.

Surgical Technique

After the surgical field was processed, two cross pins were inserted into the proximal tibial metaepiphysis perpendicular to the limb axis and parallel to the knee joint cleft, taking into account the anatomy of the peroneal nerve and without piercing the muscle. A 3.5-mm-diameter self-tapping rod was inserted 4 cm below the pins in the sagittal plane perpendicular to the tibialis pedis. The pins and rod are fixed in two rings of the device. The rings are interconnected by threaded rods. The tibia was isolated by a flap incision of the skin, subcutaneous tissue and fascia. Scar tissue was removed. The pointed bone was shortened by 2 cm. The tibial crest was cut down. After perineural injection of 1% novocaine solution, the tibial, superficial and deep peroneal and posterior cutaneous nerves were shortened. In the cortical layer, 4 linear periosteum incisions were made with a chisel from the end of the bone stump proximally in accordance with the directions of the planned corticotomies. Three periosteal plates measuring 2.5×0.5 cm and 1.5 mm thick were formed. 2 oblique corticotomies 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 fractured with a chisel. 2 bone and periosteum fragments were formed in the form of triangles 2.5 cm long and 0.9 cm wide. 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 spikes with stop pads 10 mm apart were made 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 the 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 by means of attachments and brackets. Distally, the pins are fixed to the anterior half-ring of the apparatus using 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 (Figure 1). A soft-tissue stump was formed by myodesis. The edges of the tibialis anterior muscle and the long flexor digitorum were sutured over the graft. The medial and lateral portions of the gastrocnemius muscle were percutaneously fixed slightly above the sawn-off tibial crest. The postoperative wound was sutured. Classically, according to Ilizarov, the rate of distraction should be 1 mm per day, which in most cases allows regeneration. In this case, since 2 oblique osteotomies were performed, distraction was performed in fractions of 0.25 mm 4 times a day for 24 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 nutricia.

After 7 days, simultaneous dosed distraction of both grafts along the tension rods was started. Then the apparatus was set for fixation until complete mineralization of the regenerates. After 60 days, the appliance was removed.

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

At X-ray examination after 12 days, signs of periosteal callus with cloud-like shadows were detected at the contact point along the edges of the grafts. After 24 days of distraction (31 days 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

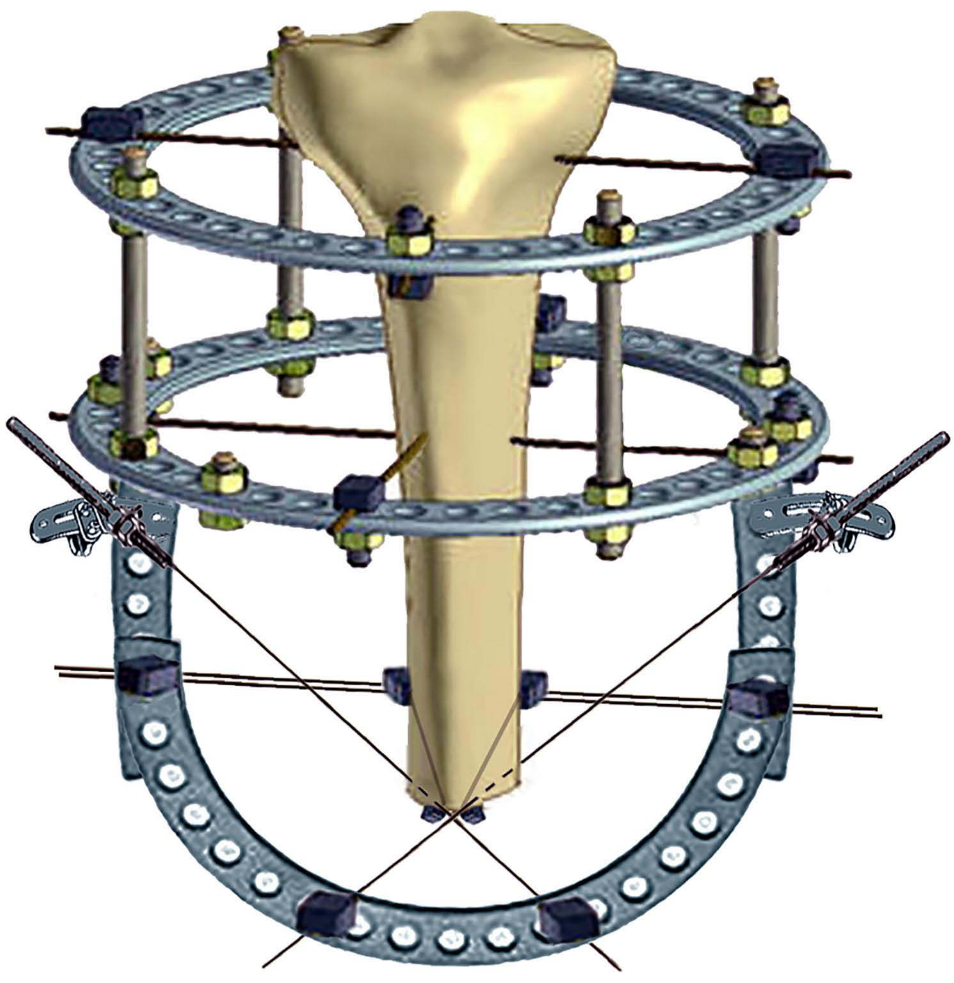

Figure 1 Scheme of reconstruction of the tibial stump after defibulation.

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was noted. A cortical-diaphyseal layer was formed at the edges of the regenerates, which testified to the maturity of distraction regenerates. The bone stump acquired the appearance of a fungus (Figure 2). The tibial support surface area prior to surgery was 4.2 cm^2 and afterward was 9.8 cm^2.

Figure 2 Radiograph of the tibial stump 3 months after surgery.

A training prosthesis and then a permanent prosthesis-hip was made.

The patient was examined one year (Figures 3 and 4) and 3 years (Figures 5 and 6) after surgery. Three years later the tibia stump is moderately conical in shape. The skin is of normal color. He 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

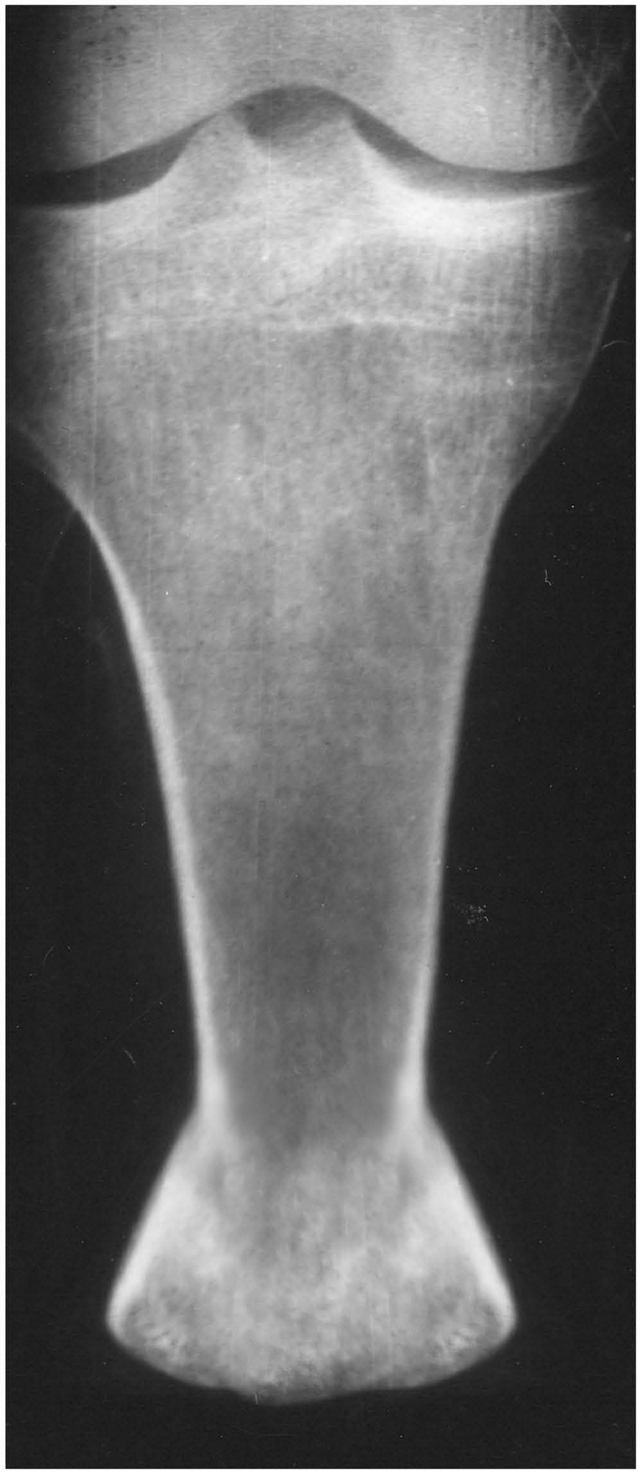

Figure 3 Radiograph of the tibial stump 1 year after surgery.

Figure 4 Photo of the tibia stump 1 year after reconstructive surgery.

stability and no pain. Gait is rhythmic and stable The stride size of the healthy and prosthetic limbs is the same. Walking on level and uneven surfaces, on inclines, and climbing stairs can be performed without restrictions. The patient can bear a direct load 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 end of the residual limb is preserved. The remodeling of the bone tissue of the residual limb is complete. The area of the support surface of the residual limb was 9.9 cm^2.

The patient's gait parameters were determined using the GaitRite system. The examination was performed upon admission to the clinic (before surgery) and during control examinations after 1 and 3 years. The results of determining the patient's gait parameters before and after treatment are shown in Table 1.

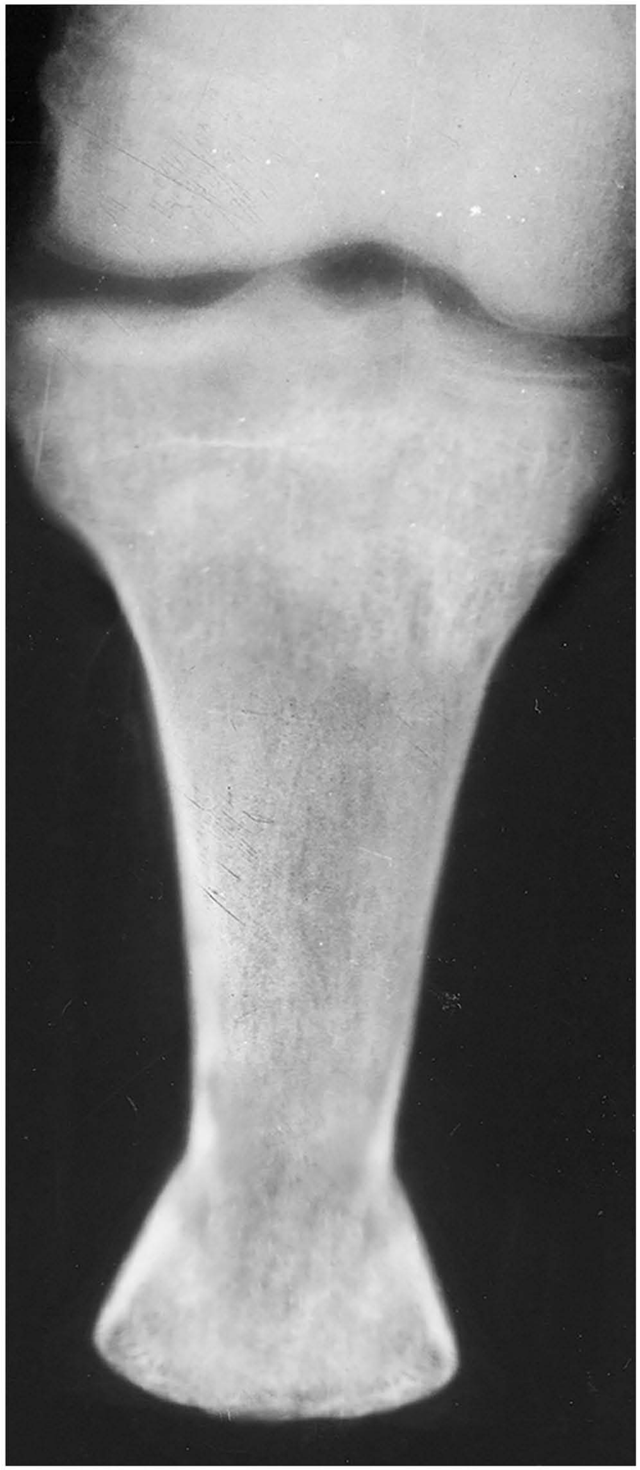

Figure 5 Radiograph of the tibial stump 3 years after surgery.

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 0.14 s, with a noticeable decrease in the duration of support on the prosthesis base. The difference in the duration of steps (Cycle Time) was 0.55 s, with a clear increase in the duration of the prosthetic limb step. The largest difference of 18.86 cm was in the Step Length, with the prosthetic limb stepping only 13.77 cm.

Figure 6 Patient with prosthesis.

The time of foot support (Single Support) on the foot of the prosthetic limb was almost three times shorter (24.1%) than on the opposite foot (71.2%), the same proportion differed in the index of double support (Double Support), that is, when the healthy limb was the support, the duration of support was short (39.9%), when the step was started with the

Table 1 Patient's Gait Parameters Before and After Treatment According to the System Data GaitRite

	Before treatment			After 1 year			After 3 year		
	Healthy	**Prosthetics**	**Dif**	**Healthy**	**Prosthetics**	**Dif**	**Healthy**	**Prosthetics**	**Dif**
Step Time (sec)	1.3	1.16	0.14	0.61	0.63	0.02	0.54	0.53	0.01
Cycle Time (sec)	1.3	1.85	0.55	1.1	1.3	0.20	1.06	1.07	0.01
Step Length (cm)	32.63	13.77	18.86	55.2	48.8	6.4	57.72	53.09	4.63
Stride Length (cm)	80.17	78.14		88.5	85.4		110.33	110.78	
Single Support (%GC)	71.2	24.1		40.2	35.6		39	38.6	
Double Support (% GC)	39.9	101.7		35.5	38.2		21.9	22.2	
Mean Normalized Velocity	0.65			0.85			1.11		
FAP Scope	53			83			92		

prosthetic limb, the duration of support increased threefold (101.7%). According to the study, the average normalized speed was 0.65. The FAP Scope functional capacity index was 53 points.

Such a pronounced asymmetry of the patient's gait was caused by the presence of pain at the end of the stump due to the absence of the fibula and the aggravation of the end of the tibia, which rested against the scar.

In 1 year after the reconstruction of the stump, there was a significant improvement in the quality of walking. The time of support decreased by half to 0.6 s for both limbs with a difference of 0.02 s. The step duration also normalized due to a decrease in the parameter of the prosthetic limb to 1.3 s, and became more symmetrical. The length of steps decreased, but still remained noticeable - 6.4 cm. The length of the short step increased, for both limbs up to 50 cm, 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 data before treatment. The overall FAP functionality score was 83 points.

The results of the study indicate a positive dynamics of walking recovery, which is due to the elimination of pain and a significant increase in the area of the mushroom-shaped support surface.

Patient is employed as a trainer. Walks 14–15 km per day. Participates in short-distance running competitions among disabled people.

Discussion and Conclusions

The use of the proposed method of reconstruction of the distal part of the tibial stump is based on the creation of compression-distraction forces in the places of contact of the formed grafts with the mother bone and dosed displacement of bone fragments in the frontal plane.[21,22] At the stage of compression the creation of constant immobility at the junction of the grafts with the maternal bed is a necessary condition for the formation of bone fusion due to the 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 (24 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.[15] 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 the anatomical 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-culcus contact surface.[16,17] Theoretically, the pressure can be minimized by increasing the residual limb end surface – creating a maximum bearing surface – because 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.[16,17] The possibility of full contact allows the hydrostatic pressure in the receiving sleeve to be increased and the distribution of body weight on the prosthesis to be improved.[10] The more heavily the distal residual limb is loaded, the more reliable the "force closure" between the residual limb and the prosthesis socket, the more painless it is to walk on the prosthesis.[10] Studies of gait dynamics have shown that reducing the pressure at the end of the stump symmetry of joint moments, which is close to walking without amputation.[23] According to data,[24] the skin and soft tissues of the stump form an important contact with the prosthesis socket and the shape of the bone stump end plays a leading role. Therefore, muscle plastic surgery with myodesis is of great importance. Along with the closure of potentially important areas for prosthetics, it is necessary to maintain the tone of the agonist-antagonist muscles. According to the available data,[25–27] preservation of the ability to perceive the limb requires 61% tension of the agonist-antagonist muscles. Such a tension is possible only with total contact prosthetics, which was sustained in this case.

One of the advantages of the proposed method, as in the case of a bone bridge, is that it eases the load on the distal fossa and provides a faster gait.[27] We agree with the statement that the preservation of muscle strength plays an important role after transtibial amputation, thanks to which it is possible to achieve gait with minimal deviations.[27] The increase in the area of the bearing surface in a patient with defibulation to some extent compensates for the loss of mechanical load transfer from the articular surface of the lateral tibial condyle.[28,29]

The functional difference of the proposed method is the development of a rollback force during a fast gait. The technique allows to obtain a more stable platform for force transfer from the hip to the ankle.

After 3 years, the walking performance for both limbs became almost symmetrical. The duration of steps and the duration of support became the same, the difference was 0.01 s. A slight difference of 4.63 cm remained in the length of the short step, but the length of the long step became the same and increased significantly to 110 cm. The percentage parameters of the stride - single and double support - were equalized. The speed of movement almost doubled to 1.11. At the end of the rehabilitation period, the functional capacity index FAP was 92 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 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, osteomyelitis of the stump, pustular skin inflammation, insufficient mastery of the external fixation apparatus, purulent and inflammatory skin diseases, diabetes mellitus, consumption of glucocorticosteroids, bisphosphonates within the last 3 months, chronic kidney disease, hyperthyroidism and hypothyroidism, chronic heart failure, tuberculosis, systemic diseases.

Potential limitations are associated with the long-term use of external fixation devices. These include the risk of infection and inflammation of the soft tissues around the pins, their eruption, and delayed fusion, which depends on the nature of the bone structure, its vascularization, and the chosen speed of distraction and fixation.

Thus, the application of the developed method of reconstruction of the distal part of the tibial stump allows to significantly increase its area, create a mushroom-shaped end of the residual limb, reduce the load per unit area, achieve uniform pressure distribution in the prosthesis sleeve, practically bring the biomechanics of walking to that of a healthy person, and increase the functional capabilities of the patient.

Ethical Considerations

The authors declare that no human or animal experiments were conducted as part of this study. Institutional permission to publish case details was not required for our case.

Consent for Publication

Written informed consent was provided by the patient to have the case details and any accompanying images published. Institutional permission was not required to publish details of the case.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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