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Forearm bone mineral density predicts subsidence of titanium mesh cage after anterior cervical corpectomy and fusion in patients with cervical spondylosis

Jinzhou Wang[1†], Zifan Wang[1†], Yang Feng[2†], Ping Xia[3], Jiangtao He[1], Qian Chen[1], Yuwei Gou[1], Baicheng Du[2*] and Kui Li[1*]

Abstract

Background Subsidence of the titanium mesh cage (TMC) is a frequent and difficult adverse effect following anterior cervical corpectomy and fusion (ACCF). Since low bone mineral density (BMD) has also been identified as an independent risk factor for TMC, forearm BMD measurement has gained more interest recently because of its accuracy and convenience. Systematic research on the precise correlation between titanium mesh subsidence risk following ACCF surgery and forearm bone mineral density is, however, insufficient.

Methods This study retrospectively evaluated 114 patients who were treated with ACCF at the Affiliated Hospital of North Sichuan Medical College between September 2020 and September 2023. Patients were divided into two groups according to whether the titanium mesh subsidence occurred during the follow-up period: the non-subsidence group and the subsidence group. The patient's age, sex, smoking history, body mass index, diabetes history, surgical stage,disease type, HU value of upper and lower vertebrae, forearm bone density, Restored height of fused segmental vertebrae and other basic information were obtained. Potential risk factors of TMC subsidence were screened by single factor analysis, and independent risk factors were found by Logistic regression analysis. ROC curve and area under curve (AUC) were used to assess forearm bone mineral density to predict TMC subsidence.

Results There were 39 incidences of titanium mesh subsidence among the 114 patients who were followed for at least 12 months. Significant differences were seen between the subsidence and non-subsidence groups in the restored height of fused segmental vertebrae, forearm BMD, HU value of upper vertebral body, and HU value of lower vertebral body. After multivariate logistic regression analysis, forearm BMD (OR 0.934; 95% CI 0.895–0.973, $P=0.034$) and lower vertebral body HU value (OR 0.915; 95% CI 0.857–0.963, $P=0.023$) were identified as independent risk variables for titanium mesh subsidence. Each 0.1 g/cm^2 increase in forearm BMD decreased the probability of titanium mesh subsidence by 6.6%. For every 1 HU rise in lower vertebral body HU value, the chance of titanium mesh subsidence decreased by 8.5%. The risk of mesh subsidence was significantly higher in patients with low forearm BMD

†Jinzhou Wang, Zifan Wang and Yang Feng contributed equally to this work.

*Correspondence:
Baicheng Du
397444502@qq.com
Kui Li
2575845269@qq.com
Full list of author information is available at the end of the article

and lower vertebral body HU value. The AUC for forearm BMD value and HU value in predicting titanium mesh subsidence were 0.858 and 0.897, respectively.

Conclusions Forearm BMD is an independent risk factor for titanium mesh subsidence after ACCF. Forearm BMD can be a valid predictor of titanium mesh subsidence after ACCF, as can HU value of the lower vertebral body.

Keywords Anterior cervical corpectomy and fusion, Forearm BMD, Titanium mesh cage, Hounsfield unit

Introduction

ACCF is one of the classic surgical procedures for the treatment of cervical spine diseases due to its less traumatic access, direct decompression, and restoration of cervical curvature [1, 2]. The use of TMC for interbody fixation and fusion can rebuild the stability of the cervical spine, and is one of the commonly used implants for ACCF [3, 4]. However, subsidence of titanium mesh has been one of the most common postoperative complications [5]. According to some research [6–9], between 34.1% and 79.7% of postoperative patients experience titanium mesh subsidence. When titanium mesh subsidence pierces into adjacent vertebrae, it can cause internal fixation relaxation, displacement, and recurring neurological symptoms, as well as reduced cervical lordosis and, in extreme situations, cervical kyphosis deformity [10]. It has been proposed that osteoporotic individuals are more prone to experience titanium mesh subsidence [11]. Dual-energy x-ray absorptiometry (DXA) is currently the gold standard for assessing bone mineral density and diagnosing osteoporosis [12]. However, Bone density measurements are typically performed in the lumbar region, and their accuracy might be influenced by lumbar spine degeneration [13]. Patients with cervical spine degeneration frequently have a mix of lumbar spine degeneration [14] and lumbar DXA scans are often not done preoperatively in patients with cervical degenerative disease. Multiple studies have shown that vertebral HU values are strongly correlated with BMD [15, 16]. Furthermore, several reports have demonstrated that vertebral HU values are effective in predicting interbody fusion subsidence after ACCF and anterior cervical discectomy and fusion (ACDF) [6, 17]. However, different studies have frequently utilized different cutoff values and measuring methodologies, and there is no uniform threshold based on CT-HU data to distinguish between low and normal BMD and determine whether anti-osteoporosis medication is required [18]. According to some recent studies [19], forearm bone densitometry may be a legitimate alternative technique to avoid false-negative results due to degenerative changes such as calcification of the abdominal aorta, degenerative bone changes, or bone matrix formation in routine lumbar measurements [20], with sufficient accuracy in determining the BMD of the midshaft skeleton. Following lumbar fusion surgery, it has been demonstrated that forearm bone density can be a reliable indicator of screw loosening and interbody fusion subsidence [21, 22]. Degenerative changes in the lumbar spine and cervical spine, in turn, often occur in combination, especially in the elderly population. The relationship between titanium mesh subsidence and forearm bone density, however, has not been thoroughly investigated. In this study, we examined cervical spondylosis patients treated with ACCF and titanium mesh implant fixation and fusion in order to look into any potential relationships between titanium mesh subsidence and forearm bone mineral density.

Methods

Patient population

Our institutional review board gave their approval to the project. This study retrospectively included patients who had ACCF for cervical spondylosis in our department between September 2020 and September 2023. (1) patients who had a clinically confirmed diagnosis of cervical spondylosis; (2) patients who had interbody fusion with titanium mesh implantation after undergoing surgery for ACCF; (3) patients who had cervical CT、forearm DXA measurement and x-rays within a week before surgery; and (4) x-rays with at least a year of follow-up. The following were the exclusion criteria: (1) patients with spinal infections, spinal malignancies, spinal injuries, or metabolic bone disease; (2) patients with concomitant immunological disorders or long-term hormone usage; and (3) patients with clinical data, follow-up loss, or inadequate preoperative and postoperative imaging (defined as missing cervical CT, forearm DXA, or X-ray images, or images of insufficient quality for analysis).

Patient and surgical factors

The following variables were collected as potential determinants of TMC subsidence: age, sex, gender, BMI, diabetes, hypertension, and illness type. We collected intraoperative data, such as surgical segment, procedure duration, and blood loss, in addition to patient data.

Dual-energy X-ray absorptiometry

Prior to surgery, the non-dominant forearm of the patient was chosen for bone densitometry, which was limited to the distal third of the ulna and radius (g/cm^2). Using an EXA-3000 Osteosys absorptiometry equipment, professionally trained personnel conducted bone density testing. A scanning current of 0.25 mA and a tube voltage of 80 kV/55 kV were among the parameters set throughout the experiment; pertinent settings were found in the literature [21]. To ensure precision, the same technician performed all scans, and the device was calibrated daily using a standard phantom. The coefficient of variation (CV) for repeated measurements was 0.9%, indicating high precision.

Measurements of HU value

All patients had preoperative cervical CT scans (Definition, Siemens).The voltage of the CT scan tube was adjusted at 120 kV. The HU values were determined according to the method previously published by Han et al. [23]. ROIs were plotted in the mid-sagittal, mid-coronal, and mid-axial planes of the C2-C7 vertebrae, and the PACS system automatically calculated the HU values. The vertebrae were selected as the upper and lower vertebrae immediately adjacent to the titanium mesh, and the ROIs were chosen to include trabeculae as much as possible, avoiding cortical bone and heterogeneous areas. Mid-sagittal pictures were combined with a reference scout axial image, and the middle area of two additional images (mid-coronal and mid-axial) was chosen using the reference scout sagittal image. Measurements were taken twice in each cervical section, and the average of the two results was calculated (Fig. 1).

Radiological assessment

Frontal and lateral cervical spine X-rays and CT examinations were performed preoperatively, and the patients were followed up periodically after the operation. The following parameters were measured in the preoperative and 1-d postoperative cervical spine frontal and lateral X-rays. Cobb's angle of the operated segment: on preoperative and postoperative lateral cervical radiographs, two parallel lines are drawn along the superior endplate of the cephalad and inferior endplate of the caudal vertebra of the resected vertebral body, and the angle of their perpendicular lines is recorded. C2-7 sagittal vertical axis(SVA):SVA is defined as the distance from the center vertical line of the C2 vertebral body to the vertical line of the upper back corner of the C7 vertebral body. Restored height of fused segmental vertebrae: On preoperative and postoperative lateral cervical radiographs, measure the height of the anterior margin of the fused segment A (the distance between the anterosuperior corner of the resected cephalic vertebrae and the anterosuperior corner of the caudal vertebrae), and the height of the posterior margin of the fused segment B (the distance between the posterosuperior corner of the resected superior vertebrae and the posterosuperior corner of the caudal vertebrae). The mean value of A + B was recorded as the fused segmental height, Restored height of fused segmental vertebrae = Postoperative fused segmental height—Preoperative fused segmental height (Fig. 2). Measurement of TMC subsidence: radiographs

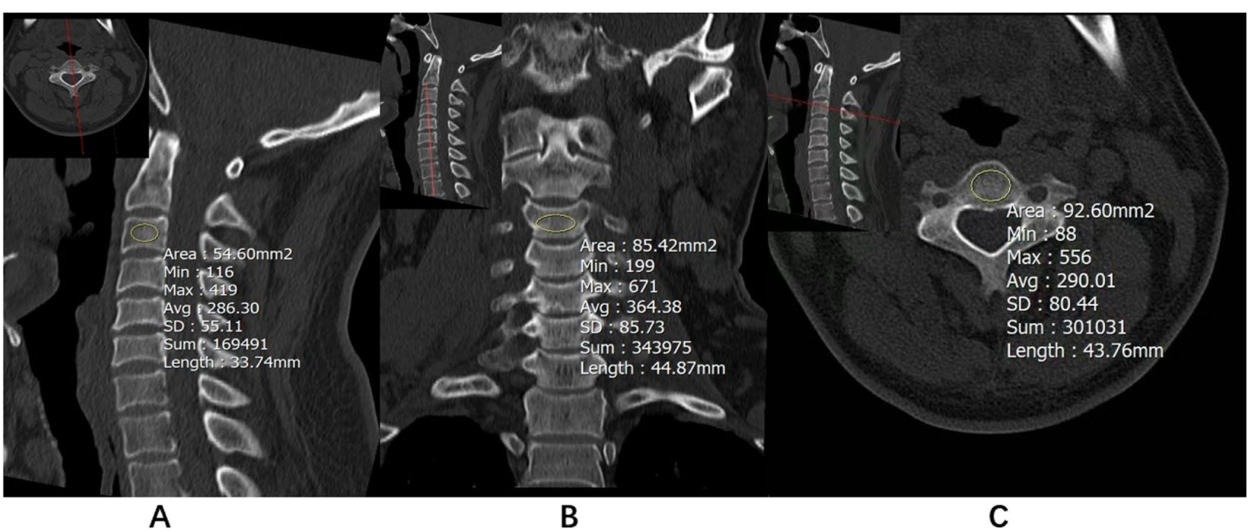

Fig. 1 According to method of Han et al. [23]. The HU values were measured on the CT images of the C2-C7 vertebral body in the midsagittal (**A**), midcoronal (**B**), and midaxial (**C**) planes, respectively

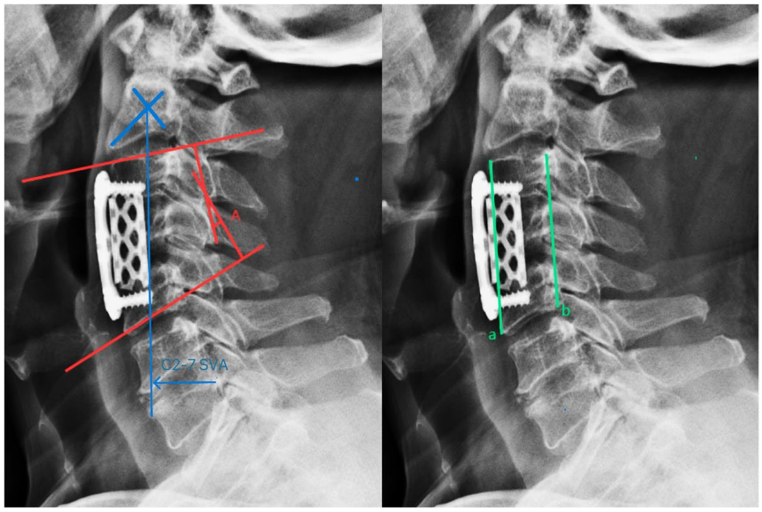

Fig. 2 Cobb angle of the surgical segment and C2-7 sagittal vertical axis (**A**). Restored height of fused segmental vertebrae (**B**)

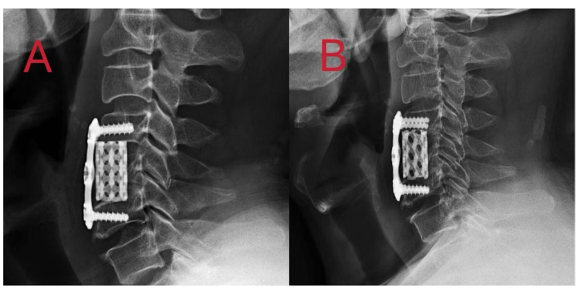

Fig. 3 First postoperative review (**A**) and postoperative follow-up radiographs of titanium mesh subsidence (**B**)

with at least 3 months of postoperative follow-up were compared with the 1-day postoperative radiographs, and the titanium mesh was considered to be subsiding if there was a decrease of $\geq$3.0 mm in A or B [9]. Typical cases are shown in Fig. 3. Patients were divided into 2 groups according to the occurrence of titanium mesh subsidence or not. All measurements were independently performed by two orthopedic surgeons, each with over five years of specialized experience in spinal surgery, who were blinded to the clinical outcomes.

Clinical assessment

All patients were assessed preoperatively and postoperatively using the Japanese Orthopaedic Association(JOA) and Neck Disability Index(NDI) scales to evaluate the patients' neurological function, the degree of spinal cord injury, the impact of daily life, and the effect of rehabilitation. The JOA scale consists of 4 sections, namely, upper extremity motor function, lower extremity motor function, sensory impairment, and bladder function, with a total score of 17 points [24]. The NDI scale consists of 10 sections [25], including personal care, daily activities, ability to work, leisure activities, ability to travel, sleep quality, concentration, neck movement restriction, and emotional state, with scores ranging from 0 to 50, with higher scores indicating more severe dysfunction. Patients were followed up with a survey by the corresponding author after discharge from the hospital.

Surgical procedure

After administering anesthesia, the patient was positioned supine with mild hyperextension of the neck. A transverse incision was made anterior to the right side of the neck, and the approach was taken between the carotid sheath and the visceral sheath to expose the cervical spine. The surgical segment was identified using G-arm fluoroscopy. A spacer was installed, and the nucleus pulposus and annulus fibrosus were removed with a spatula. The cartilage endplate was carefully excised until bleeding was observed. A portion of the vertebral body of the affected segment was resected to expose the dura mater, ensuring complete decompression of both the dura mater and nerve root. Following the release of the distractor, the appropriate titanium mesh cage (TMC) was selected based on the extent of resection, filled with autologous cancellous bone fragments, and implanted into the bone groove. The positioning of the cage was confirmed with G-arm fluoroscopy. A titanium plate of appropriate length was then installed in front of the cervical vertebra. The surgical site was irrigated, a negative pressure drain was placed, and the incision was sutured layer by layer, completing the procedure.

Statistical analysis

SPSS statistical software (US version 26) was used for analysis. Standard deviation ± mean was used to indicate continuous variables. Percentages were used to indicate quantitative indicators. Shapiro–Wilk test was used to check the normality of continuous data. Student's t-test was used for variables with normal distribution and Mann–Whitney U-test was used for variables without normal distribution. Categorical variables included sex, hypertension, diabetes, smoking status, surgical stage (C4, C5, C6), and disease type (myelopathy, radiculopathy, mixed), and Chi-square test was used for comparison. When the expected frequency is less than 5, Fisher exact test is used. The study used logistic regression analysis to identify independent variables associated with titanium mesh subsidence. The predictive value of titanium mesh subsidence was assessed using the receiver operating characteristic curve (ROC) and the area under the curve (AUC) was calculated. The ROC curve was utilized to determine the most appropriate threshold (critical value) for forearm bone density with high sensitivity and specificity, and differences were considered statistically significant if $p < 0.05$.

Results

The 114 patients (70 men and 44 women) in the statistical analysis had a BMI of 24.19 ± 2.80 and an average age of 54.43 ± 9.69 years (Table 1). During at least a 12-month follow-up, the overall incidence of titanium mesh subsidence was 34.2%, with the sinking segment occurring in 8 instances in C4, 17 cases in C5, and 14 in C6. The two groups did not differ significantly in terms of age, BMI, gender, disease type, hypertension, diabetes status, smoking status, surgical stage, surgical blood loss, fusion rate and surgery time ($P > 0.05$).The mean forearm BMD was significantly lower in the subsidence group (0.34 ± 0.05 vs 0.42 ± 0.06, $P < 0.001$) than in the non-subsidence group. Similarly, both upper vertebral CT HU values (317.85 ± 37.91 vs 385.07 ± 44.32, $P = 0.039$) and lower segmental vertebral CT HU values (255.99 ± 27.63 vs 317.47 ± 40.44, $P = 0.002$) were also significantly different between the subsidence and non- subsidence groups. There was also a significant difference in the recovery height of fused vertebrae (0.36 ± 0.08vs 0.31 ± 0.13, $P = 0.020$) (Table 2).

The relevant characteristics with P values less than 0.05 when comparing the two groups in Tables 1 and 2 were regarded as potential influencing factors of titanium mesh subsidence and were included in the univariate logistic regression analysis (Table 3).The results showed that mean HU value of lower vertebral body (OR 0.953; 95%CI 0.914,0.994; $P = 0.005$) and forearm BMD (OR 0.929; 95%CI 0.898,0.963; $P = 0.004$) were the independent risk factors for titanium mesh subsidence after ACCF. While Restored height of fused segmental vertebrae, and Mean HU value of upper vertebral body no longer had significant effects on postoperative titanium mesh subsidence. In addition, we further performed a multiple regression analysis incorporating the risk factors of forearm bone density and Mean HU value of lower vertebral body, and found that the interaction between the two had little effect, with forearm bone density (OR 0.934; 95%CI 0.895,0.973; $P = 0.034$) as well as Mean HU value of lower vertebral body (OR 0.915; 95%CI 0.857,0.963; $P = 0.023$) remained significant (Table 4).

ROC curve analysis was used to evaluate the predictive validity of the forearm BMD and HU value of the lower vertebral body for postoperative titanium mesh subsidence following ACCF (Table 5). The results showed that both forearm BMD and mean HU value of lower vertebral body could effectively predict the risk of adjacent vertebral fractures, and the AUC of forearm BMD and mean HU value of lower vertebral body were 0.858 and 0.897, respectively (Fig. 4). The cutoff point of mean HU value of lower vertebral body was 286.51 (sensitivity was 0.820; The specificity was 0.885) and the forearm BMD was 0.38 (sensitivity was 0.800; The specificity was 0.731).

Postoperative, 3 months after the operation, and the final follow-up, the subsidence group's and the non-subsidence group's JOA and NDI scores showed a considerable improvement. However, JOA and NDI scores preoperative, postoperative, 3 months after the operation, and at the final follow-up did not differ statistically significantly between the two groups (Table 6).

Discussion

This is the first study to look at the association between forearm bone density and titanium mesh subsidence, as far as we know. The findings revealed that assessing forearm bone density by forearm DXA was useful in predicting the likelihood of titanium mesh subsidence following ACCF, and that the risk of titanium mesh subsidence rose significantly when forearm bone density was less than 0.38 g/cm2. Furthermore, forearm bone density and the mean HU value of the inferior vertebrae were also strong predictors of titanium mesh subsidence.

TMC was first used in spinal surgery in 1986 [26]. It not only provides structural support for the anterior column, but also eliminates the need for additional autogenous bone, avoids complications in the donor area, and improves the rate of osseointegration [4, 27]. But titanium mesh subsidence has been more common in recent years [28], and it can cause intervertebral height loss, crumpling of the cervical ligamentum flavum, and secondary cervical foraminal stenosis, which can recompress

Table 1 Demographic and surgery characteristics

Variable	Subsidence	Non-subsidence	*P* value
patients	39	75	
Age (yrs)	57.08 ± 10.29	53.06 ± 9.17	0.602
Gender , n (%)			0.125
Male	18 (46.2)	43 (57.3)	
Female	21 (53.8)	32 (42.7)	
BMI (kg/m2)	24.38 ± 2.55	24.10 ± 2.94	0.291
Hypertension, n (%)			0.931
Yes	10 (25.6)	19 (25.3)	
No	29 (74.4)	56 (74.7)	
Diabetes, n (%)			0.755
Yes	9 (23.1)	15 (20.0)	
No	30 (76.9)	60 (80.0)	
Smoker, n (%)			0.637
Yes	15 (38.5)	36 (48.0)	
No	24 (61.5)	39 (52.0)	
Surgical segment, n (%)			0.786
C4	8 (20.5)	12 (16.0)	
C5	17 (43.6)	38 (50.7)	
C6	14 (35.9)	25 (33.3)	
Disease type, n (%)			0.357
Myelopathy	28 (71.8)	45 (60.0)	
Radicular	5 (12.8)	16 (21.3)	
Mixed	6 (15.4)	14 (18.7)	
Surgical time（min）	140.85 ± 12.77	140.16 ± 12.09	0.865
blood loss（ml）	156.31 ± 16.62	148.08 ± 20.94	0.251
Fusion rate, n (%)			0.247
Yes	35(89.7)	70(93.3)	
No	4(10.3)	5(6.7)	

Mean ± SD for continuous variables: normality was tested using the Shapiro-Wilk test with the following results: age ($P=0.495$), BMI ($P=0.418$), and duration of surgery ($P=0.078$) conformed to a normal distribution using the t-test, and blood loss ($P=0.004$) did not conform to a normal distribution using the Mann-Whitney U test. (%) for categorical variables: the *P* value was calculated by the weighted chi-square test

"*"indicates a statistically significant difference in results

Table 2 Imaging examination parameters

Variable	Subsidence	Non-subsidence	*P* value
Cobb angle correction(°)	4.91±0.54	4.83±0.56	0.619
Restored height of fused segmental vertebrae (cm)	0.36±0.08	0.31±0.13	0.020*
C2-7 sagittal vertical axis(cm)	2.21±0.78	2.06±0.72	0.468
Average forearm BMD(g/cm^2)	0.34±0.05	0.42±0.06	< 0.001*
Mean HU value of upper vertebral body	317.85±37.91	385.07±44.32	0.039*
Mean HU value of lower vertebral body	255.99±27.63	317.47±40.44	0.002*

The normality test was performed using the Shapiro-Wilk test, and the results were as follows: Mean HU value of upper vertebral body ($P=0.231$), Mean HU value of lower vertebral body ($P=0.118$), C2-7 sagittal vertical axis ($P=0.223$), and Average forearm BMD ($P=0.131$) conformed to a normal distribution using the independent samples t-test, and Cobb angle correction ($P=0.015$), and Restored height of fused segmental vertebrae ($P=0.011$) did not conform to normal distribution using the Mann-Whitney U test

Table 3 Univariable logistic regression analysis of risk factors for subsidence of titanium mesh

Variable	B	OR	95%Cl	P value
Restored height of fused segmental vertebrae	1.492	3.321	0.752,86.81	0.891
Mean HU value of upper vertebral body	0.007	1.007	0.975,1.039	0.686
Mean HU value of lower vertebral body	-0.048	0.953	0.914,0.994	0.005*
Forearm BMD	-0.072	0.929	0.898,0.963	0.004*

Table 4 Multivariate logistic regression analysis

Variable	B	OR	95%Cl	P value
Mean HU value of lower vertebral body	-0.086	0.915	0.857,0.963	0.023*
Forearm BMD	-0.067	0.934	0.895,0.973	0.034*

the spinal cord and nerve roots and ultimately result in a poor clinical outcome [29]. According to recent research, the osteoporotic population has a noticeably higher prevalence of titanium mesh subsidence [7, 30]. When the early implants are not fused, the sharp titanium mesh tends to break through the endplates and pierce into the loose vertebral bone, resulting in subsidence and collapse of the mesh. Scholars Hasegawa et al. [31] believe that the maximum load and stiffness of the titanium mesh is related to the patient's own bone density, and if the bone density decreases, the stiffness of the end plate decreases, which can lead to a decrease in the stiffness of the titanium mesh and the maximum load, and it is easier to insert into the neighboring vertebrae, which causes the titanium mesh to sink. Therefore BMD is a non-negligible factor in the discussion of TMC settlement.

Although DXA bone densitometry is commonly used on the lumbar spine (L1-4) [32], Along the x-ray projection path, DXA, a planar projection-based imaging approach, assesses the overall density of all mineral components present in the anterior and posterior vertebral body structures in addition to cancellous and cortical

Table 5 Results of ROC analysis

	AUC	95%Cl	*P* value	Cut-off	Sensitivity	Specificity
Mean HU value of lower vertebral body	0.897	0.826,0.968	＜0.001	286.51	82.0%	88.5%
Forearm BMD	0.858	0.777,0.939	＜0.001	0.38	80.0%	73.1%

The cut-off points were determined by maximizing the Youden index (secsitivity + specificity-1). For forearm BMD, the cut-off pointwas 0.38 g/cm^2; for Mean HU value of lower vertebral body, it was 286.51 HU

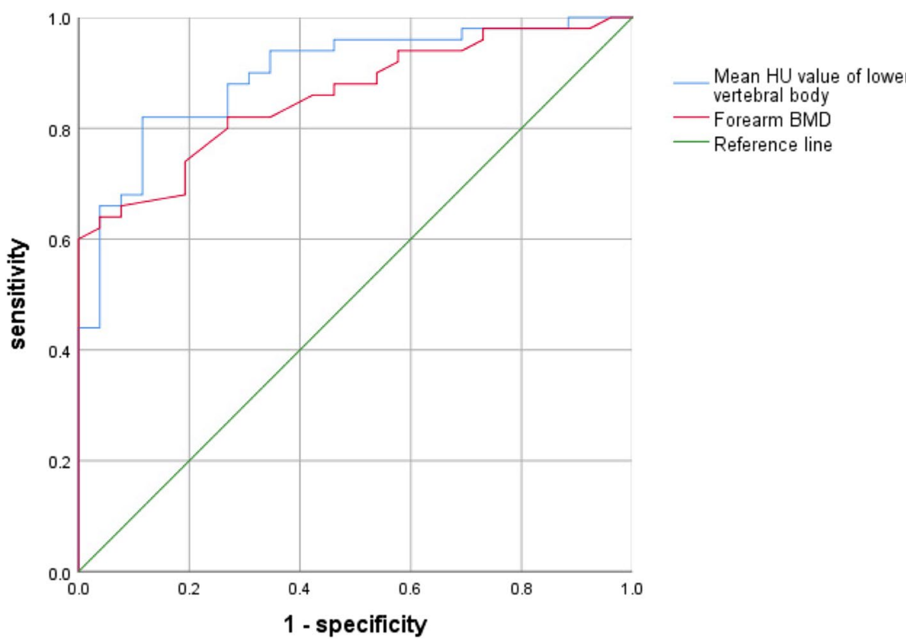

Fig. 4 ROC curve analysis and AUC of the forearm BMD and mean HU value for the titanium mesh subsidence

bone [33]. In patients with significant lumbar degenerative changes, degenerative structures such as vertebral compression fractures, calcification of the abdominal aorta, and endplate sclerosis can cause falsely high BMD readings that hide changes in real cancellous bone volume [13, 15, 34]. Vertebral HU values have gained popularity recently as a helpful measure for determining BMD and identifying osteoporosis. Several studies have found a substantial correlation between low HU values and fusion subsidence following cervical and lumbar fusion surgery [6, 17, 21, 22]. However, there is currently no set threshold based on CT-HU data to distinguish between low and normal bone mineral density, and the measurement results can be influenced by a number of factors, including contrast agent administration, measuring ROI selection, CT scan parameters, and measurer error. Consequently, it often has to be utilized in combination with other clinical evaluations and assays. Rey et al. [35] previously demonstrated a strong correlation between adult females' forearm BMD and their lumbar and femoral neck BMD. In addition, Jones et al. [36] found that forearm BMD demonstrated comparable diagnostic efficacy to lumbar spine and femoral neck BMD in the identification of osteoporosis patients. The research by Pouilles et al. [37] indicates that the bone density of the forearm can accurately reflect the bone health status of the axial skeleton and is feasible for application in OP screening. Furthermore, some studies have shown that forearm BMD can accurately predict screw loosening and cage subsidence after lumbar spine surgery [21, 22]. recent research has indicated that there is a certain degree of correlation between the bone density of the lumbar vertebrae and that of the cervical vertebrae [38]. Therefore, forearm BMD can theoretically be an important indicator for predicting bone dense-related complications after cervical spine surgery, and provide reference value for evaluating the potential risk of bone dense-related

Table 6 Comparison of clinical results between the subsidence and non-subsidence groups

Variable	Total	Subsidence	Non-subsidence	*P* value
Preoperative				
JOA	7.02 ± 1.16	6.87 ± 1.35	7.28 ± 1.46	0.345
NDI	36.93 ± 5.74	36.53 ± 5.14	37.03 ± 5.24	0.553
Postoperative				
JOA	14.13 ± 1.27*	13.72 ± 1.36	14.42 ± 1.33	0.223
NDI	16.96 ± 3.53*	16.76 ± 3.13	17.03 ± 3.26	0.374
3 months after the operation				
JOA	14.63 ± 1.67*	14.18 ± 1.21	14.92 ± 1.36	0.126
NDI	15.48 ± 2.23*	15.58 ± 2.54	15.34 ± 2.11	0.468
The final follow-up				
JOA	14.43 ± 1.47*	14.02 ± 1.42	14.90 ± 1.66	0.087
NDI	15.18 ± 2.63*	15.36 ± 2.13	15.03 ± 2.34	0.362

complications. However, there is a lack of clinical testing of this hypothesis.

At our minimum 12-month follow-up, the overall titanium mesh sedimentation rate was 34.21%. In a retrospective analysis that included 134 patients, 34.33% of patients had TMC sedimentation, which is similar to the results of this study [8]. However, in a retrospective study of 266 patients, the TMC sink rate was as high as 48.12% [28], In another cohort study of 300 patients, the TMC subsidence rate was even higher at 79.7% [9]. This may be due to different criteria for determining titanium mesh settlement, resulting in a wide variation in the overall titanium mesh settlement incidence across studies. Some scholars define titanium mesh settlement as a decrease in the height of the anterior or posterior edge of the intervertebral body at the surgical level of ≥ 2 mm [28], and some scholars define titanium mesh settlement as a loss of intervertebral height of 1–2 mm, and define heavy titanium mesh settlement as ≥ 3 mm [39]. Due to the magnification of the X-rays, a drop of more than 3 mm is more accurate from the measurement point of view. Therefore, van Jonbergen et al. [40] suggested that the criterion for titanium mesh subsidence should be a drop of more than 3 mm in intervertebral height, and this diagnostic criterion was adopted in the present study. Another factor to consider is surgical technique and the experience of the surgical team. Differences in surgical access, as well as accuracy of implant placement, use of bone grafts, and screw length, may affect the rate of subsidence. Although all surgeries in our study were performed by the same surgical team using standardized techniques, differences in surgical details across studies may explain some of the variation in reported rates. In addition our study reported a follow-up period of at least 12 months, which may have captured only the initial phase of subsidence. In other studies, longer follow-up periods may reveal further progression of subsidence, leading to higher reporting rates.

ACCF and TMC have been used extensively in clinical settings to treat cervical degenerative disorders, with positive results. TMC subsidence and postoperative clinical efficacy, however, have a contentious relationship. Ji et al. [7] tracked 73 patients treated with ACCF for three years and observed no significant difference in JOA or VAS score improvement between the subsidence and non-subsidence groups. Similarly, Wang et al. [6] did a retrospective examination of 211 patients treated with ACCF and discovered no significant difference in postoperative clinical efficacy between the TMC subsidence and non-subsidence groups. The JOA recovery rate in the group with subsidence was significantly lower than that in the group without subsidence, according to Chen et al.'s cohort study of 300 patients [9]. This suggests that TMC subsidence would have a significant impact on postoperative clinical efficacy and cause neurological function to deteriorate. Both the subsidence group and the non-subsidence group in this study had a significant improvement in their post-operative JOA and NDI scores. Despite the fact that the TMC subsidence rate in this trial reached 34.2%, the two groups'clinical effectiveness did not differ significantly.

According to earlier research [41], the cervical CT HU value may be a useful indicator of the likelihood that titanium mesh will settle following ACCF. Wang et al. [42] observed in a retrospective analysis of 126 patients having ACCF that postoperative titanium mesh subsidence and associated problems were substantially more likely to occur in individuals with low preoperative cervical CT HU values. However, due to the physical lordosis of the cervical spine, which causes a specific angle of the endplate, the axial incision is not parallel to the upper and lower endplates, and the ROI may contain a portion of the endplate. The neck proposed by Han et al. [23] was used in our investigation. HU measurements were taken on the median sagittal, median coronal, and axial planes of the vertebrae. The results showed that HU values of upper vertebrae (317.85 ±37.91 vs 385.07 ±44.32, $P=$ 0.039) and lower vertebrae (255.99 ±27.63 vs 317.47 ±40.44, $P=$ 0.002) had significant differences between the subsidence and non- subsidence groups. The sole independent risk factor for TMC subsidence, according to additional multifactor logistic regression analysis, was the lower vertebral body's HU valuation. This may be due to the fact that the lower vertebral body adjacent to the surgical site is directly underneath the titanium mesh, which bears not only the self-weight of the mesh, but also all the pressures transmitted to the lower vertebral body from the vertebral body and spinal loads above. The association between forearm bone mineral density and postoperative complications following lumbar fusion surgery has been the subject of several published investigations. Nevertheless, there remains a study gap in the prediction of titanium mesh subsidence following ACCF using forearm bone mineral density. In this investigation, the titanium mesh subsidence group's forearm bone density was substantially less than the non- subsidence group's(0.34 ±0.05vs0.42 ±0.06, $P<$ 0.001). Additional logistic regression analysis showed that forearm bone mineral density was an independent risk factor for titanium mesh subsidence after surgery, and the probability of titanium mesh subsidence decreased by nearly 6.6% for every 0.1 g/cm^2 increase. Forearm BMD was found to be a favorable predictor of screw loosening in a prior retrospective analysis of 270 patients following lumbar fusion, with a 16% increased risk of screw loosening for every unit drop in BMD [22]. Forearm BMD has a less noticeable influence on the cervical spine than the lumbar spine, maybe because lumbar fusion often entails a larger range of motion and heavier load bearing, whereas ACCF is for smaller vertebrae excision and transplantation, needing less stability. Another study [21] also found a significant difference in forearm bone density between patients with and without submerged interbody fusions after lumbar fusion.Previous studies [7] have shown that excessive intervertebral spreading may lead to excessive stress on the titanium mesh, ultimately leading to subsidence of the mesh. In this study, the average postoperative spreading distance was 0.36 ±0.08 cm in the submerged group and 0.31 ±0.13 cm in the non-submerged group, with a statistically significant difference between the two groups ($P=$ 0.020). However, further logistic regression analysis showed that excessive intervertebral spreading distance was not an independent risk factor for titanium mesh subsidence. This may be related to the shape of the mesh, material properties, and different surgical methods. In addition, ROC analysis was used to assess the predictive value of forearm BMD for titanium mesh subsidence. The AUCs of forearm BMD and mean HU value of lower vertebral body for predicting titanium mesh subsidence were 0.858 and 0.897, respectively, both of which had good predictive value, but the latter had a higher predictive value. The cutoff point for mean HU value of lower vertebral body in our study was 286.51 (sensitivity 82.0%, specificity 88.5%); the cutoff point for forearm bone density was 0.38 (sensitivity 80.0%, specificity 73.1%). In order to avoid the sinking of the titanium mesh and protect the surgical effect, spinal surgeons should pay more attention to patients with forearm bone mineral density less than 0.38 g/cm2 before surgery. Preoperative detection of bone metabolism-related enzymes in serum (such as bone-specific alkaline phosphatase, Procollagen Type I N-Terminal Propeptide and C-terminal cross-linked telopeptide of type I collagen) can be improved in combination with forearm BMD to jointly assess the risk and complications of osteoporosis. Preoperative and postoperative anti-osteoporosis therapy (such as bisphosphinate, teripartide) and nutritional intervention (such as calcium and vitamin D supplementation) can be actively used to improve bone quality. Reduces the risk of complications. A neck brace is also worn for a long time after surgery to immobilize the neck and provide additional support and protection.

Study limitations

As a retrospective study with a limited sample size and a short follow-up period, its results are susceptible to selection bias, recall bias, and confounding factors.There is a need for larger, more rigorously controlled prospective cohort studies to establish stronger evidence on the association between titanium mesh deposition and forearm BMD. In addition the present study was conducted in a single center, which limits the generalizability of our findings to a wider population, and further multicenter studies are needed to validate our results and improve their external validity. Although BMD was assessed in our study, we omitted the trabecular bone score (TBS), which may provide additional insight into the relationship between bone quality and titanium mesh deposition. The ACCF procedure is not performed by a single surgeon, and the degree of intraoperative exposure of the spinal anatomy, degree of resection of bony redundancy, adequacy of decompression, precision of screw placement, and selection of implant material and implantation technique may vary depending upon the surgeon's habits. This variability may lead to differences in outcomes, and future studies should attempt to standardize surgical techniques or account for these differences in their analyses to reduce their impact on outcomes.

Conclusions

Forearm BMD is strongly associated with cervical titanium mesh subsidence. Patients with lower forearm BMD had a significantly increased risk of titanium mesh subsidence after ACCF. Forearm BMD can be used as an effective predictor of titanium mesh subsidence after ACCF, and the CT HU value of the inferior vertebrae can also be used as an important reference parameter for predicting this complication.

Authors' contributions

JZW, KL and YF designed this study. YWG, ZFW and PX were responsible for collecting, analyzing and interpreting the data, and writing the manuscript. JTH and QC identified the case, performed the operation, and made contributions to revising the manuscript for crucial intellectual content. BCD and KL were responsible for revising the manuscript. The author(s) read and approved the final manuscript.

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Data availability

All data analyzed during this study are included within the manuscript. The datasets used and/or analyzed during this study are available from the first author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board at the Affiliated Hospital of North Sichuan Medical College. All methods were performed in accordance with the relevant guidelines and regulations. Each author certifies that all investigations were conducted in accordance with ethical principles. The participant involved in the study gave their informed consent and signed and an informed consent form.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]The Department of Orthopaedic Surgery, the Affiliated Hospital of North Sichuan Medical College, Nanchong, Sichuan Province 637000, China. [2]Department of Orthopedics, Cangxi County People's Hospital, Sichuan 628400, China. [3]The Blood Purification Centre, the Affiliated Hospital of North Sichuan Medical College, Sichuan Province, Nanchong 637000, China.

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