Research Square

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A comprehensive evaluation of bone mineral density by endplate bone quality score in patients with ossification of the posterior longitudinal ligament

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Abstract

Objective

The MRI-derived cervical endplate bone quality (EBQ) score has emerged as a novel indicator in predicting postoperative implant subsidence. However, limited systematic investigations have been conducted to evaluate the EBQ score profiles among patients with cervical ossification of the posterior longitudinal ligament (OPLL).

Methods

EBQ scores at each endplate were calculated. Propensity score matching (PSM), paired t-test, Kruskal-Wallis test, and multivariate regression analysis were used to compare EBQ scores between OPLL and other types of degenerative cervical myelopathy (DCM) patients, between genders, superior and inferior endplates, among different segments, and to identify associated factors.

Results

Both before and after PSM, OPLL patients had significantly lower individual, segmental, and adjacent inter-vertebral EBQ scores than other types of DCM patients. Females showed higher EBQ scores than males at most levels. Inferior endplate EBQ was higher than superior at all inter-vertebral segments and C3, C4, T1 vertebral levels (with C5-C7 no difference). Adjacent EBQ decreased from C2/3 to C7/T1 (no difference between C2/3-C3/4, C3/4-C4/5, C5/6-C6/7). Segmental EBQ was highest at C3, followed by C6, C4, C5, C7, T1 (with C5-C6, C7-T1 no difference). Glucocorticoid history was the sole independent factor correlated with EBQ.

Conclusions

This study systematically characterized cervical EBQ in OPLL patients. Key findings include lower EBQ in OPLL vs other types of DCM, gender-related disparities, superior-inferior endplate differences, and specific segmental EBQ trends. These results fill gaps in understanding OPLL bone quality and lay a foundation for pathogenesis research and targeted bone quality interventions.

Introduction

Cervical ossification of the posterior longitudinal ligament (OPLL) can cause spinal cord and/or nerve root compression as the ossified ligament thickens and expands, leading to neurological symptoms and impairing patients' quality of life [1, 2]. A radiological study implemented with 3-dimensional computed tomography (3D-CT) found that the overall prevalence of OPLL in the degenerative cervical myelopathy (DCM) patients attained a considerable rate of 18.22% [3]. Conservative treatment for symptomatic patients is often ineffective, and surgical intervention is required to restore the spinal canal space, stabilize the cervical spine and arrest the progression of neurological deterioration [4, 5]. Anterior cervical corpectomy and fusion (ACCF) is a common surgical option for OPLL, especially for patients with multi-segment OPLL or those involving the vertebral body [6, 7], which can achieve direct decompression, restore the height of the inter-vertebral space and the curvature of the cervical spine [8–10]. However, the instrumentation complications such as cage subsidence, titanium mesh cage subsidence is a very common complications after ACCF [11, 12], resulting in reduced inter-vertebral space height, altered cervical curvature, and even segmental kyphosis [13–15]. Thus, meticulous preoperative assessment of bone quality prior to surgical intervention plays a pivotal role in minimizing implant-related complications and enhancing surgical outcomes.

DEXA is acknowledged as the gold standard for osteoporosis diagnosis. However, DEXA has its limitations in the assessment of cervical bone quality. First, DEXA usually measures the BMD of the lumbar spine and hip, and its bone metabolism is different from it [16]. Second, DEXA has radiation exposure, which is not suitable for repeated measurements, especially for patients who need long-term follow-up [17]. Third, DEXA measurement are susceptible to interference from factors including vertebral osteophytes, vascular calcification, and lumbar deformities, thereby failing to accurately depict the actual bone quality of the vertebral bodies [18]. The endplate bone quality (EBQ) score is a novel MRI-based marker for bone quality assessment, offers several key advantages including being radiation-free and allowing assessment via routine MRI without additional scanning.

Studies showed that the EBQ score can predict the instrumentation implications after anterior cervical surgery [19, 20]. However, no studies have systematically evaluated EBQ scores across different cervical segments, their associations with patient demographics, or compared these scores between OPLL and other types of DCM cohorts.

Given these limitations, the present study aims to: (1) systematically assess the EBQ score in OPLL patients via propensity score matching-controlled comparison with other types of DCM cohorts; (2) Clarify the gender disparities in OPLL and the intra-patient EBQ distribution patterns (superior vs. inferior, cephalad vs. caudal); (3) Identify independent clinical factors associated with EBQ score, ultimately providing further insights for refining surgical strategies, optimizing preoperative planning, and enhancing risk stratification.

Methods

Study design

This study was reviewed and approved by the Medical Ethics Committee of Chengdu Wenjiang District People's Hospital, with the ethical approval number LW-KY-2025-042. Owing to the retrospective nature of the study, written informed consent from participating patients was exempted in accordance with established ethical guidelines. A consecutive series of patients diagnosed with DCM (including 254 OPLL patients and 239 patients with other types of DCM) who underwent spinal surgery from 2021 to 2024 were retrospectively reviewed. Inclusion criteria were defined as follows: (1) confirmed diagnosis of cervical OPLL or DCM; (2) availability of preoperative T1-weighted MRIs; (3) completion of dual-energy X-ray absorptiometry (DEXA) within 1 month before surgery. Patients were excluded if they met any of the following conditions: (1) a history of previous cervical spine surgery; (2) presence of modic changes; (3) spine infection; (4) dialysis patients; (5) diagnosis of rheumatoid arthritis; (6) lesions of the upper cervical spine; (7) presence of spinal tumors or tuberculosis. Demographic characteristics and clinical information were retrieved from the hospital's electronic medical record system, including age, sex, BMI, OPLL subtype, laboratory findings (encompassing serum triglycerides (TG), total cholesterol (TC), uric acid (UA), calcium, phosphorus, high-density lipoprotein (HDL), and low-density lipoprotein (LDL)), comorbidities, as well as alcohol consumption and smoking history.

EBQ scores measurement

The specific measurement for the EBQ score were referenced from a prior publication [20]. For the delineation of region of interest (ROI) on each vertebral endplate, a minimum of nine discrete points were marked along the observable surfaces of the superior and inferior endplates to facilitate manual segmentation. Subsequently, a vertical line of 0.6mm in length were extended superiorly and inferiorly from each marked point, and the region bounded by these lines was designated as the ROI. For cerebrospinal fluid (CSF) ROI measurement, the ROI was placed at the central of the cisterna magna, with meticulous avoidance of the medulla oblongata and cerebellum (Fig. 1). The EBQ score for each individual endplate was computed as the ratio of the median signal intensity (SI) of the endplate to the SI of CSF within the cisterna magna. Segmental EBQ score was defined as the mean value of superior and inferior endplate bone quality score for each vertebral body. Adjacent EBQ score was defined as the mean value of the superior and inferior endplate bone quality score in each intervertebral space. All measurements were performed utilizing the picture archiving and communication system (PACS) and a 1.5T MRI scanner (Philips Healthcare, Eindhoven, Netherlands). The MRI scanning parameters were set as follows: T1-weighted imaging (TR 486, TE 8), T2-weighted imaging (TR 2000, TE 90), and a slice thickness of 3mm. DEXA derived bone mineral density were conducted using the GE Lunar iDXA system (GE Healthcare, Waukesha, WI, USA).

Statistical Methods

All statistical analyses were conducted using SPSS software (Version 28; IBM Corporation, Armonk, New York, USA), and graphical illustrations were generated with GraphPad Prism 9.3.0 (GraphPad Software, Inc., San Diego, California, USA). The Shapiro-Wilk test was used to assess the normality of continuous variables, which were presented as median (interquartile range, IQR) due to non-normal distribution. Categorical variables were expressed as counts (percentages), and tested with the χ^2 test or Fisher's exact test. For the comparison of the EBQ score between OPLL and other types of DCM, and EBQ score between male and female, propensity score matching was performed with a 1:1 nearest-neighbor matching algorithm and a caliper width of 0.02 standard

deviations. Matching variables included age, sex, BMI, comorbidity, smoking and alcohol history, and laboratory data. Comparisons of the EBQ scores were conducted using the Mann-Whitney U test. Paired t-tests were used to analyze intra-intervertebral (superior vs. inferior endplates within the intervertebral space) and intra-vertebral level (superior vs. inferior endplates within the same vertebral body) EBQ score differences. Multiple comparisons of adjacent EBQ scores across inter-vertebral spaces (C2/3 to C7/T1) and segmental EBQ scores across vertebral bodies (C3 to T1) were adjusted using the Bonferroni correction. Univariate correlation analyses were performed to examine the associations between baseline characteristics and EBQ scores. Then multiple linear regression analysis was employed to further evaluate the independent effects of these factors on EBQ scores, Finally, the correlation coefficients were visualized using a correlation heatmap. A p-value < 0.05 was considered statistical significance.

Results

A total of 493 patients aged 25–85 years were enrolled in this study, including 254 patients with cervical OPLL and 239 patients with other types of DCM. Prior to PSM, the OPLL group was significantly younger, had a higher proportion of males, elevated body mass index (BMI), triglyceride (TG), total cholesterol (TC), uric acid (UA) levels, and higher areal bone mineral density (aBMD) compared with the other types DCM group (all $P < 0.001$) (Table 1). In the matched cohorts, males constituted the majority (54.7% vs. 55.9%), and patients with BMI over 23 kg/m² accounted for 77.65% and 75.97%, respectively. The proportions of patients with hypertension, diabetes mellitus, smoking history, and alcohol history were 35.75% vs. 34.64%, 12.29% vs. 12.85%, 14.53% vs. 15.64%, and 5.59% vs. 8.38%, respectively. Notably, the OPLL group retained significantly higher lumbar and femoral neck aBMD than the matched cohort. No significant disparities were observed in age, sex, BMI, comorbidities, smoking/alcohol history and laboratory data between the two groups after PSM (Table 2). Ultimately, the OPLL group exhibited significantly lower EBQ scores at each individual endplate, as well as lower segmental and adjacent inter-vertebral space EBQ scores, compared with other types of DCM group (Table 3).

Table 1
The demographics of patients between OPLL and Other types of DCM before propensity score matching

Characteristic	OPLL (n = 254)	Other types of DCM (n = 239)	Z value	P value
Age	57.9 (51.6, 66.0)	62.1 (55.9,69.5)	-4.03	0.000**
Sex (Male %)	171 (67.3%)	104 (43.5%)	-5.314	0.000**
BMI (kg/m^2)	25.3 (23.7, 27.5)	24.5 (22.8,26.6)	-3.536	0.000**
≤ 18.49	2 (0.79)	9 (3.77)		
18.5-22.99	44 (17.32)	64 (26.78)		
23-27.49	155 (61.03)	128 (53.56)		
27.5-32.49	57 (22.44)	34 (14.23)		
≥ 32.5	6 (2.36)	4 (1.67)		
Comorbidity (%)				
Hypertension	86 (33.86%)	82 (34.31%)	-0.106	0.916
Diabetes mellitus	34 (13.39%)	31 (12.97%)	-0.28	0.780
Ischemic heart disease	11 (4.33%)	12 (5.02%)	-0.363	0.717
Cerebral stroke	13 (5.12%)	11 (4.60%)	-0.266	0.791
Thyroid disease	9 (3.54%)	7 (2.93%)	-0.384	0.701
Glucocorticoid history	9 (3.54%)	11 (4.60%)	-0.595	0.552
Smoking history	54 (21.26%)	29 (12.13%)	-2.704	0.007**
Alcohol history	26 (10.24%)	16 (6.69%)	-1.406	0.016*
Type of OPLL, n (%)				
Continuous	44 (17.32%)			
Segmental	43 (16.93%)			
Mixed	88 (34.65%)			
Localized	79 (31.10%)			
Laboratory data				
TG, mg/dl	58.36 (38.28, 73.86)	49.11 (37.12, 69.99)	1.99	0.046*
TC, mg/dl	197.23 (166.28, 215.72)	186.78 (158.93, 219.26)	2.68	0.007**
UA, mg/dl	7.32 (5.87, 10.27)	6.44 (5.64, 9.96)	3.25	0.0013**
Calcium, mg/dl	87.78 (85.46, 91.65)	89.33 (85.46, 91.26)	-0.44	0.662
Phosphorus, mg/dl	43.70 (37.90, 48.34)	44.86 (39.06, 47.95)	-0.71	0.487
HDL, mg/dl	40.60 (35.58, 52.20)	50.32 (41.32, 62.15)	-1.23	0.225
LDL, mg/dl	116.39 (91.26, 136.51)	136.54 (102.14, 158.31)	-0.43	0.661
aBMD				
L1	1.14 (0.99, 1.29)	0.99(0.88,1.13)	-8.505	0.000**

OPLL, Ossification of the posterior longitudinal ligament; DCM, Degenerative cervical myelopathy; BMI, Body mass index; TG, Triglyceride; TC, Total cholesterol; UA, Uric acid; HDL, high-density lipoprotein; LDL, low-density lipoprotein; *, p<0.05; **,p <0.01;

Characteristic	OPLL (n = 254)	Other types of DCM (n = 239)	Z value	P value
L2	1.26 (1.10, 1.39)	1.09(0.97,1.21)	-8.57	0.000**
L3	1.33 (1.17, 1.48)	1.20(1.06,1.30)	-7.991	0.000**
L4	1.36 (1.18, 1.51)	1.18(1.06,1.34)	-8.5	0.000**
L1-4	1.21 (1.10, 1.41)	1.08(0.99,1.21)	-8.958	0.000**
Femoral neck	0.92 (0.81, 1.04)	0.85(0.75,0.95)	-5.218	0.000**

OPLL, Ossification of the posterior longitudinal ligament; DCM, Degenerative cervical myelopathy; BMI, Body mass index; TG, Triglyceride; TC, Total cholesterol; UA, Uric acid; HDL, high-density lipoprotein; LDL, low-density lipoprotein; *, p<0.05; **,p <0.01;

Table 2
The demographics of patients between OPLL and Other types of DCM after propensity score matching

Characteristic	OPLL(n = 179)	Other types of DCM(n = 179)	Z value	P value
Age	58.7(53.2, 66.9)	61.1(55.3, 68.3)	-1.556	0.12
Sex(Male %)	98(54.7%)	100(55.9%)	-0.212	0.832
BMI(kg/m^2)	24.8(23.2, 26.8)	24.8(23.1,26.9)	-0.318	0.751
≤ 18.49	2(1.12)	2(1.12)		
18.5-22.99	38(21.23)	41(22.91)		
23-27.49	104(58.10)	102(56.98)		
27.5-32.49	34(18.99)	30(16.76)		
≥ 32.5	1(0.56)	4(2.23)		
Comorbidity(%)				
Hypertension	64(35.75)	62(34.64)	-0.221	0.825
Diabetes mellitus	22(12.29)	23(12.85)	-0.159	0.874
Ischemic heart disease	8(4.47)	8(4.47)	0	1
Cerebral stroke	8(4.47)	10(5.59)	-0.483	0.629
Thyroid disease	7(3.91)	6(3.35)	-0.282	0.778
Glucocorticoid history	5(2.79)	6(3.35)	-0.306	0.76
Smoking history	26(14.53)	28(15.64)	-0.295	0.768
Alcohol history	10(5.59)	15(8.38)	-1.035	0.3
Type of OPLL, n(%)				
Continuous	24(13.41)			
Segmental	32(17.88)			
Mixed	56(31.28)			
Localized	67(37.43)			
Laboratory data				
TG, mg/dl	54.26(38.01, 69.85)	53.18(37.92, 68.93)	-0.72	0.471
TC, mg/dl	190.15(164.82, 213.57)	188.72(163.95, 214.13)	-0.58	0.561
UA, mg/dl	6.89(5.76, 9.85)	6.62(5.69, 9.73)	-0.85	0.395
Calcium, mg/dl	88.45(86.02, 90.87)	88.83(86.15, 91.02)	0.51	0.609
Phosphorus, mg/dl	44.08(38.42, 47.85)	44.39(38.65, 48.01)	0.43	0.667
HDL, mg/dl	44.23(37.51, 50.68)	45.36(38.12, 51.25)	0.81	0.428
LDL, mg/dl	123.15(96.28, 137.85)	125.02(97.65, 139.17)	0.65	0.515
aBMD				
L1	1.13(1.02,1.34)	1.01(0.93,1.07)	-5.244	0.000**

OPLL, Ossification of the posterior longitudinal ligament; DCM, Degenerative cervical myelopathy; BMI, Body mass index; TG, Triglyceride; TC, Total cholesterol; UA, Uric acid; HDL, high-density lipoprotein; LDL, low-density lipoprotein; *, p<0.05; **, p<0.01;

Characteristic	OPLL(n = 179)	Other types of DCM(n = 179)	Z value	P value
L2	1.24(1.12,1.38)	1.12(0.97,1.22)	-5.12	0.000**
L3	1.33(1.17,1.36)	1.21(1.17,1.33)	-4.655	0.000**
L4	1.38(1.21,1.54)	1.21(1.14,1.35)	-5.282	0.000**
L1-4	1.21(1.12,1.29)	1.10(1.02,1.23)	-5.331	0.000**
Femoral neck	0.91(0.84,0.98)	0.87(0.79,1.05)	-2.043	0.000**

OPLL, Ossification of the posterior longitudinal ligament; DCM, Degenerative cervical myelopathy; BMI, Body mass index; TG, Triglyceride; TC, Total cholesterol; UA, Uric acid; HDL, high-density lipoprotein; LDL, low-density lipoprotein; *, p<0.05; **, p<0.01;

Table 3
Comparison of EBQ scores between OPLL and other types of DCM cohort before and after PSM

		Before PSM			After PSM		
		OPLL (n = 254)	Other types of DCM (n = 239)	P Value	OPLL (n = 179)	Other types of DCM (n = 179)	P Value
Each individual EBQ score							
C2 EBQ score	Inferior	2.79(2.33,3.21)	3.18(2.80,3.73)	P<0.0001	2.89 (2.51,3.23)	3.09(2.73,3.74)	P<0.0001
C3 EBQ score	Superior	2.42(2.11,2.80)	2.82(2.39,3.27)	P<0.0001	2.45(2.23,2.82)	2.75(2.41,3.25)	P<0.0001
	Inferior	2.64(2.25,3.00)	3.01(2.60,3.49)	P<0.0001	2.69(2.36,3.04)	2.96(2.62,3.44)	P<0.0001
C4 EBQ score	Superior	2.21(1.92,2.63)	2.62(2.25,3.14)	P<0.0001	2.24(1.92,2.71)	2.61(2.23,3.05)	P<0.0001
	Inferior	2.44(2.07,2.81)	2.83(2.40,3.25)	P<0.0001	2.46(2.23,2.86)	2.78(2.43,3.27)	P<0.0001
C5 EBQ score	Superior	2.17(1.78,2.55)	2.47(2.09,2.84)	P<0.0001	2.21(1.99,2.66)	2.42(2.04,2.85)	P<0.0001
	Inferior	2.24(1.84,2.66)	2.57(2.12,3.02)	P<0.0001	2.32(1.93,2.75)	2.55(2.14,2.97)	P<0.0001
C6 EBQ score	Superior	2.07(1.67,2.44)	2.34(1.95,2.74)	P<0.0001	2.08 (1.72,2.44)	2.30(1.98,2.74)	P<0.0001
	Inferior	2.10(1.72,2.55)	2.43(2.03,2.88)	P<0.0001	2.13(1.85,2.62)	2.37(2.04,2.84)	P<0.0001
C7 EBQ score	Superior	1.92(1.58,2.32)	2.27(1.86,2.72)	P<0.0001	1.94(1.64,2.34)	2.21(1.82,2.63)	P<0.0001
	Inferior	2.03(1.65,2.34)	2.38(1.97,2.86)	P<0.0001	2.04(1.78,2.34)	2.29(1.92,2.84)	P<0.0001
T1 EBQ score	Superior	1.73(1.38,2.05)	2.06(1.71,2.51)	P<0.0001	1.74(1.44,2.21)	2.01(1.75,2.48)	P<0.0001
	Inferior	1.90(1.56,2.19)	2.18(1.83,2.71)	P<0.0001	1.90(1.62,2.25)	2.15(1.88,2.63)	P<0.0001
Segmental EBQ score							
C3		2.56(2.20,2.88)	2.93(2.53,3.37)	P<0.0001	2.61(2.23,2.93)	2.88(2.55,3.38)	P<0.0001
C4		2.33(2.01,2.72)	2.68(2.32,3.17)	P<0.0001	2.36(2.14,2.76)	2.66(2.32,3.15)	P<0.0001
C5		2.21(1.83,2.58)	2.55(2.12,2.93)	P<0.0001	2.28(1.95,2.63)	2.50(2.13,2.92)	P<0.0001
C6		2.39(2.02,2.69)	2.69(2.32,3.08)	P<0.0001	2.42(2.13,2.75)	2.65(2.39,3.04)	P<0.0001
C7		1.97(1.63,2.36)	2.34(1.91,2.76)	P<0.0001	1.98(1.75,2.45)	2.26(1.98,2.75)	P<0.0001
T1		1.82(1.48,2.12)	2.12(1.77,2.62)	P<0.0001	1.82(1.53,2.27)	2.08(1.74,2.54)	P<0.0001
Adjacent EBQ score							
C2/3		2.63(2.25,2.95)	3.03(2.61,3.44)	P<0.0001	2.69(2.38,3.04)	2.98(2.55,3.44)	P<0.0001
C3/4		2.46(2.10,2.82)	2.80(2.46,3.30)	P<0.0001	2.52(2.13,2.85)	2.73(2.46,3.27)	P<0.0001

EBQ, endplate bone quality; PSM, propensity score matching; OPLL, ossification of the posterior longitudinal ligament; DCM, degenerative cervical myelopathy; Segmental EBQ score, the mean value of superior and inferior endplate bone quality score for each vertebral body; Adjacent EBQ score, the mean value of the superior and inferior endplate bone quality score in each intervertebral space;

	Before PSM			After PSM		
	OPLL (n = 254)	Other types of DCM (n = 239)	P Value	OPLL (n = 179)	Other types of DCM (n = 179)	P Value
C4/5	2.32(1.95,2.66)	2.68(2.28,3.02)	P<0.0001	2.35(2.04,2.77)	2.61(2.38,3.04)	P<0.0001
C5/6	2.17(1.76,2.56)	2.46(2.08,2.90)	P<0.0001	2.21(1.97,2.63)	2.41(2.03,2.95)	P<0.0001
C6/7	2.02(1.66,2.43)	2.38(1.94,2.75)	P<0.0001	2.04(1.79,2.43)	2.30(1.93,2.75)	P<0.0001
C7/T1	1.89(1.52,2.20)	2.24(1.85,2.67)	P<0.0001	1.90 (1.62,2.24)	2.16(1.85,2.67)	P<0.0001

EBQ, endplate bone quality; PSM, propensity score matching; OPLL, ossification of the posterior longitudinal ligament; DCM, degenerative cervical myelopathy; Segmental EBQ score, the mean value of superior and inferior endplate bone quality score for each vertebral body; Adjacent EBQ score, the mean value of the superior and inferior endplate bone quality score in each intervertebral space;

Comparison of EBQ scores between male and female in OPLL patients

After PSM, 72 paired patients with OPLL were analyzed. Female patients exhibited significantly higher EBQ scores than male across most individual endplates (from C2 inferior to T1 inferior), segmental vertebral levels (C3, C5, C6, C7, T1), and adjacent inter-vertebral spaces (C2/3, C4/5, C5/6, C6/7, C7/T1). No significant differences were identified in the superior endplate of C4, segmental EBQ score of C4 and adjacent inter-vertebral space C3/4 between the two groups ($P > 0.05$) (Table 4).

Table 4
Comparison of EBQ scores between male and female in OPLL after PSM

EBQ score		Male (n = 72)	Female (n = 72)	P Value
Each individual EBQ score				
C2 EBQ score	Inferior	2.52(2.24,3.15)	3.05(2.78,3.41)	0.001*
C3 EBQ score	Superior	2.31(2.18,2.78)	2.51(2.26,3.01)	0.023*
	Inferior	2.51(2.14,2.81)	2.79(2.34,3.07)	0.022*
C4 EBQ score	Superior	2.13(1.94,2.68)	2.37(1.97,2.75)	0.153
	Inferior	2.31(1.91,2.65)	2.49(2.23,2.86)	0.033*
C5 EBQ score	Superior	2.07(1.61,2.37)	2.29(2.07,2.64)	0.012*
	Inferior	2.08(1.87,2.59)	2.38(2.01,2.85)	0.010*
C6 EBQ score	Superior	1.94(1.62,2.38)	2.20(1.88,2.69)	0.017*
	Inferior	1.94(1.63,2.36)	2.24(1.94,2.61)	0.024*
C7 EBQ score	Superior	1.77(1.59,2.27)	2.03(1.71,2.46)	0.010*
	Inferior	1.84(1.68,2.25)	2.12(1.83,2.45)	0.011*
T1 EBQ score	Superior	1.61(1.32,1.91)	1.81(1.54,2.27)	0.002**
	Inferior	1.71(1.44,2.04)	2.01(1.77,2.38)	0.000*
Segmental EBQ score				
C3		2.37(2.17,2.75)	2.69(2.37,3.09)	0.011*
C4		2.21(1.93,2.69)	2.45(2.19,2.76)	0.055
C5		2.01(1.85,2.41)	2.36(2.04,2.75)	0.006**
C6		2.15(2.07,2.54)	2.51(2.13,2.87)	0.006**
C7		1.81(1.51,2.13)	2.09(1.81,2.45)	0.008**
T1		1.60(1.46,1.99)	1.96(1.78,2.22)	0.001**
Adjacent EBQ score				
C2/3		2.44(2.28,2.95)	2.82(2.40,3.22)	0.001**
C3/4		2.27(2.12,2.71)	2.59(2.15,2.97)	0.056
C4/5		2.17(1.84,2.57)	2.44(2.10,2.78)	0.018*
C5/6		2.01(1.71,2.45)	2.28(2.07,2.68)	0.008**
C6/7		1.84(1.68,2.38)	2.12(1.88,2.55)	0.013*
C7/T1		1.74(1.57,2.05)	1.99(1.74,2.33)	0.004**

Each level EBQ score, the endplate bone quality score for each endplate; Segmental EBQ score, the mean value of superior and inferior endplate bone quality score for each vertebral body; Adjacent EBQ score, the mean value of the superior and inferior endplate bone quality score in each intervertebral space; *, $P < 0.05$; **, $P < 0.01$.

Comparison of EBQ scores for each intervertebral space and vertebral body

Paired t-test analyses were performed to compare EBQ scores between intra-intervertebral and intra-vertebral level endplate. For intra-intervertebral EBQ score comparisons, the inferior endplates were significantly higher than the superior endplate across all levels from C2/3 to C7/T1 (all P < 0.01). For intra-vertebral body EBQ score comparisons, the inferior endplates were significantly higher than the superior counterpart in the C3, C4, and T1 vertebrae (P < 0.01), whereas no statistically significant differences were observed at C5, C6, and C7 vertebrae (P > 0.05) (Table 5).

Table 5
Comparison of EBQ scores for each intervertebral space and vertebral body in OPLL cohort

Comparison item	EBQ score		t value	p value
Intervertebral space EBQ score				
C2 Inferior vs C3 Superior	2.79 (2.33,3.21)	2.42(2.11,2.80)	-6.259	0.000**
C3 Inferior vs C4 Superior	2.64(2.25,3.00)	2.21(1.92,2.63)	-7.113	0.000**
C4 Inferior vs C5 Superior	2.44(2.07,2.81)	2.17(1.78,2.55)	-5.546	0.000**
C5 Inferior vs C6 Superior	2.24(1.84,2.66)	2.07(1.67,2.34)	-3.608	0.000**
C6 Inferior vs C7 Superior	2.10(1.72,2.55)	1.92(1.58,2.32)	-3.844	0.000**
C7 Inferior vs T1 Superior	2.03(1.65,2.34)	1.73(1.38,2.05)	-5.718	0.000**
Vertebral body EBQ score				
C3 Superior vs C3 Inferior	2.42(2.11,2.80)	2.64(2.25,3.00)	-3.945	0.000**
C4 Superior vs C4 Inferior	2.21(1.92,2.63)	2.44(2.07,2.81)	-3.552	0.000**
C5 Superior vs C5 Inferior	2.17(1.78,2.55)	2.24(1.84,2.66)	-1.827	0.068
C6 Superior vs C6 Inferior	2.07(1.67,2.44)	2.10(1.72,2.55)	-1.216	0.224
C7 Superior vs C7 Inferior	1.92(1.58,2.32)	2.03(1.65,2.34)	-1.551	0.121
T1 Superior vs T1 Inferior	1.73(1.38,2.05)	1.90(1.56,2.19)	-3.467	0.001**

Intervertebral space EBQ score, the superior and inferior endplate bone quality score in each intervertebral space; Vertebral body EBQ score, the superior and inferior endplate bone quality score for each vertebral body; *P < 0.05; **P < 0.01.

Comparison of adjacent EBQ score in OPLL patients

In the OPLL cohort, adjacent EBQ scores (mean of superior and inferior endplate bone quality scores per inter-vertebral space) exhibited a gradual downward trend from the cephalad to caudal levels. Specifically, the C2/3 level had the highest score 2.63(2.25,2.95), followed by C3/4, C4/5, C5/6, C6/7, and C7/T1. After a Bonferroni correction for multiple comparisons, only C6/7 vs. C7/T1 showed statistically significant differences (adjusted P = 0.019). In contrast, other adjacent EBQ scores comparisons including C2/3 vs. C3/4, C3/4 vs. C4/5, and C5/6 vs. C6/7 showed no significant differences (adjusted P > 1.000) (Table 6).

Table 6
Comparison of adjacent EBQ score in OPLL

Level	N	EBQ score	Adjusted p-value					
			C2/3	C3/4	C4/5	C5/6	C6/7	C7/T1
C2/3	N = 254	2.63(2.25,2.95)		0.124	0.000**	0.000**	0.000**	0.000**
C3/4	N = 254	2.46(2.10,2.82)			0.172	0.000**	0.000**	0.000**
C4/5	N = 254	2.32(1.95,2.66)				0.189	0.000**	0.000**
C5/6	N = 254	2.17(1.76,2.56)					1	0.000**
C6/7	N = 254	2.02(1.66,2.43)						0.019*
C7/T1	N = 254	1.89(1.52,2.20)						

Adjacent EBQ score, the mean value of the superior and inferior endplate bone quality score in each intervertebral space; *P < 0.05; **P < 0.01.

Comparison of segmental EBQ score in OPLL patients

For segmental EBQ scores, the C3 vertebra had the highest score 2.56(2.20,2.88), followed by C6 2.39(2.02,2.69), C4 2.33(2.01,2.72), C5 2.21(1.83,2.58), C7 1.97(1.63,2.36), and T1 1.82(1.48,2.12). Multiple comparisons with Bonferroni adjustment revealed significant differences between C3 vs. C4 (adjusted P = 0.018) and C4 vs. C5 (adjusted P = 0.043). While, no significant differences were found between C5 vs. C6 (adjusted P = 0.089) or C7 vs. T1 (adjusted P = 0.162) (Table 7).

Table 7
Comparison of segmental EBQ score in OPLL

Level	N	EBQ score	Adjusted p-value					
			C3	C4	C5	C6	C7	T1
C3	N = 254	2.56(2.20,2.88)		0.018*	0.000**	0.008**	0.000**	0.000**
C4	N = 254	2.33(2.01,2.72)			0.043*	1	0.000**	0.000**
C5	N = 254	2.21(1.83,2.58)				0.089	0.000**	0.000**
C6	N = 254	2.39(2.02,2.69)					0.000**	0.000**
C7	N = 254	1.97(1.63,2.36)						0.162
T1	N = 254	1.82(1.48,2.12)						

Segmental EBQ score, the mean value of superior and inferior endplate bone quality score for each vertebral body; *P < 0.05; **P < 0.01.

Influence of clinical variables and EBQ scores

(Fig. 2) presents the Pearson correlation coefficients between clinical variables and EBQ, which confirmed that glucocorticoid history was the only independent factor associated with EBQ scores across C2-T1 endplate levels (all P < 0.05), whereas hypertension, sex, age, and BMI did not demonstrate significant independent associations with EBQ scores.

Discussion

Cervical OPLL has become a prominent subtype of DCM within the realm of spine surgeries. In contrast to other types of DCM, the surgical management of OPLL involves higher technical intricacy and carries a higher risk of perioperative complications [21–23]. Anterior cervical discectomy and fusion (ACDF) [24], ACCF [25, 26] and anterior controllable antedisplacement and fusion (ACAF)

[27–29] has been validated to achieve effective decompression in the management of OPLL, as it enables direct decompression of the spinal cord [26, 30]. However, implant subsidence remains a major clinical challenge, which can directly compromising surgical outcomes [14, 31, 32]. Consequently, preoperative assessment of cervical bone quality, particularly the contact interface of internal fixation endplate bone quality, is therefore crucial for predicting subsidence risk and guiding surgical decision-making. Through a matching design, the current study yielded three clinically meaningful key findings

First, the EBQ score between OPLL and other types of DCM patients exhibit regional specificity rather than a simple overall difference in degree, which supplements previous studies suggesting that OPLL patients have higher BMD [33–36]. Lu et al's retrospective cohort study compared the MRI-based vertebral bone quality (VBQ) scores between 135 pairs of cervical OPLL patients and cervical spondylotic myelopathy (CSM) patients, and the results demonstrated that the OPLL group had a significantly lower VBQ score at the C3 segment compared with the CSM group (median [P25, P75]: 3.3 [2.8, 3.7] vs. 3.6 [2.8, 4.1], $p = 0.028$), whereas no statistically significant differences in VBQ scores were observed at the C2, C4, C5, C6, and C7 segments between the two matched cohorts (all $p > 0.05$) [37]. A recent study with propensity score matching compared computed tomography (CT) Hounsfield Units (HU) values between 124 pairs of cervical OPLL patients and patients with other types of DCM, and indicated that the OPLL group had significantly higher DEXA T-scores. Additionally, the OPLL group exhibited significantly higher CT HU values at all cervical segments (C1-C7) and the global HU value (mean of C3-C6) than the other DCM group [38]. Potential factors underlying the similarities and discrepancies in the above mentioned findings are as follows: First, target-specific differences in measurement indicators. The EBQ score directly focuses on the local bone quality of the key stress-bearing interface (endplate) for internal fixation, whereas prior investigations have often compared global bone mineral density parameters of the vertebral body, thereby making it difficult to capture the specificity of the endplate region. Second, discrepancies in disease spectrum-the essence of OPLL may be a genetically predominant disorder characterized by ectopic ossification, while degenerative cervical myelopathy (DCM) is an environmentally driven disease featuring inter-vertebral disc degeneration.

Second, prior studies utilizing dual-energy X-ray absorptiometry (DEXA) have demonstrated that males exhibit higher hip bone mineral density (BMD) than females [39]. Consistently, a comparative study confirmed that males had a 6% higher total hip BMD and a 5% higher femoral neck BMD compared with their female counterparts, supporting the notion of gender-related predominance in overall bone density among males [40]. Consistently, our study also demonstrated that female patients exhibited significantly higher EBQ scores than male patients across most segments. Given that a higher EBQ score corresponds to poorer bone mineral density (BMD), this finding aligns with the conclusions of former studies.

Third, previous investigations into cervical spine bone quality have predominantly centered on global vertebral bone mineral density (BMD), cross-level segmental disparities, or comparisons among different disease cohorts [16, 37, 38]. To date, no studies have explored the localized, site-specific variations in endplate bone quality at either the intra-intervertebral or intra-vertebral level. In the present study, we found that at the intra-intervertebral EBQ scores, the inferior endplate was consistently higher than that of the superior endplate across all measured cervical vertebral levels (a higher EBQ score indicates lower bone mineral density). These findings run counter to the conclusions of prior studies, which have demonstrated that subsidence of both interbody cages [41–43] and titanium meshes cage [44, 45] tends to occur predominantly toward the inferior endplate according to their typical radiographic images of included cases even though the authors did not explicitly describe the direction of implant subsidence. As to the intra-vertebral level EBQ scores, we observed an almost consistently lower EBQ score at the superior endplate compared with the inferior endplate within the same cervical vertebral level, which appear to contradict previous studies showing that superior endplate injuries occur more frequently than inferior endplate injuries [46–48]. The discrepancies observed herein may be attributed to the following factors. Surgical factors (inter-vertebral distraction degree, implant position, implant diameter, endplate preparation, fixation method, and titanium mesh tilt angle) also play important roles in implant subsidence beyond endplate BMD. For the difference of vertebral superior-inferior endplate injury, fracture occurrence is a result of the interaction between intrinsic BMD and extrinsic mechanical load, while our study evaluates endplate BMD under physiological conditions rather than traumatic load conditions, which explains why the EBQ scores distribution does not directly align with fracture occurrence.

With respect to regional vertebral BMD, numerous previous investigations have sought to assess the segment-specific BMD within the cervical vertebrae. A retrospective cohort study of 156 cervical OPLL patients [37] and a cross-sectional study of 129 cervical OPLL patients [16] both demonstrated a progressive decrease in vertebral bone quality (VBQ) scores from C2 to C7, with the highest VBQ value observed at C2 and significantly lower scores at the lower cervical segments (C4-C7 or C6-C7) compared to the

upper segments. Our findings share partial consistency with these prior results but also exhibit certain discrepancies, primarily attributed to insufficient technical standardization (e.g., inconsistent imaging parameters, post-processing methods across different centers) and heterogeneity in baseline characteristics of the enrolled populations. Additionally, our results are not fully aligned with relevant clinical phenomena [49–51]. The underlying mechanism governing this phenomenon remains elusive to date, and future investigations should develop a multimodal magnetic resonance imaging protocol integrated with deep learning-based radio-density mapping technology for precise endplate assessment to further elucidate the potential pathogenic mechanisms.

Limitations

The limitations of this study warrant careful consideration. Firstly, the single medical center nature of this research and relatively substantial sample size may inherently introduce selection bias and limit the generalizability of our findings to other clinical settings. Secondly, although propensity score matching was employed to account for baseline differences that may confound the analysis, the baseline data-including disease duration, medication dosage, smoking and alcohol consumption levels, and other factors known to influence bone mineral density were not quantified in the present study. Thirdly, this study is a purely radiological investigation focusing on EBQ. It does not explore the association between these radiological scores and clinical outcomes, making it impossible to establish a link between EBQ scores and clinical outcomes. Future large-scale, prospective multicenter studies integrating radiological evaluations with clinical outcome are therefore needed to address this research gap and facilitate the translation of our radiological observations into clinical practice. Nevertheless, our findings hold significant implications for the assessment of BMD in patients with OPLL.

Conclusion

In conclusion, this research highlights significant differences in EBQ scores across cervical segments in patients with ossification of the posterior longitudinal ligament, emphasizing the need for tailored treatment strategies. The findings not only enhance our understanding of cervical spine pathology but also pave the way for future investigations aimed at improving clinical outcomes. Moving forward, it is imperative to address the identified limitations and explore the multifactorial influences on EBQ scores, thereby refining treatment approaches and ultimately improving patient quality of life.

Declarations

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Consent for publication

Written informed consent for publication was obtained from all participants.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Contributions

Wenjun Fan and Cen Liang performed all the experiments and wrote the manuscript. Bin Shi participated in the collection of experimental data, and responsible for image production. Xiongsheng Chen and Minming Lu conceived and designed the study. The authors read and approved the final manuscript.

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Figures

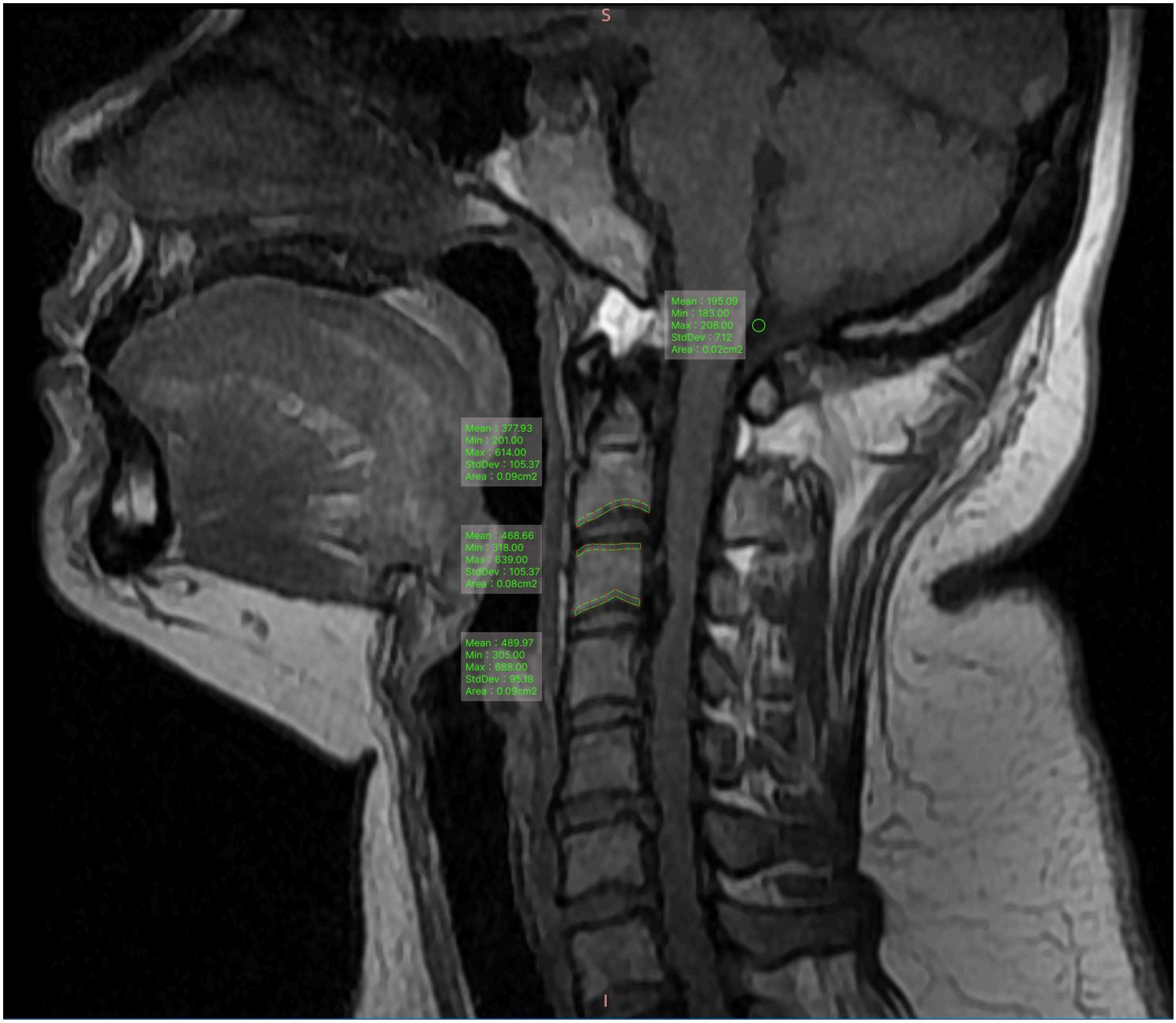


Figure 1

Illustration of manual procedures for the measurement of the EBQ score. First, a minimum of nine points along the visible superior and inferior vertebral endplate surfaces were digitised for manual segmentation. Then draw a line of 0.6mm length up and down along these points respectively, and the area formed by these points is the ROI.

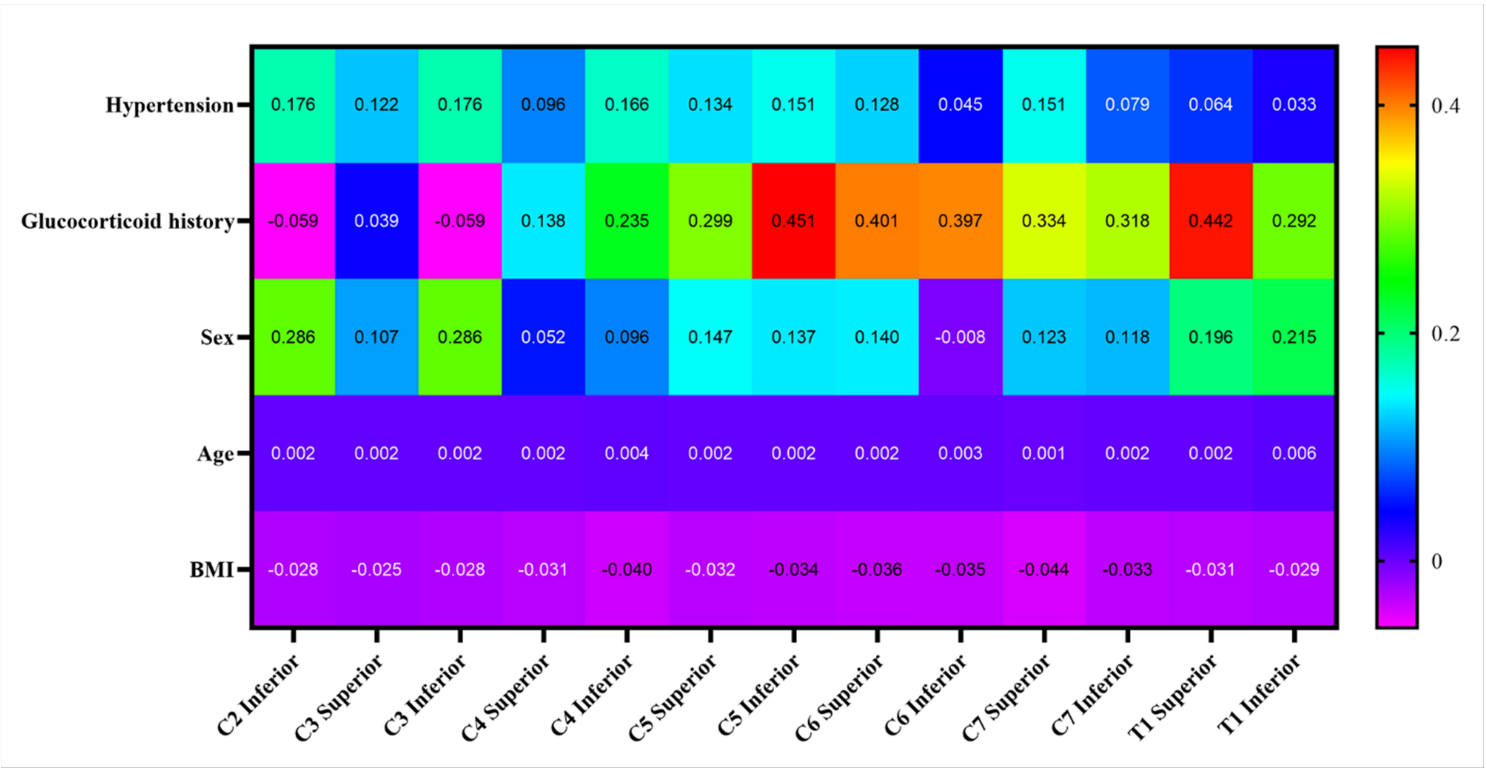


Figure 2

Pearson correlation coefficient heatmap between clinical variables and EBQ scores.