Hounsfield Units Value is a Better Predictor of Bone Mineral Density Than the Vertebral Bone Quality Score of Magnetic Resonance Imaging in Patients with Lumbar Degenerative Diseases

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Research Article

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Abstract

Background: Computed tomography Hounsfield unit (HU) and magnetic resonance imaging (MRI)-based vertebral bone quality (VBQ) score are both alternative tool to the dual energy x-ray absorptiometry(DEXA) scan T-score to quantify the bone quality. However, it is not known which method more accurately reflects vertebral bone mineral density.

Purpose: To evaluate the best method for evaluating vertebral bone mineral density in patients undergoing lumbar spine surgery.

Methods: Eighty-five patients who had at most two vertebrae with severe degeneration at L1–L4 were retrospectively reviewed.HU value was measured by axial CT image, VBQ score was calculated by T1-weighted lumbar MRI image, and L1-L4 T-score and bone mineral density (BMD) were measured by DEXA.The correlation of the vertebral HU value and VBQ score to the T-score was analyzed.

Results: There were 52 female and 33 male patients. The average age was 57.18±9.65 years . HU values had a positive correlation with BMD and T-score. The correlation coefficients between HU and T-score was 0.751(<0.001) for L1; 0.699(<0.001) for L2; 0.618(<0.001) for L3; 0.543(<0.001) for L4; and 0.677(<0.001) for L1-4.However,VBQ score had a negative correlation with BMD and T-score. The correlation coefficients between VBQ score and T-score was -0.231(<0.05) for L1; -0.246(<0.05) for L2; -0.268(<0.05) for L3; -0.252(<0.05) for L4; and -0.346(<0.01) for L1-4. The correlation coefficients of HU value at L1–L4 were higher than the correlation coefficients of VBQ score .

Conclusions: HU value was a better predictor of vertebral bone mineral density than VBQ score in patients with lumbar degenerative disease.

Introduction

Osteoporosis is defined as low bone mass and micro-architectural deterioration of bone tissue with consequent increases in bone fragility and susceptibility to fracture[1].As the population ages, osteoporosis has become a common disease worldwide.In spinal surgery, the evaluation of bone mineral density is very important. Osteoporosis is one of the main causes of complications such as fixation failure bone non-union and adjacent horizontal fracture after spinal surgery[2–3].

DEXA is presently used as the gold standard method for assessing BMD[4].However, the BMD measurements from lumbar DXA in patients with lumbar degenerative diseases are increased because of scoliosis, degenerative arthritis, osteophyte formation, bone sclerosis[5–7].Therefore, an approach to assess bone mineral density using HU values of CT images has been extensively studied [8–10].In addition,another novel technique for assessing bone quality is the VBQ score, which uses noncontrast, T1-weighted lumbar spine MRI and was moderately correlated with femoral neck and overall lowest T-score[11].Another common benefit of both approaches is the use of available or opportunistic imaging to provide meaningful data about the patient's bone quality.

However, no study assessed the association between VBQ score and vertebral T-score.We studied the correlation of the vertebral HU value and VBQ score to the T-score, and evaluated the similarity and difference between them.

Materials And Methods

Patients

The study was approved by the Ethics Committee of our hospital.Because it was a retrospective study, informed consent was waived.We reviewed patients who underwent surgery for degenerative lumbar diseases at the spinal Department of our hospital from January 1, 2019 to January 1, 2021.Inclusion criteria: patients who received lumbar CT, MRI and DEXA scan within 1 month before surgery in our hospital.The exclusion criteria were :(1) at least 3 osteophytes with severe hyperplasia between L1 and L4 according to the four-level classification system of osteophytes [12];(2) According to UCLA grading standards, at least 3 intervertebral disc degeneration between L1 and L4 reached grade 4 [13];(3) Narrowing of at least 3 adjacent facet joints between L1 and L4 (< 1 mm) accompanied by large osteophytes [14].(4) A history of lumbar surgery;(5) spinal infection, tumor or metabolic disease;(6) Anatomical identification is difficult to identify for radiometry. Finally,85 patients were selected for this study.

Bone density evaluation

BMD and T-score of each patient's lumbar spine (L1-L4) were measured by dual-energy X-ray absorptiometry(DXA, Discover A densitometers, Hologic Inc, Bedford, MA, USA).WHO’s criteria were applied [4]: osteoporosis ($T \leq -2.5$), osteopenia ($-2.5 < T < -1$) and normal BMD ($T \geq -1$).

AS previous protocol[9], PACS was used to calculate HU value. Briefly, HU values were measured by placing the elliptic region of interest (ROI) in an axial mid-body image through L1-L4(Figure 1). Include as many trabeculae as possible in ROI and avoid cortical bone and heterogeneous areas such as posterior venous plexus, bone islands, and compressed bone. The mean HU value represents the bone mineral density of vertebral trabecular bone.

As previously described [11],VBQ score was assessed using lumbar non-contrast, T1-weighted MRI.First, the ROI was placed in a mid-sagittal section to measure the signal intensity (SI) of l1-L4 vertebral body bone trabeculae(Figure 2). In patients with mid-sagittal abnormalities (eg, hemangioma, venous plexus, scoliosis changes), parasagittal slices were used to reflect bone quality. If the entire vertebral body is abnormal, the vertebral body is excluded.The SI of L1-L4 was then divided by the SI of cerebrospinal fluid (CSF) at the L3 level to obtain VBQ score(Figure 2, Formula 1).If the CSF of L3 space is completely blocked, the ROI of CSF is placed at the L2 level.All HU values and VBQ scores were measured by two independent observers and averaged for statistical analysis.

$$VBQ\ score = \frac{SI_{L1-L4}}{SI_{CSF}}$$

Statistical Analysis

SPSS 25 (SPSS, USA) software was used for statistical analysis.Interobserver reliability calculations was performed by the interclass correlation coefficient(0 represents no agreement and 1 represents perfect agreement).The correlations between HU value and BMD,VBQ score and BMD,HU value and T-score,VBQ score and T-score were evaluated by Pearson correlation coefficient and binary linear regression.For the correlation coefficient (r), r≤0.3 represents poor correlation, 0.3<r≤0.6 represents moderate correlation, 0.6 < r≤0.8 represents high correlation, and r> 0.8 represents high correlation.

Results

85 patients were included in this study, including 33 males and 55 females, with an average age of 57.18±9.65 years and BMI of 25.96±3.60 kg/m2.normal BMD was detected in 23 patients, osteopenia was detected in 37 patients,osteoporosis was detected in 25 patients. .Interobserver reliability calculations was well in measuring HU value and VBQ score, with ICCs of 0.995 and 0.971, respectively.The characteristics of these patients were summarized in Table 1.

Table 1
Demographic characteristics and bone density

Characteristics	All (n = 85)
Age (years)	57.18±9.65
Gender ratio (male: female)	33:52
BMI (kg/m2)	25.96±3.60
L1 BMD (g/cm2)	0.855±0.130
L2 BMD (g/cm2)	0.906±0.145
L3 BMD (g/cm2)	0.954±0.151
L4 BMD (g/cm2)	1.007±0.176
Average BMD of L1-L4(g/cm2)	0.931±0.142
L1 T-score	-1.53±1.15
L2 T-score	-1.33±1.30
L3 T-score	-1.25±1.37
L4 T-score	-0.60±1.59
Average T-score of L1-L4	-1.18±1.28
L1 HU value	136.05±43.87
L2 HU value	128.99±43.67
L3 HU value	121.92±44.98
L4 HU value	126.19±47.09
Average HU value of L1-L4	128.29±43.80
L1 VBQ score	3.22±0.71
L2 VBQ score	3.27±0.79
L3 VBQ score	3.30±0.81
L4 VBQ score	3.21±0.87
Average VBQ score of L1-L4	3.25±0.77

The correlations between HU value and BMD,VBQ score and BMD,HU value and T-score,VBQ score and T-score were summarized in Table 2.The correlation coefficients between HU value and BMD for L1-L4 were 0.752(<0.001),0.696(<0.001),0.615(<0.001),0.547(<0.001) and 0.677(<0.001) for the average of L1-L4; the correlation coefficients between HU value and T-score for L1-L4 were 0.751(<0.001),0.699(<0.001),0.618(<0.001),0.543(<0.001) and 0.677(<0.001) for the average of L1-L4;the

correlation coefficients between VBQ score and BMD for L1-L4 were -0.302(<0.01),-0.291(<0.01),-0.279(<0.01),-0.270(<0.05) and -0.309(<0.01) for the average of L1-L4; the correlation coefficients between VBQ score and T-score for L1-L4 were -0.231(<0.05),-0.246(<0.05),-0.268(<0.05),-0.252(<0.05) and -0.346(<0.01) for the average of L1-L4.There was a moderate or high positive correlation between HU value and BMD,HU value and T-score, while there was a negative correlation between VBQ score and BMD,VBQ score and T-score, but the correlation was poor.In addition,scatter plots showing the relationship between average HU value and average T-score, average VBQ score and average T-score are also shown in Figure3.

Table 2
The correlations between HU value and BMD,VBQ score and BMD,HU value and T-score,VBQ score and T-score

	Correlation coefficients	
	BMD	T-score
L1 HU value	0.752**	0.751**
L2 HU value	0.696**	0.699**
L3 HU value	0.615**	0.618**
L4 HU value	0.547**	0.543**
Average HU value of L1-L4	0.677**	0.677**
L1 VBQ score	-0.302**	-0.231*
L2 VBQ score	-0.291**	-0.246*
L3 VBQ score	-0.279**	-0.268*
L4 VBQ score	-0.270*	-0.252*
Average VBQ score of L1-L4	-0.309**	-0.346**
***P value < 0.05;**P value < 0.01.**		

Discussion

mineral density is critical to the strength of the motor system. Osteoporosis, which is prone to fracture, can be quantified in advance with a DEXA scan.In the United States, the estimated prevalence of osteopenia and osteoporosis in the population is 43.9% and 10.3% respectively[15].Osteoporosis is an important risk factor for many complications of spine surgery, such as screw loosening, adjacent segment disease, interbody cage subsidence and fractures[2-3,16-17]. Since DEXA can include all calcified tissue, such as calcified aorta or osteophytes in degenerative spine, and may overestimate bone mass, several alternative measurements have been developed[5-7].

HU represents the density of human tissue. The corresponding HU value of a volume element is: HU value =1000×(μx-μwater) /μwater, whereμwater andμx represent the attenuation coefficient of distilled water and a volume element on X ray respectively. The bone density is high, usually 300~3000HU[18]. Many studies have shown a good correlation between HU value and T score [8-10,18-20].Similarly, the M-score was the first MRI-based observation to use adipose tissue with high T1 signal and to assess fat infiltration in cancellous bone by measuring T1 signal in the vertebral body[21].Other study has confirmed this approach and provided evidence for the use of m-scores to assess bone quality[22].However, M-Score is of limited utility because it requires measurements to be taken using the same MRI machine.Using the principle of M-score and avoiding its defects, VBQ score was developed [11]. VBQ score was standardized with L3 space CSF SI as a reference value and could be compared between patients with different MRI machines. VBQ score has been shown to be correlated with BMD score of DXA scan [11]. MRI and CT of lumbar are routine examinations for patients undergoing lumbar surgery.Therefore,for a more accurate measurement of BMD in patients undergoing lumbar surgery, it is worth considering which measurement is more relevant to the patient's BMD.

In our study, HU values of L1-L4 were positively correlated with BMD and T-score of corresponding vertebral bodies ($P < 0.001$). Similarly, we demonstrated that the VBQ scores of L1-L4 were negatively correlated with BMD and T-scores($P < 0.05$). However, the HU value of L1-L4 was more correlated with vertebral BMD and T-score, which may be because HU value can directly measure BMD, while VBQ score indirectly reflects BMD by measuring the signal of fat.However, neither HU value nor VBQ score had a higher correlation with BMD than previous studies[9,11], which may be due to the limited sample size of our study.

Limitations

Our study has limitations.First, no matter HU value or VBQ score, the selection of the region of interest is artificial and local, which may bring errors to the measurement results. Second, although we selected patients with mild degeneration, some degeneration of these patients, such as vascular calcification and ligament ossification, would also result in a higher BMD measurement value. Thirdly, due to the retrospective study of 2-year patients, the insufficient sample size of the study may lead to bias in the experimental results.

Conclusion

HU value and VBQ scores of vertebral bodies both can be used as complementary measures to assess BMD in patients with lumbar degeneration.In addition,HU value was a better predictor of vertebral bone mineral density than VBQ score in patients with lumbar degenerative disease.

Abbreviations

CT Computed tomography

HU Hounsfield unit

VBQ Vertebral bone quality

MRI Magnetic resonance imaging

DEXA Dual energy x-ray absorptiometry

BMD Bone mineral density

ROI Regions of interest

SI Signal intensity

CSF Cerebrospinal fluid

Declarations

Ethical approval: The study was approved by the ethical committee of Third Affiliated Hospital of Hebei Medical University.

Informed consent: As a retrospective analysis, the need for individual consent was waived.

Consent for publication: As a retrospective analysis, the need for individual consent was waived.

Author contributions: Wenshuai Li and Houze Zhu equally participated in the design of the study, statistical analysis and article writing. Tong Tong participated in data collection. Zijian Hua participated in data collection. Xuan Zhao participated in language editing. Yong Shen participated in the design of the study. Linfeng Wang participated in the revision of the manuscript. All authors read and approve the final version of the manuscript.

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Conflict of interest: The authors declare no competing interests.

Data availability: Data were not stored in a repository.

References

1. Solomon D, Sue Brown A, Brummel-Smith K, et al. Best paper of the 1980s: National Institutes of Health Consensus Development Conference Statement: geriatric assessment methods for clinical decision-making. 1988. *Journal of the American Geriatrics Society.* 2003;51(10):1490-1494.doi:10.1046/j.1532-5415.2003.51471.x .
2. Lubelski D, Choma TJ, Steinmetz MP, Harrop JS, Mroz TE. Perioperative Medical Management of Spine Surgery Patients With Osteoporosis. *Neurosurgery.* 2015;77 Suppl 4:S92-

97.doi:10.1227/neu.0000000000000939.

3. Meredith DS, Schreiber JJ, Taher F, Cammisa FP, Jr., Girardi FP. Lower preoperative Hounsfield unit measurements are associated with adjacent segment fracture after spinal fusion. *Spine.* 2013;38(5):415-418.doi:10.1097/BRS.0b013e31826ff084.
4. Damilakis J, Maris TG, Karantanas AH. An update on the assessment of osteoporosis using radiologic techniques. *European radiology.* 2007;17(6):1591-1602.doi:10.1007/s00330-006-0511-z.
5. Pappou IP, Girardi FP, Sandhu HS, et al. Discordantly high spinal bone mineral density values in patients with adult lumbar scoliosis. *Spine.* 2006;31(14):1614-1620. doi:10.1097/01.brs.0000222030.32171.5f.
6. Celi M, Rao C, Scialdoni A, et al. Bone mineral density evaluation in osteoporosis: why yes and why not? *Aging clinical and experimental research.* 2013;25 Suppl 1:S47-49. doi:10.1007/s40520-013-0074-1.
7. Muraki S, Yamamoto S, Ishibashi H, et al. Impact of degenerative spinal diseases on bone mineral density of the lumbar spine in elderly women. *Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA.* 2004;15(9):724-728.doi:10.1007/s00198-004-1600-y.
8. Schreiber JJ, Anderson PA, Hsu WK. Use of computed tomography for assessing bone mineral density. *Neurosurgical focus.* 2014;37(1):E4.doi:10.3171/2014.5.Focus1483.
9. Zou D, Li W, Deng C, Du G, Xu N. The use of CT Hounsfield unit values to identify the undiagnosed spinal osteoporosis in patients with lumbar degenerative diseases. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society.* 2019;28(8):1758-1766.doi:10.1007/s00586-018-5776-9.
10. Zhang RJ, Li HM, Gao H, Jia CY, Xing T, Shen CL. Associations between the hounsfield unit values of different trajectories and bone mineral density of vertebrae: cortical bone and traditional trajectories. *American journal of translational research.* 2020;12(7):3906-3916.
11. Ehresman J, Pennington Z, Schilling A, et al. Novel MRI-based score for assessment of bone density in operative spine patients. *The spine journal : official journal of the North American Spine Society.* 2020;20(4):556-562.doi:10.1016/j.spinee.2019.10.018.
12. Nakagawa N, Kinosaki M, Yamaguchi K, et al. RANK is the essential signaling receptor for osteoclast differentiation factor in osteoclastogenesis. *Biochemical and biophysical research communications.* 1998;253(2):395-400.
13. Kim JY, Ryu DS, Paik HK, et al. Paraspinal muscle, facet joint, and disc problems: risk factors for adjacent segment degeneration after lumbar fusion. *The spine journal : official journal of the North American Spine Society.* 2016;16(7):867-875. doi:10.1016/j.spinee.2016.03.010 .
14. Weishaupt D, Zanetti M, Boos N, Hodler J. MR imaging and CT in osteoarthritis of the lumbar facet joints. *Skeletal radiology.* 1999;28(4):215-219.doi:10.1007/s002560050503.

15. McCoy S, Tundo F, Chidambaram S, Baaj AA. Clinical considerations for spinal surgery in the osteoporotic patient: A comprehensive review. *Clinical neurology and neurosurgery.* 2019;180:40-47. doi:10.1016/j.clineuro.2019.03.010.
16. Pisano AJ, Fredericks DR, Steelman T, Riccio C, Helgeson MD, Wagner SC. Lumbar disc height and vertebral Hounsfield units: association with interbody cage subsidence. *Neurosurgical focus.* 2020;49(2):E9. doi:10.3171/2020.4.Focus20286.
17. Galbusera F, Volkheimer D, Reitmaier S, Berger-Roscher N, Kienle A, Wilke HJ. Pedicle screw loosening: a clinically relevant complication? *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society.* 2015;24(5):1005-1016, doi:10.1007/s00586-015-3768-6.
18. Schreiber JJ, Anderson PA, Rosas HG, Buchholz AL, Au AG. Hounsfield units for assessing bone mineral density and strength: a tool for osteoporosis management. *The Journal of bone and joint surgery American volume.* 2011;93(11):1057-1063.doi:10.2106/jbjs.J.00160.
19. Zou D, Li W, Xu F, Du G. Use of Hounsfield units of S1 body to diagnose osteoporosis in patients with lumbar degenerative diseases. *Neurosurgical focus.* 2019;46(5):E6.doi:10.3171/2019.2.Focus18614.
20. Yaprak G, Gemici C, Seseogullari OO, Karabag IS, Cini N. CT Derived Hounsfield Unit: An Easy Way to Determine Osteoporosis and Radiation Related Fracture Risk in Irradiated Patients. *Frontiers in oncology.* 2020;10:742.doi:10.3389/fonc.2020.00742.
21. Silva BC, Broy SB, Boutroy S, Schousboe JT, Shepherd JA, Leslie WD. Fracture Risk Prediction by Non-BMD DXA Measures: the 2015 ISCD Official Positions Part 2: Trabecular Bone Score. *Journal of clinical densitometry : the official journal of the International Society for Clinical Densitometry.* 2015;18(3):309-330.doi:10.1016/j.jocd.2015.06.008.
22. Shayganfar A, Khodayi M, Ebrahimian S, Tabrizi Z. Quantitative diagnosis of osteoporosis using lumbar spine signal intensity in magnetic resonance imaging. *The British journal of radiology.* 2019;92(1097):20180774.doi:10.1259/bjr.20180774.

Figures

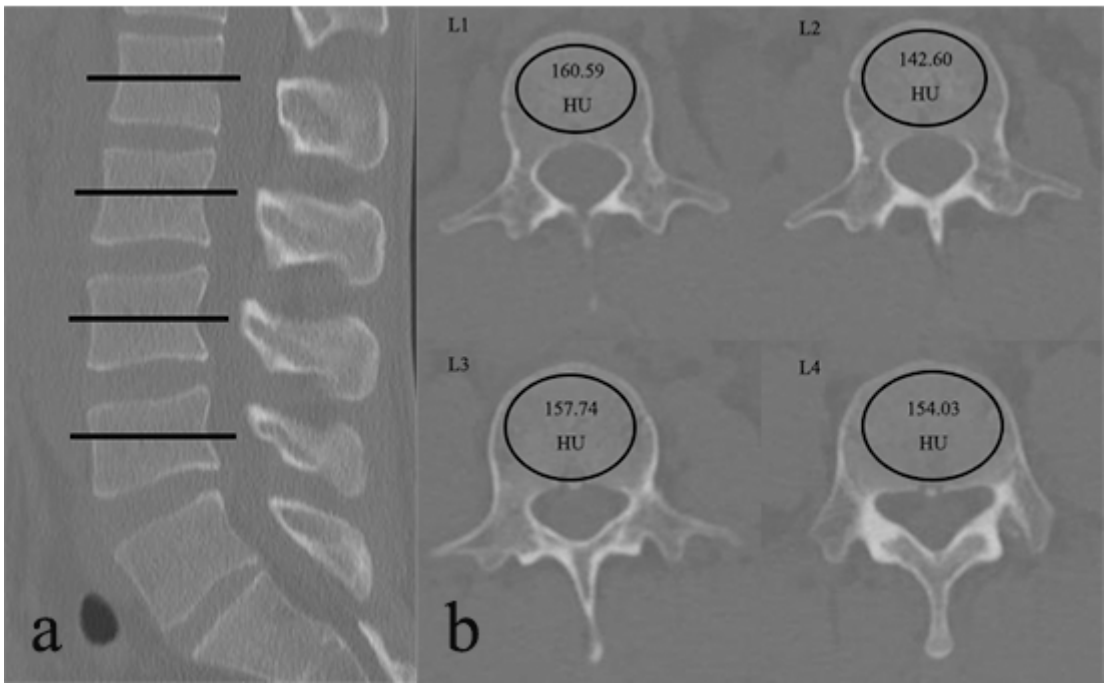

Figure 1

CT images show HU values determined using region of interest (ROI). Figure 1A shows the axial plane of ROI in the middle of the L1-L4. Figure 1B shows PACS software automatically calculates the average HU value for ROI

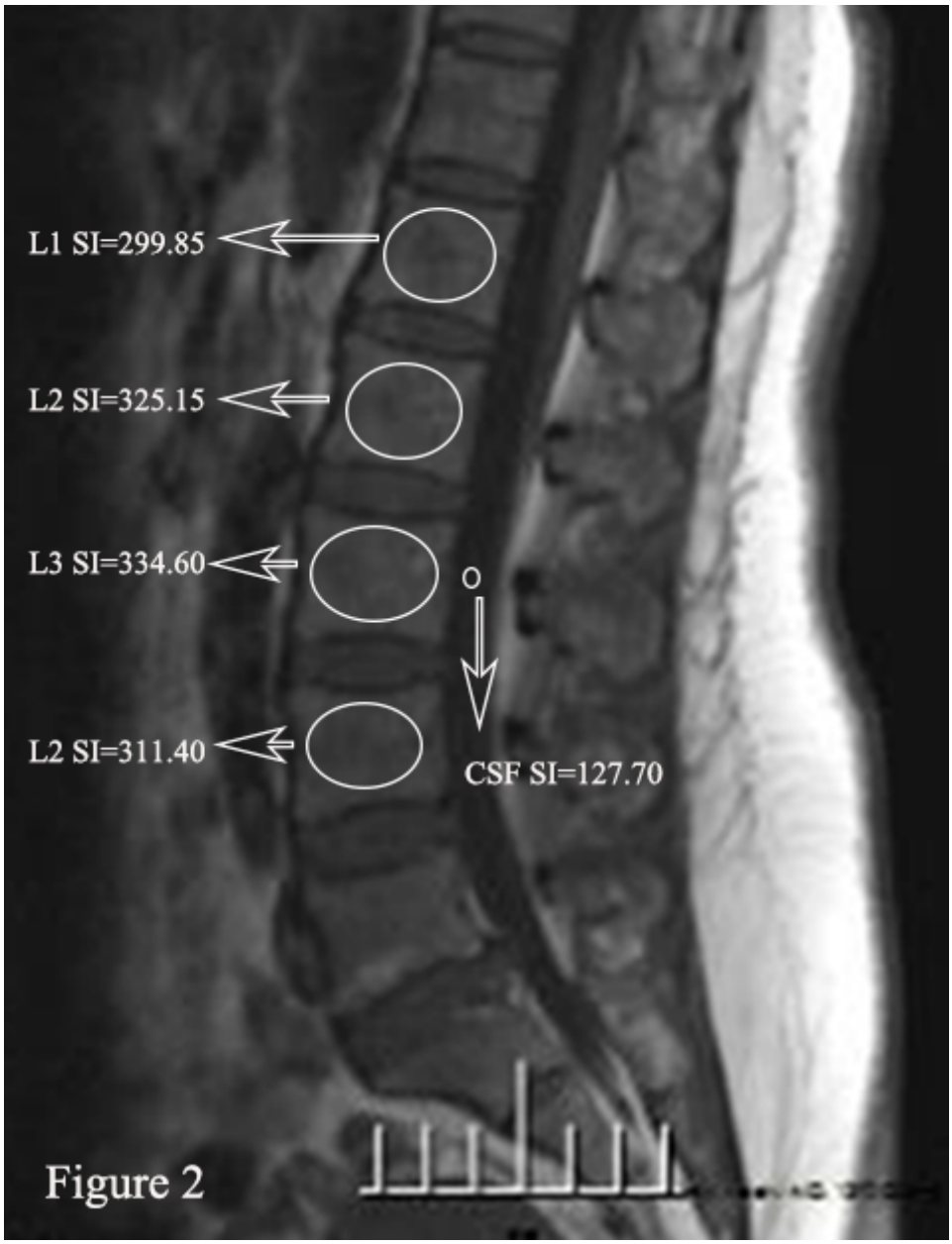

Figure 2

Non−contrast-enhanced T1-weighted MRI image shows the determination of SI of L1-L4 and SI of CSF using regions of interest (ROIs).

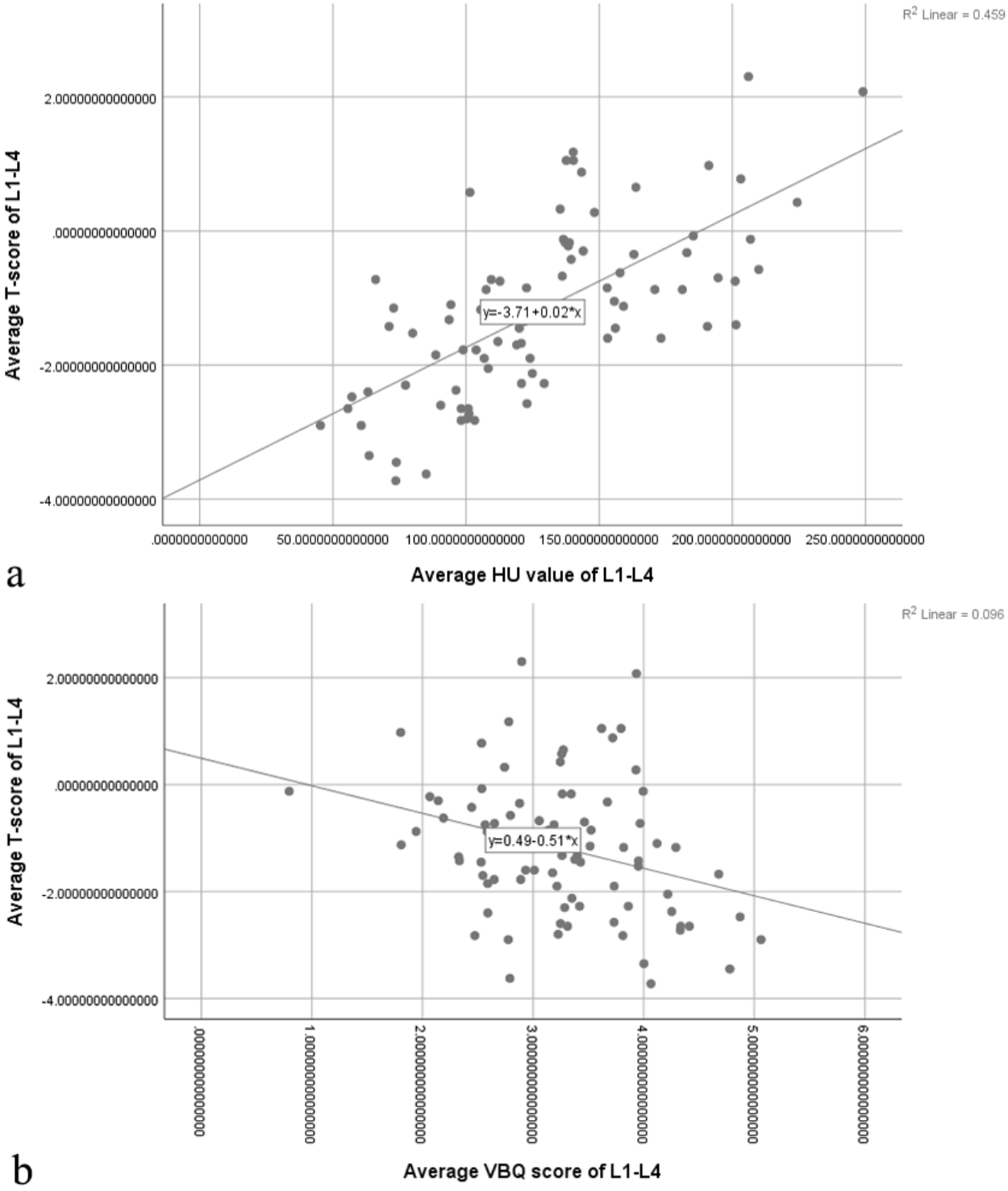

Figure 3

Scatter plots shows the correlation average HU value of L1-L4 and average T-score of L1-L4 in figure 3a. The image of 3b shows the correlation average VBQ score of L1-L4 and average T-score of L1-L4.In each figure, regression lines are also shown.

Supplementary Files

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- unnamedattachment11.xlsx