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Bilateral Stress Fractures of Amputated Tibial Stumps in the Setting of Chronic Compartment Syndrome

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Introduction: Limb amputation and subsequent prosthetics lead to significant disturbances in bone residual limb remodeling.
Aim: To familiarize specialists with the possibility of simultaneous bilateral stress fractures of amputation residual limbs resulting from intensive loads and poor-quality prosthetics causing chronic compartment syndrome. A case of bilateral stress fractures of the tibia in a 28-year-old male military serviceman with paired transtibial amputation is presented. The fractures occurred in the process of active exploration of poorly fitting prostheses, complicated by chronic compartment syndrome that masked the clinical picture.
Treatment: Rest, reopolyglucin, heparin 5000 U, furosemide, B vitamins, ascorbic acid, calcium, vitamin D, percutaneous electrical stimulation of muscles.
Techniques: Radiography, ultrasound, blood biochemistry, measurement of subfascial pressure.
Outcomes: After treatment, the phenomena of compartment syndrome disappeared, stress fractures healed, new receiving sleeves of prostheses were made, gradual dosed loads were started. 7 months after the diagnosis of stress fractures and compartment syndrome, the patient started using the prosthesis without aids. Examined 18 months later. Worked as a warehouse manager, walking an average of 4 km per day.
Conclusion: With complaints from the patient with an amputation stump of muscle and bone pain that appeared after exercise, passed after rest, and reparative reaction detected on radiographs, functional overstrain of the bone should be suspected, which can potentially lead to a stress fracture. The causes of stress fractures in the patient were acute overstrain of the bone tissue during prosthesis development, noncompliance with the loading and resting regimes, and local disturbance of the bone blood supply due to the narrowed rigid socket of the prosthesis. Stress fractures of the bone tissue of the amputation stump contain elements of insufficiency and fatigue. Chronic compartment syndrome may exacerbate and mask the stress fracture.
Keywords: transtibial amputation, stress fracture, compartment syndrome, prosthesis

Introduction

Bone, like any other material, has an exploitation level threshold of external loads, the achievement of which leads to the formation of fatigue microcracks,[1] which accumulate. Moderate intensity of microdamage formation not only occurs under physiologic conditions, but is biologically appropriate. To minimize stresses and reduce the risk of fractures, two important mechanisms have been developed in the body: first, the threshold of bone stresses and deformations stimulating modeling is below the threshold of fatigue damage formation; second, in conditions of relative deformation exceeding 4000 micro-deformations, the modeling mechanism with the formation of fibrous connective tissue is switched on.[2]

A considerable number of papers on stress fractures of bone from overload[3–11] and insufficiency[12,13] have appeared in the literature in recent years. These studies are mainly focused on frequency,[6] risk factors,[9,14] diagnostic methods, pathophysiology,[9] injury and disability patterns,[8] evaluation of the role of biomechanical factors, biochemical and genetic markers,[15] localization[8] and contingents.[6] The majority of injuries occur in the bones of the tibia,

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49–88.5%, and foot, 34%.[14,16] The most commonly affected are recruits soldiers, athletes, and dancers.[16] Research has been carried out on the peculiarities of stress fracture occurrence depending on the type of sport or the nature of pressure.[8] According to the authors[8,12] 16.6% of patients had bilateral stress fractures. Among these works we did not find any mention of the occurrence of stress fractures in patients with limb amputation. According to studies by Shevchuk VI,[17] amputation causes disturbance of bone homeostasis, blood circulation, reparative regeneration, changes in the nature of loading on bone and muscles in the process of prosthetics and can cause pathological bone remodeling.

The crossing of muscles, nerves, vessels and bones makes it considerably more difficult to form a rational relationship between these tissues, which is necessary to create a prosthetic residual limb. The suitability of the residual limb for prosthetics means its ability to enter into a correct relationship with the prosthetic socket and to withstand the uniform pressure arising in the socket. Unfortunately, not every residual limb fulfils these requirements.

In addition to amputation-related malformations (high standing of the truncus muscle and stand-off of the file, painful and adhesive scars, excessive soft tissue, excessively long or short residual limbs, club-shaped or excessively tapered residual limbs, valgus deviation of the fibula remnant, incorrect bone filing, painful neuromas, prolonged granulation and non-healing wounds), diseases resulting from prosthesis use (folliculitis, lichenisation, hyperkeratosis, traumoids, nodules, bursitis, chronic venous stasis) are a frequent cause of unsatisfactory results. The latter are the leading cause of poor-quality prosthetics and depend on both internal factors, which include the anatomical and functional state of the lower limb veins, and external factors dependent on the prosthesis.[17] The prosthesis plays a major role in preserving the functional status of the residual limb. A good and well-fitting prosthesis can both improve and deteriorate the quality of the residual limb.[18]

Case Presentation

A case of bilateral stress fractures of the tibial stumps in a 28-year-old male serviceman is presented. As a result of an anti-personnel mine explosion, he received multiple wounds of the lower extremities – complete detachment of the extremities on the right and incomplete detachment of the extremities on the left, closed abdominal trauma. In the military field hospital, after he was brought out of shock, amputation was performed according to the type of primary surgical treatment. A diagnostic laparotomy was also performed, which did not reveal any damage to internal organs. The stump wounds healed by secondary tension within 2.5 months. After the fabrication of training prostheses, the patient walked with a cane for 8 months. The size of the residual limbs stabilized. Permanent prostheses were fabricated. The patient began to actively use them, walking an average of 6–7 kilometers per day, increasing the load in terms of walking time and distance on a daily basis. On the 21st day of long and intensive walking on rough terrain, acute pain and slight swelling appeared in the proximal parts of both residual limbs. After a resting regimen for 7 days, the pain syndrome subsided. At the end of the first day, the acute pain and swelling resumed at the end of the first day.

In an effort to recover quickly, the patient self-administered non-steroidal medications and tried to walk for one more day. Since there was no improvement, he went to the hospital of his place of residence, where stump radiography, Dopplerography and coagulogram study were performed. Radiography did not reveal any pathology. Dopplerography revealed dilation of the great saphenous vein. According to the coagulogram, there was an increase in fibrinogen A (5.18 g/l) and a positive ethanol test. Thrombophlebitis of deep veins of both stumps was diagnosed. Prescriptions: bed rest, xarelto 0.15 mg 2 times a day, compresses with heparin ointment. The condition improved and the patient tried to continue using the prosthesis for 3 days. However, the pain and swelling resumed and the use of the prosthesis became difficult again. The patient came to our clinic.

Consent for Publication

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

Condition on Admission

Moved on prostheses with the help of crutches. Denture sockets are rigid, with a narrowed upper contour. Putting on and taking off the prosthesis is difficult due to swelling. The stumps at the border of the middle and lower thirds of the tibiae are moderately conical in shape. The skin of both stumps is cyanotic, shiny. There was a pronounced tissue oedema. The incomplete closure of the stumps by the muscles was noted. At palpation of the muscles and axial load, pain sharply increased on the anteromedial, lateral and posterior surfaces of the upper third of the stumps. Soft tissue and bone sensitivity were increased. Results of subfascial pressure measurement in the fascial-muscular cases: in the anterior – 3.8; lateral – 3.6; posterior – 2.5 kPA. Ultrasound examination revealed hyperechogenic elevation of the periosteum and increased blood flow. Hyperechogenicity of the periosteal tissues indicates blistering and scorching reaction of the osteocele, cortical ball rupture.

On the radiographs of the stumps taken in medical institutions before admission to our clinic, localized areas of cortical layer density loss – radiographic osteopenia – were detected in the upper third of the tibiae on the medial surface (Figure 1). On admission to our clinic, the radiographs of the stumps showed pronounced hyperostosis. Fracture lines passing through the cross-section of the thickened bone at the level of the tops of massive periosteal deposits were clearly visible (Figure 2).

Diagnosis

Incomplete stress fracture of the tibial stumps in the upper third; chronic compartment syndrome of both tibial stumps.

Vitamin D level in the blood serum 10 mg/mL (N 25–100 mg/mL). Calcium, albumin, phosphorus, alkaline phosphatase, thyroid hormone, parathormone within the limits of normal values, erythrocyte sedimentation rate (ESR) – 20 mm/hour.

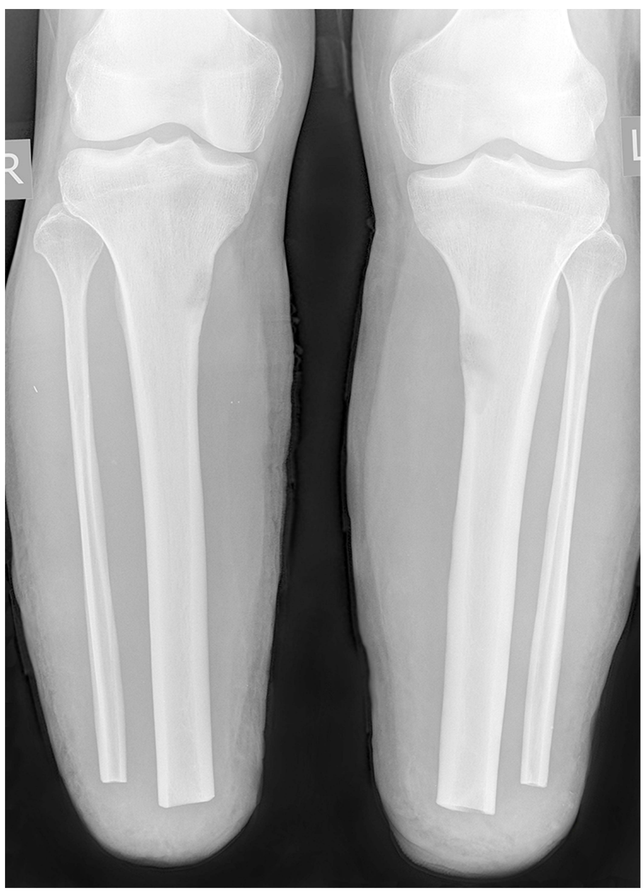

Figure 1 Radiographs of the stumps with localized areas of cortical density loss.

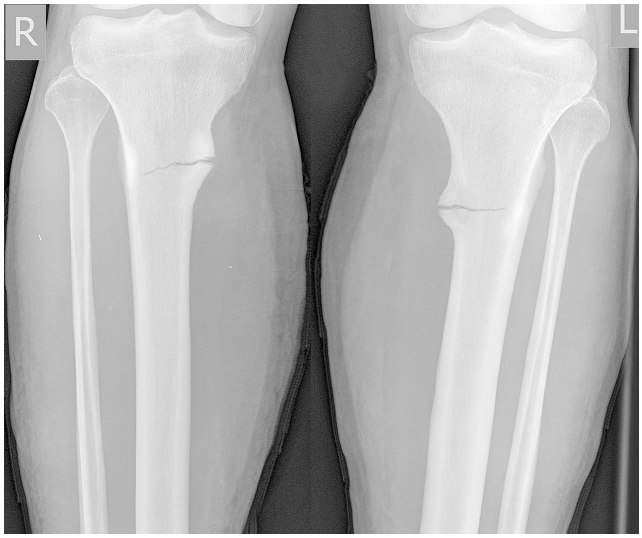

Figure 2 Radiographs of the stumps with fracture lines.

Treatment

Rest, wheelchair mobility. Reopolyglucin, heparin, sodium bicarbonate, furosemide, B vitamins, ascorbic acid, calcium 2000 mg and vitamin D 800 ME, percutaneous electrical muscle stimulation. Positive dynamics of treatment was observed starting from day 7. The pain syndrome was gradually eliminated. Cyanosis and oedema disappeared. Radiologically, the fracture gap widened, the edges of the fragments became indistinct and uneven. After 3 months of treatment, the lumen bands are filled with bone tissue (Figure 3). The bone structure in the fracture area is compacted. Compactization of the cortical diaphyseal layer has occurred. Endosteal bone formation is revealed as an area of bone sclerosing. Vitamin D level is 40 mg/mL. Alendronate 70 mg was added to the treatment. Exercises were carried out for part of movements, stretching exercises, muscle strengthening. The receiving sleeves of the prosthesis were replaced. The patient started gradual loading in the prosthesis. Walked with the help of crutches for a month, then 3 months with a cane. 7 months after the diagnosis of fractures, he started using the prosthesis without aids. The patient was examined 18 months later. Radiologically, thickening of the cortical diaphyseal layer and bands of endosteal bone formation are noted at the fracture sites (Figure 4). Uses prostheses throughout the day. Works as a warehouse manager. Walks an average of 4 km per day.

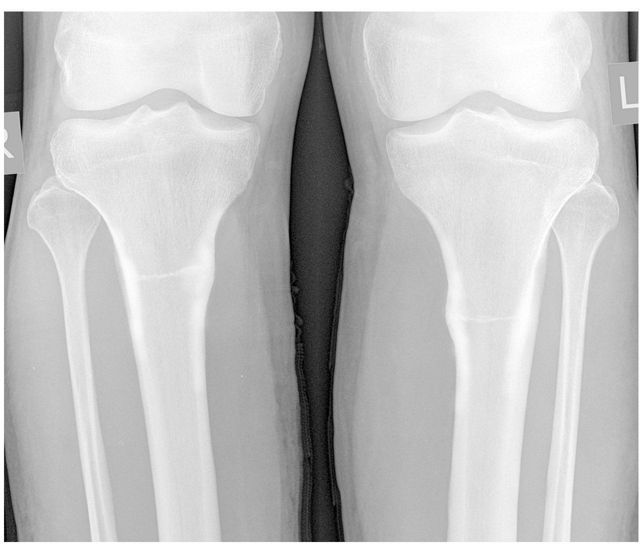

Figure 3 Radiographs of the stumps after 3 months of treatment.

Figure 4 Radiographs of the stumps after 18 months.

Discussion

When bone is subjected to constant loading, fatigue microcracks increase, causing a decrease in its mechanical stiffness and strength characteristics. There are internal and external conditions for the occurrence of localized microdamage.[19] The internal conditions include the non-uniformity of the internal force field characterized by stresses. According to data[19] small cavities and tubules present in bone significantly reduce its strength limit (vascular channels, osteocyte lacunae, tubules). Another internal condition for microdamage is the uneven quality of the material – differences in mineralization between newly formed and mature osteons and hypermineralization of areas with dead osteocytes.[2,20] External conditions of fatigue damage formation are related to the peculiarities of mechanical loads, when a) the direction of loads remains habitual, but their duration and magnitude increase, b) the direction of loads changes, but their magnitude and duration do not change. In terms of biomechanics,[21] the interaction between a large number of load cycles, muscle exhaustion, accelerated bone resorption process and local temporary hypoxia leads to bone tissue damage. Microdamage significantly alters metabolic processes and initiates osteoclast-osteoblast remodeling, which normally prevents the occurrence of fatigue fracture. As a result of physiological restructuring, bone structures adapt to the changed conditions of existence.[2] After amputation, due to massive destruction of the intraosseous vascular network, impaired sealing of the medullary cavity, muscle damage, and loss of fixation points, physiological remodeling slows down.[22] This process is aggravated by the accumulation of fatigue in the bone tissue of the residual limb. In the case of decompensation of the disturbed blood circulation, accompanied by the shutdown of intraosseous blood supply, combined with the expansion of vascular connections between the bone stump and adjacent soft tissues over a considerable length and decompensation of blood supply in the paraosseous tissues, the prerequisites for stress fractures are created. Under loading in the prosthesis, the osteoclast-osteoblast equilibrium shifts and the density of microdamage per unit volume of bone begins to increase. In the described observation, the disruption of the balance between damage formation and repair, the sudden increase in daily load caused the accumulation of microdamage and the occurrence of stress fractures.

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Stress fractures occurred in the patient due to abnormal loading of pathologic bone and should be categorized as insufficiency fractures. However, considering the athletic career, increased physical activity in training and then permanent prostheses,[8] the bone condition and the nature of the fractures with the presence of hyperostoses, they also contain elements of fatigue.[22]

According to the authors' classification[7,23] the fractures in our patient were classified as incomplete stress fracture fractures. The main role in the occurrence of stress fractures was played by poor-quality prosthetics with excessive loading and some loss of agonist-antagonist muscle tension.[1,24] In addition to a sharp increase in the intensity of loads, researchers include factors leading to stress fractures poor quality of footwear,[25,26] the nature of the terrain,[27,28] and insufficient level of physical fitness.[29] All of the above took place in the described case. Considering the paired amputation, it would be more appropriate to increase the load gradually. A decisive role in the occurrence of fractures belongs to the transition to permanent prostheses with their insufficient fitting and lack of control of the prosthetist. For prosthetics, the main factor is the patient's physical condition and his or her desire to adapt to society.

An anatomically and functionally suitable residual limb is an equally important prerequisite for successful prosthetics, which does not always meet these requirements. The prosthesis plays a major role in maintaining the functional condition of the residual limb. A good and properly fitted prosthesis can permanently improve the quality of the residual limb. The quality of the prosthesis depends on the shape of the socket. An improperly shaped prosthetic socket can completely ruin the best residual limb.[18]

For a successful prosthesis, the sleeve must ensure full contact with the residual limb, a strong connection between the residual limb and the sleeve, maximum load on the residual limb end, preservation of blood, lymphatic and innervation circulation, and the ability to be adjusted as use progresses. Full contact and load on the end of the residual limb is achieved by manufacturing a sleeve with a larger cross-section of the proximal opening, which will ensure maximum preservation of arterial, venous and lymphatic circulation and innervation. The narrowed entrance opening of the sleeve caused chronic venous stasis and edema of the end of the residual limb. If the prosthesis construction scheme is disturbed, uneven load distribution on the residual limb inside the receiving cavity occurs. Local pressure on the vascular area impedes venous circulation. In a tight receiving cavity, increased pressure on the residual limb was observed not only in the loading phase, but also in the carrying phase of the stride. Such a receiving cavity blocked the lymph venous outflow, which was aggravated by the narrowing of the upper contour of the socket. The sleeve was compressed at this point, while the distal end remained free. Without pressure from the bottom of the receiving sleeve, the soft tissues were a place of sharp slowing of blood flow. As a result of microcirculatory blockage due to intravascular blood clotting and formation of antigen-antibody reaction products, ischemic necrosis of bone and bone marrow occurs in the area of cut-off circulation. Tight fixation of the prosthesis could increase intra-abdominal pressure due to blood stasis in the vessels of the lower limbs and loss of elasticity of the tissues of the anterior peritoneal wall after laparotomy in the field hospital, and increase blood stasis in the stump. Prolonged standing on the prosthesis combined with muscle overstretching may well have increased the hydrostatic blood pressure and exacerbated the circulatory disturbance. According to known data[18] the pressure on the residual limb in tibia prostheses at the level of the seating contour exceeds physiologically acceptable values by 2–2.5 times. These factors were further summarized with an increase in subfascial pressure in the fascial-muscular cases, which, with continued loading, caused chronic compartment syndrome in the anterior, lateral, and posterior deep fascial cases. The load on the tibial stumps increased due to partial loss of peroneal support and the presence of paired amputation.[8] After amputation of both limbs, the patient uses 4 times more energy for locomotion.[18]

The goal of prosthetics is to create pressure on the residual limb so that it decreases from distal to proximal.[18] When areas of functional overstrain occur, a reparative reaction develops, which leads to a rapid increase in bone mass and hyperostosis. The development of hyperostosis from overstrain is accompanied by activation of compact bone remodeling. It causes rarification and temporary lowering of the mechanical strength limit, which we observed (Figure 1).

After amputation, as a result of a persistent increase in functional load in the bone stump, microcirculation conditions and functional relations between intraosseous and paraosseous blood supply basins change,[14,17] which causes adaptive bone remodeling. This process is greatly enhanced by increased intrathecal pressure, local hypertensive-ischemic syndrome (compartment syndrome) occurring in the conditions of closed bone-fascial cases.[30,31] An increase in subfascial pressure by 1.5–2 times causes disturbances in the arteriovenous gradient, leading to a block of capillary blood flow and promoting tissue necrosis.[31] According to the theory of changes in arteriovenous gradients,[32] it is believed that an increase in subfascial pressure leads to an increase in local pressure, which causes a decrease in the local arteriovenous gradient. Gradually, blood flow in the capillaries slows down, which leads to a decrease in metabolic processes between the blood and surrounding tissues.[30,31] In the zone of circulatory shutdown, a blockage of the microcirculatory bed occurs. Due to intravascular coagulation and the formation of antigen-antibody reaction products, ischemic necrosis of bone and bone marrow occurs. When the repetitive loading was continued without adequate rest, the constant stress on the more porous bone resulted in increased strain, accumulation of microdamage, and bone resorption due to remodeling until the microcracks fused and fracture occurred.[8] Overexertion, aggravated by impaired blood supply to the bone as a result of the compartment syndrome, only accelerated the process of stress fracture formation. Since the reparative reaction to overstrain is aimed at compensating for the changes that have occurred, it should be considered a compensatory process that causes bone thickening - hyperostosis. The resulting fractures are already classified as decompensation.

In view of the above, we, like other authors,[33] believe that biomechanical measurements of soft tissue are promising, including approaches to measure forces and pressure distributions between the stump and receiving socket, as well as assessing soft tissue deformations under load. In the future, equally promising and needed is the use of a pneumatic reconfigured socket for transtibial amputees, which can reduce interface pressure at target points by up to 61%.[34] After fracture healing, kinematics and biomechanical factors causing fractures should be monitored and corrected.

The most important limitation of the study is that it does not allow a number of theoretical and biologic explanations. In spite of the fact that clinical MRI is the most recommended technique for the early diagnosis of stress fractures, it is focused on monitoring the fissure of adjacent maternal tissues rather than on the damaged components of the bone. Both healthy and damaged bone are invisible on conventional clinical MRI.[21] Scintigraphy, which is considered the gold standard of diagnosis, was not used because of the high cost and the sufficiency of the radiographic picture. Biomarkers of bone metabolism were not studied. However, in our case, a sufficient level of diagnosis was obtained through history, typical signs, X-rays, and a thorough physical examination. However, it should be emphasized that a number of factors (circadian rhythm, irregular diet, lifestyle) can affect the variability of metabolic and bone biomarkers[35] and cannot be used for the diagnosis and prognosis of stress fractures. Genetic testing was not performed because it would not provide information to identify genetic differences, as the case was an isolated one. Another limitation was the lack of study of the trunk and lower limb movement patterns.

A number of errors were made in the diagnosis and follow-up of the patient, which are useful to consider in such cases:

- amputation pairing, loss of bone quality were not taken into account;
- type and intensity of physical activity, reduction of residual limb muscle mass were ignored;
- the factor of pain after physical activity that disappears after rest (the most common symptom of stress injuries) was not taken into account at the early stages of rehabilitation;
- the factor of swelling that persisted after rest was not taken into account;
- no prosthetist supervision;
- no MRI examination was performed at the onset of early symptoms and no area of loss of compact bone density was noted on radiographs;
- chronic compartment syndrome was not diagnosed.

The clinical significance of this information is important for surgeons, prosthetists, and rehabilitologists, as it expands their knowledge of the possibility of stress fractures in military personnel who, in their daily activities, endure heavy physical loads, including carrying weapons and ammunition, without adequate rest, which causes bone microfractures that do not have time to heal. Combat injury with limb detachment, blood loss and amputation can serve as a starting point for the development of circulatory failure in the remaining limb. The pause between the formation of the residual limb and its preparation for prosthetics causes muscle weakening and the onset of osteoporosis. Prosthetics with a support function inappropriate for the newly formed organ (residual limb) changes the nature and degree of load on the residual limb. Failure of prosthetics and the patient's desire to return to activity as quickly as possible without proper supervision by prosthetists can lead to stress fractures and compartment syndrome.

To prevent stress injuries, patients should be instructed to limit physical activity to unweighted exercise for 6 weeks. After that, activity, muscle massage, and physical procedures can be gradually increased. Regular and periodic physical activity of considerable intensity before enlistment is an important preventive measure for the development of stress fractures.

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The described case demonstrates the possibility of stress fractures in amputation residual limb stumps due to excessive strain during the development of prostheses and their poor adjustment.

Conclusions

If a patient with an amputation stump complains of muscle and bone pain that appears after exercise and passes after rest, and reparative reaction revealed on radiographs, functional overstrain of the bone should be suspected, which can potentially lead to a stress fracture. The causes of stress fractures in the patient were acute overstrain of the bone tissue during prosthesis development, noncompliance with the loading and resting regimes, and local disturbance of the bone blood supply due to the narrowed rigid socket of the prosthesis. Stress fractures of the bone tissue of the amputation stump contain elements of insufficiency and fatigue. Chronic compartment syndrome can exacerbate and mask the stress fracture.

Ethics Approval

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 report no conflicts of interest in this work.

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