ORIGINAL ARTICLE

Assessment of bone quality at the lumbar and sacral spine using CT scans: a retrospective feasibility study in 50 comparing CT and DXA data

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Abstract

Purpose Computed tomography (CT) is a standard diagnostic tool for preoperative screening for many indications in spinal and pelvic surgery. The gold standard for diagnosing osteoporosis is standard dual-energy X-ray absorptiometry (DXA). The aim of the present study was to compare the accuracy of Hounsfield unit (HU) measurements not only at the lower lumbar, but also at the sacral spine using standard CT scans.

Patients and methods Main inclusion criterion for this retrospective analysis in 50 patients was the availability of both a CT scan of the lumbar and sacral spines and a DXA scan. HUs were measured in intact vertebral bodies L4, L5 and S1. Results of the HU in CT scan were compared to the T-score and bone mineral density in DXA. A group with normal bone density (T-score higher -1, $n = 26$) was compared with a group with impaired bone density (T-score lower -1, $n = 24$).

Results A multivariant binary logistic regression analysis showed significant results for HU measurement in L4 ($p = 0.009$), L5 ($p = 0.005$) and S1 ($p = 0.046$) with respect to differentiation between normal and impaired bone quality. Cutoffs between normal and impaired bone density values for trabecular region of interest attenuation for L4, L5 and S1 are presented. In L4 100% sensitivity to detect normal bone was reached when HU was higher than 161, HU higher than 157 in L5 and HU higher than 207 in S1.

Conclusions HU measurements in CT scans have proven to be a feasible tool to additionally assess bone quality at the lumbar and sacral spine with good sensitivity, when compared with the gold standard DXA.

Level of evidence III.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.

Extended author information available on the last page of the article

Introduction

Strong and healthy bone is desirable if screws are to be safely placed and integrated in spinal surgery. Osteoporosis decreases bone strength and density, so it is reasonable to examine bone density as part of preoperative planning. The gold standard for diagnosing osteoporosis is standard dual-energy X-ray absorptiometry (DXA) [1, 2]. Many patients undergo computed tomography (CT) of the spine before surgery. Pickhardt et al. have described a CT scan-based method to analyze bone quality. They determined Hounsfield units (HU) in CT scans of the spine and correlated the results with standard dual-energy X-ray absorptiometry (DXA) [3, 4].

This technique was used to evaluate the need for an additional DXA in patients before spinal surgery if a CT is existing anyway. The aim of the present study was to compare the accuracy of Hounsfield unit (HU) measurements using standard CT scan and DXA.

Materials and methods

In order to obtain additional information on bone density in patients with planned spinal surgery, we measured the HU in vertebral bodies L4, L5 and S1 via a CT scan (as described by Pickhardt et al.) and correlated the results with DXA measurements. The results for L4 and L5 served to validate the approach of Pickhardt et al. [3, 4]. The results for S1 provided novel information.

Patients

We studied all patients admitted to our hospital for spinal surgery between June 2016 and September 2018 and for whom DXA was available. A total of 164 patients (93 females, 71 males) were identified. A total of 50 patients (27 females, 23 males) met inclusion criteria for this retrospective study. All patients were Caucasian. Patients with a preoperative CT scan of the spine were included in the final analysis. Valid assessment of bone quality was only possible when lumbar vertebral bodies 4, 5 and S1 were intact. The maximum interval between CT scan and DXA was 4 weeks. Exclusion criteria were:

- Incomplete imaging.
- DXA of the radius.
- Fracture in L4, L5 or S1.
- Previous spinal surgery to L4, L5 or S1.

- Severe degenerative changes (see supplement Fig. 5 and Fig. 6).

The cohort was also analyzed by gender, body mass index, age, medication, vitamin D deficiency and underlying diseases.

Radiological assessment

Dual-energy X-ray absorptiometry

According to the study protocol, the bone mineral density (BMD, measured in g/cm^2) was assessed for the lumbar spine and proximal femurs using central DXA—employing standard techniques in accordance with the International Society for Clinical Densitometry [5]. A Lunar Prodigy densitometer (GE Healthcare, Madison, USA) was used for the measurements. Osteoporosis was defined as a DXA T-score between -2.5 and less and osteopenia as a score between -1.0 and -2.4. Individuals with T-score higher than -1.0 were rated as having normal bone density [6].

In clinical practice, individual patients are categorized and treated according to their lowest central T-score [7], as a low BMD at one site implies an increased risk at other sites too. Analogously, in this study we also used the lowest T-score (hip or lumbar spine) for evaluation.

Simple trabecular ROI attenuation technique

All CT scans were carried out with a 16-detector row scanner (Somatom Emotion, Siemens AG Medical Solutions, Germany). The study was restricted to native scans without a contrast medium. The field of view was adapted to the individual anatomy. In every case, the entire lumbar and sacral spine were included in the assessment. For all scans, a bone and soft-tissue kernel was reconstructed with 3-mm-thick slices.

For each patient, CT vertebral body attenuation in a pre-defined region of interest (ROI) was recorded through trabecular bone in the L4, L5 and S1 vertebral bodies in Hounsfield units (HU). There was no initial step of plane angulation. The assessment was performed by placing a single oval over the trabecular bone in the axial view. The correct position in the middle of the vertebral body was double checked in the sagittal plane (see Fig. 1). The measurements were taken by a single rater on a standard PACS work station. The rater was blinded to the DXA results.

Statistics

The statistical analysis was performed with SPSS statistical software, version 24.0 (SPSS, Chicago, IL). p values < 0.05 (2-tailed) were considered statistically
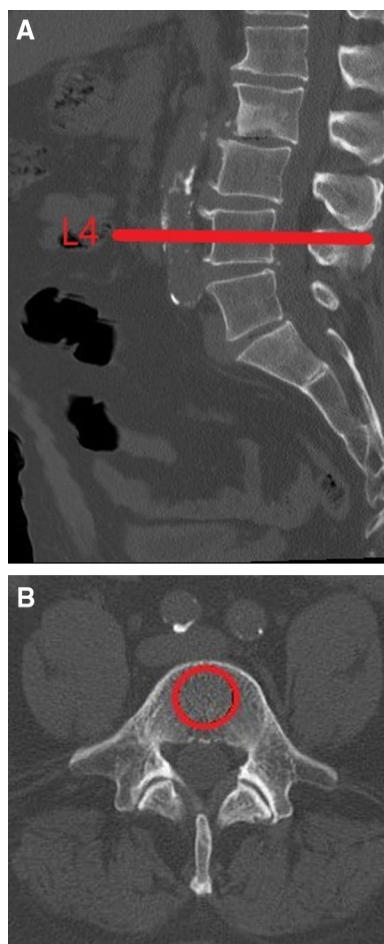
Fig. 1 CT scan of the lumbar spine. Demonstration of HU measurement in the sagittal (**a**) and axial planes (**b**)

significant. Comparison of the two groups was based on descriptive statistics, presented as proportions for categorical variables and means plus standard deviations for continuous variables.

A Chi-squared test was used to examine correlations between two categorical variables. Whenever the expected numbers in a single cell were smaller than 5, Fisher's exact test was applied to calculate p values.

Logistic regression models were used to examine correlations of metric variables with binary outcomes.

Analysis of variance (ANOVA) was performed to determine whether HU values for normal, osteopenic and osteoporotic conditions or other variables differ significantly between groups. Estimated means are presented, with the corresponding 95% confidence interval and p values. In addition, the receiver operating characteristic (ROC) curve was used to assess areas under the curve (AUC, with 95% confidence interval), as well as optimal cutoff points, and calculate sensitivity and specificity for bone disease. T-scores of -1.0 and -2.5 were used to subclassify the bone

disease as osteopenia or osteoporosis. ROC was calculated for the DXA T-score.

Results

The CT scans used in the analysis were performed to assess spinal and neuroforaminal stenosis, spondylolisthesis and scoliosis. Fifty cases were analyzed, including 23 men and 27 women. The mean age in this study was 72.28 years (± 10.18; range 31–89). In the female subgroup, the mean age was 73.44 years (± 7.06; range 57–84) and in the male subgroup 70.91 years (± 12.97; range 31–89).

The mean BMI was 27.39 (± 5.07; range 19–42; male: 26.57; female: 28.08), without significant differences with respect to gender ($p = 0.91$) or bone density ($p = 0.09$).

The mean T-score was -0.86 (± 1.24; range: -3.3 to 2.2) and the mean BMD 0.97 g/cm^2 (± 0.19; range 0.70–1.58). The T-scores in the DXA were higher than -1 in 26 patients (52%), between -1 and -2.5 in 20 patients (40%) and lower than -2.5 in 4 cases (8%). Patients were separated into those with normal ($n = 26$) and those with reduced ($n = 24$) bone density.

There were no significant differences between patients with normal or impaired bone density with respect to gender ($p = 0.247$). The group with normal bone density (T-score higher than -1) consisted of 14 male and 12 female patients, and the group with impaired bone density (T-score lower than -1) of 9 male and 15 female patients ($p = 0.272$).

Age significantly influenced bone density when measured in HU. In L4, each additional year of age reduced the density by 1.27 HU ($p = 0.028$) and in L5 by 1.48 HU ($p = 0.022$) (see Fig. 2).

The mean HU in L4 was 105 (± 41.53; range 21–236), in L5 112 HU (± 46.55; range 29–234) and in S1 151 (± 48.34; range 69–286).

In computed tomography, there were significant differences between the groups with normal and impaired bone density in values for attenuation—for L4 ($p = 0.003$), L5 ($p = 0.01$) and S1 ($p = 0.037$) (unpaired t test).

Figure 3 shows the ROC curves predicting a DXA T-score lower than -1.0 in L4, L5 and S1. At L4, the AUC for the simple ROI technique was 0.73 (0.61–0.85), at L5 0.76 (0.65–0.87) and at S1 0.65 (0.57–0.78). Multivariant binary logistic regression analysis showed significant results for HU measurement in L4 ($p = 0.009$), L5 ($p = 0.005$) and S1 ($p = 0.046$) with respect to differentiation between normal and impaired bone quality.

The cutoffs between normal and impaired bone density values for trabecular ROI attenuation at L4 were 112 HU (sensitivity 62% and specificity 75%), at L5 124 HU (sensitivity 50% and specificity 92%) and at S1 163 HU (sensitivity 50% and specificity 79%). In total, 100% sensitivity to

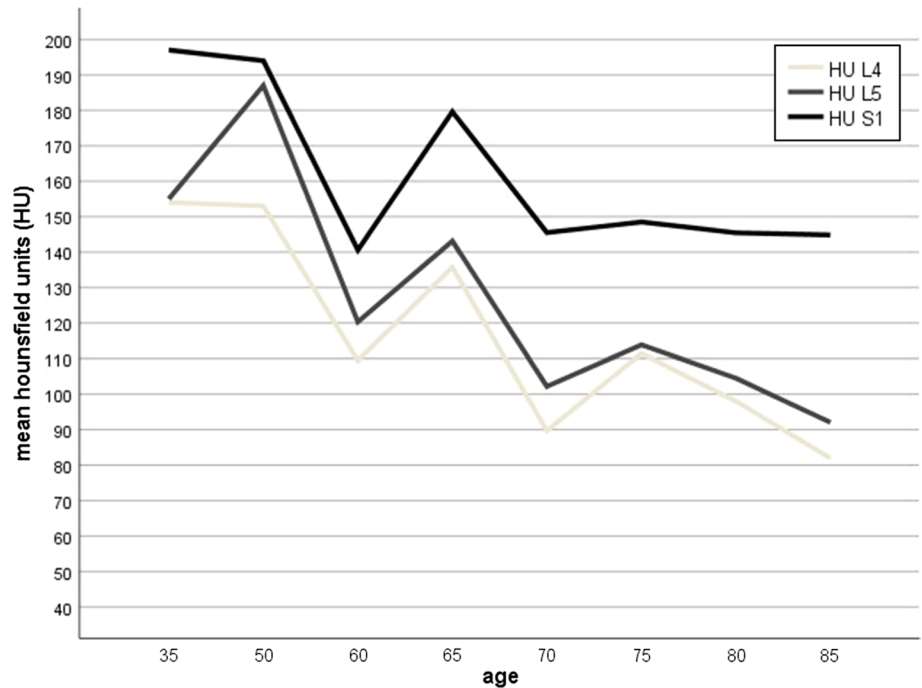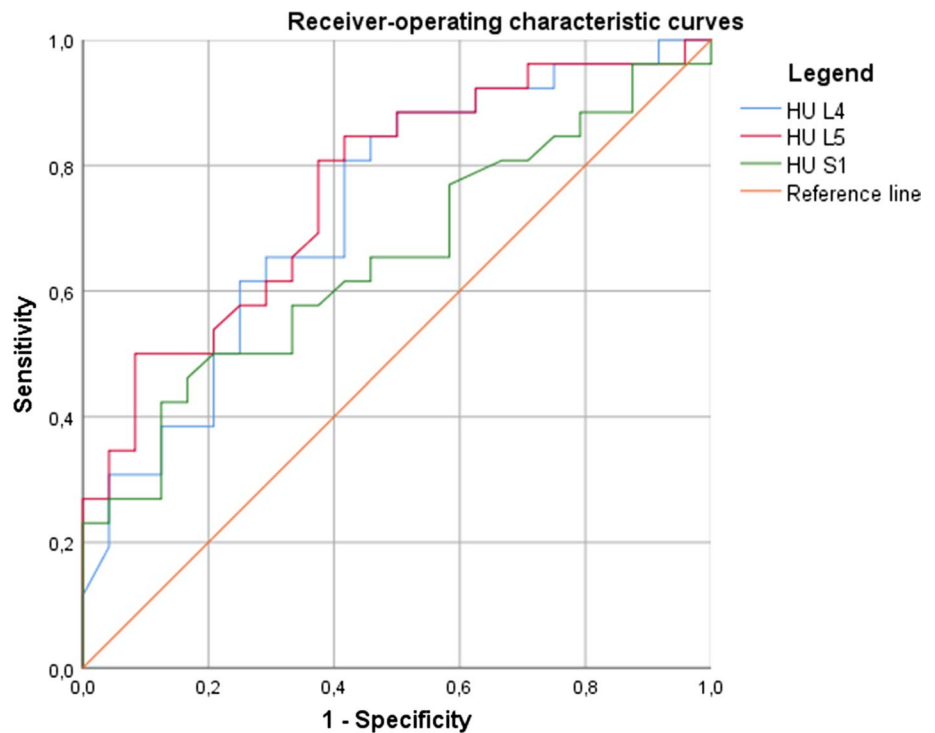**Fig. 2** Mean Hounsfield units by age in L4, L5 and S1

Fig. 3 ROC curves of L4, L5 and S1: separating normal from impaired bone density

detect normal bone was reached when HU was higher than 161 in L4, HU higher than 157 in L5 and HU higher than 207 in S1. In total, 100% sensitivity to detect osteoporosis was reached in patients with HU lower than 62 in L4, with HU lower than 58 in L5 and with HU lower than 68 in S1 (see Table 1).

Table 1 Cutoff values L4, L5 and S1

	L4	L5	S1
Normal bone	> 161 HU	> 157 HU	> 207 HU
Osteoporotic bone	< 62 HU	< 58 HU	< 68 HU

S1

In addition to the axial measurement with central ROI, other parts of the vertebral body were scanned. Bone density measured in HU was lowest in the dorsocaudal part of S1. Due to osteochondrosis, the endplate was often denser and with higher HU (see Table 2, see Fig. 4).

In S1, logistic regression analysis showed significant differences in HU between patients with normal and those with reduced bone density—for the central ($p = 0.046$), cranial ($p = 0.013$), caudal ($p = 0.014$) and dorsal parts ($p = 0.013$), but not the ventral part ($p = 0.076$).

Discussion

Spine surgeons handle patients of widely different ages and with many different medical conditions. As a result of demographic changes, age-related diseases have been increasing [8]—particularly osteoporosis [9, 10]. This study describes an attempt to use CT to additionally assess bone quality in the lower lumbar and sacral spines. The cutoff values

Table 2 Distribution of Hounsfield units in the different levels of S1 in patients with normal (A) and impaired (B) bone density

Variable	N	Mean	±	Min	Max
(A) Normal bone density ($n = 26$)					
S1 central	26	165	55.08	69.4	286
S1 cranial	26	199	56.08	84.8	338
S1 caudal	26	119	46.43	26.2	217
S1 ventral	26	187	69.7	36.3	415
S1 dorsal	26	116	50.88	−3.5	204
(B) Reduced bone density ($n = 24$)					
S1 central	24	137	35.32	76.5	204
S1 cranial	24	159	40.91	90	230
S1 caudal	24	82	45.53	15.6	201
S1 ventral	24	153	55.47	72.2	300
S1 dorsal	24	78	46.47	14.1	177

presented in this paper may be found helpful in both the diagnosis and the exclusion of the presence of impaired bone quality (see Table 1). On the one hand, it is important to estimate bone density before the operation, in order to ensure that the screw is safely placed into the vertebral body [11]. On the other hand, this information is important for the decision making of further osteologic diagnostic and therapeutic measures.

Determination of Hounsfield units in the lumbar spine has been described in a number of other papers [12–14]. To date, results were mainly based on opportunistic screening for osteoporosis using abdominal computed tomography scans. However, little information on values of the S1 is available.

In our study, HU higher than 207 was 100% sensitive to detect normal bone and HU lower than 68 had 100% sensitivity to detect osteoporosis in S1. A threshold of 163 HU exhibited balanced sensitivity and specificity for impaired bone density. These guideline values give valuable information about bone density in these cases.
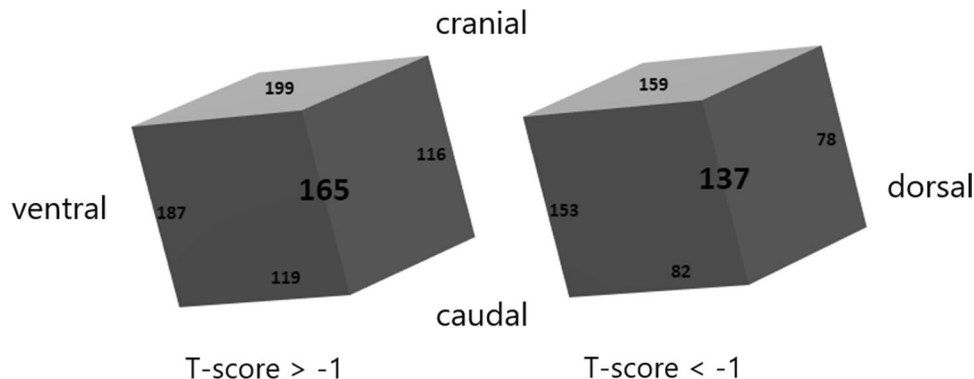
Our results show that bone density differs greatly between different parts of the S1. Previous research has demonstrated a significant interindividual variance of the anatomic shape of the sacrum, with a majority of the cases showing at least one sign of dysmorphism [15, 16]. Thus, the region of interest in S1 must be carefully selected, in order to avoid areas with extreme high or low density. This could be a reason that the values for S1 are less accurate than published values for L1–L2 [17–19]. However, the results for S1 comfortably reached significance, too, allowing us to assume that the methodology presented is suitable for both the lumbar and the sacral spine.

The influence of degenerative changes in the spine is a second important factor. In particular, osteochondrosis, facet degeneration and disk degeneration can result in false-positive high HU values [20]. Therefore, we decided to exclude this patient subgroup from our analyses, just like in dual-energy X-ray absorptiometry (DXA), CT-based. HU measurements in this patient subgroup should therefore be judged with great care [21, 22].

Fig. 4 Schematic representation of Hounsfield units in S1 in patients with *T*-score over and under −1

Our values for sensitivity and specificity are lower than those published by Pickhardt et al. [13], possibly due to the clearly smaller number of patients in our study. Due to this fact, the comparably low amount of manifest osteoporosis (8%) and the absence of pre-existing laboratory values for comparison, it was not possible to further differentiate between osteoporotic bone and osteomalacia. The first author of this study carried out all the HU measurements used for the further analyses in this study. Although the methodology used in this study is easily reproducible, the existence or extent of an inter-rater variance is therefore unknown. At last, our study is limited by its retrospective design.

In conclusion, determination of the Hounsfield units in L4, L5 and S1 via CT scans is a rapid, opportunistic and easy approach to obtain additional information on bone status. This is a good option to identify patients with impaired bone density prior to spinal surgery.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval All procedures involving human participants were in accordance with the ethical standards of the institutional and national research committees (Reference Number: WF-009/18) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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