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CASE REPORT

Reconstruction of a Short Tibial Stump with a Long Fibula Using the Ilizarov Technique: A Case Study

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Abstract: The creation of a functional tibial stump after combat injuries is sometimes too difficult. We describe a case of high amputation after a mine-blast injury. In this case, the tibia stump was too short (5 cm) and the fibula stump was too long (12 cm). There was a soft tissue reserve. The Ilizarov method was used to lengthen the tibia. The technique of the operation with exposure of the anterior medial ligament, its separation from the distal part of the bone, subperiosteal excision of the medial part of the patellar tendon from the tibia, oblique-frontal corticotomy of the tibia, which allowed to avoid undesirable complications during the distraction and to obtain a wide, strong regenerate, is described in detail. The alignment of the tibia lengths resulted in a highly functional stump with the possibility of full prosthetics. The proposed technique can be used in reconstructive operations on short stumps that require lengthening.

Keywords: corticotomy, distraction regenerate, different-sized tibiae, Ilizarov technique, stump lengthening, transtibial amputation

Introduction

Prosthetic tibial stumps cause many complications and discomfort due to insufficient socket fit.[1,2] Due to poor socket fit, up to 60%[3] of patients cannot use their prostheses. In this regard, an intensive search for new solutions that would improve the fit and comfort of the prosthesis is underway.[4,5] The authors' comprehensive approach to characterizing the mechanical properties of the soft tissues of the stump and the corresponding development of a reconfigurable pneumatic prosthesis socket is quite logical and reasonable. However, being promising, these studies have not yet gone beyond the walls of laboratories.

Prosthetics of an excessively short tibial stump with sufficient fibula length is impossible due to imbalance and weakness of the stump. Shortening the fibula would not be appropriate and would not improve the prosthesis. The available sources describe isolated cases of tibial stump lengthening with appropriate fibula length using the Ilizarov method.[6–10] However, they do not take into account some technical and anatomical aspects that can significantly affect the result of lengthening. The difference in this case is the development of a technique for lengthening the non-prosthetic high tibial stump to equalize its length with the preserved fibula, taking into account the attachment of the tendon-ligament complex and the use of a two-plane oblique-frontal corticotomy.

Case Presentation

A young man, a fighter, aged 26, previously healthy with no significant medical history or comorbidities sustained an explosive injury to his left tibia after a drone strike. Due to significant bone fracture, an atypical amputation was performed, in which the tibia was cut off in the upper quarter and the fibula was cut at the level of healthy tissue. The postoperative wound healed within 19 days. A stump was formed with a scar on the anterior-medial surface. There was an excess of soft tissue. X-rays showed the stumps of the tibia (5 cm long) and fibula (12 cm long) (Figure 1). Movement

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Figure 1 Radiograph: tibial stump before surgery.

in the knee joint is in its entirety. The patient was informed about the possibility of lengthening the tibia while maintaining the length of the fibula and forming a functional stump for full prosthetics. Possible risks and consequences were explained. 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.

Operating Technique

After processing the surgical field in the proximal tibial metaphysis by 1.5cm below the knee joint line perpendicular to the mechanical axis of the limb, two cross pins d=2.4 mm were made without piercing muscle tissue and taking into account the passage of the peroneal nerve. One of them was passed through the fibula head. The pins are fixed in the ring of the Ilizarov apparatus. A 4-cm long anteromedial vertical skin and soft tissue incision was made 2 cm below the knee joint cleft to access the tibia with scar excision. A deep medial release was performed with subperiosteal sharp dissection of the Pes anserinus and MCL (medial collateral ligament) from the tibia. After cutting the MCL from the bone, a blunt retractor is placed behind the tibia to protect the neurovascular structures. Tissue mobilisation along the medial border of the patellar tendon and tibial tuberosity. Under intraoperative X-ray control with mobile C-arm imaging system, two guide pins were inserted 3 cm below and parallel to the knee joint cleft into the tibia. A subperiosteal two-plane oblique-frontal and horizontal corticotomy of the tibia was performed directly above the guide pins using an oscillating saw (Figure 2).

The mobility of the corticotomy site was checked. The guide pins were removed. Two cross pins with stop pads were passed perpendicularly through the distal fragment of the tibia. The pins are fixed in the apparatus ring, which is connected to the proximal ring by threaded rods (Figure 2).

Interfragmental compression at the site of corticotomy. Revision, hemostasis during the operation. The wound was sutured in layers. In the postoperative period, vitamin D3, osteogenone, and calcium supplements were prescribed. For early functional loading, a semi-finished foot was fixed to the distal ring of the apparatus on the outriggers, which allowed for dosed loading from the 5th day.

On the 5th day distraction was started for 0.25 mm 4 times per day. Since the blood supply to the corticotomy area was sufficient, the fragments were fixed for 4 days. During this period, a fusion is formed over the entire contact area at

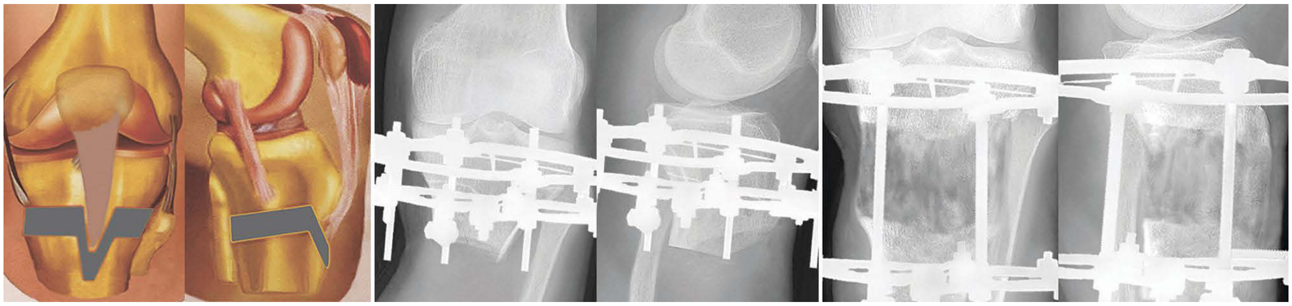

Figure 2 Corticotomy scheme and radiographs: the stump before lengthening (18.12.2020); distraction regenerate after 30 days of distraction (17.01.2021).

the corticotomy site due to proliferating intercellular tissue. During fractional dilatation of the rings as the fragments diverged, the connective tissue bridges formed between them gradually stretched and their fibers acquired longitudinal orientation. On the basis of fibers of immature connective tissue, coarse-fiber bone beams were postemporally formed. In the central part of the formed regenerate there was a connective tissue layer, which was the growth zone of the distraction regenerate. In the process of distraction, newly formed capillaries were created along the paths of tissue fluid circulation. Gradually, a large-branched spongy bone of lamellar structure was formed. During the fixation period, the connective tissue layer was fibrosized, replaced by newly formed bone, and the cortical layer was formed.

On the 15th day of distraction, control radiographs showed cloud-like shadows of medium intensity over the entire area of the diastasis. After 30 days, osteoporosis of the distal fragment was observed, and a normoplastic regenerate was formed in the interfragmental diastasis. After 60 days of distraction, a reorganization of the regenerate structure at the ends of the fragments was revealed. The regenerate consisted of intense shadows of the proximal and distal sections and a zone of lucency (Figure 2). Both parts of the regenerate retained the same structure and shadow intensity. After 80 days of distraction, the radiologic picture was clearer. The above changes were observed with continued distraction and formation of calcified regenerates. Homogeneous shadows of high intensity were determined on radiographs after 1 month of fixation. The formation of the cortical layer began. After 90 days of fixation, the apparatus was removed (Figure 3). The lucency zone at the place of the former diastasis gradually disappeared. Its disappearance was accompanied by further reorganization: the difference in the regenerate density leveled out with its gradual approach to the density of the fragments. Bone trabeculae in the distal part of the regenerate were united. A well-formed cortical plate was identified. The movements in the knee joint were in full volume.

At this time, ultrasound scan in the middle zone of the regenerate revealed vessels 0.31–0.36 mm in diameter with peripheral indices Pl=3.68 and Pl=1.5. The 7 cm long regenerate had a homogeneous structure. In terms of density, it was close to the nearby areas of the maternal bone.

10 months after the apparatus removal, on the radiographs the density of the regenerate exceeded the density of the parent bone. The cortical layer was formed around the entire perimeter of the regenerate (Figure 3). A training prosthesis was fabricated and 5 months later a permanent half limb prosthesis was fabricated.

Figure 3 Radiographs: distraction regenerate after removal of the appliance (90 days of fixation) (17.04.2021); distraction regenerate after 10 months after removal of the appliance (19.02.2022); tibial stump 3 years after surgery. (28.12.2023).

After 3 years, the radiographs showed a complete organotypic restructuring of the regenerate (Figure 3).

The Locomotor Capabilities Index (LCI) within the Prosthetic Profile of the Amputee (Canada, 1993) questionnaire was 55 out of 56 points 3 years after surgery and prosthetics.

The patient uses the prosthesis without additional means of reliance. He works as a plumber. Walks 13–15 km per day.

Discussion and Conclusions

The use of the Ilizarov method is based on the creation of compression-distraction forces at the point of contact of bone fragments and dosed displacement of the autograft into the defect. At the same time the latter was filled with the non-free graft with the formation of the distraction regenerate undergoing with time a complete organotypic rearrangement and recreating the anatomy of the segment.

Soft tissue is of particular importance in stump lengthening, which can cause a number of problems.[6] A favorable time for lengthening is when there is excess tissue.[10] If there is a lack of soft tissue and a threat of skin perforation, a tissue expander is used,[11] which is implanted subfascially at the distal end of the femoral stump and 100 mL of saline is injected weekly for 10 weeks, after which the implant is placed. The latter is fixed to the medullary canal with bone cement and bone lengthening. The disadvantage of the technique is the introduction of foreign material into the tissues and a long preparatory process. Another possible option for lengthening is preliminary transplantation of soft tissue flaps.[11]

The planned amount of stump lengthening was determined not only by the size of the compensation and sufficient soft tissue, but also by the reparative capabilities of the organism as a whole. The rate of distraction is variable and depends on the structure and condition of the parent bone and regenerate, subjective (pain) and objective (soft tissue deficiency or edema, inflammation around the percutaneous elements) reasons.

The activation of restructuring during distraction is explained by the fact that when the bone is stretched with the apparatus of a rigid design, the effect of the dynamic component on the stretched area is eliminated, since the functional load is transferred to the apparatus. The presence of a dense capillary network in the epimetaphyseal zone of the bone creates favorable conditions for compensation of local microcirculation disorders caused by corticotomy. The dynamics of distraction regenerate remodeling consistently passes through a number of stages and is not completely completed within the treatment period. By the end of the fixation period, there are only initial signs of medullary canal formation in the central part of the regenerate layer. This is also evidenced by a significant decrease in the density of the regenerate in its center compared to the anterior and posterior surfaces.

The rigidity of fixation is extremely important in the technique of distraction osteogenesis, which affects the consolidation time and the quality of the regenerate. Therefore, thick spokes with thrust pads were used. In order to ensure the possibility of maintaining constant immobility under the action of displacement forces caused by the active function, it is necessary to create a large stability margin when applying the apparatus, which is maintained after surgery by periodic compensation for the fall of the tension force. The larger the stability zone, the greater the functional load on the residual limb is permissible. Accordingly, better conditions are created for the restoration of its trophism. For the same purpose, a self-tapping rod with a diameter of 3.5 mm in the sagittal plane and a spoke in the frontal plane can be inserted perpendicularly through the distal fragment of the tibia instead of two spokes. The latter are fixed with the help of a fixator-attachment to the appliance ring. If there is uncertainty about the rigidity of fixation during distraction, a simple two-ring fixation device can be added to the lower third of the femur.

In the process of preparation for and execution of the intervention, some technical points were taken into account that have not been addressed by other authors.[6–10] The corticotomy was performed subcutaneously because the tendon-ligament complex is attached to the periosteum. The corticotomy plane was passed obliquely and horizontally so that the tuberosity remained on the proximal fragment (almost L-shaped). Such a corticotomy facilitates successful distraction and the formation of a thicker regenerate.

The period of functional rehabilitation begins from the moment of loading the semi-finished foot fixed to the Ilizarov apparatus on the outriggers, and continues until the reorganization processes reach such anatomical structure of the regenerate that will ensure the restoration of functional loading of the residual limb. As in several other studies,[10] organ remodeling of bone and regenerate occurs at this time. The remodeling of bone fragments and the base of the bone compartments of the regenerate that began during the distraction period continues during the fixation period and leads to an increase in osteoporotic changes in the bone fragments and regenerate and a delay in its organ restructuring, which continued during training and permanent prosthetics.

Over the past decades, prosthetic socket designs have been continuously improved. These improvements are characterized by the fact that they regulate pressure in several places in the socket. According to Sayed and others,[4,5,12–15] the reconfiguration zones should cover the entire residual limb surface and regulate the fit and pressure distribution completely. These studies resulted in the development of a new pneumatic reconfigurable socket for transtibial amputations.[4,5] The variable socket configuration proposed by the authors shifts pressure away from sensitive areas and compensates for residual fluctuations in stump volume. According to these authors, such a reconfigurable socket can reduce the pressure on the stump in the programmed areas by up to 61%, which is a very important factor not only after conventional amputations, but also after lengthening and reconstructive interventions. The use of such a reconfigured socket in the early period after lengthening until the regenerate is completed is especially relevant. But this is in the future.

Restrictions to the operation include stumps after amputation due to thrombotic vascular diseases, pustular inflammation of the skin, insufficient mastery of the external fixation apparatus, a long period of time for obtaining a regenerate and its reconstruction.

In the process of such reconstructive interventions, errors and complications can occur. In order to realize compression when applying the apparatus, it is necessary to create a large margin of stability, which is maintained after surgery by periodic compensation of the compression force drop. During distraction, natural conditions change dramatically and all the force generated by the apparatus is transferred to the muscles, fascial-ligamentous apparatus and preserved tissues between the ends of bone fragments. Dosed stretching of soft tissues of the stretched segment cannot provide stable fixation of bone fragments, so it is necessary to mount more complex support subsystems, which we have implemented. The more rigid the design of the apparatus and its support subsystems and the more stable the bone fragments are fixed in these subsystems, the less their lateral and axial mobility. At the end of the distraction period, the activity of bone formation may decrease, which is explained by the cessation of the redistribution of the connective tissue layer. This is caused by non-compliance with the distraction rate or temporary cessation of separation of the bone fragments. If the distraction rates are strictly adhered to, this can occur due to a mismatch between the calculated rates and the actual rates, due to bone resorption around the spokes, decreased rigidity of the apparatus, or excessive increase in tensile strength as a result of premature ossification of the connective tissue layer.

Possible complications are most often related to the insertion of the spokes. They can be divided into infectious (soft tissue suppuration, purulent arthritis, dermatitis), non-infectious (reactive arthritis, vascular and nerve injury, joint contracture). When performing the intervention, complications may occur due to compression or distraction and improper application of the apparatus (impaired innervation, impaired trophism, joint contracture). After removal of the apparatus, deformation of the regenerate or its fracture is possible. Observance of asepsis, uniform tension of the spokes, diagnosis and treatment of early and late inflammatory complications, timely removal and rewiring of the spokes will allow to stop the process. Knowledge of topographic anatomy and variants of the location of the main neurovascular bundles excludes their damage. If the vessel is damaged, the spoke should be removed and a new one should be inserted next to it. Bleeding is stopped by pressing the puncture site with a tampon. If the peroneal nerve is damaged, the spoke must be removed.

According to Latimer,[7] some patients had a significant loss of length of the regenerate after lengthening. The authors explain these facts by early functional loading. In our opinion, in order for compression during early loading not to lead to shortening, it is necessary to overstretch the regenerate up to 1–2 cm beforehand, which apparently was not taken into account by these and other researchers,[7] since there are no references to it. In addition, after the end of distraction, the distance between the rings should be increased by 1 mm once every 5–7 days.[7–9] In none of the available reports did we encounter information about exposure of the anterior medial ligament, cutting off its distal part from the bone, subperiosteal cutting off the medial part of the patella tendon from the tibial tuberosity, which could also affect the shortening of the regenerate.

Our clinical experience shows that in case of sharply expressed osteoporosis with the formation of the cortical layer due to the possibility of crumpling or secondary resorption of the porous bone area under the influence of functional overload, it is necessary to provide the conditions of the most gentle mode of increasing the functional load.

After removing the appliance, conditions of regenerate deformation or fracture may occur. Therefore, the device can be removed when the density of the regenerate on the radiograph approaches the density of the surrounding bone.

These possible errors and complications arise due to incorrect tactics and techniques of using the Ilizarov apparatus and should not be a barrier when performing reconstructive interventions on the bone stump. Such interventions can improve the quality of life of patients, and knowledge of the causes and conditions of possible errors and complications opens realistic ways to prevent them.

Using the presented clinical observation as an example, the authors demonstrated the saving tactics, real possibility, technical details, and quite satisfactory results of a non-standard variant of surgical treatment of a patient with a high tibial stump and long fibula. During the operation and postoperative period all the set tasks were solved. This made it possible to equalize the length of the tibial stumps, conduct early rehabilitation and achieve fusion of the fragments, as well as satisfactory long-term functional results of prosthetics.

Ethical Considerations

The authors declare that no human or animal experiments were conducted as part of this study.

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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