The Use of CT Hounsfield Unit Values to Identify The Bone Quality in Patients With Cervical Degenerative Diseases.

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Research article

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Abstract

Background It is well known that osteoporosis may lead to the failure of spinal surgery. As the gold standard, dual-energy X-ray absorptiometry (DXA) is used to evaluate the overall bone mineral density (BMD). Previous studies have used CT (Computed tomography) value to evaluate local bone mineral density. The objective of this study was to investigate the application value of cervical CT value in preoperative bone quality evaluation of cervical degenerative diseases.

Methods A total of 939 patients who received surgical treatment for cervical degenerative diseases in our center from January 2015 to December 2017 were retrospectively reviewed. The Hounsfield unit (HU) values were measured in middle transverse CT images of the C2–C7 on the picture archiving and communication system (PACS), and the total bone mineral density T-score of L1–L4 was obtained by dual-energy X-ray absorptiometry. The changes in the HU values of C2–C7 were observed, the correlation between the HU value of C2–C7 and the total BMD T-score of L1–L4 was analyzed, and the HU thresholds of C2–C7 for different T-scores (-2.5 < T-score <-1 or T-score ≤2.5, respectively) were identified.

Results The HU values of C2–C7 show a decreasing trend. The mean HU value of C2–C7 was 322.52 ± 89.27 HU. The average BMD T-score of L1-L4 was -0.73. The average HU value of C2–C7 was positively correlated with the average BMD T-score of L1–L4 (r = 0.487, $P < 0.001$). The HU threshold of C2–C7 was 269 HU when -2.5<T-score<-1, and it had a sensitivity of 75.7% and a specificity of 59.8% when used for screening for osteopenia; the HU threshold of C2–C7 was 269H U when T-score ≤-2.5, and it had a sensitivity of 63.8% and a specificity of 80.8% when used for screening for osteoporosis.

Conclusions The HU values of cervical vertebrae gradually decrease from C2 to C7 in patients undergoing surgical treatment for cervical degenerative disorders. The CT HU value of cervical vertebrae is positively correlated with the BMD T-score provided by lumbar DXA, which is helpful for clinical evaluation of bone quality before surgery.

1. Background

With an increasingly aging society, osteoporosis is becoming more prevalent. Dual-energy X-ray absorptiometry is the most widely used technique for diagnosing osteoporosis [1], and a T-score is used to determine whether the bone mineral density is normal. Many recent studies have explored the role of computed tomography Hounsfield unit values in the diagnosis of osteoporosis, especially in the lumbar spine [2–6]. The attenuation coefficients in a CT image are expressed in HU value, which quantifies the amount of attenuation of any specified tissue or organ. In general, a larger tissue HU value represents a higher tissue density. An abundance of research has confirmed that the HU value of a lumbar vertebra is positively correlated with BMD and T-score in patients with non-degenerative lumbar spine disease. HU value can accurately reflect the bone quality of lumbar vertebrae and can be used as a supplementary method to evaluate the density of the lumbar spine [7]. For degenerative lesions of the lumbar spine, however, DXA may overestimate the BMD; instead, the HU value of the lumbar vertebrae may reflect the actual bone quality [7, 8].

Unfortunately, few studies have investigated the role of HU values in the assessment of the cervical spine. In our current retrospective study, we explored the changes of the HU value of cervical vertebrae in patients undergoing surgery for cervical degenerative disease, the relationship between the HU value of the cervical spine and the T-score of the lumbar spine, and the application of HU value in assessing bone quality.

2. Methods

2.1 General data

This study is retrospective. The hospital institutional review board approved this study. A total of 1,170 patients with cervical degenerative diseases underwent cervical spine surgery in the Department of Orthopedics and Cervical Spine, Peking University Third Hospital, from January 2015 to December 2017. Among these, 939 eligible patients (484 males and 455 females) with a mean age of 59 years, entered the final analysis. All patients received surgical treatment, with 644 cases undergoing anterior cervical surgery and 295 cases undergoing posterior cervical surgery.

2.2 Inclusion and exclusion criteria

The subject inclusion criteria were the following: a) preoperatively diagnosed cervical spondylotic myelopathy/radiculopathy, mixed cervical spondylosis, and/or ossification of posterior longitudinal ligament; b) failed standardized conservative treatment and clear surgical indications; and c) cervical three-dimensional-CT and DXA-based BMD examination at Peking University Third Hospital within 1 month before surgery.

The subject exclusion criteria were the following: a) a history of cervical vertebrae and lumbar spine fractures or surgery; and b) cervical spine and lumbar spine bone destruction (e.g. tumors and infections).

2.3 Measurement method

Based on the findings of preoperative 3DCT of the cervical spine, the HU values of C2–C7 were measured by using the picture archiving and communication system (PACS) system (RA1000 version 3.0, General Electric Medical System (China) Co., Ltd.), and the mean of the HU values was calculated. The procedure for measurement of the HU value was as follows: on the middle-sagittal reconstruction view of C2–C7, the region of interest (ROI) was delineated as large as possible; however, this area did not include cortical bone and abnormal bone areas such as bone islands, venous sinuses, and compression fractures (Figure 1). The HU measurement for each vertebra was obtained by a PACS, and the HU value was independent from the change of CT window and level. Meanwhile, the total BMD T-score of the lumbar vertebrae was measured by DXA before surgery. When T ≥ - 1.0, normal bone mass was diagnosed; when - 2.5 < T□ - 1.0, osteopenia was diagnosed; when T ≤ - 2.5, osteoporosis was diagnosed.

2.4 Statistical analysis

Statistical analyses were performed by using SPSS 20.0 software package (IBM, USA). A two-sided test was applied, and a *P* value of <0.05 was considered statistically significant. Spearman's rank correlation was used to test the association between the cervical alignments and the HU value of the vertebral body. The General Linear Model (GLM) was used for assessing the difference between the mean T-score of L1–L4 and the mean HU value of C2–C7. Receiver operating characteristic (ROC) curves were drawn, and areas under the ROC curve (AUC) were calculated with -2.5 < T-score <-1 or T ≤-2.5 as the threshold of osteopenia or osteoporosis, respectively. When the sensitivity plus specificity was highest on the ROC curve as the critical points of the C2-C7 HU values, the sensitivity and specificity of screening for osteopenia or osteoporosis with the HU thresholds of C2–C7 were obtained.

3. Results

3.1 Measurement results

The HU values of C2–C7 were 363.43 ± 92.52 HU, 340.44 ± 80.73 HU, 338.37 ± 86.92 HU, 333.43 ± 87.49 HU, 289.98 ± 76.60 HU, and 259.43 ± 62.59 HU, respectively. The mean HU value of C2–C7 was 322.52 ± 89.27 HU.

The average total BMD T-score of L1–L4 in 939 patients, as shown by cervical DXA, was -0.73.

3.2 Correlation analysis

The cervical alignment was negatively correlated with the HU value of the vertebral body (r = -0.396, *P* < 0.001). The average HU value of C2–C7 was positively correlated with the average BMD T-score of L1–L4 (r = 0.487, *P* < 0.001) (Figure 2). When the HU values of C2–C7 were used to screen for osteopenia (-2.5 < T < -1), the area under the ROC curve was 0.726 (95% confidence interval [CI]: 0.694, 0.758) (Figure 3). The average HU value of C2–C7 was 327 HU when the sensitivity plus specificity was highest on the ROC curve, and it had a sensitivity of 75.7% and a specificity of 59.8% when used for screening for osteopenia; when it was applied for screening for osteoporosis (T ≤ -2.5), the area under the ROC curve was 0.767 (95% CI: 0.718, 0.816) (Figure 4). The average HU value of C2–C7 was 269 HU when the sensitivity plus specificity was highest on the ROC curve, and it had a sensitivity of 63.8% and a specificity of 80.8% when used for screening for osteoporosis.

4. Discussion

Osteoporosis is a systemic skeletal disease characterized by low bone mass and deterioration of the micro-architecture of bone tissue and can lead to bone fragility and an increased risk of fracture. It is common in postmenopausal women and elderly men. [1] Clinically, degenerative neck conditions are often complicated by osteoporosis. Osteoporosis can negatively affect cervical spine surgery and postoperative rehabilitation. In patients undergoing surgery due to degenerative cervical spine disorders, osteoporosis patients are more likely to receive posterior cervical fusion surgery than non osteoporosis patients; also, they tend to have more postoperative bleeding, higher probability of revision surgery, longer hospital stay, and higher hospitalization expenditure [9].

Clinically, the bone quality of cervical vertebrae is evaluated according to the T-score and BMD measured by DXA; however, whether the total BMD T-score of L1–L4 can reflect the actual bone quality of cervical vertebrae remains unclear. At present, a good option for evaluating the bone quality of cervical spine is the quantitative CT (QCT), which can accurately select a specific site for BMD measurement. Compared with DXA, QCT has higher diagnostic performance and can measure the BMD of cervical vertebrae more accurately [10, 11]. However, QCT is expensive, exposes patients to a large amount of radiation, and is available in only a small number of hospitals, which limit its wider application in the clinical settings. In recent years, some authors have attempted to use HU value to assess the condition of lumbar vertebrae and proposed corresponding threshold values for diagnosing osteoporosis. CT is a routine examination before spine surgery. and the acquisition of HU value is simple and convenient. The HU value can be used to evaluate bone quality with no additional examinations being required.

4.1 Measurement of HU values of the cervical vertebrae

To our knowledge, no literature has described the application of HU value in evaluating the bone quality of the cervical spine. Only a few studies have used QCT to investigate the BMD of cervical vertebrae, mainly in young volunteers. A study using QCT to measure the BMD of spine in healthy adult males showed that the BMD of cervical vertebrae was 256.0 ± 48.1 mg/cm^3, and it gradually decreased from the cervical vertebrae to the lumbar vertebrae [12]. CT scans on the cervical vertebrae of eight fresh cadavers revealed the overall average density of the cervical vertebral body trabecular bone was 270 ± 74 mg/cm^3[13]. In 88 patients undergoing anterior cervical surgery, the range of the BMD of the cervical vertebrae measured by QCT was 235.5–302.0 mg/cm^3 before surgery, which gradually decreased in a craniocaudal direction [14]. Another report used QCT to measure the BMD of cervical vertebrae at different anatomical locations and found that the BMD peaked at C5 and decreased in the directions of C3 and C7 (mean central vertebral body BMD for C3–C7, respectively: 336, 354, 360, 311, and 248 mg/cm^3) [15]. In a recent study, the C1-T1 BMD of 194 ACDF patients was measured by QCT. The results showed that the trabecular BMD was highest in the mid-cervical spine (C4) and decreased in the caudal direction, with an average of C1 = 253.3 mg / cm3, C2 = 276.6 mg / cm3, C3 = 272.2 mg / cm3, C4 = 283.5 mg / cm3, C5 = 265.1 mg / cm3, C6 = 235.3 mg / cm3, C7 = 216.8 mg / cm3, T1 = 184.4 mg / cm^3[16].While the varied BMD of cervical vertebrae in different studies may be related to the differences in subjects and measuring instruments, there is a consistent trend that the BMD of cervical vertebrae gradually decreases in a craniocaudal direction.

Similar results were obtained in our current study: the C2–C7 alignments were negatively correlated with the HU value of the cervical vertebrae; as the cervical alignments decreased, the HU value of the cervical vertebrae gradually decreased. In addition, the HU values of C6 and C7 were significantly lower than those of C2–C5; therefore, the fixation strength must be considered when fixing C6 and C7 vertebrae with screws. Meanwhile, the anterior cervical instruments involving C6 and C7 also need further improvements.

4.2 Utility of the HU values of cervical vertebrae in assessing BMD

In our current study, the mean HU value of cervical vertebrae was positively correlated with the total BMD T-score of the lumbar vertebrae (Figure 2). We therefore speculate that the bone quality of the cervical vertebrae is parallel with that of the lumbar vertebrae, and the total T-score of the lumbar vertebrae can, to a certain extent, reflect the bone quality of the cervical vertebrae. In clinical practice, DXA is required to assess the bone quality of cervical spine before a cervical spine surgery. If lumbar spine DXA reveals a high total T-score of the lumbar vertebrae, the quality of cervical vertebrae can also be good.

In one study on the lumbar vertebrae, HU values had a strong positive correlation with T-score in the non-degenerative group, exhibiting correlation coefficients (r) greater than 0.7; in the degenerative group, in contrast, r was 0.6 or more [7]. In our current study, the correlation coefficient ($r = 0.487$) between the average HU value of the cervical vertebrae and the T-score of the lumbar vertebrae was lower than the correlation coefficient between the HU value and the T-score of the lumbar vertebrae. The reason for this may be that the HU values and T-scores of the lumbar vertebrae in the above-mentioned study [7] were obtained from the same lumbar vertebrae, whereas the T-score in our current study was based on the total BMD T-score of L1–L4, which represents the overall bone quality of the lumbar spine.

During the measurement of the HU values of the cervical vertebrae, only the delineated vertebral trabecular bones were measured; in contrast, measurement of the T-score of the lumbar vertebrae covered all the bone mass (including the cortical bone, trabecular bone, attached structures, bone spurs, and even calcified arteries) per unit area of the lumbar vertebrae. Therefore, compared with the T-score of the lumbar vertebrae, the HU values of the cervical vertebrae can more accurately reflect the bone quality of cervical vertebrae. Thus, HU measurement can be used as an auxiliary diagnostic method to avoid missed diagnoses of cervical osteoporosis.

4.3 Utility of the HU values of cervical vertebrae in assessing bone quality before surgery

According to the World Health Organization (WHO) criteria, patients should be diagnosed with osteoporosis when the minimum T-score is ≤ -2.5, with osteopenia if the T-score is between -1 and -2.5, and as normal if the T-score is ≥ -1 [1,17]. Research by other colleagues in our center found that the threshold matching T-scores of -2.5 were 110, 100, 85, and 80 HU for L1, L2, L3, and L4, respectively, and the authors believed these HU thresholds could be applied as a complementary method to lower the rate of missed diagnoses of osteoporosis in patients with degenerative diseases of the lumbar spine [7]. Some authors have provided HU thresholds at different sites to help diagnose osteoporosis. For example, patients with an average glenoid neck HU measurement of less than 197 had a 97% chance of having abnormal BMD, while patients with an HU measurement over 257 had a 100% chance of having normal BMD [18]. Similarly, patients with a skull HU value of <610 as determined via brain CT may be considered for further evaluation for possible osteoporosis [19].

In our current study, the BMD T-score was used as the standard for diagnosing osteopenia and osteoporosis. The HU threshold corresponding to osteopenia was 327HU, which was close to the average HU values (322.52 ± 89.27 HU) of C2–C7 in 939 patients. In fact, all the patients in this group underwent cervical spine surgery due to cervical degenerative conditions, with a mean age of 59 years and an average T-score of -0.73. Some patients had osteopenia or osteoporosis. Clinicians can use the mean HU value of cervical vertebrae to assist the T-score–based diagnosis of osteopenia or osteoporosis in the lumbar spine. Osteoporosis is suspected in patients with an average HU value of less than 269 HU in C2–C7, and this threshold had a sensitivity of 63.8% and a specificity of 80.8%. In our current study, the HU values of C6 and C7 remarkably decreased; thus, if the HU value of any C2–C5 vertebrae is below 269 HU, the possibility of osteoporosis is extremely high.

A possible limitation of this study was that all our subjects were inpatients undergoing cervical spine surgery; although a healthy population was not used as a control group, in clinical settings, spine surgeons are more concerned with the bone quality of patients scheduled for surgery. This study only describes the correlation between CT value of cervical spine and DXA bone mineral density. Future longitudinal studies are needed to quantify the correlation between CT value of cervical vertebra and hardware failure, interbody subsidence and pseudoarthrosis in anterior cervical surgery.

5. Conclusion

In summary, the HU value of the cervical vertebrae gradually decreases from C2 to C7 in patients undergoing surgical treatment for degenerative cervical spine disorders. The HU value of cervical vertebrae on CT is positively correlated with the BMD T-score on DXA, which is helpful for clinical evaluation of bone quality before surgery.

Abbreviations

DXA: dual-energy X-ray absorptiometry

BMD: bone mineral density

CT: Computed tomography

HU: Hounsfield unit

PACS: picture archiving and communication system

ROI: the region of interest

GLM: General Linear Model

ROC: Receiver operating characteristic

AUC: areas under the curve

QCT: quantitative CT

Declarations

Ethics approval and consent to participate

This study was approved by the ethics committee of Peking University Third Hospital (NO:M2019144), and written informed consents were obtained from the patients.

Consent for publication

All patients signed informed consent forms to publish their personal details in this article.

Availability of data and materials

The datasets supporting the conclusions of this article are included within the article. The raw data can be requested from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

LEI HE and FEI-FEI Zhou participated in recruitment, data collection and analysis. All authors contributed to the study design and drafting of the manuscript. All authors read and approved the final manuscript.

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Figures

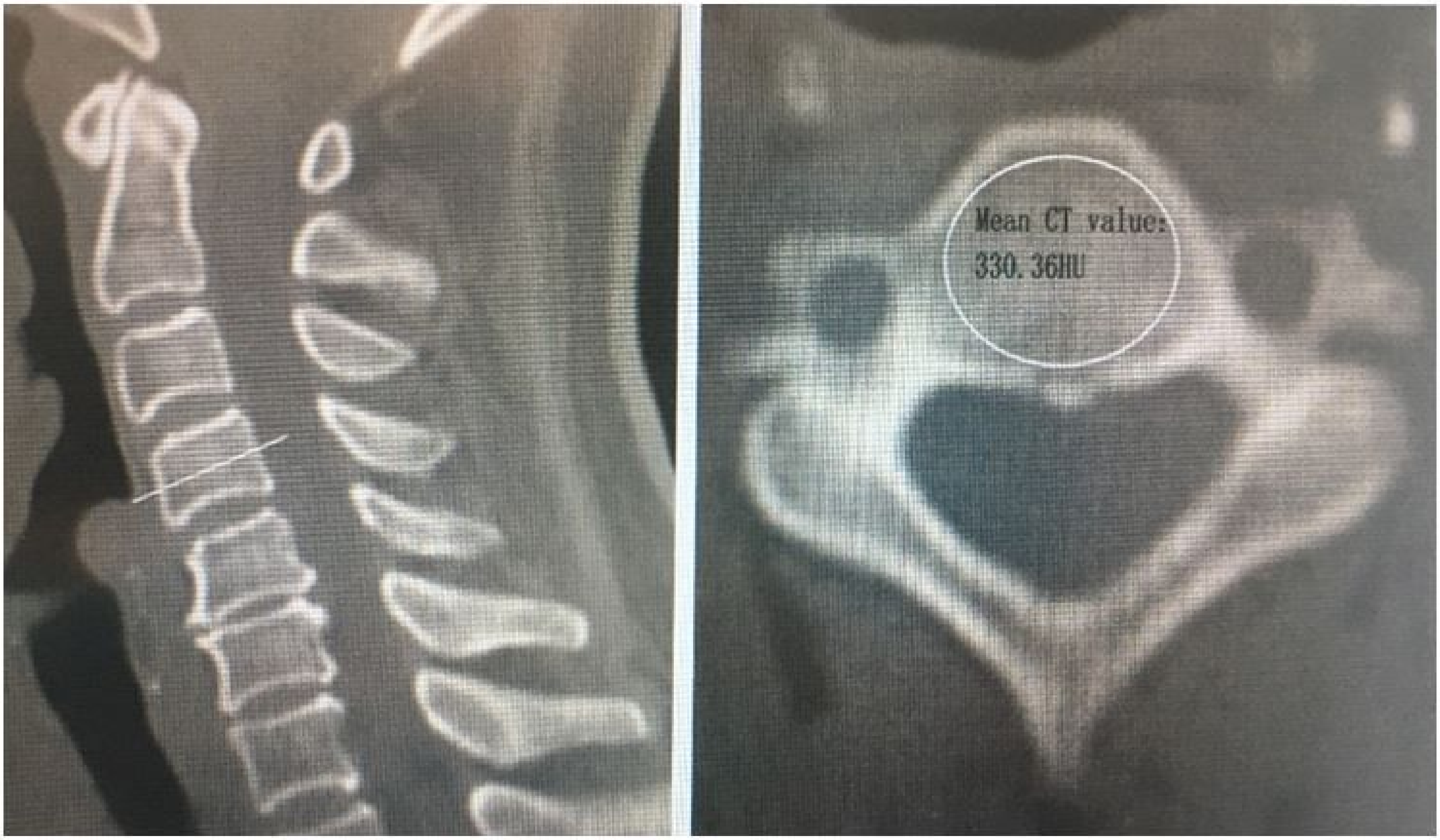

Figure 1

Measurement of HU value: the region of interest is delineated to be as large as possible on the central converse view of the vertebral body. The HU values were obtained on the PACS, and the mean values were calculated.

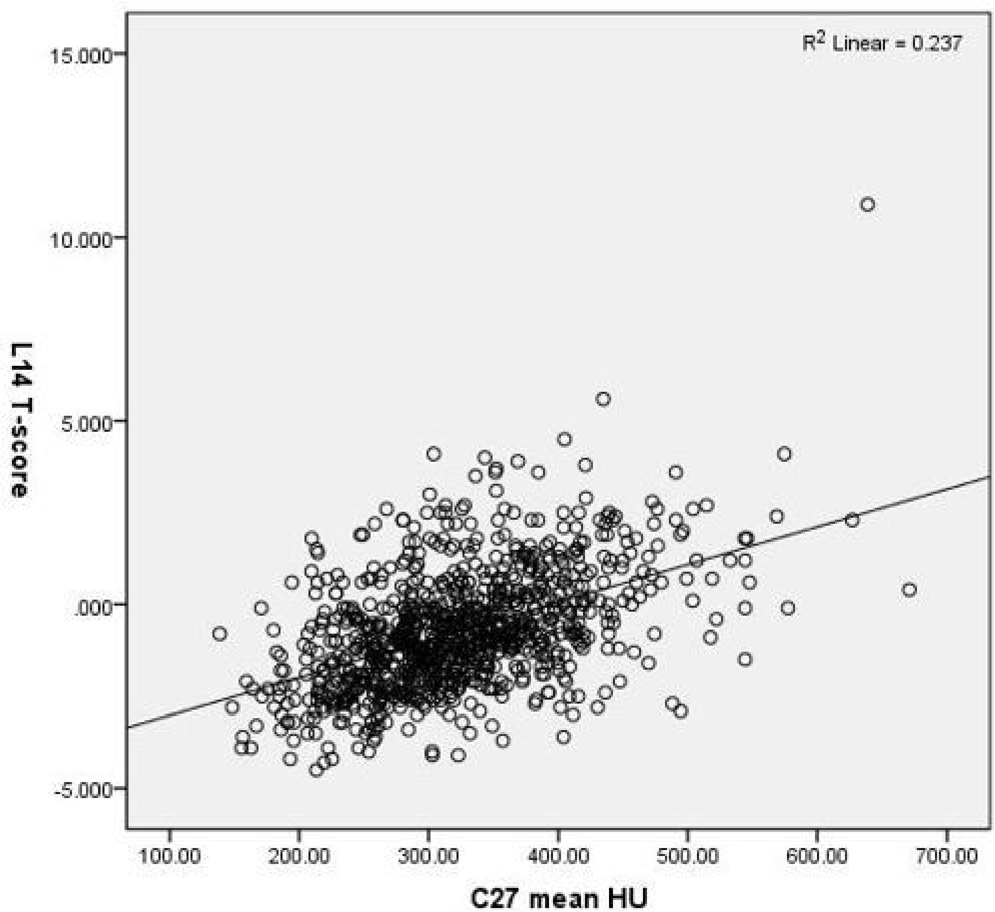

Figure 2

Scatter plot

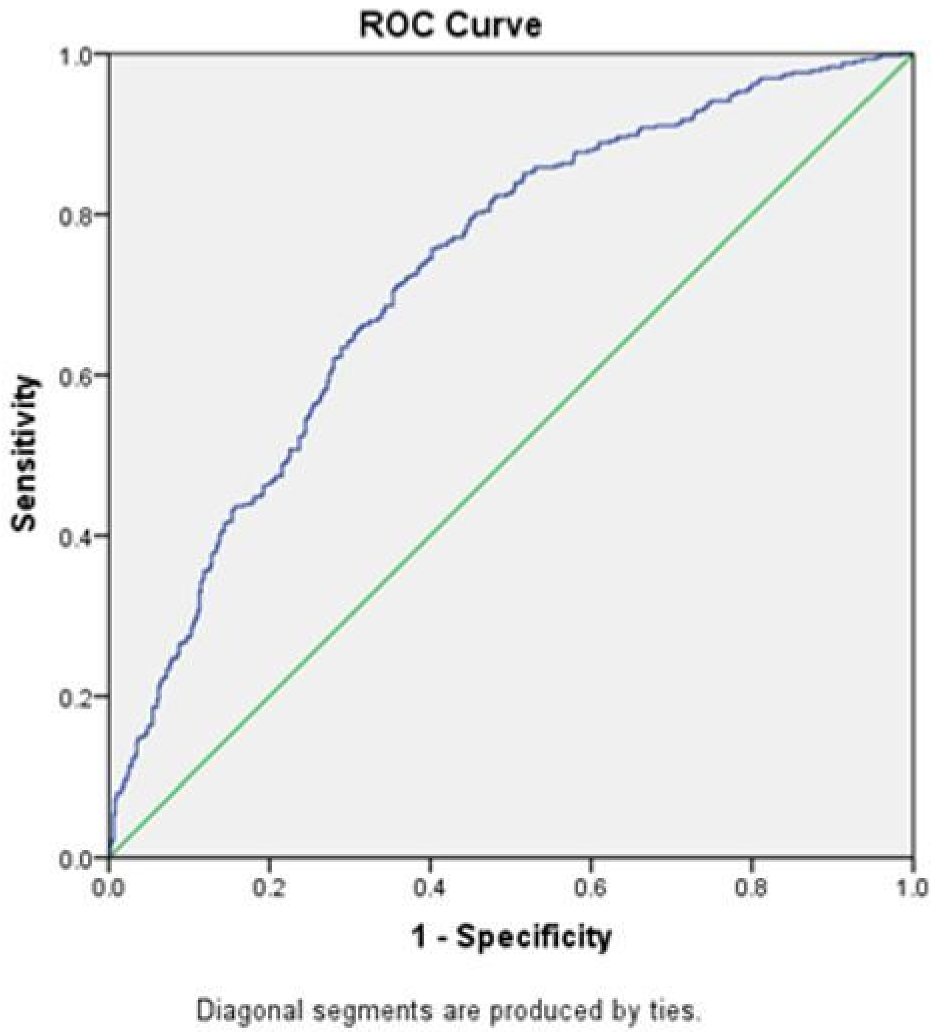

Figure 3

ROC curve for screening for osteopenia (T <-1)

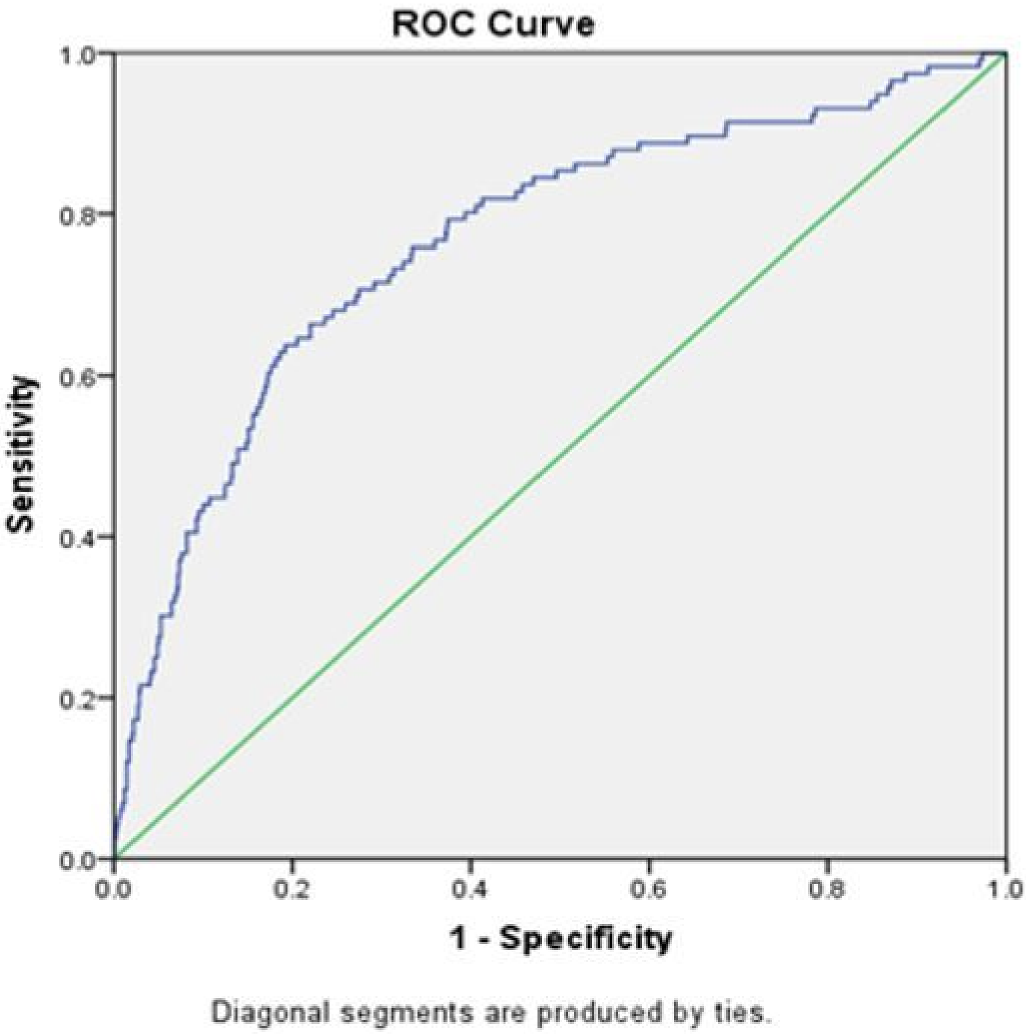

Figure 4

ROC curve for screening for osteoporosis (T <-2.5)