RADIODIAGNOSIS OF THE RESIDUAL LOWER LIMB CHANGES IN PROSTHETIC REPAIR

UDC 617.57/.58–089.844–073.7
Received 4.11.2012

© **A.Yu. Vasil'iev,** D.Med.Sc., Professor, Corresponding Member of Russian Academy of Medical Sciences, Head of the Department of Radiodiagnosis;
E.A. Egorova, D.Med.Sc., Professor, the Department of Radiodiagnosis;
M.V. Smyslenova, D.Med.Sc., Professor, the Department of Radiodiagnosis

Moscow State University of Medicine and Dentistry named after A.I. Evdokimov, Delegatskaya St., 20/1, Moscow, Russian Federation,127473

The aim of the investigation was to assess the efficiency of different radiological methods to diagnose the abnormalities and diseases of residual lower limbs after amputations.

Materials and Methods. We represented the results of stump state assessment in 120 patients after lower extremity amputation for injuries. We analyzed the possibilities of various radiological methods to determine the extremity stump condition before and after prosthetic repair.

Results. We demonstrated the advantages of digital microfocus radiography in determining structural changes of the residual bone compared to conventional radiology. Multispiral computed tomography is a clarifying method required for a more detailed type assignment and topographic anatomy characteristic of the pathological changes of the stump tissues. Ultrasound appeared to be the most informative to study soft tissue structures of the residual limb (determination of inflammatory infiltration, hematomas, neuromas, foreign bodies, and the character of hemodynamic and degenerative changes).

Key words: lower extremity stump; extremity injury and damage; digital radiography; digital microfocus radiography; multispiral computed tomography; ultrasound.

One of the reasons of limb amputation is severe damage of limb soft tissues and bones due to injuries. According to the data of the Ministry of Health Care and Social Development of the Russian Federation, in 2009 an average accident rate was 86–120 cases per 1000 of adult population. Injury rate in men is 1.5–2 times as high compared to that in women.

Severe limb damages with histotripsy (crushing) occur in 0.7% of cases from the total number of casuals with traumas. Nearly 70% of them suffer damages in everyday life, about 20% — outdoors, and finally — occupational traumatism (7%), traffic accidents (1.9%) and athletic injuries (1.1%).

Amputation is followed by the development of topographic anatomical anomalies, pathological changes of tissues, diseases and defects of a stump that prevent complete rehabilitation and significantly aggravate the patients' disability [1–3].

The residual limb defects are various: short and very long stumps, elevation of truncated muscles, bonesaw-line protrusion, and the tissue redundancy above it, muscle insertion to the scar, skin, etc. These changes usually result in blood supply disturbances and tissue damage in axial load on stump in artificial limb making it impossible to use [4, 5].

Stump diseases (osteonecrosis, osteophytes, osteomyelitis, phantom limb pains, suture sinuses, and persistent wounds) are the consequences of technical errors of the performed operations, the secondary wound infections, irrational repair, etc [1, 4].

Early and precise detection of pathological changes, stump condition assessment are essential in patients' preparation for primary prosthetic repair, as well as in the efficiency control of the final prosthetic solution.

The aim of the investigation was to assess the efficiency of different radiological methods to diagnose the abnormalities and diseases of residual lower limbs after amputations.

Materials and Methods. We examined 120 male patients with femoral and lower leg stumps after amputations due to damage. Mean age of patients was 32.6±1.2 years. During the examination the complaints and past histories were considered, as well as general condition and local state were assessed.

Radiodiagnosis of residual limbs included:

digital radiography in standard positioning in two mutually perpendicular views with further digital image processing using digitizer;

digital microfocus radiography with 5-fold image magnification on “Pardus-150” (Russia). The tube head was placed 5 cm away from a stump apex, and film cassette — under the table of the radiograph 25 cm apart; the images were further digitally processed using a digitizer.

multispiral computed tomography followed by multiplanar and three-dimensional image reconstruction;

ultrasound (US) using linear-array transducer with 5.0–8.0 MHz frequency. A stump was scanned along the anterior and posterior surfaces crosswise and lengthwise. On examination we traced the course of neurovascular bundles using both the gray scale US and pulse wave

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For contacts: Egorova Elena Alekseevna, phone: 8(495)611-01-77, +7 919-728-57-11; e-mail: eegorova66@gmail.com

Doppler, power Doppler, color flow mapping, and studied a postoperative scar thoroughly by multiple views.

Results and Discussion. The patients were prepared for primary prosthetic repair for 40–45 days after the amputation. By the end of this period a functional stump should be formed, and it has: 1) cylindrical shape of coronary part with musculocutaneous flap 1–5 cm thick; 2) preserved axis of stump bone and a compact endplate developed at bonesaw-line; 3) no clinically significant osteophytes, destruction signs, marked atrophy and osteoporosis; 4) no contractures of adjacent joints, muscular atrophies, chronic pain syndrome; 5) postoperative scar with no inflammatory signs.

Complex clinical and radiological examination of the patients carried out 1–1.5 months after the amputation of lower extremities showed the development of a functional stump ready for primary prosthetic repair in less than 10% of cases. The rest 109 patients (90.8%) were found to have abnormalities or diseases of extremity stumps that occurred under the influence of external or internal factors due to surgical procedures or secondary wound infection. The following conditions were referred to as stump abnormalities: inefficient amputation level, the change of a stump size and thickness of soft tissues, adjacent joint mobility defect, misalignment of stump axis, mainly, clinically recognized. Bone and periosteal pathologies; inflammatory and degenerative changes of an adjacent joint, soft tissues and a postoperative scar that could be reliably confirmed by radiology were considered to be stump diseases.

Abnormal, extremely long stumps (up to the level of the lower third of an extremity) requiring re-amputation were detected by standard radiography in 29 patients (24.2%), among them: in 27 (22.5%) patients the amputation was performed at the level of the lower third of the thigh, and in 2 (1.7%) patients — at the level of the lower third of the lower leg. Extremely short femoral and lower leg stumps (their length did not exceed 6–8 cm) were found in 27 patients (22.5%): 12 patients (10.0%) had amputations performed at the level of the upper third of the thigh and 15 (12.5%) — at the level of the upper third of the lower leg, and it made the prosthetic repair difficult. Abnormal stump condition in 32 patients (26.7%) was due to the redundancy or deficiency of soft tissues in the coronary part of the stump, therefore, the stumps were conical or club-shaped (Fig. 1).

Along with functional alterations and soft tissue wound healing the endplate developed at the bonesaw-line. In uncomplicated course of the postoperative period the endplate was visualized radiologically as a compact substance 2–3 mm thick, of linear form, with clear smooth contour, that completely overlapped marrowy canal (Fig. 2).

The changes in the form of distal parts of bone stump and bonesaw-line revealed by digit microfocus radiography were due to the characteristics of the endplate development, as well as the intensity of periosteal reactions that occurred

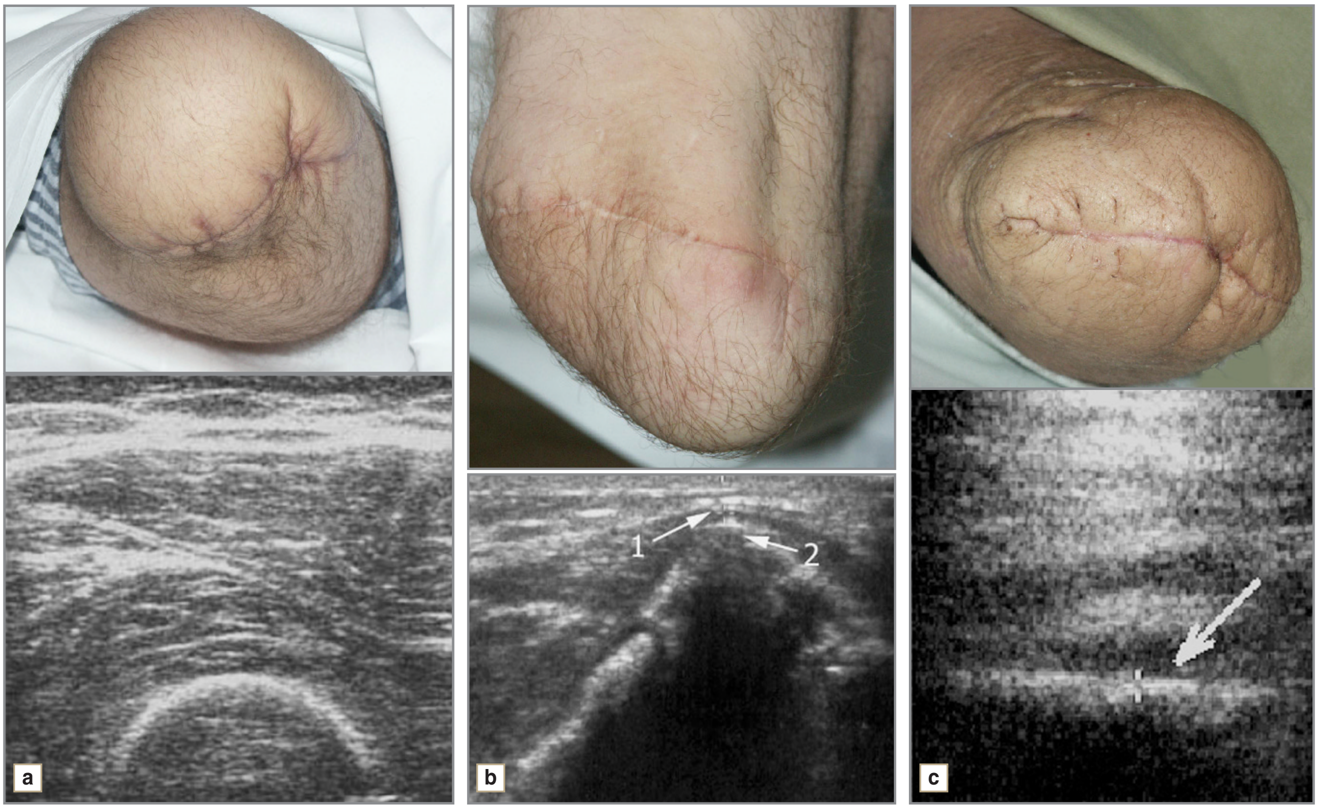

Fig. 1. Types of amputation stumps distinguished by musculocutaneous flap thickness (according to clinical study and US findings): *a* — cylindrical stump with sufficient soft tissues in the coronary part (from 3 to 5 cm); *b* — sharply conical stump with the thickness of musculocutaneous flap above the bone less than 1 cm (*1*, *2*); *c* — club-shaped stump due to soft tissue redundancy, the thickness of which exceeds 5 cm (an arrow on sonogram indicates the cortical layer)

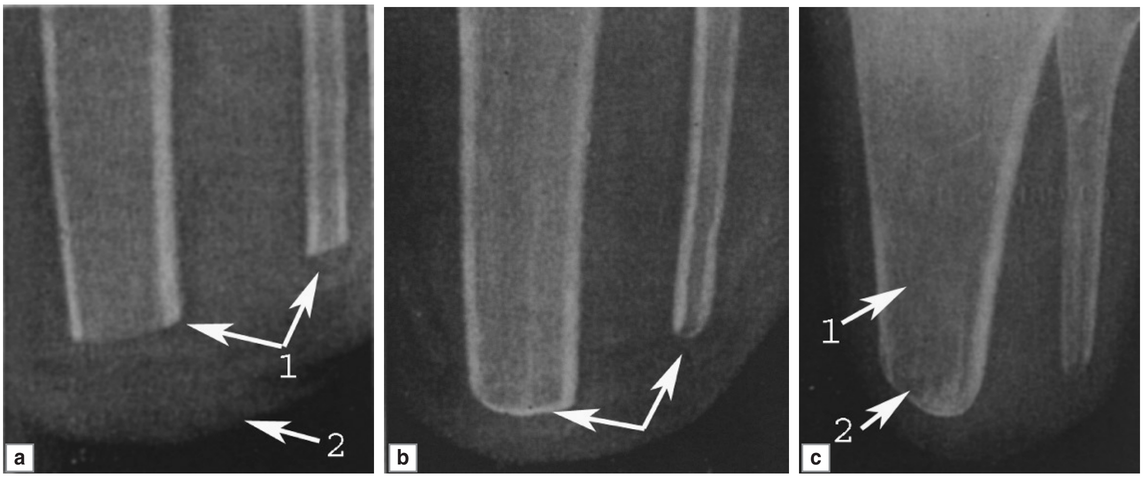

Fig. 2. Radiographic changes of the left lower leg stump of a 27-year-old patient Ch. (from film library of N.S. Kosinskaya): *a* — 6 days after the amputation, the margins of the bonesaw-line are smooth, tapered; endplates are not seen (*1*), soft tissues edema is observed (*2*); *b* — 6 weeks after the amputation, the endplates at bonesaw-lines developed, they merge with cortical substance (arrows), the bonesaw-line edges are rounded, there is no soft tissue edema; *c* — 4 years after amputation osteoporosis developed (*1*), cystic alterations (*2*) and moderate atrophy of thigh-bone stumps, their edges getting moderately cone-shaped

under the influence of various factors (contamination or aseptic conditions), and in most cases were the source of osteochondromas — osteophytes. They were characterized in accordance with the features of their structure, the base localization, and growth orientation. By the base localization, the osteophytes were divided into axial (endosteal), boundary and paraosseous osteophytes.

Axial (endosteal) osteophytes were located on bonesaw-line area and distally directed (Fig. 3). Boundary osteophytes were always at the bonesaw-line margin. Paraosseous osteophytes were found on diaphysis surface in those skeletal parts where muscles and tendons are attached, e.g. pilaster of Broca. They were subdivided into end osteophytes located within 3 cm from the bonesaw-line (Fig. 4), and basal osteophytes located over 3 cm away from the bonesaw-line, and formed due to periosteal excessive intensity, and enthesis calcification (Fig. 5).

By growth direction the osteophytes were divided into cranial, caudal, and transverse. Cranial osteophytes grew from the bonesaw-line towards an adjacent joint. Caudal osteophytes, on the contrary, grew in the direction of the bonesaw-line. Transverse osteophytes were located perpendicular to diaphysis axis.

It should be noted, that in some cases osteophytes were diagnostical findings, with no clinical presentation. Their size and dimensions had no significant effect on the stump support ability. Axial caudal osteophytes were of clinical importance since they could cause inflammatory changes of underlying tissues and marked pain senses when using an artificial limb.

In addition to the study of bone contours, position and shape by the assessment of radiodiagnostic findings, we performed a thorough analysis of bone structure, which corresponded to the norm immediately after the amputation. Degenerative processes accompanied by bone mass reduction (osteoporosis, atrophy, cystic alteration) were observed on week 4–5 after the amputation. In this period osteoporosis was detected in 70.0% of patients with femoral and lower leg stumps. Structural alterations were detected most reliably by digital microfocus radiography. Bone tissue appeared more transparent, and in spongy substance there were the radiolucent areas of round shape, 2–7 mm in size (Fig. 6).

The bone remodeling abnormalities in trabecular bone tissue of metaepiphyses had been observed long before. If the extremity stump function was limited due to the defects or diseases, structural bone changes occurred. Persisting for a long time these changes inevitably resulted in bone

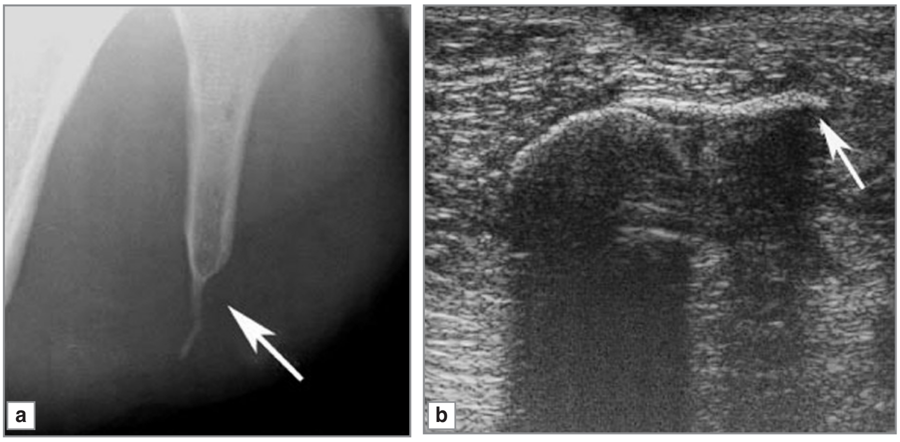

Fig. 3. Axial osteophyte of the left fibular stump: *a* — a digitized multifocal radiograph showing the osteophyte extending to the stump support end, and the tapered endplate assimilating with the osteophyte (arrow); *b* — an echogram with the view of fibular bone stump showing an axial osteophyte in the form of hyperechoic spinous lesion deforming the endplate (arrow)

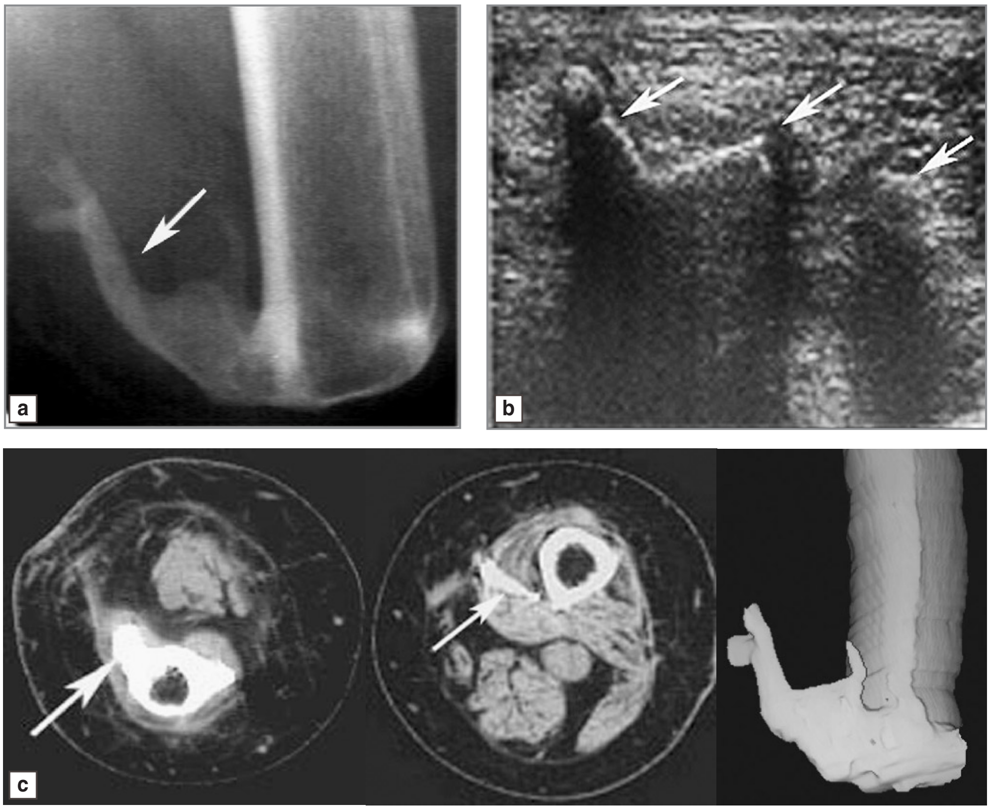

Fig. 4. The end paraosseous osteophyte of the left thigh stump (arrows) that merges with the cortical layer, deviates from the stump shaft for less than 3 cm away from the bonesaw-line extending along the tendons of the muscles. The endplate of the femoral bone stump with clear wave-like contour (*a* — digitized radiograph; *b* — echogram; *c* — computed tomograms of the stump in axial plane with three-dimensional image reconstruction)

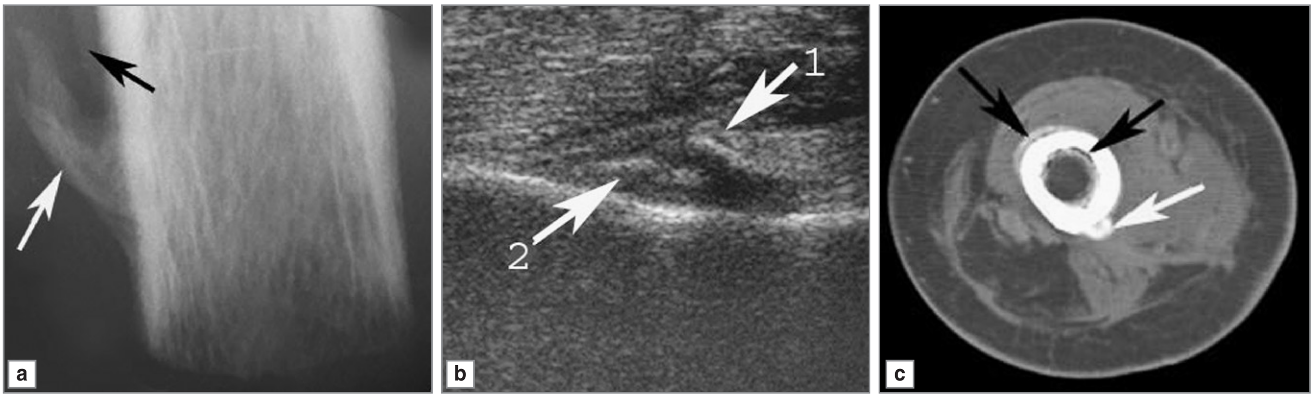

Fig. 5. Basal paraosseous osteophyte of the left thigh stump: *a* — a digitized multifocus radiograph showing a basal conical osteophyte with bone density, extending along the course of the tendons of the muscles, deviates from the shaft for more than 3 cm away from the bonesaw-line merging with the cortical layer (white arrow). There is observed the periosteal reaction in the form of linear periostitis (black arrow); *b* — the osteophyte (*1*) and thickened periosteum (*2*) in the form of hyperechoic structures are clearly seen on an echogram; *c* — a computed tomogram in transverse scanning shows the dilation of bone marrow canal more than 3 cm away from the bonesaw-line, along the medial surface there is seen the osteophyte base, its density is close to cortical substance of bone (white arrow), there is multiple-contour of the opposite part of the cortical layer due to periosteal and endosteal apposition with smooth, indistinct margins (black arrows)

atrophy. Bone stump got thin, turning from cylindrical into conical. In 32 patients (26.7%) with lower extremity stumps, who underwent damage amputation, bone atrophy resulted from neurotrophic disorders in nerve injuries, active reflex (due to chronic pain syndrome) or passive (therapeutic) immobilization. In final prosthetic solutions, atrophy involved, as a rule, stump distal parts only. In case there was no prosthetic repair, atrophy was more expressed, and the stump end was sharply conical, tapered.

Against the background of atrophy and osteoporosis in 60.0% of cases 2–3 months after the amputation there were observed the cystic alterations not only near the bonesaw-line, but also in more proximal parts. As time passed, the process was gradually progressing and reached its maximum by the 5–6th months after the amputation. In this period in 75.0% of patients, cystic alterations in amputation stumps were associated with osteoporosis in 97.1% of cases, and in 65.7% in addition to the abovementioned there was bone atrophy as well.

Thus, in stump skeleton there simultaneously occurred the processes of reparative and degenerative changes, and their intensity was due to the degree of the amputated limb functional compensation and the developed complications.

Significant functional and structural damage was found in 17.5% of patients with lower extremity stumps in osteomyelitis, which complicated the wound healing after the amputation. Osteomyelitis should be differentiated from aseptic osteonecrosis or the so called coronary osteonecrosis (according to D.G. Rokhlin); it developed against the background of tissue damage caused by direct trauma, thromboses, and vascular embolism, as well as technical errors made when performing surgical procedures (high transaction of periosteum, poor blood supply and denervation of flaps, etc).

Unlike septic osteoporosis, aseptic osteoporosis occurs only in the end area of the stump. Most frequently small parts of the bonesaw-line necrotized, less frequently – its most part. In aseptic osteonecrosis there was lacunar bone resorption without suppuration. No end bone atrophy was observed; on the contrary, it looked thickened due to ossification periostosis. Inflammatory changes of soft tissues were insignificant (Fig. 7).

After the detailed stump skeleton study we examined the condition of the soft tissues, and estimated them both visually, and by US, the latter enables to determine adequately: 1) tissue contours (smooth, irregular) and thickness (thinning or thickening); 2) structural changes of skin, subcutaneous fat, muscular tissue (atrophy, adipose, fibrous or combined degeneration, inflammatory changes with or without fistula, traumatic focal pathology — hematomas, seromas, pseudocysts, neuromas); 3) postoperative scar condition (size, contour, position, abnormal changes); 4) the presence of foreign

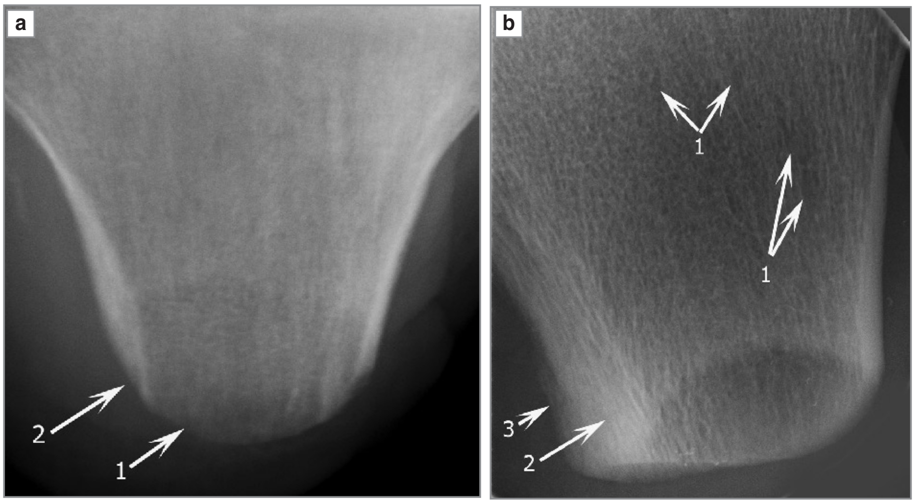

Fig. 6. Extremely short stump of the left lower leg of a 28-years-old patient Kh. (4 weeks after amputation): *a* — a digitized radiograph of the frontal view of the stump showing a smooth bonesaw-line of tibial bone, an endplate is not seen (*1*), transparency of bone tissue is increased, cortical layer is seen indistinctly, with separation of fibers (*2*); *b* — a digitized multifocus radiograph with 5-fold magnification in addition to the changes of spongy substance of the bone stump revealed by standard radiography, shows multiple radiolucent foci of 2.0–5.0 mm (*1*), the cortical layer is spongious (*2*), with linear periosteal apposition (*3*)

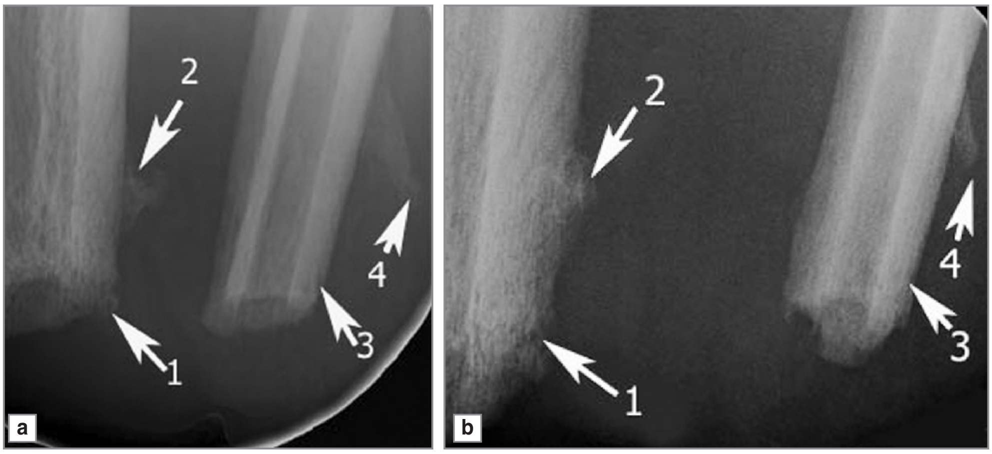

Fig. 7. Digitized radiographs of the left lower leg stump in front (*a*) and oblique (*b*) views show the irregularity of bonesaw-lines of thigh-bones amputated on the same level. No endplates are seen. There is lacunar resorption of the bone distal parts from lateral side with necrotizing bone fragments (*1*, *3*). Detached periosteum, its boundary is over 3 cm away from the bonesaw-lines, with ossification signs; paraosseous basal osteophytes are forming, with cranial (*2*) and caudal (*4*) growth direction. Conclusion: coronary osteonecrosis of the stumps of thigh-bones of the left lower leg

bodies; 5) blood flow change (thrombophlebitis of the great saphenous vein in 1.7% of patients, arteriostenosis in proximal parts of the stump — in 27.5% and in the bandage place — in 60.8% patients).

Conclusion. We compared the possibilities of various radiological techniques applied to estimate lower extremity stumps after amputations performed after damages, and the cmparison indicates the necessity to use a complex clinical and radiological study. Digital microfocus radiography gives objective information on the condition of femoral and lower leg stump skeleton, and has advantages over standard radiography in detecting thin structural changes of bone tissue.

Ultrasound was found to be highly informative in revealing blood supply disturbances of lower extremity stumps, as well as focal and diffuse pathological changes of soft tissues that can make the prosthetic repair difficult.

Multispiral computed tomography is an additional method required in diagnostically complex cases to receive the details of the obtained data and clarify the condition of the stump skeleton and soft tissues.

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