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Bone mineral density of lumbar vertebrae in patients with degenerative spinal diseases

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Abstract

Introduction Bone mineral density (BMD) of the vertebrae is a critical issue before performing stabilizing interventions at the lumbar level. Determination of BMD in Hounsfield units (HU) according to CT data is a more accurate method versus to the "gold" standard – densitometry. **Purpose** To determine BMD of key anatomical areas of the lumbar vertebrae in HU and correlate with densitometry data. **Methods** A retrospective cohort of patients was studied prior to decompression and stabilization intervention at the lumbar level. The BMD of each lumbar vertebra in its different anatomical regions in HU was assessed according to CT of the lumbar spine and was compared with densitometry data. **Results** In the roots of the L2-S1 arch of the vertebrae, BMD was significantly higher than in the bodies of the same vertebrae ($p < 0.01$); in the L1 and S1 vertebrae, the difference in BMD between the body and the roots of the arch was not significant. An increase in the density of bone tissue in the vertebral bodies to the underlying levels was determined; BMD in the roots of the arch also increases, but only up to the L5 vertebra. BMD in the roots of the arch of the S1 vertebra is significantly lower than in the overlying L5 vertebra ($p = 0.032$). **Discussion** The obtained findings supplement the reported data in the current literature. The HU value is a more accurate and significant parameter of BMD, which should be considered in the practice by a spinal surgeon. **Conclusions** According to CT data of the lumbar spine, the BMD of L2-L5 in the arch roots is significantly higher than in the vertebral bodies. The BMD of the S1 vertebra in the arch roots is significantly lower than in the L5 vertebra. It may be the reason of high failure rate of caudal fixation at this level. Particular attention should be paid to the planning and surgical techniques in patients not only with osteoporosis but also with osteopenia. BMD findings obtained by densitometry in these conditions do not have a significant difference.

Keywords: bone mineral density, lumbar spine, Hounsfield units, computed tomography (CT), degenerative diseases of the spine

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INTRODUCTION

Decompression and stabilizing operations have been widely used in the surgical treatment of degenerative diseases of the lumbar spine. However, in 1 to 27 % of patients with normal bone tissue parameters and in 60 % of patients with decreased bone density, bone tissue resorption around screws and interbody implants, subsidence of the latter is detected after decompression and stabilization operations [1, 2]. Bone tissue resorption around the screws can cause failure of the artifact block, chronic pain syndrome, fracture of bone structures, and migration of the implant which requires a revision intervention [3, 4]. Decreased bone mineral density is one of the most important risk factors for screw fixation failure [5, 6].

Evaluation of bone density by densitometry is the "gold" standard of preoperative planning and is able to identify patients at risk. It has been shown that severe degenerative changes in the lumbar spine affect the interpretation of densitometry results and lead to false-negative values [7, 8]. Subsequently, it may interfere with the correct planning of surgical tactics. Thus, it was proposed to determine the mineral density of bone tissue with CT scanning of the lumbar spine, estimating the density in Hounsfield units (HU) [9, 10]. This method is capable to measure the density of cancellous bone, excluding cortical bone, what is important in patients with reduced BMD. Based on the density of the L1 vertebra, threshold values of 110 HU for detecting osteoporosis and 135 HU for detecting osteopenia were established. The specificity of these parameters is 90 % [9]. Moreover, since CT of the lumbar spine is a common preoperative examination for patients who are scheduled for decompression and stabilization surgery, bone density can be measured using CT without additional costs and radiation exposure.

For the surgeon, the important anatomical areas of the vertebra are the pedicles of the arch, through which the pedicle screws are passed, and the vertebral body. Failure of screw fixation occurs in the cranial and caudal segments with polysegmental fixation and in the caudal segment with single-level fixation [5, 11, 12]. It was found that the HU of L1 to L4 vertebrae is a significant predictor of bone resorption around the screws [1, 8, 13]. Threshold values of HU in the L3 (≤ 130 HU in the vertebral body, ≤ 340 in the pedicle including cortical bone) were determined. In lower values, the probability of screw fixation failure significantly increases. However, there are no such data for the most frequently operated lower lumbar segments L4-L5 and L5-S1. Do they have the same patterns as the overlying vertebrae?

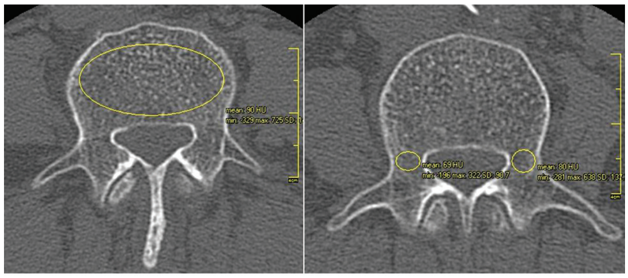
Despite the existence of studies on the HU level of the vertebrae in patients with degenerative diseases of the spine, the issue of the features of the bone tissue of the vertebrae at different levels of the lumbar spine remains debatable. The purpose of the work was to determine the HU parameters of the key anatomical zones of the lumbar vertebrae and their correlation with densitometry data.

MATERIAL AND METHODS

The design of the study was a retrospective cohort study. The study included patients of the Department of Degenerative Diseases of the Spine admitted for decompression and stabilization interventions at the lumbar level. The study was approved by the local ethics committee and performed in accordance with the Declaration of Helsinki. Inclusion criteria were indications for decompression-stabilization intervention at the lumbar level, examination with the use of densitometry and CT of the lumbar spine at the preoperative stage. The criteria for exclusion from the study were previous stabilizing intervention at the lumbar level, and traumatic changes in the lumbar vertebrae.

Demographic and radiological data were analyzed. Radiological diagnostic data included assessment of bone mineral density with densitometry (HOLOGIC) and CT scans of the lumbar spine (Definition, Siemens). Densitometry for bone mineral density assessed the L1-L4 vertebral bodies, femoral necks and the non-dominant forearm. The T-score was calculated automatically. A T-score value > -1.0 was considered normal, a value of ≤ -1.0 indicated osteopenia, and a T-score ≤ -2.5 diagnosed as osteoporosis.

Bone mineral density of the body of each of L1-S1 vertebrae was determined with CT. The measurement was performed on mid-axial sections of the vertebral body (Fig. 1a). In addition to the main method for determining the mineral density of the vertebral bodies, the density of bone tissue in the pedicles of the vertebral arch was calculated. Axial sections of CT images were used for calculations, measuring bone density three times at the widest point of each pedicle (Fig. 1b); the data of one vertebra were averaged.



a b

Fig. 1 Measurement of bone mineral density: a – vertebral body; b – pedicles of the arch

Trabecular bone was included in the measurement area, while cortical bone and posterior venous plexus were excluded. The calculation of BMD in Hounsfield units (HU) was performed automatically by the software program. The average bone mineral density of L1-L5 vertebrae in HU was used to determine the mineral density of the lumbar spine as a whole.

Statistical analysis

The results of the study were processed using the calculation of descriptive statistics (for quantitative variables, the mean value is M, the standard deviation is m, the results are presented as M ± m) and by comparing quantitative and qualitative signs in the studied groups of patients. Nonparametric methods were used for the analysis. Differences between the compared mean values of the studied parameters in the groups were assessed using the nonparametric Mann-Whitney U-test. The level of threshold statistical significance (p) was equal to 0.05 ($p \leq 0.05$). SPSS 15.0 software was used for statistical data processing.

RESULTS

The study included 57 patients, mean age 56.1 ± 11.9 years (range, 25 to 75 years), 22 (38.6 %) males and 35 (61.4 %) females among them. Osteopenia was diagnosed in 15 patients and osteoporosis in 5 patients with densitometry; in the remaining patients (n = 37), bone mineral density was within normal limits.

Characteristics of the bone tissue of patients according to CT data of the lumbar spine, measured at admission, are presented in Table 1. The HU value in patients with normal densitometry levels was significantly higher than in patients with osteopenia and osteoporosis ($p < 0.05$). This pattern was traced both for the vertebral bodies and for the pedicles of the arch. At the same time, the HU value in patients with osteopenia and osteoporosis did not differ from each other ($p > 0.05$).

Table 1

BMD of vertebrae, CT findings in the lumbar spine, HU

	Vertebral body	Pedicles
Norm (n = 37)	171.9 ± 43.7	207.3 ± 44.7
Osteopenia (n = 15)	130.6 ± 23.9	162.1 ± 19.0
Osteoporosis (n = 5)	114.7 ± 51.1	129.3 ± 72.6
Norm vs osteopenia	0.002	< 0.001
Norm vs osteoporosis	0.012	0.032
Osteopenia vs osteoporosis	0.553	0.554

Bone density of the bodies of all lumbar vertebrae increased from cranial to caudal vertebrae. However, in the pedicles of the vertebral arch, bone density increased only up to the L5 vertebra; in the pedicles of S1 vertebra, bone density was lower than in the L5 vertebra (Table 2).

Table 2

Bone density of lumbar vertebral levels, HU

Spinal level	Vertebral body	Pedicles	p-value
L1	145.5 ± 49.4	156.4 ± 62.9	0.482
L2	144.6 ± 50.9	174.9 ± 53.4	0.001
L3	137.2 ± 46.6	187.5 ± 55.5	< 0.001
L4	143.9 ± 49.9	208.6 ± 61.9	< 0.001
L5	159.9 ± 59.6	212.3 ± 57.7	< 0.001
S1	191.1 ± 54.1	192.6 ± 51.5	0.941

In general, in the pedicles of L2-S1 vertebrae, the density of bone tissue was significantly higher than in the bodies of the named vertebrae; in L1 and S1 vertebrae, the difference in bone density between the body and the pedicles was insignificant.

In patients with normal bone tissue parameters according to densitometry data and in patients with osteopenia, the difference in the density of the vertebral body and pedicles was significant only in L2-L5 vertebrae, while in patients with osteoporosis, the difference at all levels was insignificant (Table 3). Moreover, the density of bone tissue in the pedicles of the S1 vertebra was significantly lower than in the overlying L5 vertebra (p = 0.032).

Table 3

Significance of differences in bone density of the vertebral body and pedicles of the vertebral arch at the levels of the lumbar spine, p-value

Spinal level	Norm, difference between body and pedicles	Osteopenia, difference between body and pedicles	Osteoporosis, difference between body and pedicles
L1	0.371	0.436	1.000
L2	0.030	0.016	0.420
L3	0.000	< 0.001	0.690
L4	< 0.001	< 0.001	0.730
L5	< 0.001	< 0.001	1.000
S1	0.598	0.115	0.841

DISCUSSION

Bone resorption around the screw does not necessarily mean segment instability and requires reoperation. However, Bredow et al. reported that the rate of revision surgery in the event of resorption was about 50 % [1]. As far as the majority of patients with degenerative diseases of the spine are people of the older age group who need surgical treatment with extended screw fixation, the combination of such risk factors greatly increases the likelihood of bone resorption around the screws and failure of the metal structure [14].

Resorption is a consequence of remodeling of the bone tissue surrounding the screw due to a decrease in the load transmitted through the bone tissue between the structural elements, as well as due to excessive load and microdestruction of the bone above and below the implant structure [6]. Moreover, high local stresses at the interface between the bone and the screw due to inadequate anterior support may also lead to bone resorption around the screws [15]. Bone tissue of reduced density hardly undergoes the process of remodeling. Therefore, patients with osteopenia and osteoporosis are more at risk of metal structure instability. In patients with degenerative diseases of the spine, the determination of bone density in the HU according to CT data more accurately reflects the true value [16], and also predicts the likelihood of bone resorption around the screws with greater sensitivity and specificity [1, 9]. Thus, in patients with degenerative diseases of the spine with normal indicators of bone tissue according to densitometry, osteoporosis was detected in 25.9 % of cases with the use of CT of the lumbar spine [17]. Moreover, it has been shown that the value of bone density in the L1 vertebra of 135 HU is the threshold for diagnosing osteoporosis (sensitivity and specificity of about 75 %) [9]. Our study patients with osteoporosis and osteopenia had vertebral bone density below this threshold (114.7 ± 51.1 and 130.6 ± 23.9, respectively). However, bone density in patients with osteoporosis and osteopenia had no significant differences in the intergroup comparison (p > 0.05).

Moreover, it has been shown that the value of bone density of 110 HU [18] of the vertebral bodies of the lumbar spine is the threshold for the occurrence of resorption around pedicle screws. In our study, only in patients with diagnosed osteoporosis, the value of bone density equal to 114.7 ± 51.1 HU was close to the mentioned above value, despite the fact that resorption was detected in all the studied patients.

According to the literature, threshold values were calculated using the averaged values of one lumbar vertebra. Thus, the main reason for choosing the L1 vertebra was its accessibility in opportunistic CT studies (CT of the abdominal cavity, chest organs) [19, 20]; the L3 vertebra was chosen due to its neutral position and the lower possible influence of other resorption initiation factors, except for a decrease in bone mineral density [21]; also L1-L4 vertebrae were chosen by the authors for the calculation of threshold values due to their availability for CT study and densitometry. This rationale for the choice of the authors does not seem correct, since screw fixation is much more frequently performed on the lower lumbar segments of the spine.

Bone density is not similar at the levels of the lumbar spine. Thus, the data are very inconsistent, despite similar measurement techniques. Possibilities of measurement in different planes have been discussed. However, it was shown that mid-axial slices are optimal [22, 23]. Zou et al. determined that bone density decreases towards the underlying vertebrae, ranging from 120.2 ± 39.4 HU at L1 to 107.0 ± 41.6 HU at L4 [8]. Berger Groch et al. found the increase in bone density of the lumbar vertebrae towards the lower levels; the body of the L4 vertebra was 105 ± 41.53 HU; body of L5 vertebra 112 ± 46.55 HU; body of S1 vertebra 151 ± 48.34 HU [16]. According to a large cohort study by Pickhardt et al., bone density is the lowest at the L3 level and increases slightly at higher and lower levels [20]. There are also data on the absence of a significant difference in the HU values of the vertebrae of the lumbar spine, and fluctuations in bone density are insignificant [24]. In our study, the density of bone tissue in the vertebral bodies increased towards the underlying levels from 145.5 ± 49.4 HU to 191.1 ± 54.1 HU. The inconsistent results of the investigators can be explained by heterogeneous patient populations, opportunistic studies, and the large standard deviation (SD) of mean values by each investigator, suggesting a large scatter in density measurements.

Calculation of bone density of specific zones of the vertebra is not common, more often the measurements are averaged [1, 9, 13]. Measuring bone density separately in the pedicles is appropriate, since this zone experiences maximum stress during transpedicular fixation of the spinal motion segment, in contrast to the vertebral body itself [25, 26].

The S1 vertebra is often used as the caudal level for fixation, since the L5-S1 level is one of the most operated for degenerative diseases of the spine. However, by performing L5 and S1 densitometry, the vertebrae are not analyzed due to their anatomical location. Bone resorption around screws in S1 is generally higher than around screws of the above levels (15.6-46.5 % versus 10-20 %) [11, 27, 28]. This is due to the fact that the sacrum consists mainly of cancellous bone and is subjected to greater mechanical stress than other segments [19]. The anatomical features of the pedicles in the S1 vertebra, namely, their larger diameter and shorter length compared to the lumbar vertebrae, indicate that bone resorption around the S1 screw may occur due to the structural features of the body and pedicles of the S1 vertebra [11, 29]. The lateral masses of the sacrum have a significantly lower bone density than the body of the S1 vertebra [30]. According to the results of our study, bone tissue density was significantly higher in the pedicles than in the vertebral bodies at the levels L2-L5, and did not have significant differences in L1 and S1 vertebrae. Moreover, the pedicles of the S1 vertebra had a lower density than the pedicles of the L4 and L5 vertebrae (192.6 ± 51.5 HU vs. 208.6 ± 61.9 and 212.3 ± 57.7, respectively). Moreover, bone resorption around the screw most often occurs in the area of the roots and pedicles, to a lesser extent, around the screws in the vertebral body. Given these features, it is more reasonable to calculate the threshold values for resorption around the screws based on the bone density of the vertebral arch roots.

Based on our own data and on the current literature, we recommend measuring lumbar vertebral bone density using CT of the lumbar spine in all patients who are scheduled for stabilizing interventions. HU values are more accurate, sensitive, and specific than densitometry. More high-quality studies are needed to compare bone density values obtained with bone densitometry and CT with the results of surgical treatment of patients.

The limitation of this study is the small sample size. Therefore, in order to raise the level of evidence, it is necessary to conduct large-scale studies involving patients of different age groups and different pathologies of the spine.

CONCLUSION

According to CT of the lumbar spine, bone density in the arch pedicles is significantly higher than in the vertebral bodies of L2-L5 vertebrae. The density of the bone tissue of the S1 pedicles is significantly lower than the one in the L5 vertebra. It may cause a high risk of caudal fixation failure at this level. Particular attention should be paid to planning and surgical techniques in patients not only with osteoporosis, but also with osteopenia detected by densitometry. These groups of patients do not have a significant difference in BMD if assessed by densitometry.

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