Original Article

Development and validation of a pediatric nutritional screening score (PNSS) for hospitalized children

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Background and Objectives: There is no evidence on the most effective nutritional screening tool for hospitalized children. The objective of this study was to develop and validate a pediatric nutritional screening tool to assess undernutrition risk upon hospital admission. **Methods and Study Design:** The study had a two-phase prospective observational design. A novel pediatric nutritional screening score (PNSS) was developed and sensitivity, specificity, and reliability were evaluated by comparing with a complete dietetic assessment. Length of hospital stay, weight loss, disease complications, and nutritional support were recorded. **Results:** PNSS consisted of three elements: disease with malnutrition risks, changes in food intake, and anthropometric measurements, with a score of 0–2 for each element. The optimal cut-off score to identify patients (n=96) at risk of undernutrition was two. The agreement between PNSS and the complete dietetic assessment was moderate (κ=0.435, 95% CI=0.373–0.498). Sensitivity and specificity values of PNSS were 82% (95% CI=76%–87%) and 71% (95% CI=67%–74%), respectively. Inter-rater agreement had a κ value of 0.596 (95% CI=0.529–0.664, p<0.001). The percentage of children with undernutrition risk was 44.9%. Children with oncologic, gastrointestinal, and cardiac diseases were most likely to be at risk of undernutrition. The at-risk group was associated significantly with longer length of hospital stay and higher percentage of weight loss compared with the not-at-risk group. **Conclusion:** PNSS is the first nutritional screening tool developed for hospitalized children and validated in a large population of patients in China.

Key Words: nutritional screening tool, pediatric patients, undernutrition, clinical outcome, validation

INTRODUCTION

Undernutrition is common in hospitalized children. It has been reported that the prevalence of illness-related malnutrition among children admitted to hospitals in the USA, Canada, and Germany ranges from 6% to 51%.[1-3] Higher prevalence rates have been reported in children with an underlying disease.[4] One recent prospective multicenter study (n=2,400) showed that body mass index (BMI) was <-2 standard deviation score (SDS) in 7.0% (4.0%–9.3%) of patients upon hospital admission in fourteen pediatric departments of twelve European countries.[5] Illness-related malnutrition is associated with prolonged length of hospitalization (LOS), reduced quality of life, and increased health care costs.[5] Additionally, nutritional status further deteriorates in approximately 20% to 50% of children during their hospital stay.[6-10] International organizations such as the European Society for Pediatric Gastroenterology, Hepatology, and Nutrition (ESPGHAN) and the American Society for Parenteral and Enteral Nutrition (ASPEN) recommend that hospitalized children be screened for undernutrition.[11,12] Therefore, it is crucial to develop a simple, useful, and cost effective pediatric nutritional screening tool.

Nutrition screening is a process that identifies individuals with malnutrition or at risk of malnutrition. Several pediatric nutritional screening tools have been developed, for example the simple pediatric nutrition screening tool (PNST),[13] the Pediatric Digital Scaled Malnutrition Risk Screening Tool (PeDiSMART),[14] the Pediatric Yorkhill Malnutrition Score (PYMS),[15,16] the Screening Tool For Risk Of Nutrition Status and Growth ($STRONG_{kids}$),[7] the Screening Tool For the Assessment of Malnutrition in Pediatrics (STAMP),[17] and the Subjective Global Nutritional Assessment (SGNA).[3] However, there is no evidence on which is the most effective nutritional screening

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tool. Results from a seven study meta-analysis (n=1,629 children) suggested that the predictive accuracy of these nutritional screening tools needs to be further evaluated.[18] Furthermore, these tools have not been properly validated in a large population of hospitalized children.

In China, studies on this subject are emerging. Currently, there is no widely accepted nutritional screening tool for the detection of undernutrition risk among children. In the past five years, $STRONG_{kids}$, PYMS, and STAMP, which were developed by European researchers, have been implemented in several pediatric hospitals. However, the selection and interpretation of these nutritional screening tools may differ among different racial and ethnic groups. It has been reported that the types and severity of diseases included in these screening tools are not sufficient to account for clinical diagnoses in China.[19] Therefore, the aim of the study was to develop and validate a simple and reliable nutritional screening tool to assess undernutrition risk among hospitalized children in China, so that appropriate nutritional interventions can be implemented at an early stage.

MATERIALS AND METHODS

Subjects

This study was performed in eight pediatric wards (five medical and three surgical wards) of Xin Hua Hospital from Shanghai Jiao Tong University School of Medicine. This study was characterized by two phases: a development phase, which took place between July 2013 and December 2013, and an evaluation phase, which took place between May 2014 and October 2015.

Children were eligible to participate if they were one month to 17 y of age with an expected hospital stay >24 h. Exclusion criteria included preterm infants during the first 24 months of life, patients in intensive care units, presence of dehydration/edema, and conditions interfering with anthropometric measurements.

Development of a nutritional screening tool

The development of a novel pediatric nutritional screening score (PNSS) was based on the nutritional screening guidelines of the European Society of Clinical Nutrition and Metabolism (ESPEN)[20] and modified according to Chinese clinical practice. PNSS consisted of three elements (Figure 1): (a) disease with malnutrition risks; (b) changes in food intake during the previous week; and (c) nutritional status (assessed by anthropometric measurements). Each element received a score of 0 to 2 with a maximum total score of 6. Certain diseases increase the risk of malnutrition (Figure 1), thereby emphasizing the importance of implementing nutritional interventions.[21] A disease score of 0 is indicative that the protein requirements of the patient are normal/slightly high and can be met via the diet or supplements. A disease score of 1 is indicative that protein requirements are high and can be met with nutritional support. A disease score of 2 is indicative that protein requirements are substantially high and cannot be met with nutritional support; however, protein breakdown and N loss could be significantly reduced.[20]

Body composition (BC) of pediatric patients older than three years of age was measured with a bioelectrical impedance analyzer (InbodyS10; InBody Co. Ltd, Seoul, Korea). Additionally, the patients were screened by PNSS. BC measurements were performed by dietitians at least two hours after eating and with an empty bladder within 24 h of hospital admission. The measurements of fat-free mass (FFM) classified the patients into two categories: 'undernutrition' or 'no undernutrition' according to FFM references values of China.[22]

Evaluation of the nutritional screening tool

Validation study

Patients consecutively admitted to the pediatric wards were screened for eligibility during a one and half year period. Upon admission, a nutritional screening questionnaire (Figure 1) was completed by a dietitian to assess risk of undernutrition.

Criterion validity

A complete dietetic assessment was performed within 48 hours of hospital admission by a dietitian blinded to the nutritional screening results. The complete dietetic assessment involved a detailed dietary history including amount and type of foods consumed, medical notes, gastrointestinal symptoms, appetite changes, anthropometric measurements, weight changes, and biochemical evaluation. Energy and protein intakes were calculated according to the Chinese Food Composition Tables.[23,24] The dietetic assessment classified patients into two categories: 'at-risk' or 'not at-risk' of undernutrition.

Inter-rater reliability

Each PNSS questionnaire was completed upon patient admission by two independent dietitians in a blind design. Inter-rater reliability was calculated.

Comparisons with other nutritional screening tools

The dietitians used PNSS and three similar pediatric nutritional screening tools (PYMS, STAMP, and $STRONG_{kids}$) upon patient admission and compared the results to the complete dietetic assessment.

Anthropometric measurements

Body weight was measured by ward nurses upon hospital admission and at discharge. Supine length or standing height was measured upon admission only. Body weight and height were measured with an infant scale with an attached infantometer (Seca 376 electronic baby scale; Seca Ltd, Hamburg, Germany) in children < 2 y of age and with an electronic scale and a stadiometer (RGZ-120; Shanghai Dongfang scales Co. Ltd, Shanghai, China) in children ⩾ 2 y of age. Body weight was recorded to 0.1 kg; height/length was recorded to 0.1 cm. BMI was calculated as body weight (kg)/[length or height (m)]^2. Anthropometric data was plotted on WHO Child Growth standard charts (http://www.who.int/childgrowth/standards/en/; http://www.who.int/growthref/en/).

Clinical outcome parameters

LOS, weight loss, complications (body temperature >38.5°C and/or gastrointestinal symptoms such as diarrhea and vomiting),[5] and nutritional support during hospitalization were recorded. A reduction of ≥2% from

Demographic data

Name:	Medical Record No:
Ward:	Admission date:
Sex: M / F	Age:
Weight on admission: kg	Weight at discharge: kg
Height/Length: cm	BMI= kg/m^2
Diagnosis:	Interview Date:

Nutritional screening

A. Disease with malnutrition risks

0 = Slight or not
1 = Moderate
2 = Severe

B. Food intake during the previous week

0 = Normal
1 = Decrease ≤ 50% of estimated requirement
2 = Decrease > 50% of estimated requirement

C. Anthropometry

0= WFA-Z / BMI-Z > -1SD
1= -2SD < WFA-Z / BMI-Z ≤ -1SD
2= WFA-Z / BMI-Z ≤ -2SD

Screening total score

0–1 not at risk;
≥ 2 with or at risk of undernutrition; refer to nutritional intervention and follow up

Diseases with malnutrition risks

None or slight	• Day surgery • Diagnostic biopsies	
Moderate	• Minor surgery • Infantile hepatitis syndrome • Gastro-esophageal reflux • Acute diarrhea • Chronic liver disease • Inflammatory bowel disease • Chronic cardiac disease	• Immunodeficiency disease • Oncology remission • Diabetes • Anemia • Renal failure • Nephritis Nephrotic syndrome • Inherited Metabolic Disease
Severe	• Major surgery • Chronic diarrhea • Severe pancreatitis • Anorexia nervosa • Chylous ascites • Intestinal failure • intestinal fistula	• Respiratory failure • Oncology on active treatment • Severe food allergies • Burns • Trauma • Severe sepsis • Chronic cardiac disease

Figure 1. Pediatric Nutritional Screening Score (PNSS)

the reference body weight was selected as 'weight loss'.[10]

Ethical considerations

The study protocol was approved by the ethics committee of Xin Hua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine (China; Approval No. XHEC-D-2013-043). The parents of the patients received written information of the study and provided written consent.

Statistical analysis

Data were recorded in an EpiData 3.1 database and checked twice to ensure that the original medical records were correct. Data analysis was performed using the Statistical Package for the Social Sciences for Windows (version 17.0, SPSS Inc., Chicago, IL, USA). Descriptive data were presented as mean ± standard deviation (SD), proportion (%), or median (range) for non-normally distributed data. Parameters were compared with Student's t test (for normally distributed data) or Kruskal-Wallis test (for non-normally distributed data). Percentages were compared with the chi-square test. Agreement between nutritional screening tools and inter-rater agreement were assessed using the Cohen's κ statistics. Receiver operating characteristic (ROC) curves were used to classify patients into at risk of undernutrition or not at risk of undernutrition. Youden's index was used to determine the optimal cut-off score. ROC analysis was performed to determine the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of the

Table 1. Sensitivity and specificity of PNSS at different cut-off scores

Cut-off score	Subjects at risk of malnutrition (n=96)		
	Sensitivity (%)	Specificity (%)	Youden's index (%)
0.5	100	13.5	13.5
1.5	86.4†	79.7†	66.1‡
2.5	72.7	93.2	66.0
3.5	36.4	94.6	31.0
4.5	31.8	97.3	29.1
5.5	4.6	100	4.5

†Sensitivity and specificity of the nutritional screening tool in identifying different categories of undernutrition risk at its best cut-off score.
‡Youden's index (= sensitivity + specificity - 1) represents best cut-off score.

nutritional screening tool using the complete dietetic assessment as the reference method. The effects of malnutrition risk on the clinical outcomes were determined by Univariate analysis of variance and adjusted for relevant confounders. $p<0.05$ was considered to be statistically significant.

RESULTS

Nutritional screening tool

PNSS and BC were assessed in 96 pediatric patients (6.8±2.9 y of age; 46 boys). The results revealed a significant negative correlation between PNSS scores and FFM (r = -0.542; $p<0.001$). Low FFM identified 23% of patients (n=22) at risk of undernutrition and 77% of patients (n=74) not at risk. A large AUC is indicative of high sensitivity and specificity. The cut-off value between not at risk and at risk of undernutrition had an AUC of 0.881 ($p<0.001$). A cut-off point of 2 provided the optimal distinction (Youden Index=66.1%) with a sensitivity of 86% (95% CI=67%–95%) and a specificity of 80% (95% CI=69%–87%), resulting in two categories: 0–1 (not at risk of undernutrition) and 2–6 (at risk of undernutrition). When compared with FFM data, PNSS (cut-off score of 2) had a PPV of 56% (95% CI=39%–71%) and an NPV of 95% (95% CI=87%–98%) (Table 1).

Characteristics of participants in evaluation phase

A total of 2,830 children met the inclusion criteria in the evaluation phase. PNSS was applied in 93% (2,632/2,830) of the children (2.92 (IQR: 0.92-6) y of age; 1,256 boys); 40 children were discharged prior to the dietetic assessment and incomplete data were obtained from 158 children.

Risk categories in hospitalized children

Overall, 44.9% of the children were at risk of undernutrition. Upon admission, the three systemic diseases that were most associated with high nutritional risk were oncologic, gastrointestinal, and cardiac diseases. Moreover, the incidence of children with high nutritional risk (52.3%) was higher among 1–3 year olds (44.1%, $p<0.001$) and 3 year olds (41.5%, $p<0.001$).

Criterion validity

PNSS and a complete dietetic assessment were performed in 847 patients. Among these patients, 217 patients (25.6%; 95% CI=23%–29%) were at risk of undernutrition based on the dietetic assessment results, whereas 361 patients (42.6%; 95% CI=39%–46%) were at risk of undernutrition based on the PNSS results (cut-off score ≥2). Table 2 shows the distribution comparison within each risk category for PNSS and the dietetic assessment.

Inter-rater reliability

In this study, 847 (31.2%) of the 2,632 patients were evaluated by two dietitians. The inter-rater agreement had a κ value of 0.596 (95% CI=0.529–0.664, $p<0.001$), representing a moderate agreement. Most of the discrepancies were obtained when classifying disease with malnutrition risks.

Speed of administration

It took approximately 10.6±3.1 min to calculate PNSS for 2,632 patients.

Comparison with other nutritional screening tools

Compared with the complete dietetic assessment, PYMS had high specificity and low sensitivity. $STRONG_{kids}$ had higher sensitivity, low specificity, and a fair agreement with the dietetic assessment. STAMP and PYMS had moderate agreement with the dietetic assessment. (Table 3)

Clinical outcomes parameters

The median LOS was 10 days (IQR: 7–15 days) in the

Table 2. Cross-classification of patients at risk of undernutrition risk based on PNSS and a complete dietetic assessment

	Pediatric nutritional screening score (PNSS)		Total (n=847)
	At-risk	Not at-risk	
Complete dietetic assessment, n (%)			
At-risk	178 (21.0)	39 (4.6)	217 (25.6)
Not at-risk	183 (21.6)	447 (52.8)	630 (74.4)
Total, n (%)	361 (42.6)	187 (54)	847 (100)
κ (95% CI)	0.435 (95% CI=0.373–0.498)		
Sensitivity (%)	82% (95% CI=76%–87%)		
Specificity (%)	71% (95% CI=67%–74%)		
PPV	49% (95% CI=44%–54%)		
NPV	92% (95% CI=89%–94%)		

PPV: positive predictive value; NPV: negative predictive value.

Table 3. Comparison between dietetic assessment and other nutritional screening tools

	PYMS n=638		STAMP n=638		STRONGkids n=638	
Dietetic assessment	Low risk†	High risk	Low risk†	High risk	Low risk†	High risk
Not at-risk	472	23	405	90	298	197
At-risk	73	70	40	103	24	119
κ (95%CI)	0.506 (0.431–0.581)		0.479 (0.403–0.555)		0.304 (0.239–0.369)	
Sensitivity (%)	49.0%		72.0%		83.2%	
Specificity (%)	95.4%		81.8%		60.2%	
PPV	75.3%		53.4%		37.7%	
NPV	86.6%		91.0%		92.6%	

PPV: positive predictive value; NPV: negative predictive value.
†Low- and medium-risk categories grouped.

'at-risk' group and 7 days (IQR: 5–10 days) in the 'not at-risk' group. Univariate analysis revealed that age (F=8.90, $p<0.001$), nutritional support (F=389.6, $p<0.001$), and disease classification (F=15.1, $p<0.001$) were significantly related to LOS. After adjusting for these confounders, LOS was longer in the 'at-risk' group than in the 'not at-risk' group (Wald=80.0, $p<0.001$).

More 'at-risk' children lost weight than 'not at-risk' patients (20.9% vs 14.9%, F=14.912, $p<0.001$). Univariate analysis revealed that age (F=5.279, $p<0.001$), nutritional support (F=20.985, $p<0.001$), and disease complications (F=8.097, $p=0.004$) were significantly related to weight loss. After adjusting for these confounders, the percentage of weight loss in the 'at-risk' group remained higher than in the 'not at-risk' group (Wald=18.334, $p<0.001$).

Compared with the 'not at-risk' children, a higher percentage of 'at-risk' children experienced disease complications (8.9% vs 5.9%, F=8.491, $p=0.004$). After adjusting for age, nutritional support, and disease classification, there were no significant differences in disease complications between the two groups (Wald=0.801, $p=0.371$).

DISCUSSION

PNSS represents the first pediatric nutritional screening tool developed for hospitalized children and validated in a large population of patients in China. Children at risk of undernutrition upon admission had longer hospital stays and higher prevalences of weight loss compared with children not at risk of undernutrition. The results of this study revealed that PNSS is a reliable screening tool for the early detection of undernutrition risk among hospitalized children.

The developed nutritional screening score, PNSS, included measures of potential undernutrition, disease with malnutrition risks, and changes in food intake. The list of diseases included in PNSS was based on published evidence[1,2,7,17] and the consensus of multidisciplinary professionals (pediatricians, dietitians, and nutritionists). The types of diseases included in PNSS were sufficient to account for clinical diagnoses in China. The criterion for 'disease with malnutrition risks' reflected the degree of nutritional requirements. Reduced food intake is a major contributor to malnutrition in hospitalized children and has been incorporated into most of the pediatric nutritional screening tools.[7,14,15,17] For simplicity and practical purposes, the investigator recorded whether food intake was usual, >50%, or ≤50% of the daily dietary allowance. A simple pediatric nutritional risk score, which was developed by Sermet-Gaudelus et al, identified that food intake ≤50% of the diet allowance represents a significant predictor of nutritional depletion.[10] Therefore, the description of inadequate food intake categories in this study appeared to be reasonable to dietitians. Anthropometric measurements are considered objective and effective methods for malnutrition assessment in pediatric patients. Furthermore, body weight and body height or length measurements are usually part of the routine hospital admission process and completed by nursing staff. Even though anthropometric measurements require a considerable amount of time, they were included in PNSS.

The score system of PNSS was calibrated following the assessment of body composition, which is considered an objective marker of nutrition in pediatric patients. Reduced FFM index is associated with higher undernutrition risk, morbidity, mortality, and poor functional status and outcome.[14,15] The significant negative correlation between PNSS scores and fat-free mass data confirmed that the PNSS score is related to pediatric malnutrition. A cut-off score of two allowed the classification of patients into two categories. A total PNSS score <2 was indicative of patients not at risk of undernutrition, while a PNSS score ≥2 was indicative of patients at risk of undernutrition who required further nutritional assessment and interventions. However, there are some limitations to using BIA in children with altered hydration, especially following impedance and FFM measurements. We should exclude patients who had dehydration/edema during the developmental phase of the study.

The clinical usefulness of nutritional screening tools is determined by their predictive validity, concurrent validity, reproducibility, and practicality.[25] A complete dietetic assessment was used to evaluate the sensitivity, specificity, and PPV of nutritional screening tools because there is no gold standard for the assessment of the nutritional status of hospitalized children. The complete dietetic assessment has been used as a validation method in previous studies.[15-17,26] In our study, the sensitivity, specificity, and negative predictive value of PNSS were 82%, 71%, and 92%, respectively. The sensitivity of PNSS was similar to that of $STRONG_{kids}$, but higher than that of STAMP and PYMS. However, $STRONG_{kids}$ had lower specificity than PNSS. The negative predictive value of PNSS was similar to that of STAMP and $STRONG_{kids}$, but slightly higher than that of PYMS. Screening tools should have

high sensitivity to minimize the number of false-negative results.[27] Sensitivity is more important than specificity, because a false-positive result will only subject the patient to a detailed nutritional assessment, whereas a false-negative result can result in an undetected condition.[28] Therefore, based on the results, PNSS was a reliable screening tool. The sensitivity of the screening tools ranged from 59%[16] to 100%[29] and the specificity ranged between 53% and 92%.[16] Differences among studies could be attributed to the use of different reference standards. In addition to the complete dietetic assessment, SGNA and anthropometric measurements have been used as gold standards.[13,15,28,30] Therefore, it is difficult to determine the superiority or inferiority of one tool over the other when there is no universally accepted gold standard.

Compared with the tool developed by Sermet-Gaudelus et al and with SGNA, which are both time consuming, PNSS was simple and practical. PNSS took 10 min to complete, while STAMP was completed in 10 to 15 min[25] and $STRONG_{kids}$ required only 5 min.[22] Both STAMP and PNSS require the interpretation of growth charts. On the other hand, $STRONG_{kids}$ does not include any anthropometric measurements,[30] which may be considered a disadvantage due to the lack of an objective evaluation.

In terms of reproducibility, PNSS showed moderate agreement (κ=0.596) between the two dietitians. The reported inter-observer agreement varied from moderate (κ=0.4–0.59)[16] to perfect (κ=0.921).[17] STAMP had the highest inter-observer agreement.[17] When clinical diagnoses are not included in the list of diagnoses of PNSS, there is potential for bias in the estimation of disease risks. The accuracy of classification of disease with malnutrition risks will be improved after careful assessment of the list of diseases.

Our study confirmed that patient allocation according to PNSS was associated with clinical outcome measures. The results revealed that children at risk of undernutrition had significantly longer LOS and higher weight loss rates compared with children with no risk of undernutrition after adjusting for age, nutritional support, and classification of diseases. Disease complication was not significantly associated with malnutrition risk after controlling for confounding variables. A nutritional screening tool that predicts nutrition-related clinical outcomes upon admission is probably the most valuable, because nutritional intervention may influence outcomes such as LOS or complication risk and will demonstrate that early intervention is cost effective.[25] In addition to PNSS, there are nutritional screening tools that incorporate a model of predictive validity and outcome parameters, including weight loss during hospitalization (PRNS), complications after surgery (SGNA), and LOS (SGNA and $STRONG_{kids}$). However, the predictive validity obtained from observational studies demonstrating adverse outcomes is insufficient.[25] There is no evidence whether nutritional intervention in children at high risk improves these outcome parameters. It is necessary to perform further studies to evaluate whether children at risk of developing undernutrition during their hospital stay will benefit from nutritional interventions.

This study had some limitations. First, this study did not calculate inter-rater reliability data among nurses. Future studies will focus on the evaluation of nurse-administered PNSS. Second, PNSS did not account for overnutrition. Currently, PNST is the only screening tool that takes overnutrition and undernutrition into account. Given the increasing prevalence of overweight and obese pediatric inpatients in developing countries, PNSS should be modified to detect overnourished children.

Lastly, our study was a single-center case series survey. A multicenter prospective cohort study would allow the cross-validation of PNSS in a more diverse demographic and the evaluation of the effect of nutritional support on clinical outcomes in at-risk children.

Conclusions

We developed and evaluated PNSS, the first nutritional screening tool developed for hospitalized children in China. PNSS was validated in a large population of hospitalized children, and the results revealed that PNSS was a simple and reliable screening tool for the detection of undernutrition risk. Children who are at risk of undernutrition (PNSS score $\geq$2) should be referred to a detailed nutrition assessment and confirmed cases should undergo nutritional interventions.

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AUTHOR DISCLOSURES

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