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Hounsfield unit correlates with intervertebral disc degeneration in premenopausal and menopausal women: a radiological study

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Abstract

Objectives This study aims to investigate whether Hounsfield unit (HU) value is correlated with intervertebral disc (IVD) degeneration (IVDD) by comparing premenopausal with menopausal women patients.

Methods A total of 101 female patients who underwent treatment in our hospital between February 2022 and February 2023 were retrospectively reviewed and included in this study. All patients were divided into either the premenopausal group or the menopausal group, according to age and menopause status. The changes in disc height index (DHI) on X-ray, the Hounsfield unit (HU) value on computed tomography (CT), and the area of the nucleus pulposus (NP) on magnetic resonance imaging (MRI) were assessed and compared between the two groups.

Results There is a significant difference in the Pfirrmann grading of T12-S1 discs between the premenopausal and menopausal groups; the menopausal group has more degenerated discs compared with the premenopausal group ($P < 0.001$). There is no significant difference in DHI measurements between the premenopausal and menopausal groups. HU values in the premenopausal group are greater compared with the menopausal group from T12 to S1 vertebrae (all $P < 0.001$). Regarding the NP area on MRI, the L2-L3 IV disc space have a bigger area in the premenopausal group compared with the menopausal group ($P = 0.029$), with no significant difference in other IVD segments.

Conclusions The HU value on CT is significantly decreased with IVDD progression after menopause. The change in HU value could indirectly reflect vertebral bone mineral density. Therefore, the decline of estrogen after menopause leads to vertebral osteoporosis, which might contribute to IVDD progression.

Keywords Intervertebral disc degeneration, Menopause, Estrogen, Hounsfield unit, Disc height index

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Introduction

One of the important causes of low back pain (LBP) in clinical work is intervertebral disc (IVD) degeneration (IVDD), but the pathogenesis of IVDD is still unclear. The causes of IVDD may be related to factors such as age, inflammation, trauma, hormones, and genetics [1–2]. Since the 1950s, spinal surgeons have been using imaging modalities to diagnose IVDD, which remains the most widely used method to this day [3]. Nowadays, the diagnosis of all forms of IVDD in clinical practice is based on imaging methods, and imaging technology is constantly developing [4].

The simplest and most intuitive way to diagnose IVDD in clinical work is through imaging methods evaluation, such as X-ray, computed tomography (CT), and magnetic resonance imaging (MRI) [5]. Among all imaging methods, MRI is one of the most commonly used techniques for diagnosing IVDD. Considering the economic situation and time efficiency, CT is much more extensively used than MRI [6]. Disc height index (DHI) is measured in the sagittal plane of the lumbar spine through X-ray, and studies have shown that DHI could reflect the progression of IVDD [7]. The Hounsfield unit (HU) is a density metric measurement on CT and a simple and effective method for evaluating vertebral bone mineral density (VBMD), which has been associated with IVDD [8–10]. IVDD can be observed by measuring the area of the nucleus pulposus (NP) on T2-weighted MRI images, characterized as reduced signaling of the NP and annulus fibers [11].

Estrogen is a group of steroid hormones secreted from the ovaries [12]. Estrogen helps to slow down bone breakdown and promote bone growth. Over time, the decline in estrogen levels, particularly after menopause, lead to disrupts the balance between osteoblastic bone formation and osteoclastic bone resorption. These pathophysiological changes ultimately manifest as reduced vertebral bone mineral density (VBMD), deteriorated microarchitectural integrity, and heightened susceptibility to osteoporotic fractures [13–14]. Menopausal women are more likely to experience various metabolic disorders, such as dyslipidemia, fat redistribution, and altered visceral fat accumulation [15]. As a result, they are highly susceptible to changes in body composition, energy metabolism, and weight gain [16]. The average menopause time for Chinese women is about 50 years old, and the content of estrogen in the body significantly decreases after menopause [17]. To the best of our knowledge, there have been few studies so far reporting the correlation between HU value and IVDD in premenopausal and menopausal women patients with lumbar disc disease. Thus, this study was designed and performed to investigate how HU value correlates with IVDD in premenopausal and menopausal women.

Materials and methods

Ethics

This study was approved by the Institutional Care and Use Committee of Hebei Medical University Third Hospital (Approval No. K2022-022-1).

Patients

Inclusion criteria: (1) Degenerative lumbar spine disease patients. (2) Full lumbar spine lateral position X-ray, lumbar spine CT, and lumbar spine MRI, the imaging data were evaluated DHI changes, HU value, the area of NP, and IVDD evaluation. (3) Pre-menopause patients aged between 40 and 50 years old and menopause patients aged between 50 and 60 years old. Exclusion criteria: (1) Patients have a history of spinal trauma, spinal fracture, spinal surgery, spinal tuberculosis, spinal tumors, and other spinal inflammation, which may directly affect the spinal structure. (2) The patient had incomplete imaging data, a history of cervical surgery, or long-term use of hormone drugs due to other diseases. (3) A history of alcoholism and smoking addiction (smoking more than 2 cigarettes/day and drinking more than 50 mL/day). Patients included in this study was admitted into our hospital between February 2022 and February 2023. X-ray, CT and MRI imaging were performed within a short period after the patients were admitted into our hospital, usually 2 to 3 days and divided into two groups according to age: premenopausal women group (40–50 years old) and menopausal women group (50–60 years old).

Data collection and assessment

General statistics were recorded for the patients, including age, height, weight, and Pfirrmann grading, where Pfirrmann grading was performed independently by two spinal surgeons. All patients' X-ray were scanned by a direct digital multi-function X-ray camera (Siemens, Erlangen, Germany), 64-slice multi-detector CT scanner (Siemens, Erlangen, Germany) according to the following parameters: slice thickness 3.0 mm, distance 3.0 mm, tube voltage 120 kV and MRI T2-weighted sagittal 3.0T scanner (Philips, Amsterdam, Netherlands) based on the parameters: echo time 100.00ms, multi-coil, slice thickness 4.0 mm. All imaging data were obtained from the PACS (Picture Archiving and Communication Systems) Imaging System for T12 to S1. Disc degeneration on MRI T2-weighted sagittal images was classified as grade I to grade V according to the Pfirrmann grading [18]. If two spinal surgeons gave different Pfirrmann grade evaluations on the same disc, a third spinal surgeon was invited to make the final decision. Intraclass correlation coefficient (ICC) analysis of the Pfirrmann grade was performed to detect the reliability of ratings among these raters (Table 1).

Table 1 Intraclass correlation coefficient (ICC) analysis for Pfirrmann grade of intervertebral disc degeneration

Disc segment	95% CI	Intraclass correlation
T12-L1	(0.805, 0.895)	0.855
L1-L2	(0.910, 0.953)	0.934
L2-L3	(0.898, 0.947)	0.925
L3-L4	(0.854, 0.922)	0.892
L4-L5	(0.735, 0.853)	0.800
L5-S1	(0.868, 0.930)	0.903

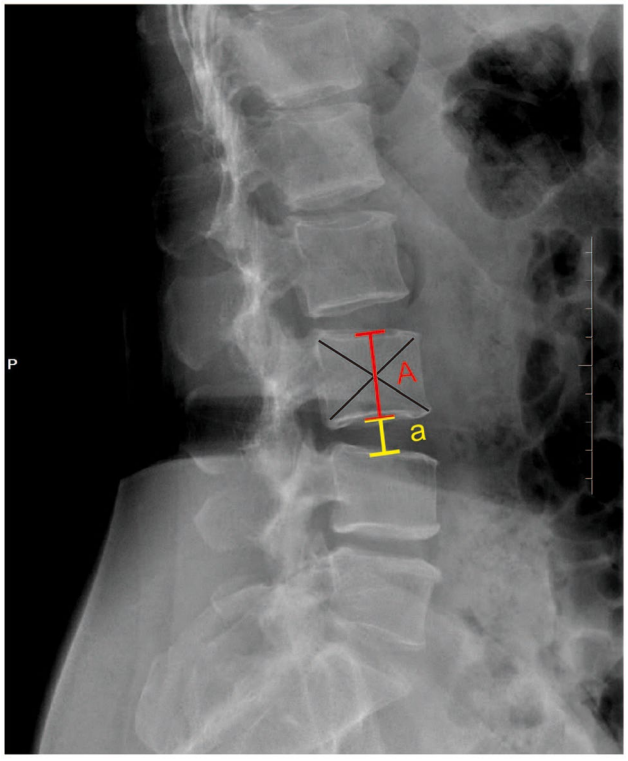

Fig. 1 Disc height index (DHI) on X-ray. DHI = a/A

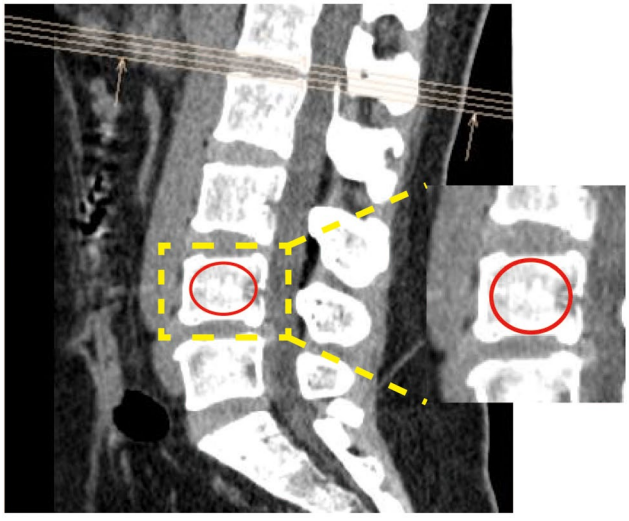

Fig. 2 The Hounsfield unit (HU) Value on computed tomography (CT)

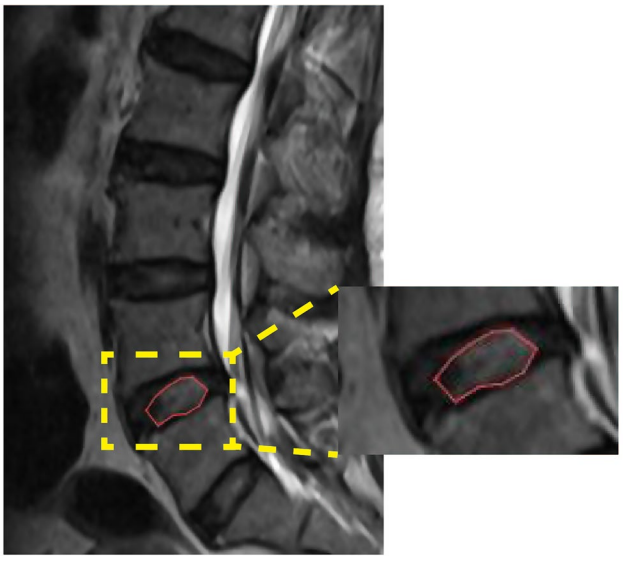

Fig. 3 The area of nucleus pulposus (NP) on magnetic resonance imaging (MRI)

DHI measurement

The measurement of DHI was performed as follows. Measure the height on the midsagittal X-ray image of the T12-S1 vertebral body, connect the diagonal of the vertebral body, draw A straight line at the lower edge of the vertical vertebral body through the intersection of the two diagonal lines, and measure the height, denoted as A; extend the straight line along the line a to measure the height of the disc, denoted as a DHI = a/A (Fig. 1) [7].

HU value measurement

The interest region of the entire vertebral body was measured on the midsagittal plane CT image of the T12-S1 vertebral body, and the elliptical region of interest was drawn as large as possible, excluding the cortical margin and basilar vertebral venous foramen (Fig. 2) [19].

NP area measurement

The area of NP in the IVDs on MRI was measured as follows. We manually plotted the interested region of the NP area in the central sagittal section on the MRI T2-weighted image in T12-S1 vertebrae and the values were recorded (Fig. 3) [20].

Statistical analysis

Data analysis was conducted using the statistical software SPSS 27.0 (SPSS, Inc., Chicago, IL, USA). Measurement data were expressed as mean ± standard deviation (SD). The age and BMI were compared using the independent sample t-test. Chi-square tests were used to compare the Pfirrmann grading between the groups. Independent sample t-tests were used to compare the DHI changes on X-ray, HU values on CT, and the area of NP in the IVDs

on MRI. The evaluation criteria of ICC are: 0 is not credible and 1 is fully credible. It is generally believed that a reliability coefficient below 0.4 indicates poor reliability, and greater than 0.75 indicates good reliability. $P<0.05$ was considered statistically significant.

Results

Characteristics of the patients

A total of 101 female patients were included in this study, including 35 premenopausal women with an average age of 45.7 ± 3.4 years old and a BMI of 25.6 ± 3.5 kg/m^2, and 66 menopausal women with an average age of 56.6 ± 3.1 years old and BMI of 25.4 ± 3.2 kg/m^2. The minimum age is 40 years old, while the maximum age is 60 years old. The Pfirrmann grades of the IVD segments of T12-S1 in the premenopausal groups are II (131 discs, 62.4%), III (50 discs, 23.8%), IV (23 discs, 10.9%), and V (6 discs, 2.9%), respectively. The Pfirrmann grades of the IVD segments of T12-S1 in the menopausal groups are II (34 discs, 8.6%), III (137 discs, 34.6%), IV (120 discs, 30.3%), and V (105 discs, 26.5%), respectively. Overall, there is a significant difference in Pfirrmann grading of T12-S1 between the premenopausal and menopausal groups ($P<0.001$, Table 2). The menopausal group has more severely degenerated discs compared with the premenopausal group.

Changes of DHI, HU value, and the area of NP

There is no significant difference in DHI changes on X-ray between the premenopausal and menopausal women groups (Table 3). HU value on CT of T12, L1, L2, L3, L4, L5, and S1 is 194.38 ± 41.69, 192.84 ± 37.43, 185.27 ± 40.47, 180.29 ± 47.73, 184.40 ± 54.67, 189.74 ± 54.74, and 241.56 ± 67.72 in the premenopausal women group and 140.25 ± 37.92, 135.02 ± 33.16, 127.49 ± 30.47, 121.67 ± 45.20, 127.38 ± 46.07, 137.54 ± 41.36, and 187.46 ± 47.83 in the menopausal women group, respectively (Table 4). There are significant statistical differences at each IVD segment in the premenopausal and menopausal women groups (Fig. 4a). From the line chart, it can be seen that the changes of HU value on CT from T12 to L5 are not significant, but the HU value on the S1

Table 2 Comparison of general data in the premenopausal and menopausal women groups

	Premenopause	Menopause	Cases	*P* value
N	35	66	101	-
Age	45.7 ± 3.4	56.6 ± 3.1	-	*<0.001*
BMI	25.6 ± 3.5	25.4 ± 3.2	-	0.233
Pfirrmann Grade, T12-S1 (No. of discs)	210 (100%)	396 (100%)	606	
Pfirrmann Grade I	0 (0%)	0 (0%)	0	-
Pfirrmann Grade II	131 (62.4%)	34 (8.6%)	165	*<0.001*
Pfirrmann Grade III	50 (23.8%)	137 (34.6%)	187	
Pfirrmann Grade IV	23 (10.9%)	120 (30.3%)	143	
Pfirrmann Grade V	6 (2.9%)	105 (26.5%)	111	

Table 3 Disc height index of T12-S1 in the premenopausal and menopausal women groups

	Premenopause	Menopause	*P* value
T12-L1	0.31 ± 0.06	0.32 ± 0.07	0.183
L1-L2	0.32 ± 0.08	0.34 ± 0.07	0.410
L2-L3	0.37 ± 0.07	0.37 ± 0.06	0.945
L3-L4	0.37 ± 0.07	0.37 ± 0.09	0.617
L4-L5	0.34 ± 0.10	0.33 ± 0.10	0.543
L5-S1	0.28 ± 0.08	0.28 ± 0.09	0.973

Table 4 Hounsfield unit value of T12-S1 in the premenopausal and menopausal women groups

	Premenopause	Menopause	P value
T12	194.38 ± 41.69	140.25 ± 37.92	<0.001
L1	192.84 ± 37.43	135.02 ± 33.16	<0.001
L2	185.27 ± 40.47	127.49 ± 30.47	<0.001
L3	180.29 ± 47.73	121.67 ± 45.20	<0.001
L4	184.40 ± 54.67	127.38 ± 46.07	<0.001
L5	189.74 ± 54.74	137.54 ± 41.36	<0.001
S1	241.56 ± 67.72	187.46 ± 47.83	<0.001

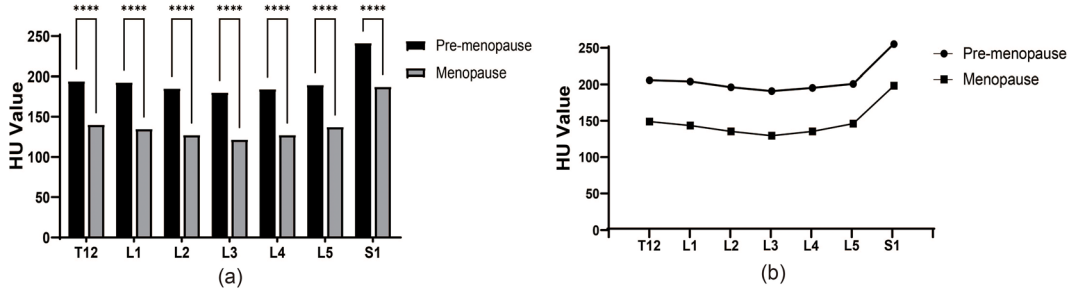

Fig. 4 Results of the Hounsfield unit (HU) value on computed tomography (CT). (**a**) Statistical results of HU value on CT from T12 to S1 in the pre-menopause and menopause women groups. (**b**) The changing trend of HU value on CT from T12 to S1 in the premenopausal and premenopausal women groups. ***$p<0.001$

Table 5 MRI area of nucleus pulposus in lumber T12-S1 in the premenopausal and menopausal women groups

	Premenopause	Menopause	*P* value
T12-L1	0.83 ± 0.24	0.85 ± 0.26	0.664
L1-L2	1.08 ± 0.32	1.02 ± 0.39	0.421
L2-L3	1.44 ± 0.34	1.26 ± 0.47	***0.029***
L3-L4	1.51 ± 0.37	1.42 ± 0.62	0.357
L4-L5	1.41 ± 0.66	1.38 ± 0.73	0.845
L5-S1	1.29 ± 0.49	1.30 ± 0.60	0.890

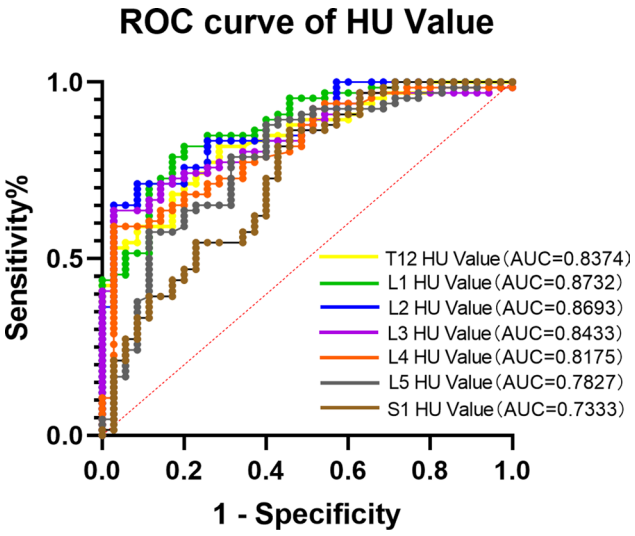

Fig. 5 Results of the receiver operating characteristic (ROC) curve of Hounsfield unit (HU) value on computed tomography (CT)

segment greatly increases to be the maximum value both in the premenopausal and menopausal women groups (Fig. 4b). Regarding the NP area on MRI, only the L2-L3 shows a significant difference in the premenopausal and menopausal women groups, with no significant difference in other segments (Table 5). Through the area under the receiver operating characteristic (ROC) curve evaluation model performance, it can be found that the area under curve (AUC) under the ROC curve evaluated by HU value of T12-S1 for IVDD was 0.8374, 0.8732, 0.8693, 0.8433, 0.8175, 0.7827 and 0.7333, respectively (Fig. 5).

Discussion

This study was performed to investigate how HU value correlates with IVDD in premenopausal and menopausal women by comparing the changes of DHI, HU value on CT, and the area of NP on MRI of T12-S1 IVDs. As a result, there is a significant difference in HU value between the premenopausal and menopausal groups. HU value in the premenopausal group is bigger than the menopausal group. HU value is a simple and effective method to evaluate VBMD [9], indicating that the obvious decline of estrogen in menopausal women leads to a significant decrease in VBMD, resulting in IVDD. The results of the HU value may be useful as an objective and quantitative tool to identify early changes in IVDD and provide new management strategies for clinicians to diagnose and treat IVDD more accurately.

Osteoporosis is a systemic bone disease caused by decreased bone density and quality, destruction of bone microstructure, and increased bone fragility, which increases the risk of fracture for patients [21]. Estrogen has a regulatory effect on bone, especially in postmenopausal women (The average age of menopause of Chinese women is 50 years old), who may suffer from severe osteoporosis due to reduced hormone levels [17, 22]. Corresponding clinical studies have confirmed that after ovariectomy, estrogen levels in women will decrease significantly for a long period, which will promote the progress of IVDD. It can be seen that estrogen levels will affect the progress of IVDD in clinical studies [23]. However, studies on the association of VBMD and IVDD have not yielded consistent results. Most scholars believe that VBMD calcifies the cartilage endplate of the lumbar vertebrae, resulting in a reduced supply of nutrients in the IVDs and further promoting the occurrence of IVDD [24]. Subcutaneous fat tissue thickness (SFTT) has been reported to be positively correlated with the presence and severity of IVDD [25]. Another study found that an increase in SFTT and a decrease in epidural fat tissue thickness (EFTT) were both correlated with IVDD. This suggests that EFTT plays a protective role in IVDD, and this finding could be linked to obesity-related mechanical stress and inflammatory damage [26]. A previous study has found that IVDD is more common or more severe in older women than older men, which further suggests that postmenopausal women accelerate IVDD due to relative estrogen deficiency [27].

Studies have shown that DHI is a risk factor in women, especially older women [28]. Through the study of imaging data, it was found that the incidence and risk factors of lumbar spine disease are related to DHI. The degree of DHI decline in elderly women is higher than that in elderly men, and the prevalence and severity of IVDD are also higher than that in elderly men [29–30]. However, there is no significant correlation between DHI and IVDD in our study of premenopausal and menopausal women. On T2-weighted MRI images, IVDD was manifested by the reduced signal of NP and annulus fibers, and studies found that T2-weighted MRI images were sensitive to changes in IVD collagen and water content, and T2 relaxation time decreased with IVDD [11]. Age-related decreases in the area of NP in the IVDs on T2-weighted MRI images have been reported [31]. With the increase of women's age, the area of NP in the IVDs on MRI decreases more rapidly, although women tend to have higher T2-weighted values before the age of 50 years old, this trend is reversed in menopausal women [20]. In

this study, it was found that the area of NP in the IVDs on MRI in the menopausal women group was reduced compared to that in the premenopausal women group, but there was no significant difference between the two groups, and only the area of NP in the IVDs on MRI in L2-L3 was significantly different between the two groups, which may be since there was no significant difference in age between the two groups, although the two groups were divided according to whether they were menopausal or not.

The HU value of the lumbar vertebrae measured on CT can represent its bone density, and the accuracy of measurement can be improved by measuring the average HU value of the vertebrae region of interest on CT [8–9, 32–33]. Some studies have found that the HU value is inconsistent at all levels of the cervical spine, and the distribution in the vertebral body is uneven. With the increase in women's age, the vertebral bone mass and vertebral osteoporosis will be decreased, and the HU value will also decline, which can cause or exacerbate IVDD [10]. It has been reported that in elderly women, VBMD reflected by HU value is correlated with IVDD, which is consistent with our study [34]. Our study found that the Pfirrmann grading of the menopausal women group was higher and the HU value was significantly lower compared with the premenopausal women group, indicating that the decline of estrogen in the menopausal women would lead to the decrease of VBMD, leading to osteoporosis and thus aggravating IVDD. The results of the area under the ROC curve show that the HU value prediction model can better predict IVDD in premenopausal and menopausal women and has good prediction value. In the future, the HU value can be used to simply judge the VBMD of women before and after menopause to diagnose and prevent the occurrence of IVDD.

In this study, patients were grouped according to whether the women were menopausal or not, and it was found that the HU value of the lumbar cancellous bone decreased in the postmenopausal women group. We believe that there could be several reasons for this. The first and most important reason is that the HU values are a simple and effective way to assess VBMD [9]. Compared with the premenopausal women group, the HU value of the postmenopausal women group is significantly decreased, indicating that the reduction of estrogen in postmenopausal women will affect calcium metabolism and lead to a decrease in bone mineral density of cancellous bone. Secondly, studies have found that with the increase of age, the bone mass of human cancellous bone will begin to be lost [35]. In females, the dynamic balance between osteoblasts and osteoclasts will change due to the increase of age, destroying bone microstructure. Additionally, after menopause, the decline of estrogen will further senescence and apoptosis of NP cells. Studies have shown that estrogen can inhibit the abnormal apoptosis and inflammation of NP cells by activating NF-κB, PI3K-Akt, and ERK signaling pathways, enhance the tolerance of NP cells to inflammation and oxidative stress, reduce the aging and apoptosis of NP cells, and thus delay the progression of IVDD [2–36]. Thirdly, due to the unit volume pressure of different vertebrae being different, according to Wolf's Law, it is known that the structure of the bone is affected by the direction of mechanical stimulation [37]. Our study found no significant change in the variation trend of HU value in the sagittal position of the lumbar spine from T12-L5, but the HU value suddenly increased in the S1 segment. The HU value in the S1 segment was the highest among all the studied segments. This may be attributed to several factors, including S1 being a fusion bone, the different cross-sectional area of the vertebrae, and the different selection and measurement methods of the area of NP. The changing trend of HU value in the different vertebrae and the correlation of IVDD need further study.

There are some limitations in this study. Firstly, the sample size of this study is relatively small. Further investigation with a large sample size is needed to validate the findings of our study. Secondly, Certain confounding factors such as bone mineral density (BMD), physical activity levels, and body composition could significantly influence IVDD progression but have not been considered in this study. These variables are also our study limitations. Finally, the patients included in this study were all Asians. Thus, further studies are required to focus on patients from other ethnicities.

Conclusions

The HU value on CT is significantly decreased with IVDD progression after menopause. The change in HU value could indirectly reflect vertebral bone mineral density. Therefore, the decline of estrogen after menopause leads to vertebral osteoporosis, which might contribute to IVDD progression.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-025-05770-8.

Supplementary Material 1

Supplementary Material 2

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None.

Author contributions

G conducted data acquisition and drafted the article. Z performed data analysis. T provided statistical software and conducted data analysis and interpretation. L performed data acquisition and edited the manuscript. N performed literature research and edited the manuscript. Y reviewed and edited the manuscript and made critical revisions for important intellectual

content. H designed and supervised the study, obtained funding, reviewed and edited the manuscript, and finalized the article.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare no competing interests.

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