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Dynamics of tibial cortical bone density in patients with closed lower leg fractures at treatment stages

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Purpose To study the dynamics of tibial cortical plate density during treatment of tibial fractures with transosseous osteosynthesis using computed tomography **Material and methods** Multislice computed tomography was used to study the density of the cortical plate in 35 patients with closed tibial fractures managed with Ilizarov fixation at various stages of treatment. **The results** showed that the density of the cortical plate of the intact tibia in patients with tibial fractures had topographic differences. It was greater in the diaphysis region that in the metaphysis ($p < 0.01$). Total density values of the cortical plate differed from the indices in the middle zone, in the lateral and medial parts. The density of the cortical plate in patients with tibial fractures decreased both in the intact and in the injured limb during treatment, but fluctuations of density did not exceed 150-200 HU. **Conclusion** The method of multislice computed tomography enables a dynamic study of cortical plate density and degree of its restructuring during treatment of fractures to solve the issue of fixation and rehabilitation period duration.

Keywords: tibia, fracture, cortical plate, computed tomography

INTRODUCTION

Fractures of the lower leg bones are among the most common limb injuries. They comprise from 20 to 37.3 % in the structure of the total of fractures of all locations and up to 60 % of fractures of tubular bones [1-5]. Among the fractures of both bones of the lower leg, the most frequent are spiral fractures on the border of the middle and lower thirds. Treatment of fractures of the distal part of the lower leg is still quite a difficult task, which is due to both the severity of the injury itself and possible errors in diagnosis and treatment, which results in a long period of working incapability, and in some cases, disability [2, 6-8]. An important issue in the treatment of fractures of the lower leg bones is the cost of their treatment. According to American authors, the expenditures range from 3,400 to 5,300 US dollars depending on the treatment method while the financial costs for the society range from 12,500 to 17,300 USD [2, 9].

Multi-position radiography is the main method for diagnosing fractures of the lower leg bones and their union [10-13]. However, radiography is not sufficient in examination of the fractures in the proximal or distal part of the tibia and control of their repair with transosseous osteosynthesis. Therefore, various imaging techniques are used such as ultrasound, MRI, MSCT [11, 14-18].

The union of lower leg fractures may differ in the type of prevailing bone callus (periosteal, endostal, intermediary), time of its remodeling and assimilation with bone cortex (cortical plate), the strength of which is the main criterion in assessing the degree of fracture union by fixation with different methods. The most objective criterion for assessing the state of the cortical plate is its density and three-zonal structure, determined with the method of computed tomography [19-21].

The purpose of the study was to evaluate the density of the cortical plate in patients with closed fractures of the lower leg bones in the intact and injured extremity which was fixed with the Ilizarov apparatus at various stages of treatment.

MATERIAL AND METHODS

The computed tomography (CT) and multislice computed tomography (MSCT) was used in 35 patients aged 25 to 50 years with closed oblique and transverse fractures of the lower leg bones in the middle third and at the border with the lower third. There were 25 males and 10 females. MSCT studies were performed with the scanners Siemens Somatom AR-HP, GE Light Speed VCT and Toshiba Scanner Aquilion-64. The

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data were processed with the main CT console or with the help of MMS LEONARDO. In axial sections, the total and local density of the cortical plate of the intact and injured tibia was measured at different levels before treatment (**Fig. 1**). The total and local density of the cortical plate was determined after 28-30 days of fixation, after the dismantling of the apparatus and at long term in all patients (**Fig. 1**).

The study was carried out in accordance with the ethical standards of the Helsinki Declaration of the World Medical Association as amended by the ministry of health of the Russian Federation. It was approved by the Ethical Committee of the RISC for RTO of the ministry of health of the Russian Federation. All patients signed informed consent for the publication of scientific findings without their identification.

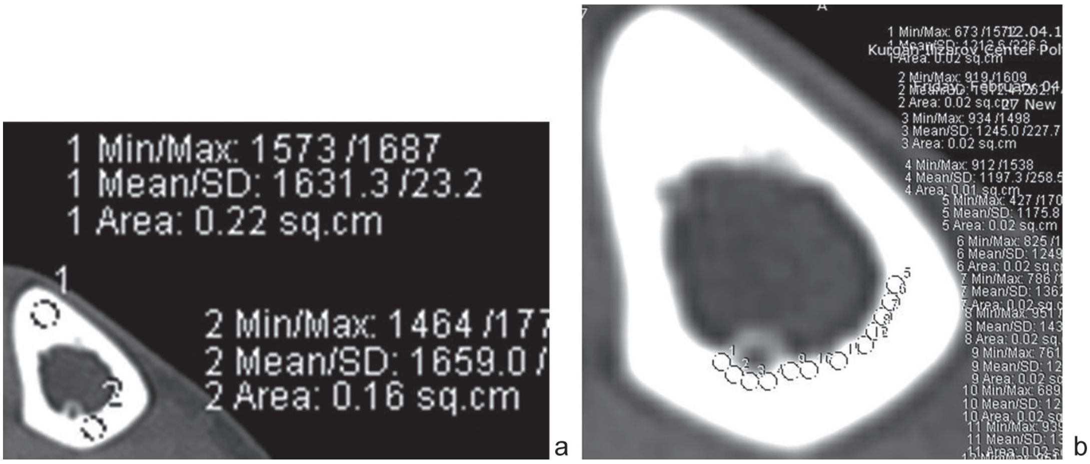

Fig. 1 MSCT of the tibia in a patient with a closed fracture of the tibia; axial slice; measurements of the total density of the cortical plate along the anterior and posterior surfaces of the tibia (a) and local density of the layer of the internal plates of the cortical plate along the posterior surface of the tibia (b)

RESULTS

Differences in density of the cortical plate of the metaphysis and diaphysis both in the intact limb and in the damaged one were revealed in patients with closed fractures of the diaphysis of the lower leg bones. In the anterior metaphysis, the density of the cortical plate at the level of the tibial tuberosity was lower than on the posterior surface, and differed by 661.89 ± 67.21 HU ($p < 0.001$) (**Fig. 2**).

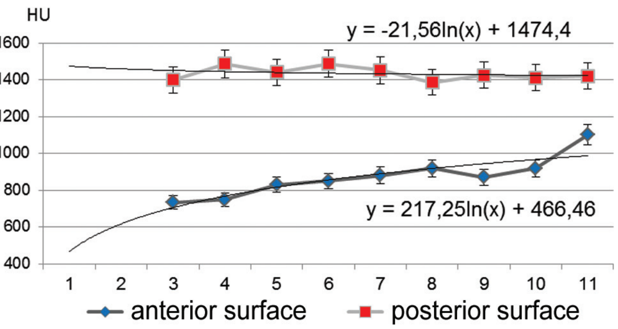

Fig. 2 Diagram of the cortical plate density along the anterior and posterior surfaces in the metaphysis of the intact tibia in patients with fractures of the lower leg bones

Figure 3 shows the axial section of the tibia at the metaphysis level the with cortical plate density measurements on the anterior and posterior surfaces.

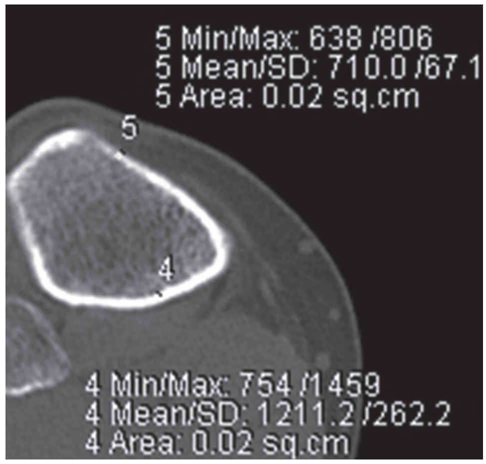

Fig. 3 MSCT of the lower leg of the patient with a fracture of the tibia: axial section at the metaphysis level. The density of the tibial cortex on the anterior surface is 710.0 ± 67.1 HU (point 5), on the posterior one – 1211.2 ± 262.2 HU (point 4)

In the area of diaphysis, the differences in the total density of the cortical plate along the anterior and posterior surfaces were unreliable.

There was a significant increase in the density of the cortical plate along the bone from the metaphysis in the distal direction. All the patients showed an increase in the density of the cortex in the distal direction when measuring it on the MPR in the sagittal plane. The maximum values (1681.25 ± 33.19 HU) were in the middle third of the diaphysis (**Fig. 4**).

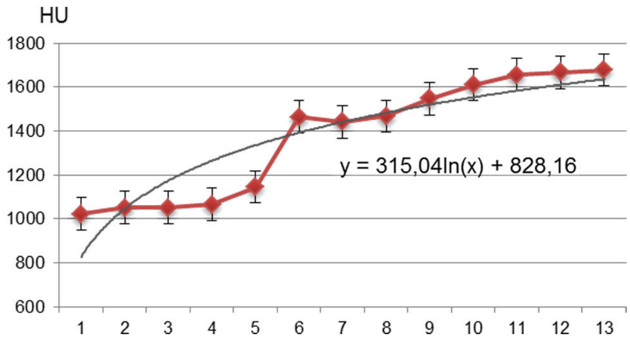

Fig. 4 Diagram of the cortical plate density in the metaphyseal and diaphyseal parts of intact tibia in patients with closed fractures of the lower leg bones (points 1-4 – metaphysis, 5 – at the border with diaphysis, 6-9 – upper third of the diaphysis, 10-13 – middle third of the diaphysis)

Measurement of the local density of the cortical osteon layer in the injured and intact tibias showed a significant difference from the density of the cortex inner and outer layers (**Fig. 5**).

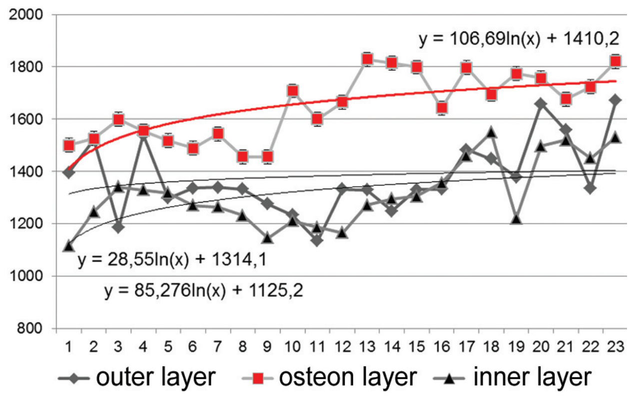

Fig. 5 Diagram of the cortical plate local density of the intact tibia

Table 1 presents quantitative indices of the density of different cortical bone layers of the tibia in the intact limb.

Table 1

Density of the cortical bone layers in the tibial diaphysis of the intact limb in patients with lower leg fractures (HU)

Area of measurments	M ± σ
Layer of external plates	1378.84 ± 186.97
Osteon layer	1724.54[1] ± 117.38
Layer of internal plates	1288.43 ± 151.51

[1] – $p < 0.05$ difference in density of the osteon layer from the layers of internal and external plates

Moreover, there was a significant difference in the density of the osteon layer along the anterior and posterior surfaces of the cortical plate at the level of the diaphysis ($p < 0.05$) (**Fig. 6**).

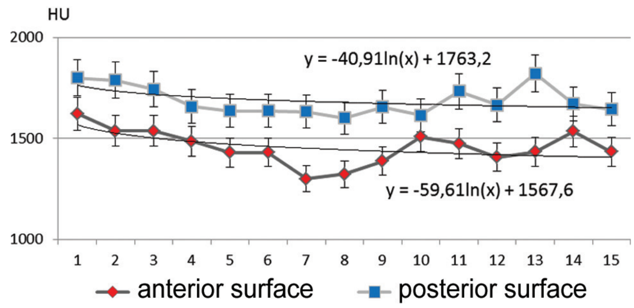

Fig. 6 Diagram of the density of the cortical bone osteon layer at the level of the tibial diaphysis on the anterior and posterior surfaces of the intact limb

The density of the inner and outer layers of the anterior and posterior surfaces differed; however, these differences were unreliable.

After completion of fixation, the density of the cortical plate of the injured limb was different from the intact one, which was especially evident in the density of the osteon layer. However, even at a distance of 1.5 cm from the fracture line, the density of the osteon layer of the cortical plate was not lower – 1534.59 ± 40.91 HU (**Fig. 7**).

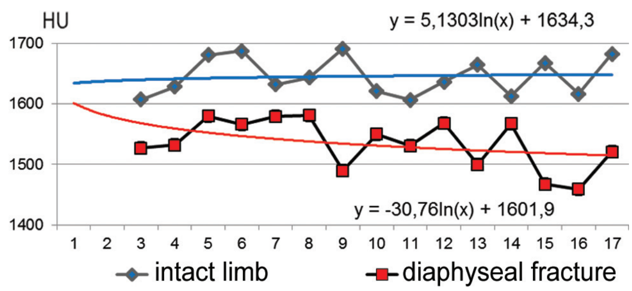

Fig. 7 Diagram of the osteon layer density in the cortical plate in the upper third of the diaphysis on the intact and injured limbs after the end of the fixation of the fracture of the tibia in the middle third (78.5 ± 9.5 days) (intact limb, diaphyseal fracture)

The total density of the cortical plate in the injured limb was lower in this period than it the intact one (1421.74 ± 78.4 HU). After 9 months it increased to 1617.15 ± 174.16 HU. In the fracture zone, the density of the cortical plate was 1436.76 ± 24.49 HU (**Fig. 8**).

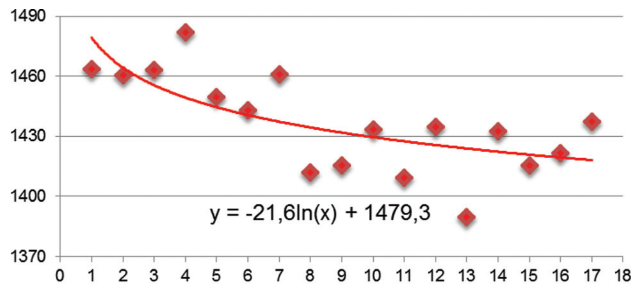

Fig. 8 Diagram of the total density of the cortical plate in the fracture zone at 9 months after treatment

The study of the tibial cortical bone density at different time points of observation showed that after apparatus removal its values were decreased, but in the long-term period (1 year after treatment), the density corresponded to normal values (**Fig. 9**).

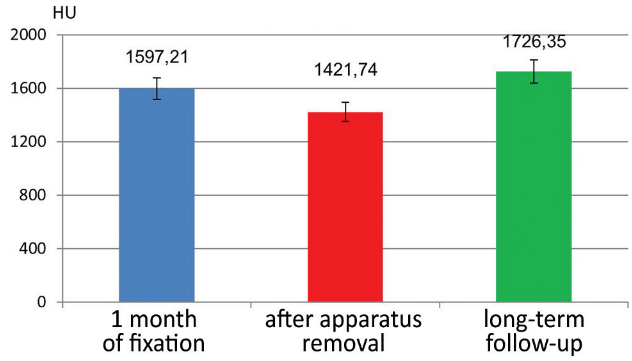

Fig. 9 Dynamics of the total density of the tibial cortical plate at different observation periods

DISCUSSSION

Our studies showed that the values of the cortical plate density when measuring a section extending over its entire thickness differed from the values in the middle zone (osteon layer), in its outer parts (the layer of external bone plates), in the inner part (system of internal common plates). The data obtained by us correlate with the results of N. Kanatani et al. (2006) who, when analyzing the transverse section of the mouse bone with the pQCT method, found that the middle layer of the cortical plate contains twice as many mineral substances as the outer layer and the inner layer (600 and 300 mg/cm^3) [22]. Higher osteon layer density was confirmed by determination of this parameter in Hounsfield units with the MSCT method, which we had found in patients with various pathologies of long bones.

Differences in the total density of the cortical plate in the metaphyseal and diaphyseal parts of the tibia were also revealed. Measuring the density at one point or in a small area of the cortical plate can lead to an erroneous conclusion (both to increased density or reduced one) and subsequent unreasonable recommendations on the timing of the apparatus removal and the limb functional loading following it. Based on this, we came to the conclusion that it is necessary to carry out both general and local density measurements in order to have a complete picture of the cortical bone quality [21]. The density of the cortical plate in patients with tibial fractures during treatment decreased both in the intact and in the injured limb, but the density fluctuations did not exceed 150-200 HU. In the area adjacent to the fracture, the density of the cortical plate decreased by no more than 138.7 ± 56.4 HU. In the long-term treatment period, the density of the cortical plate was normal in the diaphysis of the tibia.

Our data on the density of the cortical plate at different periods of treatment in patients with fractures of the tibia differ from those obtained previously by V.I. Shevtsov et al. (2008) [14]. This is due to the technique of measuring the cortex density. In the work cited, the density was measured on a small portion of the cortical plate in its central part, which corresponded to the density, mainly of the osteon layer. Therefore, the cortical plate density values were somewhat bigger than with the measurement technique used in this study. Density, first of all, was measured over the entire thickness of the cortical plate; then the density of the osteon layer, the layer of internal and external plates was determined. It allowed us to obtain a more objective evaluation.

CONCLUSIONS

1. The density of the cortical plate of the intact tibia in patients with lower leg fractures had topographic differences (it was lower in the metaphyseal region than in the diaphyseal region, $p < 0.01$).

2. The values of cortical plate density when measuring a section extending over the entire thickness differed from the values in the middle zone (osteon layer), in its outer regions (the layer of external bone plates), in the internal part (the system of internal common plates).

3. The density of the cortical plate in patients with lower leg fractures bone during treatment decreased both in the intact and in the injured limbs, but the fluctuations of density did not exceed 150-200 HU. In the area

adjacent to the fracture, the density of the cortical plate decreased by no more than 138.7 ± 56.4 HU.

4. In the long-term period, the density of the cortical plate had normal values characteristic for the tibial diaphysis.

The findings obtained in this study would assist as criteria to assess the degree of fracture union, develop recommendations for the duration of treatment, the timing of the apparatus removal and the functional load on the affected limb in the rehabilitation process.

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