CLINICAL ARTICLE

The Association between High Preoperative MRI-based Vertebral Bone Quality (VBQ) Score and Titanium Mesh Cage Subsidence after Anterior Cervical Corpectomy and Fusion

Qiujiang Li, MD[1], Ce Zhu, MD[1], Qinghong Xia, MS[2], Huiliang Yang, MD[1], Limin Liu, MD[1], Ganjun Feng, MD[1], Yueming Song, MD[1]

[1]*Department of Orthopaedics, Orthopaedic Research Institute, West China Hospital, Sichuan University and* [2]*Operating Room of Anesthesia Surgery Center, West China Hospital, Sichuan University/West China School of Nursing, Sichuan University, Chengdu, China*

Objective: Recently, the MRI-based vertebral bone quality (VBQ) score has been shown to correlate with Hounsfeld units (HU) value, dual-energy X-ray absorptiometry (DEXA) T-score and predict osteoporotic fractures. Preoperative cervical HU value is an independent correlative factor for early titanium mesh cage (TMC) subsidence after anterior cervical corpectomy and fusion (ACCF). However, to date the direct association between cervical VBQ score and TMC subsidence has not been studied. This study aims to investigate the predictive effect of cervical VBQ score derived from sagittal non-contrast-enhanced T1-weighted MRI on the early TMC subsidence after ACCF.

Methods: Patients who underwent one-level ACCF from January 2016 to January 2020 were included. We retrospectively collected baseline data on age, sex, body mass index (BMI), disease type, level of surgery and radiology parameters. The cervical VBQ score was measured using preoperative non-contrast-enhanced T1-weighted MRI. Univariate and multivariate logistic regression analysis were performed to screen the independent risk factors of TMC subsidence. The receiver operating characteristic (ROC) curve and area under curve (AUC) were performed to assess the predictive ability of TMC subsidence based on the cervical VBQ score. Spearman correlation analysis was used to determine the correlations between the cervical VBQ score and TMC subsidence.

Results: A total of 134 patients who underwent one-level ACCF were included in this study, and 46 (34.33%) patients had TMC subsidence. Univariable analyses demonstrated that the age, TMC placement depth and VBQ score were associated with subsidence. The cervical VBQ score in the subsidence group was significantly higher than that in the no subsidence group (3.75 ± 0.45 *vs.* 3.20 ± 0.42, $p < 0.001$). The multivariate logistic regression analysis proved that the higher VBQ score (odds ratio[OR] = 13.563, 95% confidence interval [CI] 4.968 - 37.031, $p < 0.001$) was the only variable that significantly predicted subsidence. Using a VBQ score cutoff value of 3.445, the cervical VBQ score yielded a sensitivity of 69.6% and a specificity of 85.2% with an AUC of 0.810 to differentiate patients with subsidence and with no subsidence.

Conclusion: Preoperative higher cervical VBQ score is an independent risk factor for TMC subsidence after ACCF. The cervical VBQ score may be a valuable tool for assisting in distinguishing the presence of TMC subsidence.

Key words: Anterior cervical corpectomy and fusion; Bone mineral density; Cage subsidence; MRI; Vertebral bone quality

Address for correspondence Yueming Song, MD, Department of Orthopaedic Surgery and Orthopaedic Research Institute, West China Hospital, Sichuan University, Chengdu, China 610041 Tel: +86 028-85422573; Email: sym_cd@163.com
Qiujiang Li and Ce Zhu contributed equally to this study.
Ganjun Feng and Yueming Song contributed equally to this study and should be considered co-corresponding authors.
Received 31 May 2023; accepted 29 September 2023

Orthopaedic Surgery 2024;16:303–311 • DOI: 10.1111/os.13931

Introduction

Anterior cervical corpectomy and fusion (ACCF) is an effective treatment for cervical spondylosis (CS), which can adequately relieve spinal cord compression by direct decompression and improve the prognosis of patients.[1,2] After cervical corpectomy, most bone defects require reconstruction using allografts, autografts, artificial bones. Autologous graft is widely accepted as a gold standard due to its advantages of good osteogeneration, osteoconduction, and osteoinduction.[3,4] However, some patients are still subject to postoperative complications arising from the donor site, including persistent pain, infection, donor site hematoma. In contrast, the application of allograft bone is limited by pseudarthrosis and delayed healing. In recent years, titanium mesh cage (TMC) filled with autologous bone has been widely used in ACCF with satisfactory clinical results.[5–7] However, TMC often shows high cage subsidence during early postoperative period. According to related reports, the risk of early postoperative subsidence of TMC varies from 9% to 79.7%.[8–10] Severe subsidence is associated with poor neurological recovery and clinical outcomes. In addition, excessive subsidence to adjacent vertebrae may lead to reconstruction failure and recurrence of neurological symptoms.[11]

TMC subsidence is associated with multiple factors such as the number of fusion, endplates damage, cage size, cage position, and cage material properties.[8,10,12] In addition to the above factors, low bone mineral density (BMD) is also an important risk factor associated with cage subsidence.[13–15] Previous studies have found that preoperative cervical Hounsfeld units (HU) value is an independent correlative factor for early TMC subsidence after one level ACCF.[9] A new MRI-based vertebral bone quality (VBQ) score has emerged as an alternative to dual-energy X-ray absorptiometry (DEXA) for measuring BMD.[16–19] Recently, the MRI-based vertebral bone quality (VBQ) score has been shown to correlate with HU value, DEXA T-score and predict osteoporotic fractures.[18] Higher VBQ scores have been shown to be a risk factor for cage subsidence and reoperation after lumbar fusion.[16,17] As far as we know, no previous research has evaluated the association of VBQ score with TMC subsidence after ACCF.

Therefore, in this retrospective study, we measured VBQ scores based on preoperative cervical MRI to: (i) assess VBQ score and other potential risk factors of TMC subsidence: and (ii) to assess its predictive value for TMC subsidence following ACCF.

Methods

Patients

This was a retrospective, single-center, and consecutive cohort study. We included 134 patients who underwent one-level ACCF with TMC between January 2016 and January 2020. The study was approved by the ethics committee of our hospital (No. 2023-250), and all patients signed an informed consent form. Inclusion criteria were as follows: (i) diagnosis of cervical spondylosis confirmed by imaging and physical examination; (ii) patients underwent preoperative 3.0 T cervical magnetic resonance image (MRI), including at least T1-weighted MRI; and (iii) no history of spine surgery. Exclusion criteria were as follows: (i) patients with obvious contraindications to surgery; (ii) patients with tumors, tuberculosis, or infections; (iii) patients with serially ossification of the posterior longitudinal ligament (OPLL) and severe ossification of the ligamentum flavum; and (iv) patients lacking complete clinical follow up data more than 1 year after surgery. The detailed flowchart is shown in Figure 1.

Surgical Technique

The surgery procedures were performed by one of four senior orthopedic spine orthopedic surgeons with more than 20 years of experience. The level of surgery was determined by physical examination and radiological examination. All preoperative tracheoesophageal push training was performed to prevent postoperative dysphagia. All patients received general anesthesia and a right-sided anterior cervical approach. After prevertebral fascia incision, the vertebral body and anterior part of the disc were exposed. After removal of the intervertebral disc and subtotal vertebrectomy, the endplates at both ends were completely preserved. Then the posterior longitudinal ligament and the osteophytes of vertebrae posterior margin were removed and the nerve root and dura will be decompressed adequately. After complete decompression, the appropriate TMC was selected according to the extent of resection and autologous cancellous bone fragments were taken and implanted into the bone socket. Then, the TMC was inserted into the corpectomy defect and an appropriately sized Atlantis anterior cervical plate system was applied to all patients to achieve immediate stabilization. Finally, a drainage tube was placed after washing, and the incision was sutured layer by layer. All patients were required to wear a cervical collar for 12 weeks after surgery and were followed up regularly.

Clinical Assessment

All patient-related information was obtained from medical records. Clinical information, including age, sex, BMI, concomitant diseases (diabetes, hypertension) and other general information was collected preoperatively. Clinical assessments, including pain visual analogue scale (VAS), Japanese Orthopaedic Association (JOA) and neck disability index (NDI) scores, were collected from all patients preoperatively, immediately postoperatively, at 3 months postoperatively and at the final follow-up.

Radiological Assessment

Some radiological parameters on plain radiographs (cervical lordosis, segmental height, segmental angle, TMC tilt angle and TMC placement depth) were measured. Cervical lordosis (CL): the angle formed between C2 and C7 lower endplate. Segmental height (SH): the distance between the midpoint of the superior endplate of the upper vertebral body and the midpoint of the inferior endplate of the lower vertebral body

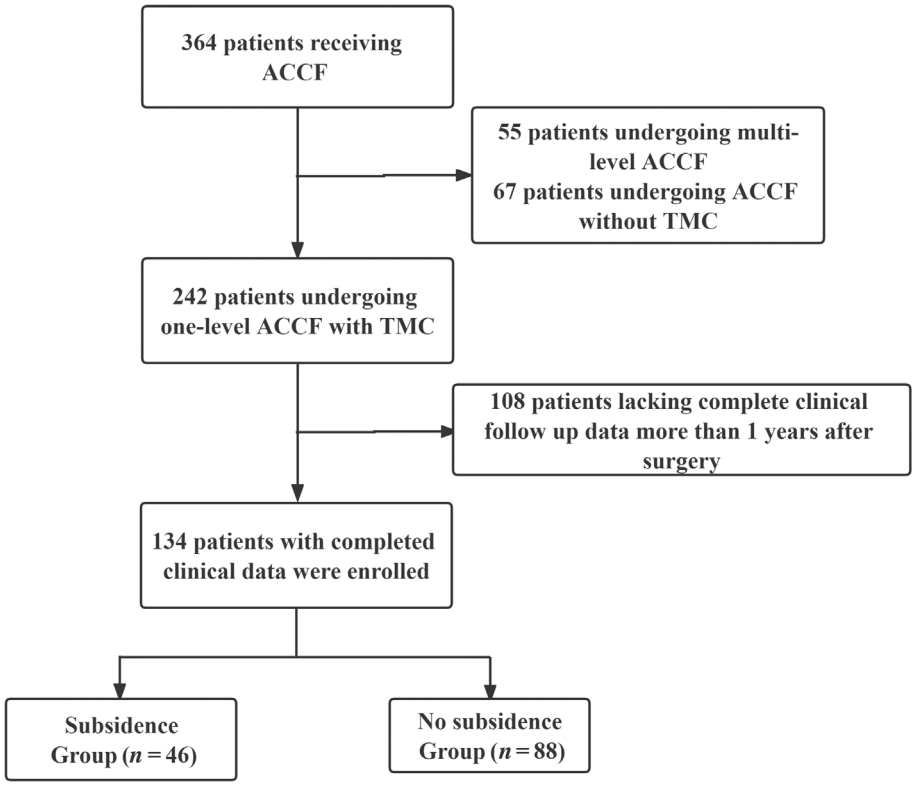

FIGURE 1 Flowchart of patient selection in the study.

in the fused segment on static and lateral X-ray. Intervertebral distraction height was defined as postoperative SH minus preoperative SH. Segmental angle (SA): the angle formed between the superior endplate of the upper vertebral body and the inferior endplate of the lower vertebral body in the fused segment. TMC tilt angle (TA): the angle formed between the lower plane of the titanium cage and the level of the upper endplate of the inferior vertebral body. Placement depth (PD): the distance between the posterior edge of the titanium cage and the posterior edge of the vertebral body. The correction of CL, SH and SA were defined as the D-value between 1-week postoperative and preoperative. The cage subsidence was defined as any loss of SH exceeding 3 mm.

All imaging parameters were measured by two surgeons not involved in the initial procedure and analyzed using the mean of the two measurements (Figure 2).

MRI-based Assessments

The VBQ score measurement method was shown as previously report.[20] First, we placed the region of interest (ROI) in the medullary portions of C3 through C6 vertebral bodies to obtain the average signal intensity (SI). Then, the average SI was divided by the signal intensity of the cerebrospinal fluid (CSF) at the level of C5 to obtain the VBQ score. Measurements were usually obtained from mid-sagittal section of non-enhanced T1-weighted MRI images. In order to exclude cortical bone, we defined the ROI as the area determined 3 mm from the upper and lower endplates. When the ROI could not be placed at the C5 CSF due to obstruction, the CSF at the level of C4 or C6 was utilized. The higher the VBQ scores were, the more the adipose tissue existed and the lower the BMD were. In other words, VBQ scores were negatively correlated with BMD (Figure 3).

Statistical Analysis

Independent *t*-tests or analysis of variance (ANOVA) was used for continuous variables, and the chi-square test or Fisher's exact test was used for categorical variables. We used univariate analysis for preliminary screening the risk factors of cage subsidence. Further multivariate logistic regression analysis was performed to screen the independent risk factors. The correlation between the cervical VBQ score and TMC subsidence was analyzed with a Spearman correlation test. The receiver operating characteristic (ROC) curve was used to evaluate the predictive ability of TMC subsidence and the area under the curve (AUC) was calculated. The ROC curve was used to establish the most suitable threshold (cut value) for VBQ score with high sensitivity and specificity. Intraclass correlation coefficient (ICC) was used to assess the interobserver and intraobserver reliability of VBQ score measurements, and ICC ≥ 0.75 was considered to have good reliability. SPSS, version 23.0 (SPPS, Chicago, IL, USA) was used for statistical analysis. Differences were considered significant if p value <0.05.

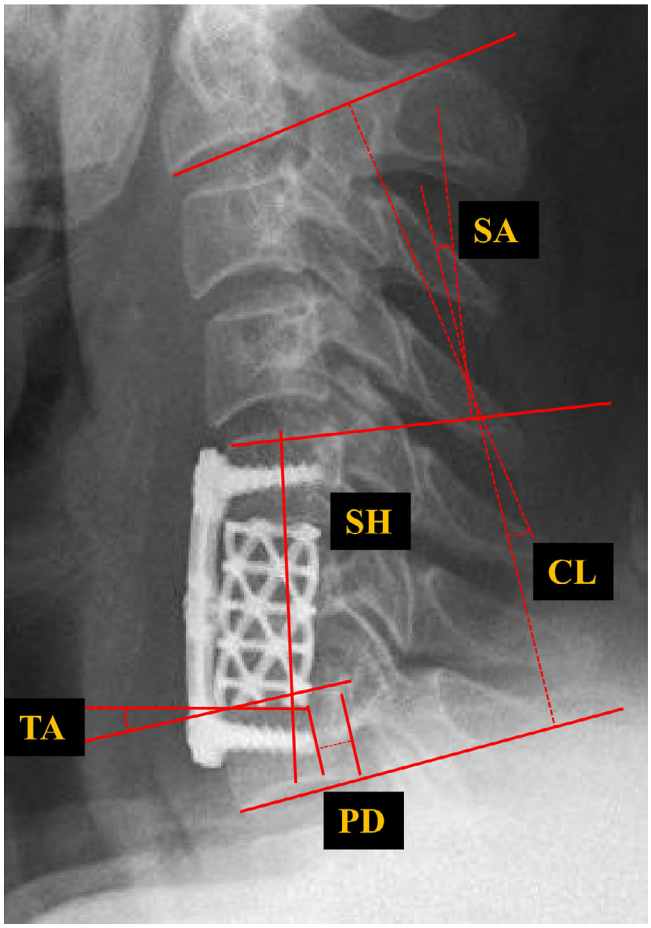

FIGURE 2 Radiographic evaluation of TMC position. Cervical lordosis (CL): the angle formed between C2 and C7 lower endplate. Segmental height (SH): the distance between the midpoint of the superior endplate of the upper vertebral body and the midpoint of the inferior endplate of the lower vertebral body. Segmental angle (SA): the angle formed between the superior endplate of the upper vertebral body and the inferior endplate of the lower vertebral body. TMC tilt angle (TA): the angle formed between the lower plane of the titanium cage and the level of the upper endplate of the inferior vertebral body. Placement depth (PD): the distance between the posterior edge of the titanium cage and the posterior edge of the vertebral body.

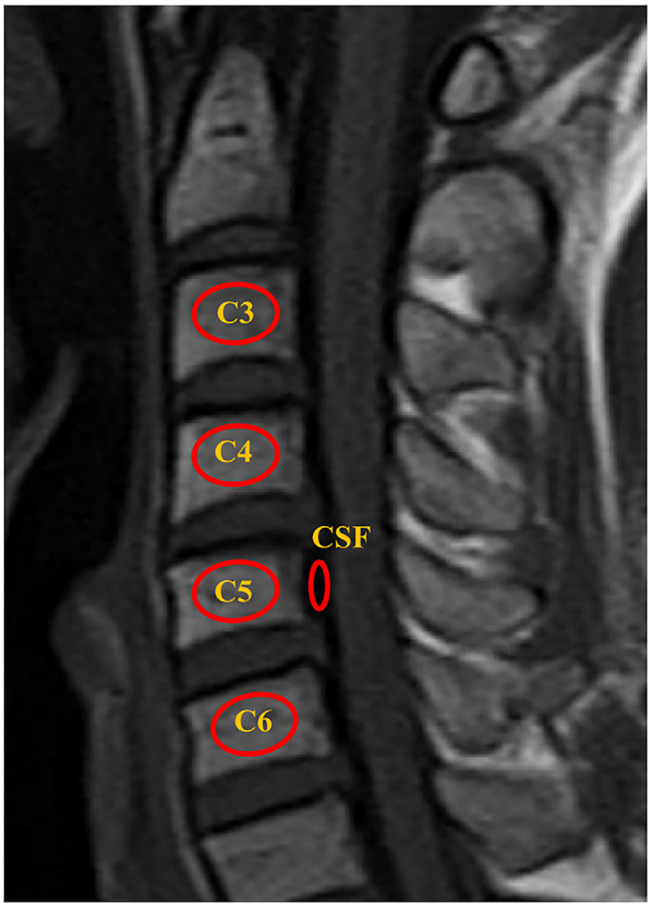

FIGURE 3 An example of a signal intensity measurement for the vertebral bone quality score based on sagittal non-contrast-enhanced T1-weighted magnetic resonance imaging of the cervical spine. CSF, cerebrospinal fluid.

Results

Study Population

Of the 364 of patients who met inclusion criteria, 134 patients were included. The reasons for exclusion included multi-level for 55 patients, without TMC for 67 patients and missing the complete clinical follow up for 108 patients (Figure 1). The mean age for included patients was 55.59 ± 6.52 years, 72 (53.73%) were male and 62 (46.27%) were female. The mean BMI was 24.82 kg/m^2 (SD 3.24) and the mean VBQ score measured was 3.39 (SD 0.50). Diabetes, hypertension, and coronary heart disease were diagnosed in 33 (24.63%), 51 (38.06%), and 12 (8.96%) patients, respectively. The most common level of surgery was C5 (36.57%), followed by C4 (33.58%) and C6 (29.85%). The mean follow-up duration was 44.04 ± 11.67 months (Table 1).

Interobserver and Intraobserver Agreements

Interobserver and intraobserver agreements between two spine surgeons were near perfect, the ICC value and Kappa coefficients of variables were all greater than 0.80, which were defined to be excellent reliability (Table S1).

Demographic Characteristics and Radiographic Parameters

Subsidence was observed in 46 of 134 patients (34.33%). The level of surgery of subsidence occurred in 17 cases in C5, 19 cases in C6, and 10 cases in C7. Univariable analyses demonstrated that the age, PD and VBQ score were associated with subsidence. VBQ score in the subsidence group was significantly higher than that in the no subsidence

TABLE 1 Summary of demographic and surgery characteristics

Variable	Value
No. of patients	134
Age, years	55.59 ± 6.52
Sex (F/M)	72/62
BMI, kg/m^2	24.82 ± 3.24
Charlson comorbidity index score (%) (0; 1; 2)	76/44/14
Diabetes (yes/no)	33/101
Hypertension (yes/no)	51/83
Coronary heart disease (yes/no)	12/122
Current smoker (yes/no)	27/107
Alcohol abuse (yes/no)	32/102
Disease type (myelopathy; radicular; mixed)	89/19/26
Level of surgery (C4; C5; C6)	45/49/40
Hospital stays, day	8.95 ± 1.69
Surgery time, min	93.10 ± 15.62
VBQ score	3.39 ± 0.50
Follow-up duration, months	44.04 ± 11.67

group (3.75 ± 0.45 vs. 3.20 ± 0.42, $p < 0.001$) (Table 3). Similarly, significant differences in age and PD were also observed (Tables 2 and 3). Also, the TMC length was 2.94 ± 0.50 cm in the no subsidence group and 3.09 ± 0.46 cm in the subsidence group. The intervertebral distraction height was 0.36 ± 0.09 cm in the no subsidence group and 0.38 ± 0.07 cm in the subsidence group. There was no significant difference observed in other factors, as depicted in Tables 2 and 3.

Clinical Parameters

The VAS and JOA score significantly improved in both groups at 1 week, 3 months postoperative and at final follow-up. However, there were no significant differences in the VAS and JOA score between the two groups in preoperative, 1 week, 3 months postoperative, and at the final follow-up (Table 4).

TABLE 2 Demographic and surgery characteristics of patients with and without subsidence

Variable	No subsidence ($n = 88$)	Subsidence ($n = 46$)	p value
No. of patients	88	46	
Age, years	54.73 ± 6.62	57.24 ± 6.08	0.034
Sex (F/M)	47/41	25/21	0.918
BMI, kg/m^2	25.04 ± 3.17	24.40 ± 3.35	0.279
CCI score (%) (0; 1; 2)	51/27/10	25/17/4	0.727
Diabetes (yes/no)	20/68	13/33	0.480
Hypertension (yes/no)	36/52	15/31	0.347
Coronary heart disease (yes/no)	6/82	6/40	0.231
Current smoker (yes/no)	15/73	12/34	0.215
Alcohol abuse (yes/no)	19/69	13/33	0.390
Disease type (myelopathy;radicular; mixed)	58/12/18	31/7/8	
Level of surgery (C4; C5; C6)	28/30/30	17/19/10	0.331
Hospital stays, day	8.84 ± 1.51	9.15 ± 2.00	0.355
Surgery time, min	91.31 ± 14.50	96.52 ± 17.22	0.066
Follow-up duration, months	44.95 ± 11.87	42.30 ± 11.19	0.213

TABLE 3 Radiographic parameters of patients with and without subsidence.

Variable	No subsidence ($n = 88$)	Subsidence ($n = 46$)	p value
CL, °			
Preoperative	15.13 ± 6.94	14.83 ± 7.44	0.819
Postoperative 1 week	18.98 ± 6.34	19.04 ± 6.59	0.955
D-value	3.85 ± 3.24	4.21 ± 3.23	0.538
SH, cm			
Preoperative	4.82 ± 0.78	5.11 ± 0.98	0.067
Postoperative 1 week	5.40 ± 0.80	5.68 ± 0.98	0.080
D-value	0.58 ± 0.17	0.57 ± 0.20	0.824
SA, °			
Preoperative	4.22 ± 3.12	4.61 ± 2.79	0.486
Postoperative 1 week	9.37 ± 3.71	10.14 ± 2.94	0.226
D-value	5.15 ± 1.90	5.53 ± 2.12	0.287
TA, °	7.43 ± 4.65	8.52 ± 3.42	0.127
PD, mm	5.94 ± 1.68	5.29 ± 1.35	0.017
TMC length, cm	2.94 ± 0.50	3.09 ± 0.46	0.096
Intervertebral distraction height, cm	0.36 ± 0.09	0.38 ± 0.07	0.161
VBQ score	3.20 ± 0.42	3.75 ± 0.45	<0.001
Fusion rate at final-up	86/88	42/46	0.088

Predictive Factors for TMC Subsidence

On multivariate logistic regression, higher VBQ score (odds ratio[OR] = 13.563, 95% confidence interval[CI] 4.968 - 37.031, $p < 0.001$) was the only variable that significantly predicted subsidence (Figure 4). Detailed results of the effect size of each variable in the multivariate analysis are shown in Figure 4. In addition, we performed additional correlation analyses to explore whether TMC subsidence was associated with a higher VBQ score. Figure 5 showed a positive, significant correlation between subsidence and VBQ score ($r = 0.509$, $p < 0.001$). To evaluate the diagnostic efficiency, ROC curve was drawn and shown in Figure 5, the AUC was 0.810. The cutoff point was specified from

TABLE 4 Clinical parameters of patients with and without subsidence.

Variable	No subsidence ($n = 88$)	Subsidence ($n = 46$)	p value
VAS			
Preoperative	5.91 ± 0.78	5.94 ± 0.65	0.849
Postoperative 1 week	2.65 ± 0.74	2.89 ± 0.80	0.081
Postoperative 3 months	2.02 ± 0.93	2.24 ± 0.64	0.162
Final follow-up	1.55 ± 0.93	1.72 ± 0.72	0.240
JOA			
Preoperative	12.33 ± 2.90	12.76 ± 2.85	0.412
Postoperative 1 week	15.90 ± 2.85	16.40 ± 2.89	0.345
Postoperative 3 month	16.16 ± 2.96	16.70 ± 2.96	0.321
Final follow-up	15.60 ± 2.80	15.96 ± 2.61	0.478

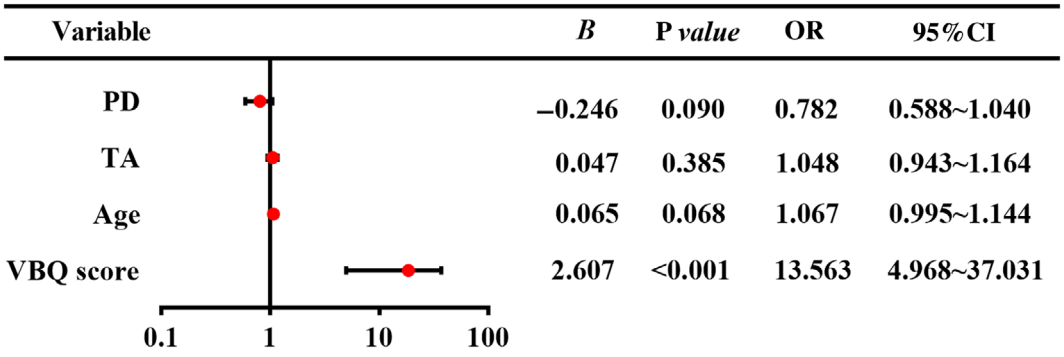

FIGURE 4 Forest plot of multivariate logistic regression analysis for potential risk factors of subsidence. PD, placement depth; TA, tilt angle.

the ROC curve using the optimal intersection of specificity and sensitivity. The optimal cutoff for TMC subsidence was calculated as 3.445 with a sensitivity of 69.6% and specificity of 85.2% (Figure 6).

Discussion

In this study, we introduced a novel MRI-based vertebral bone quality (VBQ) score in ACCF. The results showed significantly higher VBQ scores with the presence of TMC subsidence and preoperative higher cervical VBQ score was an independent risk factor for TMC subsidence after ACCF. The cervical VBQ score may be a valuable tool for assisting in distinguishing the presence of TMC subsidence.

Clinical Outcomes and TMC Subsidence

Anterior cervical corpectomy and fusion is a commonly used surgical procedure to release the spinal cord compression by bony structures in the anterior approach, and its decompression effect is clear.[21] Importantly, these TMC applied avoided complications arising from autologous iliac bone graft such as pain, hematoma, and infection in the donor area, which greatly reduced the length of time in bed and would achieve higher bone fusion rate. Our results showed significant improvements in the aspects of VAS and JOA scores after surgery, indicating that ACCF is an effective surgical treatment for cervical spondylosis, which is consistent with the existing literature.[22–25] However, during the follow-up period, we found no significant differences in postoperative VAS and JOA score between the two groups, indicating that TMC subsidence was not correlated with surgical progression. Previous investigations on the correlation between TMC subsidence and clinical outcomes have reported conflicting results.[16] Studies by Zhou *et al.*[26] and Oh *et al.*[14] showed no significant relationship, while Yao *et al.*[27] showed that postoperative JOA scores were poorer in patients with cage subsidence. The possible reason may be largely related to the measurement and diagnostic criteria of subsidence. Van Jonbergen *et al.*[28] suggested that postoperative intervertebral height loss should be greater than 3 mm. Several studies classified the subsidence of TMC as mild (1–3 mm) and severe subsidence (≥3 mm). The measurement error of setting the standard as 2 mm is relatively large. Therefore, we set the standard as the subsidence of the TMC measured

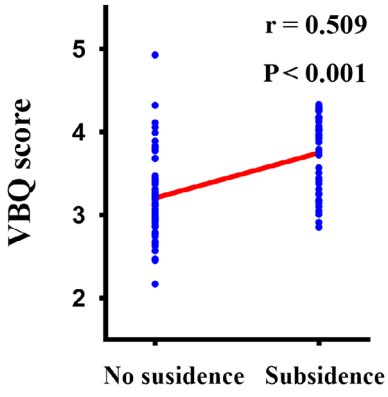

FIGURE 5 Graph showing a positive, significant correlation between subsidence and VBQ score ($r = 0.509$, $p < 0.001$).

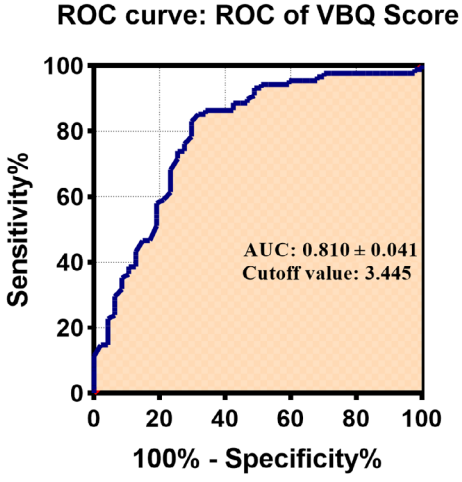

FIGURE 6 ROC curve analysis and AUC of the VBQ score. ROC, receiver operating characteristic.

by lateral cervical X-ray at greater than 3 mm. Of 134 patients, 46 patients (34.33%) demonstrated TMC subsidence. Excessive subsidence to adjacent vertebrae may lead to reconstruction failure and recurrence of neurological symptoms. However, we did not observe patients with obvious clinical symptoms in our study. This result may in part explain the lack of correlation between TMC subsidence and surgery progression.

VBQ Score and TMC Subsidence

Previous studies showed that multiple potential risk factors contribute to the TMC subsidence, including advanced age, osteoporosis, TMC tilt angle, and placement depth.[8,12,29] Although there was a significant difference in age between the two groups in our study, age was not an independent risk factor. It may be related to the lower mean age of the population included in this study. Older patients often have osteoporosis, and the decrease in bone mass leads to a decrease in BMD and destruction of trabecular structures.[30,31] With increasing osteoporosis severity, superior and inferior endplate maximum stress will increase more, which increases the potential risk of implant subsidence.[32] Meanwhile, older patients often have a combination of different degenerative changes in the spine that lead to increased BMD, including calcification, sclerosis or osteophyte formation, which can lead to false negative results, consequently causing missed diagnosis.[33–35] In addition, dual-energy X-ray absorptiometry (DEXA) is not a routine test before cervical spine surgery and previous study showed limited significance of cervical DXEA for clinical guidance. Ehresman *et al.*[36] presented a novel tool based on sagittal non-contrast-enhanced T1-weighted magnetic resonance imaging, VBQ score, for clearly distinguishing healthy and osteopenic/osteoporotic patients. VBQ scores reflect fat replacement in the medullary regions of the lumbar vertebrae, while BMD may be confounded by bone size changes, osteophyte and sclerosis of bone. Hu *et al.*[16] found the VBQ score to be an independent predictor of cage subsidence, and the VBQ score had better correlation to the amount of subsidence than the DEXA T-score. However, this notion has not yet been confirmed in the cervical spine. This is the first study to predict TMC subsidence by measuring cervical VBQ score, the results showed VBQ score was significantly higher in the subsidence group than that in the no subsidence group and VBQ score was also a significant independent risk factor of TMC subsidence after ACCF.

Significant Predictors of TMC Subsidence

In addition to the VBQ score, the position of the TMC was found to be closely associated with cage subsidence. Zhang *et al.*[37] also reported a lower subsidence rate of cage located whole epiphysis. Compared to the no subsidence group, TMC position was closer to the central disc space in the subsidence group.[38,39] The results of this study also found that the TMC placement depth was significantly lower in the subsidence group than that in the no subsidence group. Therefore, TMC should be implanted as anterior as possible to obtain high resistance against subsidence. When tilt angle is 0°, the lower edge of TMC is perfectly parallel to the endplate, the contact area is maximum and the forces at each contact point are the same. When tilt angle is too great, the lower edge of TMC will be in point contact with the endplate and the stresses on TMC will be concentrated at one point, which will result in loss of fused segment intervertebral height. All TMC used in our study were placed as parallel to the endplate as possible, which might be one reason why there was no significant difference in TMC tilt angle between two groups.

Strengths and Limitations

No previous study has attempted to correlate preoperative MRI with TMC subsidence after.

ACCF. Our study is the first to introduced a novel MRI-based vertebral bone quality (VBQ) score in ACCF. However, there are still some limitations of our study. First, this is a retrospective study in a single center, and small sample was another limitation for the study. Further prospective large-sampled randomized controlled studies are needed to confirm the current findings. Second, DEXA was not routinely performed on these patients and thus this study failed to demonstrate a significant association between hip, lumbar spine BMD and cervical VBQ scores. The findings of this study should be interpreted with caution due to the above limitations and prospective data collection and closer clinical follow-up will be the focus of future studies.

Conclusions

This is the first study to show that cervical VBQ score can independently predict postoperative TMC subsidence in patients undergoing ACCF surgery. The preoperative cervical VBQ score may serve as a simple and valuable tool of TMC subsidence to help clinicians accurately identify individuals with high subsidence risk.

Author Contributions

All authors had full access to the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Qiujiang Li and Ce Zhu. Acquisition of data: Qiujiang Li, Ce Zhu and Qinghong Xia. Analysis and interpretation of the data: Qiujiang Li and Ce Zhu. Drafting of the manuscript: Qiujiang Li, Ce Zhu, and Qinghong Xia. Statistical analysis: Qiujiang Li and Ce Zhu. Obtained funding: Ce Zhu, Ganjun Feng, and Yueming Song. Study supervision: Qiujiang Li, and Yueming Song.

Acknowledgments

All listed authors have made substantial contributions to the manuscript and do not have any conflicts of interest.

Funding Information

This study was supported by Sichuan Provincial Science and Technology Department Key Projects (No. 2022YFS0260); the 1-3-5 project for disciplines of excellence, West China Hospital, Sichuan University (ZYGD21001); the National Natural Science Foundation of China (82072386 and 82102521).

Conflict of Interest Statement

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Ethics Statement

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the West China hospital (No. 2023-250). Written informed consent was obtained from the parents.

Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

Table S1. The Kappa coefficients and ICC value of variables between two spine surgeons.

References

1. Badhiwala JH, Ahuja CS, Akbar MA, Witiw CD, Nassiri F, Furlan JC, et al. Degenerative cervical myelopathy-update and future directions. Nat Rev Neurol. 2020;16(2):108–24. https://doi.org/10.1038/s41582-019-0303-0
2. Nouri A, Cheng JS, Davies B, Kotter M, Schaller K, Tessitore E. Degenerative cervical myelopathy: a brief review of past perspectives, present developments, and future directions. J Clin Med. 2020;9(2):535. https://doi.org/10.3390/jcm9020535
3. Xu S, Wang G, Yang J, Zhang S, Song Y, Wang Q. Anterior debridement, bone grafting and fixation for cervical spine tuberculosis: an iliac bone graft versus a structural manubrium graft. BMC Musculoskelet Disord. 2022;23(1):236. https://doi.org/10.1186/s12891-022-05177-0
4. Arnold PM, Vaccaro AR, Sasso RC, Goulet B, Fehlings MG, Heary RF, et al. Six-year follow-up of a randomized controlled trial of i-FACTOR peptide-enhanced bone graft versus local autograft in single-level anterior cervical discectomy and fusion. Neurosurgery. 2022;92:725–33. https://doi.org/10.1227/neu.0000000000002290
5. Wang Y, Zhan Y, Yang H, Guo H, Zhang H, Zhao Q, et al. A novel anatomic titanium mesh cage for reducing the subsidence rate after anterior cervical corpectomy: a finite element study. Sci Rep. 2021;11(1):15399. https://doi.org/10.1038/s41598-021-94787-0
6. Hur JW, Ryu KS, Ahn S, Kim JS, Chung HJ, Song MS. Comparative analysis of 2 different types of titanium mesh cage for single-level anterior cervical corpectomy and fusion in terms of postoperative subsidence and sagittal alignment. Clin Spine Surg. 2020;33(1):E8–E13. https://doi.org/10.1097/BSD.0000000000000938
7. Fengbin Y, Jinhao M, Xinyuan L, Xinwei W, Yu C, Deyu C. Evaluation of a new type of titanium mesh cage versus the traditional titanium mesh cage for single-level, anterior cervical corpectomy and fusion. Eur Spine J. 2013;22(12):2891–6. https://doi.org/10.1007/s00586-013-2976-1
8. Tang Y, Geng X, Li F, Sun Y, Jia L, Zhou S, et al. Factors affecting titanium mesh cage subsidence in single-level anterior cervical corpectomy and fusion for ossification of the posterior longitudinal ligament. J Orthop Surg Res. 2022;17(1):515. https://doi.org/10.1186/s13018-022-03409-6
9. Wang Z, Mei J, Feng X, Deng C, Tian X, Lv J, et al. Low cervical vertebral CT value increased early subsidence of titanium mesh cage after anterior cervical corpectomy and fusion. J Orthop Surg Res. 2022;17(1):355. https://doi.org/10.1186/s13018-022-03239-6
10. Ji C, Yu S, Yan N, Wang J, Hou F, Hou T, et al. Risk factors for subsidence of titanium mesh cage following single-level anterior cervical corpectomy and fusion. BMC Musculoskelet Disord. 2020;21(1):32. https://doi.org/10.1186/s12891-019-3036-8
11. Abudouaini H, Wu T, Liu H, Wang B, Chen H. The predictive value of Hounsfield units for titanium mesh cage subsidence after anterior cervical corpectomy and fusion. Front Surg. 2022;9:1012364. https://doi.org/10.3389/fsurg.2022.1012364
12. An TY, Kim JY, Lee YS. Risk factors and radiologic changes in subsidence after single-level anterior cervical corpectomy: a minimum follow-up of 2 years. Korean J Neurotrauma. 2021;17(2):126–35. https://doi.org/10.13004/kjnt.2021.17.e23
13. Xi Z, Mummaneni PV, Wang M, Ruan H, Burch S, Deviren V, et al. The association between lower Hounsfield units on computed tomography and cage subsidence after lateral lumbar interbody fusion. Neurosurg Focus. 2020;49(2):E8. https://doi.org/10.3171/2020.5.FOCUS20169
14. Oh KW, Lee JH, Lee JH, Lee DY, Shim HJ. The correlation between cage subsidence, bone mineral density, and clinical results in posterior lumbar interbody fusion. Clin Spine Surg. 2017;30(6):E683–9. https://doi.org/10.1097/BSD.0000000000000315
15. Brenke C, Dostal M, Scharf J, Weiss C, Schmieder K, Barth M. Influence of cervical bone mineral density on cage subsidence in patients following stand-alone anterior cervical discectomy and fusion. Eur Spine J. 2015;24(12):2832–40. https://doi.org/10.1007/s00586-014-3725-9
16. Hu YH, Yeh YC, Niu CC, Hsieh MK, Tsai TT, Chen WJ, et al. Novel MRI-based vertebral bone quality score as a predictor of cage subsidence following transforaminal lumbar interbody fusion. J Neurosurg Spine. 2022;1-9:654–62. https://doi.org/10.3171/2022.3.SPINE211489
17. Soliman M, Aguirre AO, Kuo CC, Ruggiero N, Azmy S, Khan A, et al. Vertebral bone quality score independently predicts cage subsidence following transforaminal lumbar interbody fusion. Spine J. 2022;22(12):2017–23. https://doi.org/10.1016/j.spinee.2022.08.002
18. Jones C, Okano I, Arzani A, Dodo Y, Moser M, Reisener MJ, et al. The predictive value of a novel site-specific MRI-based bone quality assessment, endplate bone quality (EBQ), for severe cage subsidence among patients undergoing standalone lateral lumbar interbody fusion. Spine J. 2022;22(11):1875–83. https://doi.org/10.1016/j.spinee.2022.07.085
19. Soliman M, Aguirre AO, Kuo CC, Ruggiero N, Khan A, Ghannam MM, et al. A novel cervical vertebral bone quality score independently predicts cage subsidence after anterior cervical Diskectomy and fusion. Neurosurgery. 2022;92:779–86. https://doi.org/10.1227/neu.0000000000002269
20. Razzouk J, Ramos O, Ouro-Rodrigues E, Samayoa C, Wycliffe N, Cheng W, et al. Comparison of cervical, thoracic, and lumbar vertebral bone quality scores for increased utility of bone mineral density screening. Eur Spine J. 2023;32(1):20–6. https://doi.org/10.1007/s00586-022-07484-5
21. Sangondimath G, Mallepally AR, Marathe N, Mak KC, Suman S. Degenerative cervical myelopathy: recent updates and future directions. J Clin Orthop Trauma. 2020;11(5):822–9. https://doi.org/10.1016/j.jcot.2020.07.012
22. Ji H, Xie X, Zhuang S, Zhang C, Xie L, Wu X. Comparative analysis of three types of titanium mesh cages for anterior cervical single-level corpectomy and fusion in term of postoperative subsidence. Am J Transl Res. 2020;12(10):6569–77.
23. Cawley DT, Alzakri A, Fujishiro T, Kieser DC, Tavalaro C, Boissiere L, et al. Carbon-fibre cage reconstruction in anterior cervical corpectomy for multilevel cervical spondylosis: mid-term outcomes. J Spine Surg. 2019;5(2):251–8. https://doi.org/10.21037/jss.2019.03.08
24. Wang S, Xiang Y, Wang X, Li H, Hou Y, Zhao H, et al. Anterior corpectomy comparing to posterior decompression surgery for the treatment of multi-level ossification of posterior longitudinal ligament: a meta-analysis. Int J Surg. 2017;40:91–6. https://doi.org/10.1016/j.ijsu.2017.02.058
25. Liu X, Min S, Zhang H, Zhou Z, Wang H, Jin A. Anterior corpectomy versus posterior laminoplasty for multilevel cervical myelopathy: a systematic review and meta-analysis. Eur Spine J. 2014;23(2):362–72. https://doi.org/10.1007/s00586-013-3043-7
26. Zhou QS, Chen X, Xu L, Li S, Du CZ, Sun X, et al. Does vertebral end plate morphology affect cage subsidence after transforaminal lumbar interbody fusion? World Neurosurg. 2019;130:e694–701. https://doi.org/10.1016/j.wneu.2019.06.195
27. Yao YC, Chou PH, Lin HH, Wang ST, Liu CL, Chang MC. Risk factors of cage subsidence in patients received minimally invasive transforaminal lumbar interbody fusion. Spine. 2020;45(19):E1279–85. https://doi.org/10.1097/BRS.0000000000003557
28. van Jonbergen HP, Spruit M, Anderson PG, Pavlov PW. Anterior cervical interbody fusion with a titanium box cage: early radiological assessment of fusion and subsidence. Spine J. 2005;5(6):645–9. https://doi.org/10.1016/j.spinee.2005.07.007
29. Li J, Zhang J, Tong T, Shen Y. Influence of Modic changes on cage subsidence and intervertebral fusion after single-level anterior cervical

corpectomy and fusion. J Invest Surg. 2022;35(2):301–7. https://doi.org/10.1080/08941939.2020.1855487
30. Lins VN, Da SNJ, Do NC, Barros NJ, Oliveira DSA. Association between bone mineral density and nutritional status, body composition and bone metabolism in older adults. J Nutr Health Aging. 2021;25(1):71–6. https://doi.org/10.1007/s12603-020-1452-y
31. Berto P, Maggi S, Noale M, Lopatriello S. Risedronate versus alendronate in older patients with osteoporosis at high risk of fracture: an Italian cost-effectiveness analysis. Aging Clin Exp Res. 2010;22(2):179–88. https://doi.org/10.1007/BF03324794
32. Wang Z, Ma R, Cai Z, Wang Z, Yang S, Ge Z. Biomechanical evaluation of stand-alone oblique lateral lumbar interbody fusion under 3 different bone mineral density conditions: a finite element analysis. World Neurosurg. 2021;155:e285–93. https://doi.org/10.1016/j.wneu.2021.08.049
33. Li XP, Li XY, Yang MH, Zhu SW, Wu XB, Zhang P. Changes of bone turnover markers after elderly hip fracture surgery. J Bone Miner Metab. 2021;39(2):237–44. https://doi.org/10.1007/s00774-020-01140-y
34. Andersen T, Christensen FB, Langdahl BL, Ernst C, Fruensgaard S, Ostergaard J, et al. Fusion mass bone quality after uninstrumented spinal fusion in older patients. Eur Spine J. 2010;19(12):2200–8. https://doi.org/10.1007/s00586-010-1373-2
35. Zou D, Sun Z, Zhou S, Zhong W, Li W. Hounsfield units value is a better predictor of pedicle screw loosening than the T-score of DXA in patients with lumbar degenerative diseases. Eur Spine J. 2020;29(5):1105–11. https://doi.org/10.1007/s00586-020-06386-8
36. Ehresman J, Pennington Z, Schilling A, Lubelski D, Ahmed AK, Cottrill E, et al. Novel MRI-based score for assessment of bone density in operative spine patients. Spine J. 2020;20(4):556–62. https://doi.org/10.1016/j.spinee.2019.10.018
37. Zhang X, Wu H, Chen Y, Liu J, Chen J, Zhang T, et al. Importance of the epiphyseal ring in OLIF stand-alone surgery: a biomechanical study on cadaveric spines. Eur Spine J. 2021;30(1):79–87. https://doi.org/10.1007/s00586-020-06667-2
38. Grant JP, Oxland TR, Dvorak MF. Mapping the structural properties of the lumbosacral vertebral endplates. Spine. 2001;26(8):889–96. https://doi.org/10.1097/00007632-200104150-00012
39. Hou Y, Yuan W. Influences of disc degeneration and bone mineral density on the structural properties of lumbar end plates. Spine J. 2012;12(3):249–56. https://doi.org/10.1016/j.spinee.2012.01.021