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ORIGINAL RESEARCH

Prealbumin Adjusted Prognostic Nutritional Index May Predict the Postoperative Survival and Free Walking Abilities of Patients with Hip Fractures: A Multi-Center Follow-Up Study

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Background: This multi-center study aims to develop and validate the Prealbumin-adjusted Prognostic Nutritional Index (PAPNI), hypothesizing that it would enhance prognostic prediction for hip fracture patients compared to traditional indices.

Methods: Data from 771 patients (Cohort 1) and 673 patients (Cohort 2) were retrospectively analyzed. The PAPNI was formulated by substituting albumin with prealbumin in the Prognostic Nutritional Index (PNI) formula, with its weight optimized using receiver operating characteristic (ROC) curves. All individuals were followed up for 1 year. The relationships between PAPNI and outcomes were explored.

Results: In both cohorts, PAPNI demonstrated superior predictive accuracy for 1-year mortality and free walking ability compared to PNI, prealbumin, and lymphocyte count alone. Patients with low PAPNI exhibited significantly higher mortality rates and lower free walking rates. Multivariate analyses confirmed PAPNI as an independent predictor for outcomes of hip fracture.

Conclusion: PAPNI, incorporating prealbumin, offers a more accurate and convenient method for predicting postoperative survival and functional recovery of hip fractures, providing a basis for early nutritional intervention.

Keywords: PAPNI, Hip fracture, prealbumin, outcomes

Introduction

Aging societies are becoming increasingly prevalent worldwide, and hip fractures, among the most lethal fractures in older populations, have garnered significant attention from both researchers and clinicians globally.[1] In 2019, hip fractures accounted for approximately 14.2 million incident cases and 2.9 million years lived with disability worldwide.[2] Hip fracture patients have a high mortality rate, with the one-year post-surgery mortality rate reaching up to 14.77%.[3] The primary causes of mortality following hip fractures, even after surgery, are not the fractures themselves, but complications arising from the loss of mobility, such as hypostatic pneumonia, bedsores, and so on.[4,5] The prolonged bed rest, the presence of multiple organ dysfunction, the exacerbation of comorbid conditions following fractures, and poor nutritional status may all have significant effects on the occurrence of these complications.[6,7]

Therefore, accurately assessing the functional status of patients is crucial. Nutritional status has long been recognized as a significant factor that can influence the outcomes of various surgical procedures and medical conditions.[8] Previous studies have indicated the prognostic roles of nutritional status in hip fractures.[9] Malnutrition holds dual significance in the context of hip fractures. On the one hand, it serves as a risk factor for the occurrence of hip fractures. On the other hand, among patients who have sustained a hip fracture, malnutrition diminishes their capacity to regain the functional abilities they had before the fracture.[10] Research indicates that older individuals suffering from malnutrition typically

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exhibit a poorer functional status before the fracture event and often only achieve a partial recovery of their pre-fracture level of independence in performing activities of daily living following a hip fracture.[11] In contrast, older individuals with satisfactory nutrition are more likely to experience an improvement in their functional status by the time of hospital discharge after a hip fracture.[12] Moreover, malnutrition is more prevalent in geriatric patients who have a higher comorbidity burden. These conditions also act as risk factors for complications that may arise following hip fracture surgery, which may cause poor outcomes of hip fracture.[13]

Numerous tools are available for nutritional assessment, including Prognostic Nutritional Index (PNI), Mini Nutritional Assessment Short-Form (MNA-SF), and so on.[9,10,14,15] However, these tools often have limitations in specific diseases or patient conditions. Previous research reported the predictive abilities of prealbumin (PAB) in hip fracture patients, which was confirmed in recent studies.[9] Moreover, although PNI has less predictive power than prealbumin, its prognostic values in hip fractures were still reported in some studies.[16] Given PAB's short half-life, it can better reflect the body's condition following a fracture. We hypothesized that replacing albumin in the PNI formula with prealbumin and selecting an appropriate weight would enhance the prediction of hip fracture prognosis. In this study, we expanded the application of PAB as a predictive indicator by incorporating it into the traditional PNI index to form a novel nutritional assessment index, the Prealbumin-adjusted Prognostic Nutritional Index (PAPNI). Previous research in this field has predominantly been constrained by single-center designs and limited sample sizes. In this study, we also conducted validation using cohorts from Shanghai in eastern China and Nanyang in central China. We aim to construct a new nutritional index that can more accurately and conveniently predict hip fractures, provide early assessment of nutritional status in these patients, offer evidence for early nutritional intervention, and ultimately improve patient outcomes.

Material and Methods

Populations

The current study adopts a multi-center retrospective design, encompassing two distinct cohorts. Cohort 1 originates from the Department of Traumatology of Shanghai East Hospital (December 2017 and May 2022), while Cohort 2 is derived from the Emergency Trauma Center of Nanyang Second People's Hospital (January 2017 and January 2022). The current multi-center follow-up study expands on Cohort 1 by incorporating an additional patient cohort (Cohort 2), which was coordinated and communicated by Zhibang Zhao. Cohort 2 was derived from a prior study that investigated the predictive value of anthropometric measurements in geriatric hip fracture patients.[17] We used Cohort 1 as a validation set to develop the PAPNI. Given that baseline data and outcomes were available for Cohort 2, we incorporated it as an additional validation set to assess the PAPNI's predictive power for hip fracture outcomes.

We declare that these studies were conducted in accordance with the Declaration of Helsinki and obtained approval from the Ethics Committee of East Hospital and the Ethics Committee of Nanyang Second People's Hospital. We have ensured the protection of patient privacy in compliance with the principles of the Declaration of Helsinki and relevant regulations on patient confidentiality. Written informed consent was obtained from all participants upon admission to the hospital, which included permission to access medical records (such as general information, laboratory tests, etc)., outcome data, and consent for publication.

To ensure the consistency of the two cohorts, we established identical inclusion and exclusion criteria. Individuals meeting these criteria in each cohort were ultimately included. The inclusion criteria were: a, underwent surgery for hip fracture; b, age ≥ 50 years; c, had complete data. The exclusion criteria were: a, high-energy fractures; b, pathological fractures; c, suffered from severe liver disease; d, suffered from severe renal insufficiency; e, lost to follow-up. The detailed number of excluded individuals is summarized in Figure 1.

Data Collection

In this study, we gathered and summarized the baseline characteristics of participants, which included age, sex, electrocardiogram assessments, chest radiographs, and various blood tests, and so on. All laboratory parameters were based on the first blood draw obtained within 24 h of admission to ensure consistency, and PNI and PAPNI were

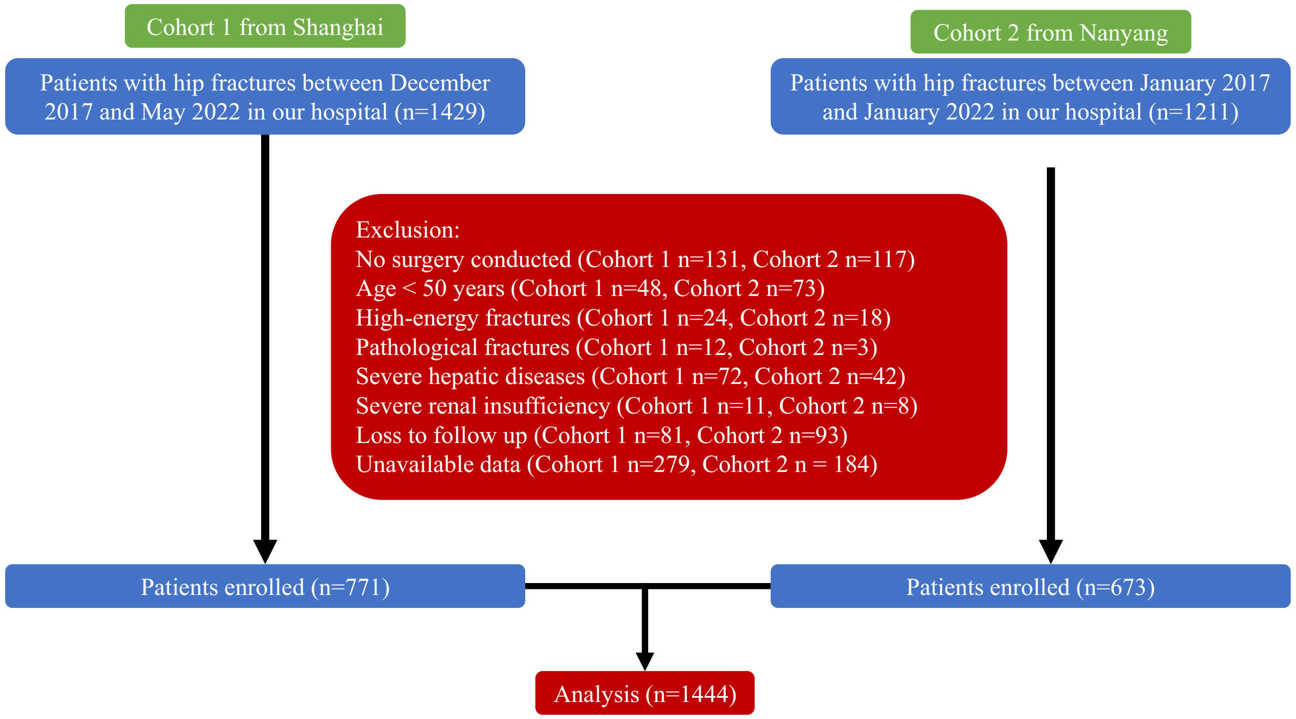

Figure 1 Overall design of our study.

calculated from these values. In this study, the electrocardiogram and chest radiograph results were deemed “abnormal” only when they had a clinical impact on the management of hip fracture. We also documented patients’ comorbidity statuses and evaluated the burden of comorbidities using the Charlson Comorbidity Index (CCI) as a means of assessing.[18]

Patients were followed up for one year post-surgery, and their outcomes were collected. The primary outcomes assessed were survival status and free walking ability at 3 months, 6 months, and 1 year. Free walking ability was defined as the capacity to perform basic life activities independently. Survival time was calculated from the date of surgery to the date of death from any cause. Patients still alive at the last follow-up were treated as censored data in the analysis.

Nutrition Index

The PNI is calculated using the following formula:[16]

$$\text{PNI} = \text{ALB (g/L)} + 5 \times \text{lymphocyte count } (\times 10^9/\text{L})$$

In this study, PNI was converted into binary variables based on the risk cutoff point of 45.

We developed the PAPNI by substituting ALB with PAB in the formula of PNI. Given that the range of PAB is higher than that of ALB, we attempted to adjust its weight to find a suitable threshold. Based on the formula PNI = ALB (g/L) + 5 × LYM ($\times 10^9$/L), we fixed the coefficient of LYM. Then, using the one-year mortality rate of Cohort 1 as the main outcome and the PAPNI with different weights (w) of PAB as the predictive indicator, we constructed receiver operating characteristic (ROC) curves, with Area Under Curve (AUC) as the main evaluation index. Initially, through a linear approach with the weight resolution set at 0.005 and the range from 0.01 to 1, we roughly determined the range of weights (Figure 2A):

$$\text{PAPNI} = w \times \text{PAB (mg/L)} + 5 \times \text{LYM}$$

After identifying the interval with the highest ROC value, we further refined the weight through a new curve method, setting the weight resolution at 0.1 and the range from 1.1 to 20, specifically defining the weight as (Figure 2B):

$$\text{PAPNI} = \text{PAB (mg/L)}/k + 5 \times \text{LYM}$$

Finally, weight was determined to be 12.8, resulting in the PAPNI formula:

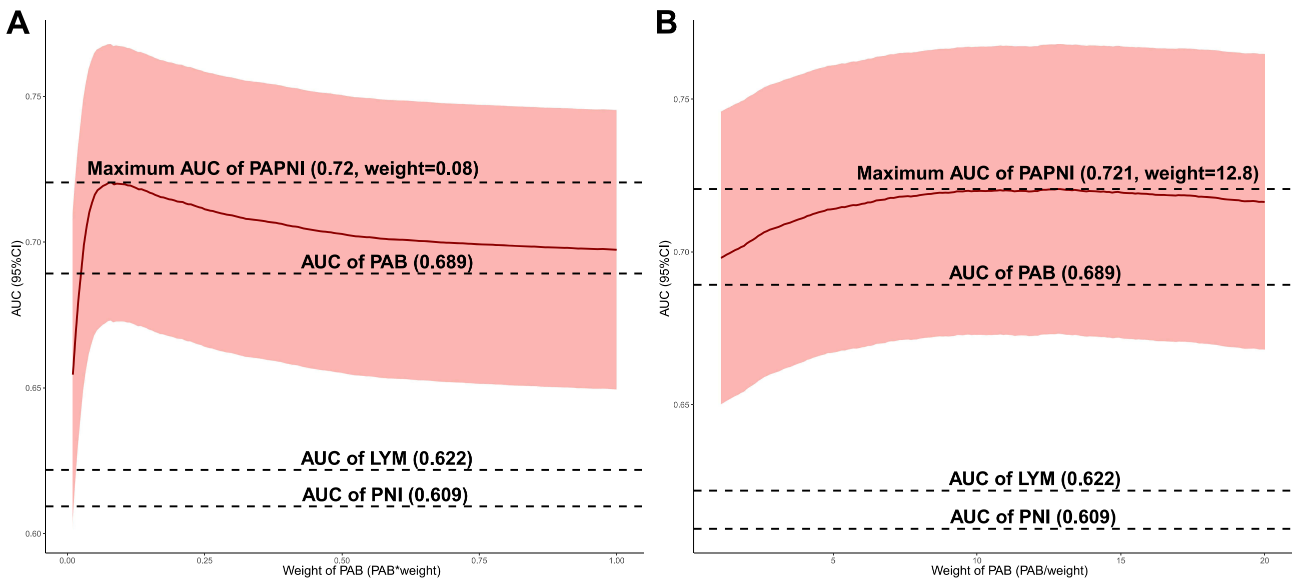

Figure 2 Selection of the weight of PAB in PAPNI. (**A**) using PAB × weight; (**B**) using PAB / weight.

$$\text{PAPNI} = \text{PAB}/12.8 + 5\times\text{LYM}$$

Statistical Analyses

In this study, continuous variables were presented as mean ± standard deviation and analyzed using Independent Student's T-tests for normally distributed data; non-normally distributed data were expressed as median (interquartile range) and assessed via Wilcoxon rank-sum tests. Categorical variables were described as counts (percentages) and analyzed using Chi-squared tests or Fisher's exact test. ROC curve analysis was performed to evaluate the prognostic ability of the index and to identify the optimal cutoff point of PAPNI. Univariate Cox models were then constructed to evaluate the predictive value of PAPNI, and variables that were significant in the univariate models were included in the multivariate models. Logistic regression analyses were also conducted to determine the predictive value for walking ability at 1 year, with univariate and multivariate models established similarly to the Cox models. The sample size calculation was based on the following assumptions derived from previous studies: a 1-year mortality rate of 20% after hip fracture, PAPNI comprising two predictors (PAB and LYM), an anticipated ROC curve AUC of 0.75 with a 95% confidence interval width ≤ 0.10, a 15% loss to follow-up, and 15% multicenter variability. Using the method proposed by Riley et al, the required minimum sample size for each center was estimated to exceed 300 patients.[19] All statistical analyses were conducted using R software version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria), with a significance level of $P < 0.05$ set for rejecting the null hypothesis.

Results

General Information

Finally, a total of 771 participants in Cohort 1 and 673 participants in Cohort 2 were included (Figure 1). 122 deaths were observed in Cohort 1 and 114 deaths in Cohort 2. The baseline data of both cohorts were provided in Table 1. Cohort 1 exhibited a median age of 75 years, with 67.53% of participants being female and a median BMI of 22.58 kg/m^2. Cohort 2 had a median age of 73 years, 66.86% female participants, and a median BMI of 21.75 kg/m^2. Significant differences were found between the two cohorts in age ($p < 0.001$), BMI ($p < 0.001$), smoking history ($p = 0.008$), alcoholism history ($p = 0.023$), surgical procedure ($p < 0.001$), hypertension ($p = 0.029$), time from injury to surgery ($p < 0.001$), GLU ($p = 0.002$), and PAB ($p = 0.031$).

Table 1 Baseline Characteristics of Cohorts 1 and 2 Included in Our Study

Variables	All Individuals (n = 1444)	Cohort 1 (n = 771)	Cohort 2 (n = 673)	p value
Sex (female)	970 (67.22%)	520 (67.53%)	450 (66.86%)	0.788
Age (years)	74.00 [65.00, 83.00]	75.00 [67.00, 84.00]	73.00 [64.00, 81.00]	<0.001
BMI (kg/m^2)	22.22 [19.49, 25.03]	22.58 [20.52, 24.97]	21.75 [18.16, 25.42]	<0.001
Fractures history (yes)	221 (15.30%)	124 (16.08%)	97 (14.41%)	0.379
Smoking history (yes)	130 (9.00%)	55 (7.13%)	75 (11.14%)	0.008
Alcoholism history (yes)	59 (4.09%)	23 (2.98%)	36 (5.35%)	0.023
Location of fracture (femoral neck)	722 (50.00%)	381 (49.42%)	341 (50.67%)	0.635
Surgical procedures (arthroplasty)	584 (40.44%)	273 (35.41%)	311 (46.21%)	0
Anesthesia (spinal)	7 (0.48%)	3 (0.39%)	4 (0.59%)	0.857
CCI score (>4)	340 (23.55%)	172 (22.31%)	168 (24.96%)	0.236
Electrocardiogram (abnormal)	813 (56.30%)	425 (55.12%)	388 (57.65%)	0.334
Chest radiograph (abnormal)	680 (47.09%)	346 (44.88%)	334 (49.63%)	0.071
Hypertension (yes)	784 (54.29%)	398 (51.62%)	386 (57.36%)	0.029
Polytrauma (yes)	193 (13.37%)	95 (12.32%)	98 (14.56%)	0.212
Time from injury to surgery (Days)	5.00 [4.00, 5.00]	4.00 [3.00, 6.00]	5.00 [5.00, 5.00]	<0.001
ALB (g/L)	38.00 [33.15, 42.00]	38.00 [35.00, 41.00]	37.50 [30.35, 45.07]	0.333
GLU (mmol/L)	6.04 [5.21, 7.28]	6.01 [5.34, 7.47]	6.11 [4.96, 7.20]	0.002
PAB (mg/L)	178.50 [135.00, 214.00]	180.00 [147.00, 210.50]	174.00 [114.00, 221.00]	0.031
LYM (10^9/L)	1.22 [0.87, 1.61]	1.19 [0.91, 1.56]	1.24 [0.82, 1.67]	0.587
PNI (scores)	44.20 [39.50, 49.00]	44.30 [40.99, 47.72]	43.96 [36.56, 52.04]	0.508

Abbreviations: BMI, body mass index; CCI, Charlson comorbidity index; ALB, albumin; GLU, blood glucose; PAB, prealbumin; LYM, lymphocyte count; PNI, Prognostic Nutritional Index.

Selection of the Weight of PAB in PAPNI

To identify the optimal PAB weight in PAPNI, we first explored weights (w) between 0.01 and 1.00 (step 0.005) in the linear form PAPNI = w × PAB + 5 × LYM, using the AUC of PAPNI for predicting 1-year mortality in Cohort 1 via ROC curves as a variable to plot a curve (Figure 2A). The AUC first increased and then decreased as the weight rose from 0 to 1, peaking at a weight of 0.08. The summary of the AUC for each weight was summarized in Supplementary Table 1. Because this peak was broad, to pinpoint the exact optimal weight, we generated additional curves using division-based methods (Figure 2B and Supplementary Table 2). Briefly, we re-parameterized the formula as PAPNI = PAB/k + 5 × LYM and re-scanned k from 1.1 to 20.0 (step 0.1). The resulting AUC-k curve was parabolic with a sharp maximum at k = 12.8, yielding the final coefficient 1/12.8 ≈ 0.078, numerically consistent with the first-stage optimum but providing finer resolution and better clinical interpretability. Consequently, the PAPNI formula was determined as: PAPNI = PAB/12.8 + 5×LYM.

Relationship Between PAPNI and Outcomes of Hip Fracture

The weights of PAPNI were determined based on Cohort 1 data. Subsequently, we assessed the relationship between PAPNI and outcomes. As shown in Figure 3A, PAPNI demonstrated superior predictive accuracy for one-year mortality compared to the other three indicators in Cohort 1 (AUROC: 0.721, 95% CI: 0.673–0.768). Figure 3B further confirms that PAPNI maintained the highest predictive performance in Cohort 2 (AUROC: 0.741, 95% CI: 0.698–0.785), despite being derived from Cohort 1 and the presence of baseline differences between the two cohorts. Moreover, PAPNI exhibited high predictive capacity for one-year walking ability (Cohort 1: AUROC: 0.634, 95% CI: 0.593–0.676; Cohort 2: AUROC: 0.680, 95% CI: 0.635–0.724) in both cohorts (Figures 3C and D).

Based on the ROC curve in Figure 3A and the Youden index, the optimal cutoff value for PAPNI was determined. Patients were categorized into the low PAPNI group (PAPNI ≤ 19) or the normal group. Table 2 outlines the differences in mortality and independent walking rates between these groups at various time points. In both cohorts, the low PAPNI group showed significantly higher mortality rates at 3, 6, and 12 months, along with lower independent walking rates. Kaplan-Meier survival curves validated these findings (Figure 4). In Cohort 1, there were significant differences in

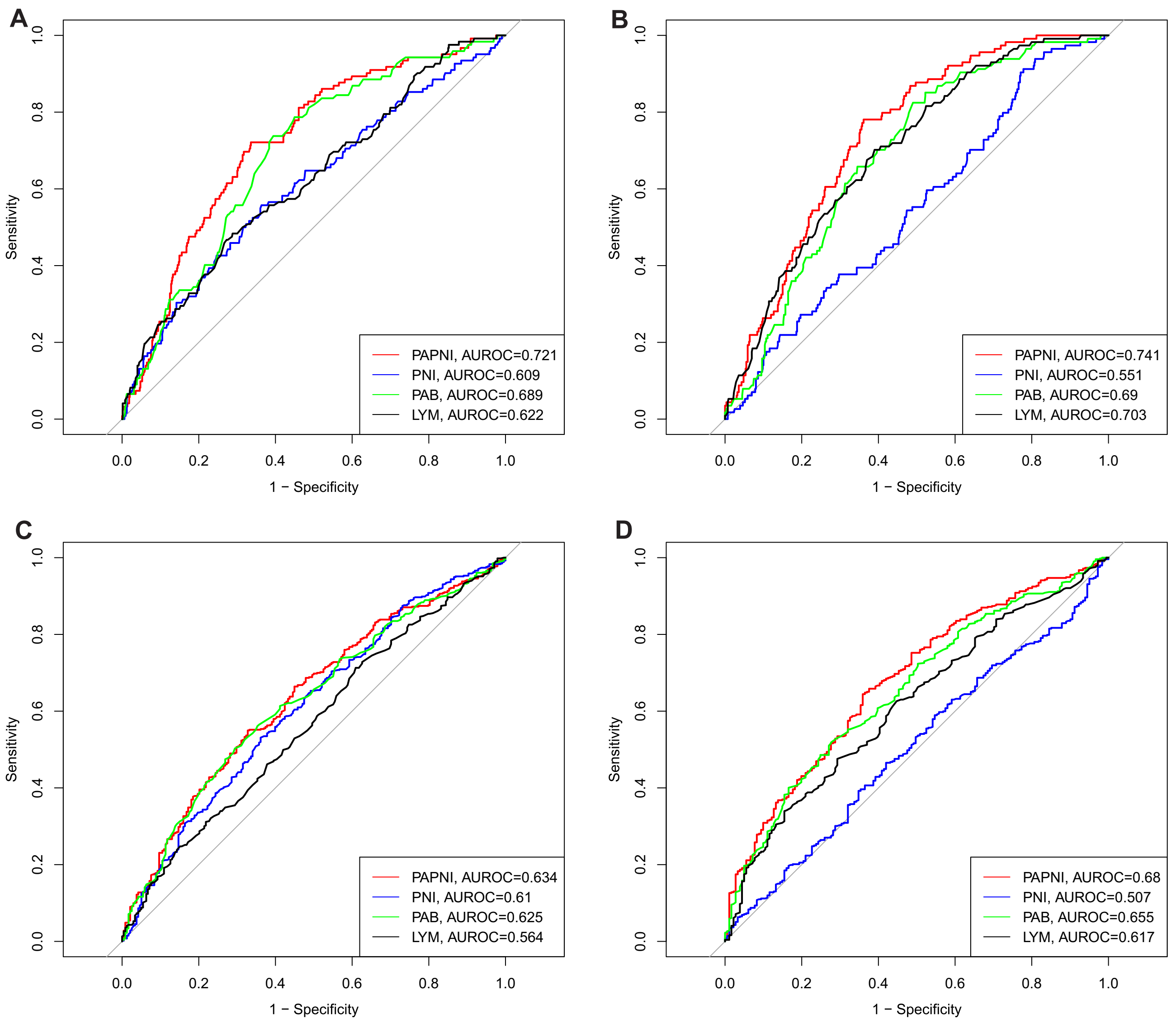

Figure 3 ROC curves of PAPNI, PNI, PAB, and LYM for prognosticating the survival and free walking ability at 1 year in Cohort 1 and Cohort 2. (**A**) For 1-year survival of Cohort 1; (**B**) For 1-year survival of Cohort 2; (**C**) For 1-year free walking ability of Cohort 1; (**D**) For 1-year free walking ability of Cohort 2.

survival probabilities between the low and normal PAPNI groups (Log-rank $p < 0.001$), as well as between the low and normal PNI groups (Log-rank $p = 0.016$). However, in Cohort 2, survival probabilities differed significantly only between the low and normal PAPNI groups (Log-rank $p < 0.001$), with no significant difference observed between the low and normal PNI groups (Log-rank $p = 0.230$).

Prognostic Values of PAPNI

To clarify the prognostic value of PAPNI and reduce confounding biases, we constructed multivariable models. Initially, univariate Cox models were used to select variables significantly associated with mortality in both cohorts, which were then included in multivariable Cox models. The results of univariate Cox models are summarized in Supplementary Table 3. In Cohort 1, the multivariable Cox model included location of fracture, age, chest radiograph, hypertension, and CCI, and in Cohort 2, it included age. Both continuous and dichotomized PAPNI and PNI were incorporated into these models to evaluate their prognostic value for one-year mortality, as shown in Table 3.

In Cohort 1, both PAPNI and PNI could predict one-year mortality in the univariate model. However, after covariate adjustment, PNI's predictive significance disappeared, whereas PAPNI retained its significance. In Cohort 2, PNI was

Table 2 Comparison of Outcomes of Individuals with Normal PAPNI and Low PAPNI in Cohorts 1 and 2

Cohort 1				
Outcomes	**All individuals (n = 771)**	**Normal PAPNI (n = 473)**	**Low PAPNI (n = 298)**	**p value**
3-month mortality	28 (3.63%)	9 (1.90%)	19 (6.38%)	< 0.001
6-month mortality	45 (5.84%)	16 (3.38%)	29 (9.73%)	< 0.001
1-year mortality	122 (15.82%)	37 (7.82%)	85 (28.52%)	< 0.001
3-month free walking ability	180 (23.35%)	131 (27.70%)	49 (16.44%)	< 0.001
6-month free walking ability	431 (55.90%)	298 (63.00%)	133 (44.63%)	0.001
1-year free walking ability	533 (69.13%)	360 (76.11%)	173 (58.05%)	< 0.001
Cohort 2				
Outcomes	**All individuals (n = 673)**	**Normal PAPNI (n = 370)**	**Low PAPNI (n = 303)**	**p value**
3-month mortality	21 (3.12%)	6 (1.62%)	15 (4.95%)	< 0.001
6-month mortality	51 (7.58%)	11 (2.97%)	40 (13.20%)	< 0.001
1-year mortality	114 (16.94%)	25 (6.76%)	89 (29.37%)	< 0.001
3-month free walking ability	155 (23.03%)	95 (25.68%)	60 (19.80%)	< 0.001
6-month free walking ability	379 (56.32%)	235 (63.51%)	144 (47.52%)	0.001
1-year free walking ability	492 (73.11%)	305 (82.43%)	187 (61.72%)	< 0.001

Abbreviation: PAPNI, Prealbumin-adjusted Prognostic Nutritional Index.

never significant, but PAPNI remained significant after adjustment. Overall, in both cohorts, increased PAPNI was associated with a reduced risk of one-year mortality. Conversely, patients with low PAPNI had a significantly higher risk of death compared to the normal group.

For predicting one-year independent walking ability, we used logistic regression, and the results mirrored those of the Cox models. The results of univariate logistic models were summarized in Supplementary Table 4, and the results of multivariate models were shown in Table 4. In Cohort 1, the multivariate logistic models were adjusted for location of fracture, age, chest radiograph, hypertension, and ALB, and were adjusted for age, hypertension, and surgical procedures in Cohort 2. As PAPNI increased, the probability of one-year independent walking also increased. Patients with low PAPNI had a significantly lower probability of independent walking compared to the normal group. Again, PNI's predictive power was not significant.

Discussion

The newly developed PAPNI demonstrates remarkable superiority in predicting postoperative survival and functional recovery in hip fracture patients. By substituting albumin with prealbumin, PAPNI leverages prealbumin's shorter half-life to more accurately reflect patients' nutritional status following fracture.[20] This adjustment enhances its sensitivity in capturing dynamic changes in nutritional status, which is critical for prognosis. The optimized weight of prealbumin further refines the index, maximizing its predictive power. Compared to traditional PNI and other single indicators, PAPNI consistently shows higher AUC values in ROC curve analyses across both cohorts. This indicates its ability to more precisely stratify patients' risks, enabling identification of those with a poor prognosis for timely intervention.

From a clinical perspective, PAPNI holds great potential for guiding nutritional intervention in hip fracture patients. Early identification of patients at high risk of adverse outcomes allows for the timely implementation of targeted nutritional support.[12] For instance, patients with low PAPNI values may benefit from enhanced nutritional therapy to improve their nutritional status, potentially reducing postoperative complications and enhancing functional recovery. This proactive approach could optimize resource allocation and improve patient outcomes. Moreover, PAPNI's simplicity and convenience make it easily applicable in clinical settings, requiring only routine blood tests, thus facilitating widespread adoption.

The higher specificity of PAPNI compared to PNI can be primarily attributed to the sensitivity of prealbumin. The original PNI index is mainly composed of albumin and lymphocyte counts. However, an increasing number of studies have confirmed the role of prealbumin over albumin in prognosis.[9,20,21] Prealbumin has a short half-life, which makes it more responsive to

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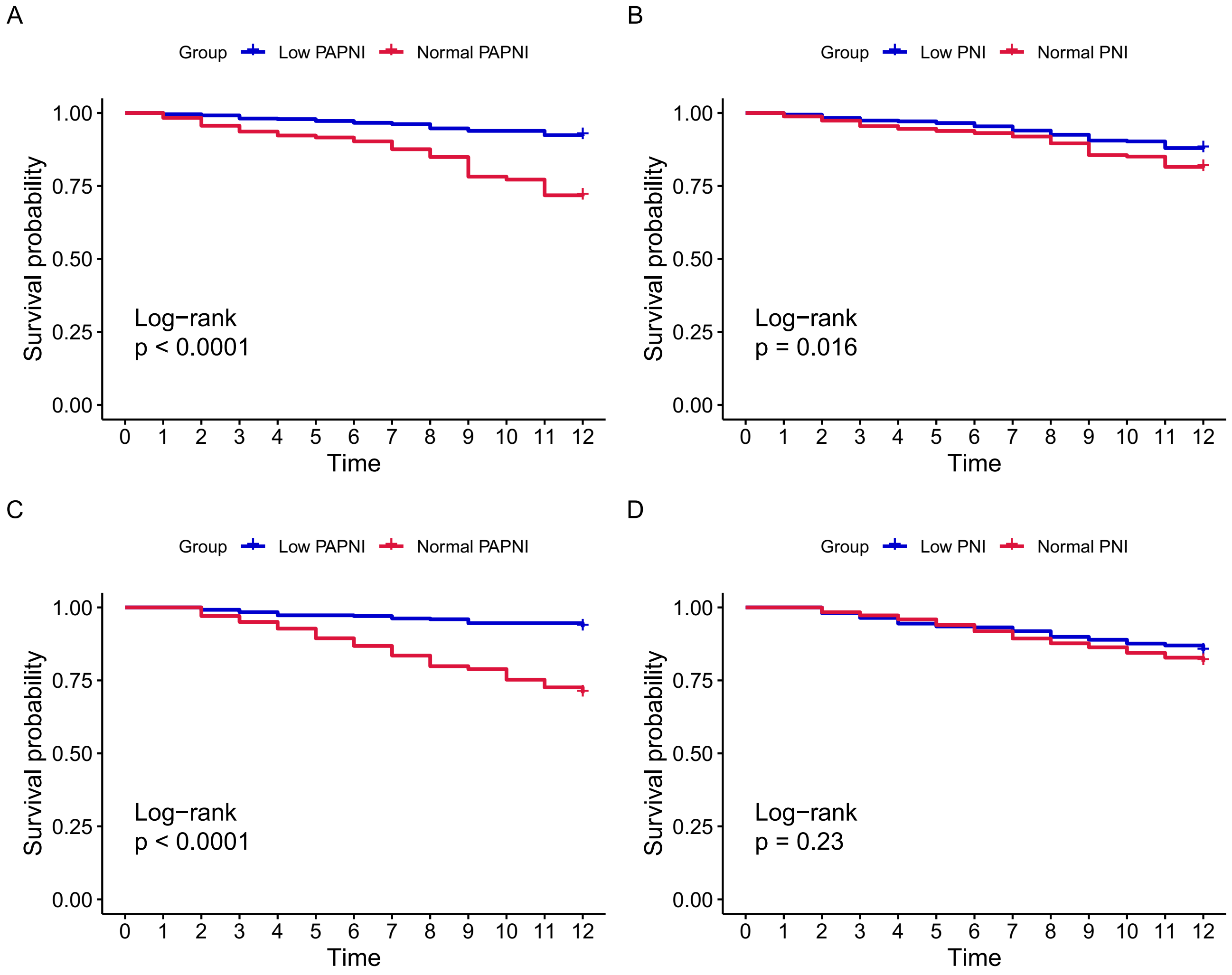

Figure 4 Kaplan-Meier curves of PAPNI and PNI for 1-year survival in Cohort 1 and Cohort 2. (**A**) individuals with normal and low PAPNI in Cohort 1; (**B**) individuals with normal and low PAPNI in Cohort 1; (**C**) individuals with normal and low PAPNI in Cohort 2; (**D**) individuals with normal and low PAPNI in Cohort 2.

acute changes in nutritional status and inflammatory conditions.[22] Unlike albumin, which has a longer half-life of about 20 days, prealbumin's half-life is approximately 2 days.[23] This allows prealbumin to more promptly reflect recent changes in a patient's nutritional intake and the body's inflammatory response.[24] In clinical settings, this sensitivity can be particularly advantageous in scenarios where rapid assessment of a patient's nutritional and inflammatory status is crucial, such as in the immediate postoperative period, injury, or during acute illness.[25–27] The shorter half-life of prealbumin enables it to serve as a more dynamic marker, capturing short-term fluctuations that might be missed by albumin measurements. This dynamic nature, combined with its role as a precursor to albumin synthesis, positions prealbumin as a more specific indicator in the PAPNI, enhancing the index's ability to predict clinical outcomes with greater precision than the traditional PNI. Additionally, the incorporation of lymphocyte count in both indices remains valuable, as it continues to provide important information about the patient's immune status, which is integral to overall prognosis.[13,28]

Previous studies have explored the prognostic value of various nutritional indices in hip fracture patients, but they were often limited by single-center designs and small sample sizes. This study expands on prior research by incorporating two distinct cohorts, enhancing the generalizability of the findings. Furthermore, prior studies primarily focused on either mortality or functional outcomes separately. In contrast, this study comprehensively evaluates both survival and functional recovery, providing a more holistic understanding of the prognosis. The results align with studies emphasizing

Table 3 Multivariate Cox Models of PAPNI and PNI for 1-year Survival in Cohort 1 and Cohort 2

Cohort 1				
Variables	**Univariate Model**		**Multivariate Model**	
	HR (95% CI for HR)	**p value**	**HR (95% CI for HR)**	**p value**
Continuous PAPNI	0.879 [0.849, 0.910]	<0.001	0.905 [0.873, 0.940]	<0.001
Low PAPNI	4.083 [2.775, 6.007]	<0.001	2.893 [1.954, 4.284]	<0.001
Continuous PNI	0.941 [0.912, 0.971]	<0.001	0.983 [0.950, 1.017]	0.332
Low PNI	1.573 [1.085, 2.281]	0.017	0.995 [0.683, 1.448]	0.979
Cohort 2				
Variables	**Univariate Model**		**Multivariate Model**	
	HR (95% CI for HR)	**p value**	**HR (95% CI for HR)**	**p value**
Continuous PAPNI	0.898 [0.873, 0.923]	<0.001	0.898 [0.873, 0.924]	<0.001
Low PAPNI	4.947 [3.174, 7.712]	<0.001	4.213 [2.698, 6.579]	<0.001
Continuous PNI	0.983 [0.964, 1.002]	0.072	0.988 [0.970, 1.006]	0.2
Low PNI	1.259 [0.866, 1.830]	0.228	1.182 [0.813, 1.720]	0.381

Notes: In Cohort 1, the multivariable model was adjusted for location of fracture, age, chest radiograph, hypertension, and CCI, and in Cohort 2, it was adjusted for age.

Abbreviations: PAPNI, Prealbumin-adjusted Prognostic Nutritional Index; PNI, Prognostic Nutritional Index.

Table 4 Multivariate Logistics Models of PAPNI and PNI for 1-year Free Walking Ability in Cohort 1 and Cohort 2

Cohort 1				
Variables	**Univariate Model**		**Multivariate Model**	
	OR (95% CI for OR)	**p value**	**OR (95% CI for OR)**	**p value**
Continuous PAPNI	1.091 [1.058, 1.126]	<0.001	1.042 [1.006, 1.080]	0.024
Low PAPNI	0.434 [0.317, 0.593]	<0.001	0.679 [0.473, 0.974]	0.035
Continuous PNI	1.067 [1.037, 1.098]	<0.001	1.056 [0.991, 1.130]	0.105
Low PNI	0.524 [0.380, 0.717]	<0.001	0.783 [0.484, 1.266]	0.318
Cohort 2				
Variables	**Univariate Model**		**Multivariate Model**	
	OR (95% CI for OR)	**p value**	**OR (95% CI for OR)**	**p value**
Continuous PAPNI	1.097 [1.069, 1.127]	<0.001	1.090 [1.061, 1.121]	<0.001
Low PAPNI	0.344 [0.240, 0.488]	<0.001	0.380 [0.263, 0.546]	<0.001
Continuous PNI	1.000 [0.983, 1.017]	0.96	0.998 [0.981, 1.016]	0.831
Low PNI	1.110 [0.788, 1.562]	0.549	1.154 [0.811, 1.644]	0.426

Notes: In Cohort 1, the multivariable model was adjusted for location of fracture, age, chest radiograph, hypertension, and ALB, and in Cohort 2, it was adjusted for age, hypertension, and Surgical procedures.

Abbreviations: PAPNI, Prealbumin-adjusted Prognostic Nutritional Index; PNI, Prognostic Nutritional Index.

the critical role of nutritional status in post-hip fracture recovery, while also advancing the field by introducing an improved nutritional index.

To contextualize the discriminative ability of PAPNI, we compared its AUC with those reported by recent prognostic models derived from dedicated hip-fracture cohorts. Zwiers et al prospectively validated the Nottingham Hip Fracture

Score (NHFS), the Hip-fracture Estimator of Mortality Amsterdam (HEMA), and physician assessment in 244 Dutch patients and reported AUCs of 0.74. 0.78 and 0.79, respectively, for 1-year mortality.[29] Similarly, a recent Chinese cohort study demonstrated that the ASAgeCoGeCC Score effectively predicted 1-year mortality after hip fracture, achieving an AUC of 0.84.[30] A European cohort evaluated six models—CCI, the Orthopaedic Physiologic and Operative Severity Score for the enUmeration of Mortality and Morbidity (O-POSSUM), the Estimation of Physiologic Ability and Surgical Stress (E-PASS), and so on. All models achieved an AUC greater than 0.70, with the highest reaching 0.77.[31] In our study, PAPNI achieved AUCs of 0.721 (Cohort 1) and 0.741 (Cohort 2) for 1-year mortality, indicating a similar ability in discrimination. While these comparisons are limited by differences in population and geographic setting, they suggest that the incorporation of prealbumin into a simple nutritional index can attain discriminative performance at least comparable to established multidomain risk scores.

Despite its strengths, this study has limitations. Its retrospective design may introduce inherent biases. Future prospective studies should further validate PAPNI's effectiveness. Additionally, the study focused on Chinese patients, and external validation in diverse populations is needed to confirm its universal applicability. Because procalcitonin, C-reactive protein, or interleukin-6 were not available, we could not adjust for acute inflammatory states that may transiently lower prealbumin and potentially attenuate PAPNI's specificity. Future prospective studies should include serial inflammatory markers to refine the index. Finally, the specific mechanisms underlying the association between PAPNI and prognosis warrant further investigation. Future research could explore how nutritional interventions based on PAPNI influence patients' outcomes, providing more direct evidence for its clinical utility.

Conclusion

In summary, the Prealbumin-adjusted Prognostic Nutritional Index (PAPNI) demonstrates superior predictive accuracy for both 1-year mortality and free walking ability in patients with hip fractures compared with traditional indices. Its ease of calculation from routine blood tests makes it readily applicable in daily clinical practice. Early identification of patients with low PAPNI allows timely nutritional intervention, potentially improving postoperative survival and functional recovery. Prospective, multicenter studies are warranted to validate these findings and to explore the impact of PAPNI-guided nutritional strategies on long-term outcomes.

Data Sharing Statement

The datasets analyzed in the current study are available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate

We declare that these studies were conducted in accordance with the Declaration of Helsinki and obtained approval from the Ethics Committee of East Hospital and the Ethics Committee of Nanyang Second People's Hospital. We have ensured the protection of patient privacy in compliance with the principles of the Declaration of Helsinki and relevant regulations on patient confidentiality. Written informed consent was obtained from all participants upon admission to the hospital, which included permission to access medical records (such as general information, laboratory tests, etc.), outcome data, and consent for publication.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors have declared that no competing interests exist in this work.

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