

Association Between Poor Nutritional Status and Increased Risk for Subsequent Vertebral Fracture in Elderly People with Percutaneous Vertebroplasty

Xin-Yue Fang¹, Hao-Wei Xu¹, Hao Chen¹, Shu-Bao Zhang¹, Yu-Yang Yi¹, Xiao-Yong Ge¹, Shan-Jin Wang¹⁻³

¹Department of Spinal Surgery, Shanghai East Hospital, Tongji University School of Medicine, Shanghai, People's Republic of China; ²Institute of Spinal Diseases, Jingtangshan University, Jiangxi, People's Republic of China; ³Department of Orthopedic, Shanghai East Hospital, Ji'An Hospital, Jiangxi, People's Republic of China

Correspondence: Shan-Jin Wang, Tel +86-21-38804518 ext 12025, Fax +86-21-63595958, Email kingspine@163.com

Background: The relationship between a poor nutritional state and the risk of fractures has not been investigated. This study aimed to investigate the ability of the Controlling Nutritional Status (CONUT) and Geriatric Nutritional Risk Index (GNRI) to predict the incidence of subsequent vertebral fracture (SVF) after percutaneous vertebroplasty (PVP).

Methods: A total of 307 women and 138 men over 50 years old who underwent PVP for osteoporotic vertebral compression fracture (OVCF) were included. Blood biochemical indexes, body mass index (BMI), bone mineral density (BMD), physical function, and muscle strength were measured at baseline. Cox regression analysis was used to determine whether nutritional state was an independent predictor for SVF.

Results: During follow-up, 35 (25.4%) men and 85 (27.7%) women suffered SVF. Patients with SVF had lower BMI, serum albumin levels, GNRI scores, grip strength, lumbar BMD, and Short-Physical Performance Battery (SPPB) scores and higher fall rates and CONUT scores ($P < 0.05$). Compared with normal nutrition, mild malnutrition was associated with higher risk for SVF (women: HR 2.37, $p=0.001$, men: HR 2.97, $p=0.021$ by GNRI; women: HR 2.36, $p=0.005$, men: HR 3.62, $p=0.002$ by CONUT) after adjusting for confounding factors. Those with moderate–severe malnutrition also had a higher risk of SVF. Kaplan–Meier analysis showed that poor nutrition state was significantly associated with lower SVF-free survival ($P < 0.05$). The area under curve (AUC) for predicting SVF was 0.65 and 0.73 for the GNRI and 0.67 and 0.66 for the CONUT in men and women, respectively.

Conclusion: GNRI and CONUT are simple and effective tools for predicting SVF in patients undergoing PVP. Health management and nutrition supplement after PVP is a potentially effective prevention strategy against SVF.

Keywords: nutrition status, osteoporotic vertebral fracture, percutaneous vertebroplasty, subsequent vertebral fracture

Introduction

As the population continues to age worldwide, the incidence rates of osteoporotic vertebral compression fracture (OVCF) appear to have been increasing. A cross-sectional study¹ investigating 20,416 participants aged >40 years determined an osteoporosis prevalence rate of 5.0% and 20.6% and a vertebral fracture incidence rate of 10.5% and 9.7% in men and women, respectively. Another study² including 210 postmenopausal women showed that the overall prevalence of vertebral fractures was 26.19%, with 9.52% having multiple vertebral fractures. Recurrent chronic pain at the fracture site and complications caused by long-term bed rest not only bring considerable economic burdens to the society but also significantly reduce quality of life.³

PVP is a minimally invasive spinal surgery pioneered by Deramond and Galibert in 1984.⁴ Given the advantages of minimally invasive surgery, such as short operative time, local anesthesia, and rapidly pain relief,⁵ PVP has become a ubiquitous approach for treating OVCF and can significantly improve the quality of life of patients with OVCF. However, recent reports have indicated an increasing incidence of new vertebral refractures after PVP. Mazzantini et al⁶ investigated 141 patients who had undergone PVP for a 2-year follow-up, finding that the rates of SVF were 44.3% and

22.6% in the glucocorticoid and nonglucocorticoid groups, respectively. Rho et al⁷ followed 147 patients treated with PVP/PKP, finding that 18.4% of patients developed subsequent symptomatic vertebral compression fractures.

Malnutrition is an important risk factor for adverse complications after orthopedic surgery.⁸ The Geriatric Nutritional Risk Index (GNRI) and Controlling Nutritional Status (CONUT) have been used to evaluate a patient's nutritional status since 2005.⁹ These two indicators can well identify malnourished populations and have a good ability for predicting adverse outcomes of some diseases. Yagi et al¹⁰ showed that preoperative CONUT scores could be used to predict postoperative complications, including pneumonia, heart failure, and refracture in patients after hip fracture. Nagai et al¹¹ assessed the nutritional status of 187 conservatively treated OVCF patients using GNRI and confirmed that malnourished patients had reduced activities of daily living scores and increased risk of falling, which had already been recognized as a risk factor for fractures. Moreover, malnourished patients tend to have a lower BMI, and a lower BMI is related to a higher risk of fracture. Johansson et al¹² demonstrated that low BMI was a risk factor for hip and all osteoporotic fracture. Therefore, given that poor nutritional state may potentially increase the risk of fractures, identifying and assessing patient nutritional status may be helpful in establishing treatment strategies and methods for preventing refractures. Currently, no suitable nutritional index can predict the incidence of vertebral fracture after PVP. This study aimed to investigate whether GNRI and CONUT can predict the incidence of SVF after PVP.

Methods

Study Population

This population-based prospective cohort study was approved by the ethics committee of Shanghai East Hospital. All participants agreed to the use of their clinical data for this study and provided their written informed consent. The study protocol complied with the ethical rules for human experimentation stated in the Declaration of Helsinki. According to our inclusion and exclusion criteria, 445 patients (307 women and 138 men) who underwent PVP for single-segment OVCF at our hospital between January 2017 and December 2021 were included. All participants agreed to the use of their clinical data for this study and provided their written informed consent. The inclusion criteria were as follows: (1) preoperative imaging [radiography, computed tomography, magnetic resonance imaging (MRI)] confirming a single-segment acute OVCF (vertebral body height loss >than 15% and bone marrow edema with vertebral collapse); (2) those who underwent a unilateral approach according to the indications of PVP surgery, and were injected with 3 to 5 mL of bone cement; (3) taking calcium and vitamin D supplements and anti-osteoporosis measures (bisphosphonates or teriparatide) after PVP treatments; and (4) age over 50 years. The exclusion criteria were as follows: (1) incomplete preoperative imaging or medical records; (2) pathological fractures caused by cancer, infection, and inflammation or high-energy traumatic fractures; (3) imaging data showing bone cement leakage; (4) presence of metabolic bone diseases other than osteoporosis, including Cushing's disease, hyperthyroidism, hyperparathyroidism, thyroid cysts, or hypothyroidism; and (5) use of glucocorticoids.

Data Collection

Age, sex, weight, height, history of falls, serum albumin, hemoglobin, total lymphocyte count, total cholesterol levels, basic disease, BMI, lumbar BMD (L1–4), handgrip strength, 6-m gait speed, time to complete 5 stands, and SPPB scores were measured at baseline. The GNRI was calculated using the following formula: $GNRI = [1.489 \times Alb(g/L)] + [41.7 \times (body\ weight/ideal\ body\ weight)]$. If body weight was greater than the ideal weight, the body weight/ideal body weight = 1. The Lorentz formula was used to calculate the ideal weight, namely: ideal weight (men) = height – 100 – [(height – 150)/4]; ideal weight (women) = height – 100 – [(height – 150)/2.5]. The GNRI was categorized as severe (<82), moderate (≥82, <92), mild (≥92, <99), and normal (≥99).¹³ CONUT scores were based on the sum of serum albumin (0, 2, 4, 6), total cholesterol levels, and total lymphocyte count (0, 1, 2, 3), which were classified as severe (≥9), moderate (5–8), mild (2–4), and normal (0–1).¹⁴

The region of interest and communication system (ROI) of the picture archiving and communication system program was used to draw the contours of bilateral paraspinal muscle (multifidus and erector spinae, PSM), and measure their cross-sectional area (CSA). Thereafter, these images were analyzed by axial T2-weighted MRI. In an upright posture, the

maximum anatomical CSA of PSM and PS was located at the L4/5 disc levels. Therefore, we measured the CSA of the intervertebral disc and bilateral mean paravertebral muscles by mapping their ROI at the L4/5 disc level. The relative CSA (rCSA: ratio of muscle to disc at the same level) was calculated to eliminate the influence of body size.¹⁵ The method for assessing the degree of fatty infiltration of the PSM was based on Kim et al.¹⁶

Definition of SVF

Follow-up was performed monthly at the outpatient department for the first 3 months after PVP and every 3 months thereafter. MRI was performed a new vertebral fracture was suspected. SVF was defined as the occurrence of vertebral fractures at different positions during follow-up. MRI showed a decrease in height of the nonsurgical vertebrae and T2-weighted imaging showed high attenuation. All patients' SVF were recorded during the follow-up period.

Statistical Analyses

Student's *t*-test was used for normally distributed data, whereas the Mann–Whitney *U*-test was used for non-normally distributed data. Continuous variables were shown as mean \pm standard deviation. Pearson's chi-square test or Fisher's exact test was used to compare categorical variables. Pearson or Spearman correlation analysis was used to explore the correlation between age, BMI, Hb, lumbar BMD (L1–4), handgrip strength, 6-m gait speed, SPPB, CSA of the PSM, fatty infiltration degree, and nutritional indicators (GNRI and CONUT). The accuracy of the GNRI and CONUT for predicting SVF was determined using receiver operating characteristic curve analysis and area under curve quantitative analysis. The survival curve was drawn using the Kaplan–Meier method, and a Log rank test was used to compare the survival time of each group. A Cox proportional hazards model was used to analyze the relationship between the GNRI, CONUT and SVF risk in the models. To control for confounding variables, the model was adjusted for age, history of smoking, diabetes, fracture site, anti-osteoporosis drugs. All statistical analyses were performed using SPSS version 26 (IBM, Corp., Armonk, NY, USA), with $P < 0.05$ indicating statistical significance.

Results

During follow-up, a total of 445 patients (307 women, 138 men) were analyzed. 421(94.6%) of patients had rapid relief from pain after PVP. There was no significant difference between SVF and non SVF group in the percentages of residue symptoms (5% vs 5.5%, $p=0.823$). 426 (95.7%) patients chose bisphosphonates and 19 (4.3%) patients chose teriparatide as the follow-up treatment plan after PVP. Moreover, there was no significant difference in postoperative medication between the SVF group and non-SVF group (bisphosphonates: 96%vs 95%, $p=0.643$). Patient characteristics are shown in [Table 1](#). SVF occurred in 35 (25.4%) men and 85 (27.7%) women. Compared with participants without SVF, those with SVF had lower levels of BMI, serum albumin, lumbar BMD (L1–4), handgrip strength, 6-m gait speed, SPPB, and relative CSA of the PSM but higher incidences of falls and malnutrition ($P < 0.05$). Among the SVF group, only women had a high degree of paraspinal muscle fatty infiltration ($P < 0.05$).

Linear correlation results are shown in [Table 2](#). The GNRI was correlated with BMI ($r = 0.229$, $P = 0.007$ in men; $r = 0.384$, $P < 0.001$ in women), lumbar BMD (L1–4) ($r = 0.332$, $P < 0.001$ in men; $r = 0.320$, $P < 0.001$ in women), handgrip strength ($r = 0.634$, $P < 0.001$ in men; $r = 0.285$, $P < 0.001$ in women), SPPB ($r = 0.426$, $P < 0.001$ in men; $r = 0.232$, $P < 0.001$ in women), and the CSA of the PSM ($r = 0.303$, $P < 0.001$ in men; $r = 0.193$, $P = 0.001$ in women). CONUT scores were correlated with SPPB in both sexes and with BMI, Hb, lumbar BMD (L1–4), handgrip strength, 6-m gait speed, time to complete 5 stands, SPPB, CSA of the PSM, and paraspinal muscle fatty infiltration in women.

According to GNRI and CONUT, mild malnutrition and moderate to severe groups were associated with higher SVF risk ($P < 0.05$ in both men and women) in the unadjusted analysis. After adjusting for age, history of smoking, diabetes, fracture site, and anti-osteoporosis drugs use, the results remained statistically significant ([Table 3](#)). People in the mild and moderate–severe malnutrition groups evaluated by the GNRI and CONUT had a higher incidence of SVF regardless of sex ($P < 0.05$ for Log rank test for both). However, no difference in the cumulative incidence of SVF was observed between patients with mild and moderate–severe malnutrition ($P > 0.05$ for Log rank test for both; [Figure 1](#)).

Table 1 Comparison of Clinical Characteristics Between the Non-Refractures and Refractures

	Male			Female		
	Non-Refractures (n=103)	Refractures (n=35)	P	Non-Refractures (n=222)	Refractures (n=85)	P
Age (Year)	68.25±8.27	69.29±5.35	0.491	69.51±9.75	70.62±6.63	0.332
BMI (kg/m ²)	22.34±1.71	20.29±2.01	<0.001	22.92±2.96	21.47±2.99	<0.001
Diabetes, yes	24(23.3%)	8(22.9%)	0.957	49(22.1%)	20(23.5%)	0.784
Hypertension, yes	35(34.0%)	12(34.3%)	0.974	66(29.7%)	27(31.8%)	0.728
Drinking, yes	19(18.4%)	9(25.7%)	0.356	39(17.6%)	17(20.0%)	0.621
Smoking, yes	28(27.2%)	12(34.3%)	0.424	31(14.0%)	15(17.6%)	0.418
Anti-osteoporosis drugs use, yes	31(30.1%)	9(25.7%)	0.621	54(24.3%)	23(27.1%)	0.621
History of falls, yes	43(41.7%)	24(68.6%)	0.006	90(40.5%)	60(70.6%)	<0.001
Fracture site						
Thoracolumbar	84(81.6%)	24(68.6%)	0.108	173(77.9%)	63(74.1%)	0.479
Lumbar	19(18.4%)	11(31.4%)		49(22.1%)	22(25.9%)	
Serum albumin level (g/dl)	40.70±4.38	37.22±5.72	<0.001	40.18±4.64	36.56±6.47	<0.001
Hemoglobin (g/l)	124.42±18.35	128.69±12.66	0.204	129.55±21.57	124.09±21.39	0.048
Lumbar BMD (L1-4)	-2.52±1.14	-3.18±0.71	0.002	-2.86±1.05	-3.66±0.70	<0.001
Handgrip strength, kg	21.41±4.96	18.26±5.76	0.002	21.71±5.59	18.81±6.01	<0.001
6-m gait speed, m/s	0.93±0.14	0.83±0.12	<0.001	0.89±0.17	0.82±0.18	0.002
Time to complete 5 stands, s	12.53±4.71	17.01±2.96	<0.001	12.62±4.55	14.90±3.69	<0.001
SPPB, score	9.35±1.58	7.63±1.72	<0.001	8.85±1.81	7.94±1.38	<0.001
CSA of the disc (mm ²)	1366.96±204.71	1412.09±215.64	0.268	1367.73±208.30	1382.45±214.71	0.583
CSA of the PSM (mm ²)	2816.78±462.84	2475.57±274.86	<0.001	2614.31±290.24	2511.33±218.65	0.003
Relative CSA of the PSM (mm ²)	2.11±0.48	1.79±0.34	<0.001	1.95±0.35	1.86±0.30	0.026
Paraspinal muscle fatty infiltration degree (%)	34.84±9.76	37.94±10.16	0.111	35.37±12.15	41.4±13.66	<0.001
GNRI						
Normal (≥99)	80(77.7%)	16(45.7%)	<0.001	99(44.6%)	21(24.7%)	<0.001
Mild (≥92, <99)	18(17.5%)	8(22.9%)		100(45.0%)	43(50.6%)	
Moderate-Severe (<92)	5(4.9%)	11(31.4%)		23(10.4%)	21(24.7%)	
COUNT						
Normal (0-1)	71(68.9%)	10(28.6%)	<0.001	94(42.3%)	15(17.6%)	<0.001
Mild (2-4)	28(27.2%)	17(48.6%)		91(41.0%)	40(47.1%)	
Moderate-Severe (≥5)	4(3.9%)	8(22.9%)		37(16.7%)	30(35.3%)	

Abbreviations: BMI, body mass index; BMD, bone mineral density; SPPB, Short-Physical Performance Battery; CSA, cross-sectional area; PSM, paraspinal muscle; GNRI, Geriatric Nutritional Risk Index; COUNT, Controlling Nutritional Status.

There were 45 (32.6%) and 26 (18.8%) patients with mild malnutrition, and 12 (8.7%) and 16 (11.6%) patients with moderate–severe malnutrition among men evaluated via CONUT and GNRI, respectively. The rate of malnutrition was higher among women than men, with 131 (42.7%) and 143 (46.6%) patients having mild malnutrition and 67 (21.8%) and 44 (14.3%) patients having moderate to severe malnutrition as evaluated by CONUT and GNRI, respectively. There were 9 (6.5%) and 37 (12.1%) patients identified as malnourished by the CONUT and GNRI among men and women, respectively (Figure 2). Figure 3 shows the AUC for predicting the risk of SVF in each model. Accordingly, the AUC values among men were 0.669 and 0.650 for the CONUT and GNRI, respectively. No difference in the AUC of CONUT and GNRI was observed among men ($P = 0.806$). Among women, the AUC values were 0.660 and 0.732 for the CONUT and GNRI, respectively, with a significant difference between both indicators ($P = 0.045$).

Table 2 Correlations Between the GNRI, CONUT and the Other Variables

Variables	Male				Female			
	GNRI	P	COUNT	P	GNRI	P	COUNT	P
Age	0.086	0.314	-0.135	0.114	-0.011	0.854	-0.077	0.176
BMI	0.229	0.007	-0.028	0.747	0.384	<0.001	-0.264	<0.001
Hemoglobin	0.016	0.854	-0.068	0.43	0.331	<0.001	-0.341	<0.001
Lumbar BMD (L1-4)	0.332	<0.001	-0.008	0.925	0.320	<0.001	-0.273	<0.001
Handgrip strength	0.634	<0.001	-0.141	0.099	0.285	<0.001	-0.311	<0.001
6-m gait speed	0.268	<0.001	0.077	0.369	0.166	0.004	-0.401	<0.001
Time to complete 5 stands	0.063	0.464	0.004	0.959	-0.239	<0.001	0.398	<0.001
SPPB	0.426	<0.001	-0.237	0.005	0.232	<0.001	-0.368	<0.001
CSA of the disc	0.02	0.813	-0.118	0.166	-0.110	0.055	-0.082	0.151
CSA of the PSM	0.303	<0.001	0.137	0.109	0.193	0.001	-0.126	0.027
Relative CSA of the PSM	0.21	0.013	0.164	0.055	0.185	0.001	-0.125	0.029
Paraspinal muscle fatty infiltration degree (%)	0.153	0.073	-0.157	0.065	-0.424	<0.001	0.394	<0.001

Abbreviations: BMI, body mass index; BMD, bone mineral density; SPPB, Short-Physical Performance Battery; CSA, cross-sectional area; PSM, paraspinal muscle; GNRI, Geriatric Nutritional Risk Index; COUNT, Controlling Nutritional Status.

Table 3 Association Between Nutrition Status and Subsequent Vertebral Fracture Risk Stratified by Sex: Multivariable Cox Regression Analysis

	Male				Female			
	Crude Model	P	Adjusted Model	P	Crude Model	P	Adjusted Model	P
GNRI								
Normal (≥ 99)	1	-	1	-	1	-	1	-
Mild (≥ 92 , < 99)	2.43(1.03–5.72)	0.042	2.97(1.18–7.46)	0.021	2.33(1.38–3.94)	0.002	2.37(1.40–4.02)	0.001
Moderate-Severe (< 92)	5.17(2.40–11.18)	<0.001	5.31(2.20–12.78)	<0.001	3.52(1.92–6.47)	<0.001	3.50(1.86–6.56)	<0.001
CONUT								
Normal (0–1)	1	-	1	-	1	-	1	-
Mild (2–4)	3.45(1.58–7.54)	0.002	3.62(1.60–8.19)	0.002	2.39(1.32–4.33)	0.004	2.36(1.30–4.28)	0.005
Moderate-Severe (≥ 5)	6.04(2.38–15.32)	<0.001	6.78(2.44–18.82)	<0.001	3.45(1.87–6.47)	<0.001	3.39(1.79–6.43)	<0.001

Notes: Adjusted factors: age, history of smoking, diabetes, fracture site, anti-osteoporosis drugs use. Values are hazard ratio (95% confidence intervals).

Abbreviations: GNRI, Geriatric Nutritional Risk Index; COUNT, Controlling Nutritional Status.

Discussion

Recently, there has been increasing evidence to demonstrate the association between poor nutrition state and the risk of fractures among both sexes. Our study found that 35/138 (25.4%) men and 85/307 (27.7%) women had suffered SVF during follow-up. Additionally, poor nutritional status evaluated via the GNRI and CONUT have been identified as risk factor for the occurrence of SVF after PVP. Numerous authors have reported similar findings. Notably, Di Monaco et al¹⁷ also found that among 817 patients with hip fracture, low GNRI score (< 82) increased the risk of occurrence of concurrent upper limb fractures. Moreover, a post-hoc analysis of 1342 patients undergoing hemodialysis followed up for 5 years revealed that a low GNRI is a risk factor for bone fractures.¹⁸

We noted that patients with SVF had lower levels of BMI and that a poor nutritional state was correlated with low BMI. Several studies have indicated a relationship between BMI and new OVCF after PVP. In a meta-analysis¹⁹ including 559 new VCFs cases and 1736 controls followed up for at least 12 months, low BMI, low BMD, and intervertebral cement leakage have been identified as risk factors for new vertebral fractures after PVP. To eliminate surgery as a confounding factor, we excluded patients with bone cement leakage. Another population-based cohort study involving 5549 men and 5428 women reported that a decrease in BMI was significantly associated with an increased risk of fractures among nonsmokers.²⁰ Moreover, a study among 54,934 Nurses' Health Study participants²¹ revealed that low BMI was associated with higher vertebral fracture risk.

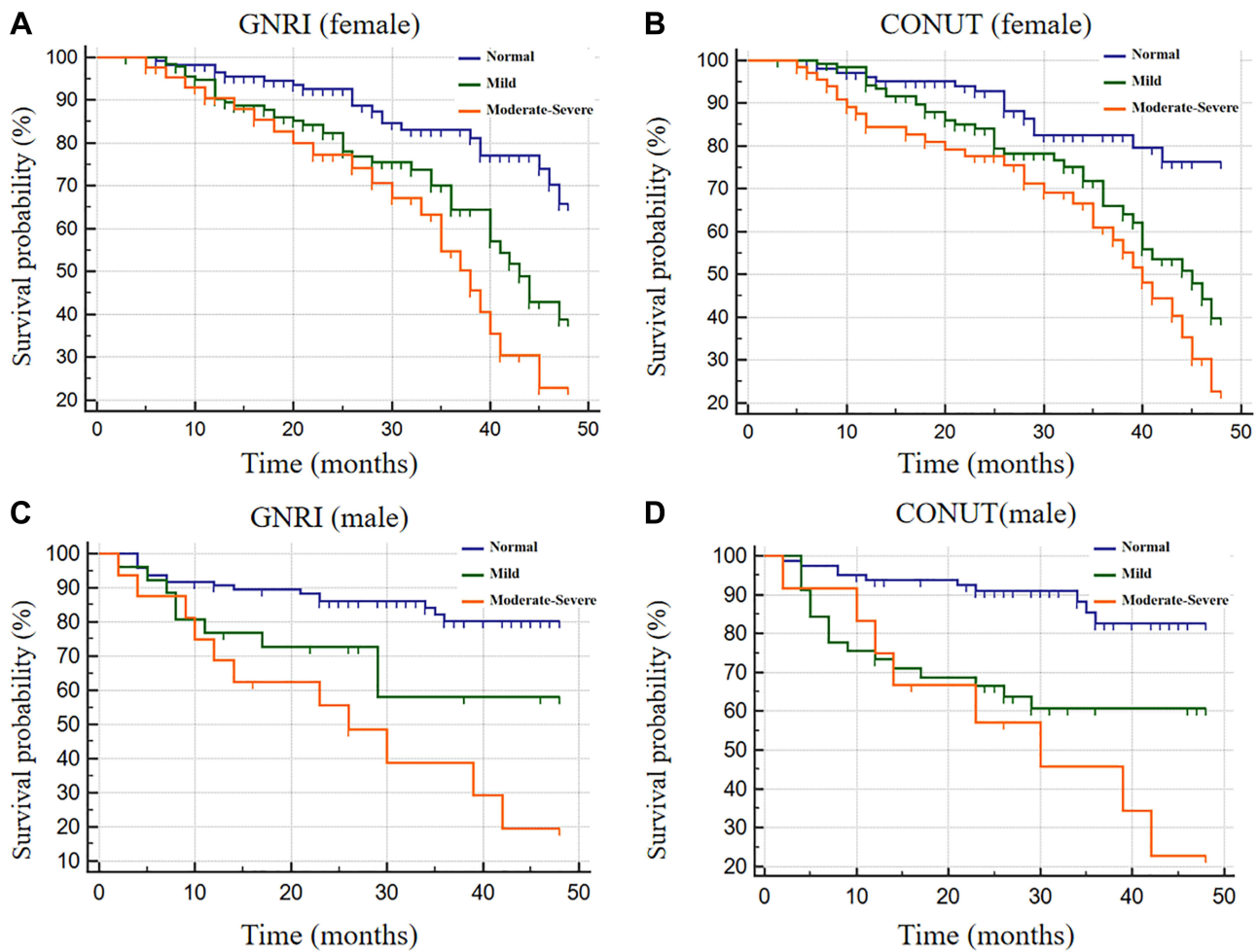


Figure 1 Cumulative incidence (95% confidence interval) of subsequent vertebral fracture, stratified based on sex. **(A)** Kaplan–Meier curves of the groups categorized based on GNRI in female. **(B)** Kaplan–Meier curves of the groups categorized based on CONUT in female. **(C)** Kaplan–Meier curves of the groups categorized based on GNRI in male. **(D)** Kaplan–Meier curves of the groups categorized based on CONUT in male.

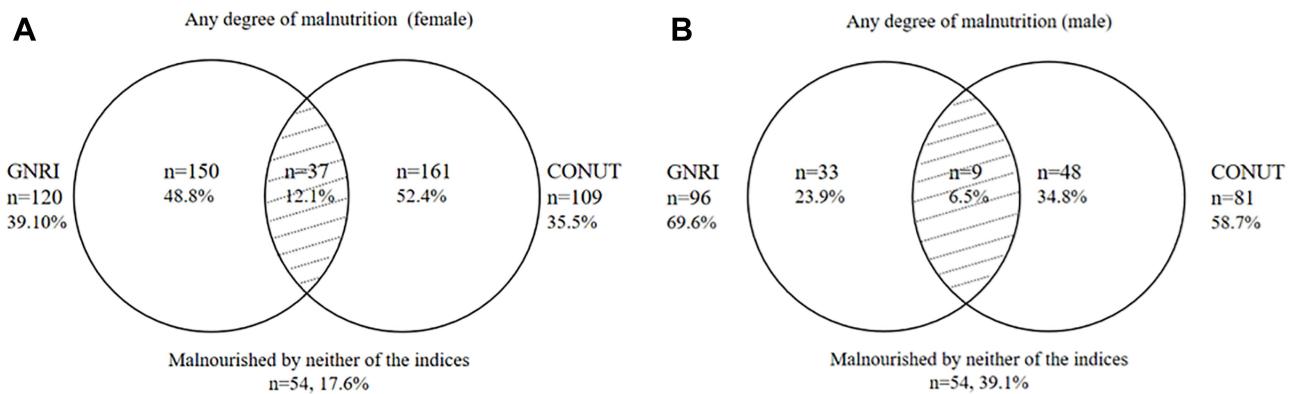


Figure 2 Prevalence rate of malnutrition among patients according to the GNRI and CONUT. The numbers of patients categorized as malnourished by both nutritional indices were indicated using an overlapping shadow, whereas the zone outside the circle indicates the number of patients not categorized as malnourished by each score. **(A)** Any degree of malnutrition in female. **(B)** Any degree of malnutrition in male.

Patients with high CONUT scores often had low BMI,^{22,23} with a negative correlation found between the CONUT and GNRI scores.²⁴ Evidence has shown that BMI was a useful indicator of malnutrition in older adults.²⁵ Therefore, malnourished patients as determined by GNRI and CONUT are more likely to suffer SVF after PVP surgery.

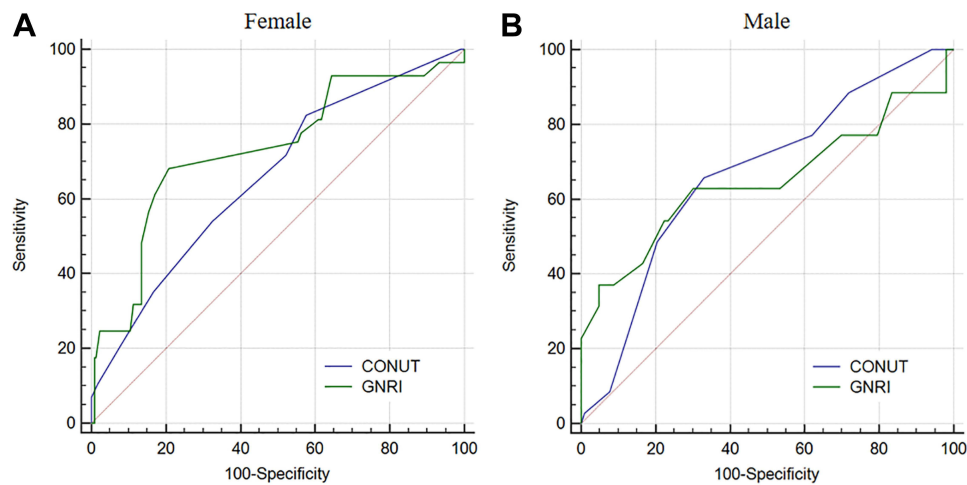


Figure 3 Receiver operator characteristic curve for GNRI and CONUT to predicting SVF. **(A)** The AUC was 0.73 for the GNRI and 0.66 for the CONUT in female. **(B)** The AUC was 0.65 for the GNRI and 0.67 for the CONUT in male.

Our results showed that low GNRI and high CONUT scores were associated with higher occurrence rates of falls. A study²⁶ of 6040 French elderly community-dwellers followed up for a mean of 12 years found that malnourished participants had a higher risk of falling and fractures. Takako et al¹¹ investigated 187 patients with OVCF treated conservatively and followed up for at least 6 months, finding that low GNRI scores decreased the acquisition of activities of daily living and increased the risk for falls. Moreover, a study²⁷ among 2971 older Dutch home care clients demonstrated that people who suffered from falls were more likely to be malnourished than the general population and that malnutrition could predict the occurrence of falls. We hypothesize that patients with malnutrition had reduced body weight and skeletal muscle mass because of increased catabolism of muscle and fat, resulting in reduced balance and walking ability and leading to increased risk of falls.

Patients in the SVF group had weaker handgrip strength, smaller CSA of the PSM, lower GNRI scores, and higher CONUT scores. PSM strength and mass are crucial for maintaining spinal sagittal balance and global alignment. Ikchan et al²⁸ found that fatty degeneration of PSM enhanced the instability of the lumbar vertebra, which influences the progression of spinal column collapse in patients with OVCF. Tokeshi et al²⁹ also reported that decreased leg muscle mass was a risk factor for OVCFs. Furthermore, Zhang et al³⁰ demonstrated that SVF was more likely to occur in women and men with a handgrip strength <18 and <28 kg, respectively. Moreover, nutritional status was closely associated with muscle mass and strength. A study among 234 elderly (≥ 60 years old) outpatients with type 2 diabetes mellitus showed that the GNRI scores were positively correlated with the skeletal muscle index and handgrip strength.³¹ Tanaka et al³² also demonstrated that handgrip strength was correlated with GNRI and CONUT scores and that the five-times sit-to-stand test and SPPB were correlated with CONUT score. Inose et al³³ investigated 225 patients with acute OVCF, followed up for 1 year, and found that the use of rigid braces can reduce the risk of SVF by 67%. After PVP surgery, all patients were asked to use rigid braces to reduce the anterior translation of the upper spine and prevent refracture. Given that the PSM acts as a powerful brace for the waist, maintaining a healthy nutritional status may help the PSM prevent excessive forward flexion and decrease the load on the anterior column and lumbar vertebra, thereby potentially decreasing the risk of SVF.

Our study showed a positive relationship between the GNRI and BMD in both sexes. Several studies have revealed that the nutritional status was associated with BMD. One review³⁴ indicated that BMD, bone strength, bone trabecula, and cortical microstructure were positively correlated with total protein intake. López-Larramona et al³⁵ reported that patients with malnutrition assessed using CONUT had lower BMD and vitamin D levels and higher risk of fracture. Qing et al³⁶ recruited 1130 older participants, showing that a higher GNRI scores were positively correlated with BMD at different anatomical sites, in both sexes but especially in women. Moreover, Wang et al³⁷ enrolled 417 participants with type 2 diabetes mellitus, reported that GNRI was positively correlated with total lumbar and hip BMD and that GNRI

was a more powerful predictor for osteoporosis than albumin or BMI. Therefore, patients with good nutritional status have higher BMD, which is beneficial for preventing the occurrence of SVF.

Patients with bone fractures are more likely to be malnourished. On the one hand, fracture and consequent pain and discomfort maybe affect patients' appetite, thereby reducing the intake of protein. On the other hand, the loss of wound protein leads to negative nitrogen balance and increased protein decomposition, further leading to hypoalbuminemia. A study among 2245 Kuopio Is-chemic Heart Disease study participants³⁸ showed that low serum albumin was associated with an increased risk for future hip, humeral, and wrist fractures. As such, long-term malnutrition and braking on the bed in fracture patients can lead to weight loss, decreased muscle strength and mass, decreased BMD, and increased fall risk. Poor nutritional status may contribute to SVF, and vertebral fracture also aggravates malnutrition. They are in a reverse correlation. Patients' nutritional status should also be considered after PVP, with long-term nutritional supplementation perhaps being a good strategy for the prevention of SVF.

Our study has several limitations worth noting. First, this was a retrospective study conducted at a single institution on a limited patient population. Second, CONUT scores may be influenced by dehydration, inflammation, and immune and nutritional status. For instance, lymphocyte counts may be disproportionately low when associated with acute bacteremia or certain hematologic diseases. Hence, a higher CONUT score may not definitively represent malnutrition. Third, this observational study did not demonstrate any nutritional interventions that might improve outcomes in the patient population after PVP. Despite the lack of ideal AUC scores of GNRI and CONUT for SVF, there is a clear correlation between SVF and poor nutritional status in our study. Finally, only vertebral fractures were recorded in this study, and no further statistical analysis was made on fractures in other sites, given that the main aim of this study was to explore the influence of nutritional status on SVF after PVP. More prospective clinical studies are needed to confirm the relationship between nutritional status and fractures at other sites.

Conclusion

Our study showed that the patients with SVF had lower GNRI scores and higher CONUT scores. Poor nutritional state was associated with lower levels of BMI, grip strength, lumbar BMD, and physical function, and higher rates of falls. The risk of SVF was significantly higher in patients with malnutrition. As such, the GNRI and CONUT can be useful screening tools to identify poor nutritional status and predict the occurrence of SVF after PVP. Maintaining a healthy nutritional status after PVP may be an effective prevention strategy against SVF.

Abbreviations

CONUT, Controlling Nutritional Status; GNRI, Geriatric Nutritional Risk Index; SVF, subsequent vertebral fracture; PVP, percutaneous vertebroplasty; OVCF, osteoporotic vertebral compression fracture; BMI, body mass index; BMD, bone mineral density; SPPB, Short-Physical Performance Battery; AUC, area under curve; MRI, magnetic resonance imaging; ROI, region of interest; PSM, paraspinal muscle; CSA, cross-sectional area.

Author Contributions

All authors contributed to data analysis, drafting or revising the article, have agreed on the journal to which the article will be submitted, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

Funding

This work was funded by the Training Program for Academic and Technical Leaders of Major Disciplines in Jiangxi Province-Leading Talents Project (20213BCJ22011), Key Projects of Natural Science Foundation of Jiangxi Province (20212ACB206032), Aging and Health of Women and Children Research Project of Shanghai Municipal Health Commission (2020YJZX0116) and the Science and Technology project of Jiangxi Provincial Health Commission (202140997).

Disclosure

Xin-Yue Fang and Hao-Wei Xu are co-first authors for this study. Xin-Yue Fang, Hao-Wei Xu, Hao Chen, Shu-Bao Zhang, Yu-Yang Yi, Xiao-Yong Ge and Shan-Jin Wang declare that they have no conflicts of interest in this work.

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