Original Article

Comparative analysis of malnutrition diagnosis methods in lung cancer patients using a Bayesian latent class model

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Background and Objectives: There are no consensus criteria for malnutrition diagnosis in clinical settings, the Global Leadership Initiative on Malnutrition (GLIM) criteria were developed to facilitate global comparisons of malnutrition prevalence, interventions and outcomes. Validation to assess usefulness in clinical practice is essential, however, the imperfect nature of reference standards used in concurrent validation may result in biased estimates of diagnostic accuracy. The Bayesian latent class model (BLCM) can assess the diagnostic performance when a "gold standard" is absent. This study's objective was to assess the diagnostic performance of the GLIM criteria in comparison with the Nutritional Risk Screening 2002 (NRS-2002) and the Patient Generated Subjective Global Assessment (PG-SGA) in lung cancer patients using a BLCM. We hypothesized that the GLIM criteria are more sensitive and specific for malnutrition diagnosis in lung cancer patients. **Methods and Study Design:** 1,384 patient records retrospectively obtained from the "Investigation on Nutrition Status and its clinical outcome of common Cancers" (INSCOC) study were used to determine the prevalence of malnutrition, sensitivity (Se) and specificity (Sp) by applying a BLCM. **Results:** The prevalence of malnutrition was 0.56. The sensitivity and specificity of the GLIM criteria were Se: 0.85 and Sp: 0.88; Se: 0.74 and Sp: 0.85 for NRS-2002 and Se: 0.96 and Sp: 0.89 for PG-SGA. **Conclusions:** Although the GLIM criteria were acceptable for malnutrition diagnosis, PG-SGA is superior for determining cancer-associated malnutrition. Because of its fair sensitivity, NRS-2002 was best equipped to screen out patients not at nutritional risk.

Key Words: lung cancer, malnutrition, diagnostic test evaluation, Bayesian latent class model, GLIM criteria

INTRODUCTION

Cancer patients are extremely susceptible to malnutrition because of their individual characteristics, the cancer itself, and the aggressive treatment involved.[1] The prevalence of cancer-associated malnutrition is high and differs depending on the screening and assessment method applied.[2] The incidence of malnutrition increases as the disease progresses, eventually affecting 80% of cancer patients.[3] Additionally, studies have indicated a high prevalence of malnutrition in lung cancer patients ranging from 45-79.4%.[4,5]

There is currently no universal definition of malnutrition,[1] and no consensus criteria for malnutrition diagnosis in clinical settings.[6] The inherent differences between criteria and methodology makes the comparison of the efficacy of nutrition interventions across different studies onerous.[7] Furthermore, due to the advances in our under-

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standing of the contributions of disease or inflammation, the concepts of malnutrition in the current International Classifications of Diseases (ICD-10) may be irreconcilable with the techniques/nomenclature currently used in research and clinical practice.[6] Because of this deficiency, the standardization of nutritional assessment and therapy in cancer patients is limited.[8] Therefore, the establishment of a global consensus for malnutrition diagnosis in adult clinical care settings is crucial.[6]

In order to standardize the global clinical practice of malnutrition diagnosis, the GLIM criteria were developed.[6,9] These criteria would facilitate the comparison of malnutrition prevalence, interventions and outcomes internationally; support the development of global standards of care and promote the aforementioned global comparisons using created databases.[6] However, these criteria are relatively new and not well validated.[10] Additionally, although the criteria are based on the collective experience of numerous specialists, it is important to assess their applicability in a variety of patient subgroups.[2]

Validation is often performed by comparing the tool of interest to a reference/gold standard. In practice, however, there is usually no gold standard method. When an imperfect reference standard is used for validation, the sensitivity and specificity either may be underestimated or overstated.[11] This will in turn lead to significant misinterpretations and conclusions about diagnostic performance and disease prevalence.[12] The apparent diagnostic errors of a new test may be a reflection of errors in the imperfect reference standard rather than the test's poor performance.[13] Ultimately, this could negatively influence patient diagnosis and health outcomes. The BLCM is a method that estimates the diagnostic accuracy even when the true disease status is unobserved (latent). Because it is unaffected by the imperfect nature of the reference standard, it is suitable for assessing the validity of nutritional tools in the absence of a gold standard.

It is on this background, therefore, that we aimed to determine the prevalence of malnutrition and assess the diagnostic performance of the newly introduced GLIM criteria in comparison with the already established NRS-2002 and the PG-SGA in Chinese lung cancer patients using a BLCM.

METHODS

Study design

This study was a retrospective analysis of clinical data to assess the validity of the newly introduced GLIM criteria as compared to NRS-2002 and PG-SGA in Chinese lung cancer patients using a BLCM. The data used were extracted from an observational multicentre, hospital-based prospective cohort study titled, "INSCOC" (Registration number: ChiCTR1800020329). The INSCOC study aims to determine the relationship between nutritional status and clinical outcomes in patients with malignant tumours.[14] That study was approved by the Medical Ethics Committee of Army Medical Centre. All study participants were provided with written informed consent at baseline in accordance with the Declaration of Helsinki. For this research, data collected at nutritional screening were used.

Participants

The data utilized in this study were collected from lung cancer patients admitted to various Chinese hospitals between 2012 and 2019. Patients were considered if they met the following criteria; "aged ≥18 years, cancer diagnosis confirmed by pathology, hospitalized cancer patients with tumour diagnosed as local, metastatic and/or local regional relapse imaging, conscious, no communication barriers, able to answer the study questionnaires and willingness to participate in the study". "Patients who were hospitalized more than twice during the investigation, organ transplantation, pregnant women, Human Immunodeficiency Virus (HIV) infection or Acquired Immunodeficiency Syndrome (AIDS) diagnosis or admitted to the intensive care unit (ICU) at the beginning of recruitment" were excluded.[15]

Data extraction

Demographic data extracted for each patient included; age, sex, family cancer history and cancer stage, Body Mass Index (BMI), anthropometric measurements such as mid arm circumference (MAC), upper arm muscle circumference (MAMC), left calf circumference (CC), hand grip strength (HGS), urea nitrogen, pre-albumin, white blood cell (WBC) count, neutrophil count and lymphocyte count.

The data cleaning procedure involved 1) identifying the variables that were relevant and eliminating any that had missing data, 2) any participant data that lacked the information needed to determine the GLIM criteria diagnosis were also eliminated.

Nutritional screening and assessment

Upon admission, all patients were screened and assessed for malnutrition using the NRS-2002 and PG-SGA respectively by a trained dietitian within 48 hours, and their resultant scores were recorded.

NRS-2002

The NRS-2002 is a simple and well-validated tool that was developed by Kondrup et al.[16] The European Society for Parenteral and Enteral Nutrition (ESPEN) recommends it for hospitalized patients.[17,18] This tool incorporates pre-screening, which is composed of four questions. If a question is answered positively, screening follows which assesses undernutrition and severity of the disease according to whether they are absent, mild, moderate or severe.

Undernutrition is estimated using BMI, recent weight loss percentage and changes in food intake, while the estimation of the severity of disease is somewhat arbitrary with both static and dynamic parameters.[16,19] The NRS-2002 includes an additional component assessing age. An age of ≥70 years is considered as a risk factor and gives a score of 1.[19] The final score ranges from 0-7 and patients with a total score ≥3 are considered to be at nutritional risk, already malnourished and in need of nutritional therapy.[16,20]

PG-SGA

The PG-SGA was adapted from the Subjective Global Assessment (SGA) and recommended by the American

Dietitian Association and the Chinese Society of Clinical Oncology Expert Committee for use in cancer patients.[21,22] The PG-SGA is also well validated and is apt in predicting clinical outcomes such as shorter survival, postoperative complications and reduced tolerance to chemotherapy.[23]

It consists of two assessments. The first assessment is completed by the patient using a check box format while the second assessment was completed by a health professional. A further enhancement to this tool was made to create the scored PG-SGA. It incorporates a numerical score as well as provides a global rating of well nourished, moderately or suspected of being malnourished or severely malnourished. Each component of the scored PG-SGA can be awarded a point in the range 0–4 depending on the impact of the symptom on the nutritional status. The total score obtained provides guidance to health professionals on the nutrition intervention required.[24] Scores of ≤1, 2-8 and ≥9 are indicators of well-nourished, moderately malnourished and severely malnourished patients respectively.[25]

The PG-SGA is currently considered the standard for screening and evaluating the nutritional status of cancer patients in clinical studies by the Oncology Nutrition Dietetic Practice Group of the American Dietetic Association.[26,27] It has been shown to be valid and reliable with 98% sensitivity and 82% specificity in predicting SGA classification.[24] Using the PG-SGA, there is not only a reduced time for patient interaction and shortened clinic flow but also a proactive prevention of malnutrition by identifying and triaging for necessary interventions.[6]

Malnutrition diagnosis using the GLIM criteria

The GLIM criteria was instituted by the GLIM initiative and partly formulated from the previous definition developed by the ESPEN. It assesses the phenotypic characteristics of an individual but also incorporates the aetiology of the disease, which had not been included in the concepts of malnutrition in the ICD classification of disease. It was developed based on fundamental phenotypic and aetiologic criteria that are already in use worldwide.

Phenotypic criteria

In order to determine unintentional weight loss, changes in body weight were used. These anthropometric measurements were conducted using a standardized protocol by trained medical professionals.[15] The percentage weight loss in the past six months was determined using the current weight and weight one month ago. The 5% weight loss was calculated and used as a cut-off point signifying unintentional weight loss (% weight loss >5% within the past 6 months indicates the presence of unintentional weight loss).[6,15] The BMI was calculated using the current body weight and height. Cut-off points specific to the Asian population were used to determine the presence of low BMI (<18.5 if <70 years; <20 if ≥70 years).[28] See Table 1 for detailed cut-off points including severity grading.

To determine reduced muscle mass (RMM), GLIM recommends "measurement using dual energy absorptiometry or other validated body composition measures such as bioelectrical impedance, ultrasound, computed tomography or magnetic resonance imaging". Nevertheless, these measurements were not available from the clinical data used in this study. Therefore, alternative measures involving the physical examination of anthropometric measures such as calf circumference were used as endorsed by GLIM.[6,28] RMM was determined using a combination of CC and body weight standardized hand grip strength (HGS/W) calculated separately for each gender. This is because a study conducted by Liangyu Yin et al indicated that the CC and HGS/W method is optimal to assess RMM for the GLIM criteria. A value of <p15 for CC and HGS/W was defined as positive for stage I malnutrition while a value of <p5 for CC and HGS/W was defined as stage II malnutrition.[8]

Aetiologic criteria

The presence of aetiologic criteria was determined using disease burden or inflammation. According to T. Cederholm et al., "most chronic organ diseases such as congestive heart failure, chronic obstructive pulmonary disease, rheumatoid arthritis, chronic kidney or liver disease and cancer are associated with chronic or recurrent inflammation of a mild or moderate degree".[10] Given that cancer is considered an aetiologic criterion, all patients were considered to have an aetiologic criterion present. See Table 1.

A malnutrition diagnosis was determined based on the presence of at least one phenotypic and aetiologic criteria as previously described.[6]

Statistical analyses

Descriptive statistics

Descriptive statistical analysis was conducted using IBM SPSS 25.0.[29] A two-sided test approach with $p<0.05$ was used to indicate statistical significance. The Kolmogorov Smirnov (KS) test was conducted to test whether the variables were normally distributed. Normally distributed continuous variables were to be reported as mean ± SD while skewed continuous variables were to be reported as median and interquartile range (IQR). Categorical variables were to be reported as frequencies and percentages. To compare patients' general characteristics according to nutrition status and the significance of differences between the two groups, the independent t-test for normally distributed continuous variables or the Mann Whitney test for skewed data was to be used while the Pearson's Chi squared test or Fisher's exact test was to be used for categorical variables.

BLCM

These analyses were conducted using R studio,[30] and Win BUGS software.[31] The BLCM has become a suitable substitute for the traditional assessment of diagnostic performance using a somewhat flawed reference standard. In the absence of a gold standard, the diagnostic performance of the GLIM criteria, NRS-2002 and PG-SGA were determined using a 2-class latent class model structured to account for conditional dependence.[32,33] In this model, 7 unknown parameters were estimated, including the sensitivity and specificity of each method, which were assumed constant in this population, as well as the prevalence.

Table 1. Phenotypic and aetiologic criteria (GLIM criteria) for malnutrition diagnosis

A. Phenotypic criteria			
	Weight loss (%)	Low body mass index (kg/m^2)	Reduced muscle mass
Stage I/Moderate malnutrition	5-10% within the past 6 months	<18.5 if <70 years <20 if ≥70 years	Calf circumference <p15, weight-standardized hand grip strength <p15
Stage 2/Severe malnutrition	>10% within the past 6 months	<17.0 if <70 years <17.8 if ≥70 years	Calf circumference <p5, weight-standardized hand grip strength <p5
B. Aetiologic criteria			
Inflammation or disease burden Presence of cancer or WBC count			

[†]p15: the 15th percentile; p5: the 5th percentile; PG-SGA: Patient Generated Subjective Global Assessment. Percentile values of calf circumference (male: p15=30 cm, p5=28 cm; female: p15=28.5 cm, p5=26 cm); percentile values of weight-standardized hand grip strength (male: p15=0.32, p5=0.22; female: p15=0.21, p5=0.16).

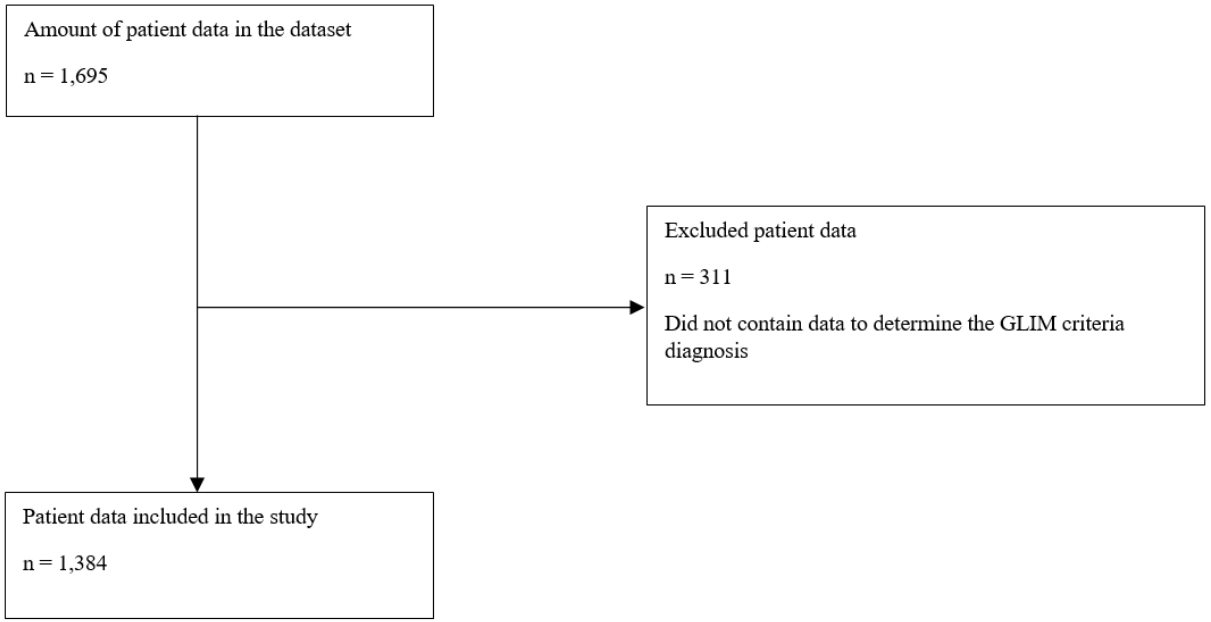

Figure 1. Flowchart of patient data selection. GLIM: Global Leadership Initiative on Malnutrition.

In order to determine these estimates, prior knowledge of the variables to be estimated (past literature),[10,34-36] was combined with the observed data (diagnostic test results) to generate a posterior distribution of the variable, which is an update of the variable's real value. Using the Gibbs Sampling (Markov Chain Monte Carlo (MCMC)) method, posterior distributions were estimated using 5,000 iterations in Win BUGS. Convergence diagnostics were conducted using dynamic trace plots, running quantile plots and autocorrelation function plots. Each parameter was expressed as mean and 95% credible interval (CrI).[32,37]

RESULTS

There were 1,695 lung cancer participants in the original dataset, of which 1,384 had the data needed to determine the presence of malnutrition according to the GLIM criteria, NRS-2002 and PG-SGA and were included in this study. See Figure 1.

The KS test conducted on the included continuous variables indicated that none of the variables were normally distributed. Therefore, all continuous variables were described using the median and IQR. Categorical variables were described using frequencies and percentages. See Table 2.

Patients' characteristics

Patients' general characteristics for the complete dataset (n = 1,384) according to nutrition status as determined by the GLIM criteria, NRS-2002 and PG-SGA are shown in Table 2. Of the 1,384 lung cancer participants, 993 (71.7%) were male while 391 (28.3%) were female. The median age was 62 (IQR: 55-67) years with 249 (18.0%) being aged ≥ 70 years. Overall, 381 (27.3%) patients were diagnosed with malnutrition according to the GLIM criteria (211 had moderate malnutrition and 170 had severe malnutrition), 311 (22.5%) patients were considered to be at nutritional risk by the NRS-2002, while 1,007 (72.8%) patients were diagnosed with malnutrition by the PG-SGA (777 had moderate malnutrition and 230 had severe malnutrition). According to all the methods, 365 (26.4%) patients were well nourished/not at nutritional risk/normal while 238 (17.2%) patients were malnourished/at nutritional risk.

Bayesian estimates

Table 3 summarizes the estimates of diagnostic performance and prevalence based on our BLCM. The GLIM criteria had good sensitivity and specificity of 0.85 (95% CrI: 0.76, 0.92) and 0.88 (95% CrI: 0.73, 0.97). NRS-2002 had the lowest sensitivity of 0.74 (95% CrI: 0.68, 0.80) and good specificity of 0.85 (95% CrI: 0.81, 0.89). The PG-SGA exhibited the highest sensitivity and specificity of 0.96 (95% CrI: 0.91, 0.99) and 0.89 (95% CrI: 0.81, 0.96) respectively. The prevalence determined by the BLCM was 0.56 (95% CrI 0.30, 0.80).

DISCUSSION

In this study, we used a BLCM to assess diagnostic strategies in lung cancer-associated malnutrition. In the absence of a gold standard, we implemented a 2-class latent class model to determine the sensitivity, specificity of each test as well as the prevalence. To the best of our knowledge, this is the first study evaluating the diagnostic performance of the GLIM criteria as compared to NRS-2002 and PG-SGA in Chinese lung cancer patients using these methods. See Figure 2 for a general overview of the evaluated tools.

According to the BLCM in this study, the true prevalence of malnutrition in the study population was 0.56. This is somewhat different from past research. According to a study by Liangyu Yin, the malnutrition rate in lung cancer patients is 0.24,[8] while another study found the prevalence of malnutrition in lung cancer patients to be 0.26.[38] Other studies have indicated that the prevalence of malnutrition in lung cancer patients ranges from 45 - 79.4%.[4,5] Variations in patient characteristics and the differences in methods used to obtain the GLIM diagnosis could explain the disparities in malnutrition rate or prevalence.

The GLIM criteria according to our research, showed a good sensitivity and specificity of 0.85 and 0.88 respectively. A survey of literature indicated that few other studies used a BLCM to determine the diagnostic performance of these criteria. Different outcomes from those achieved in this study were revealed when a concurrent validation approach was applied. The sensitivity and specificity of the GLIM criteria were 0.76 and 0.73, respectively in a cancer care ambulatory context.[35] Another study by Rosnes et al. in a Nutrition Outpatient Clinic with predominantly cancer patients found that the GLIM criteria, without screening had a sensitivity and specificity of 0.76 and 0.80 respectively.[39]

When PG-SGA was employed as a reference standard, research in ambulatory cancer patients found that, the sensitivity was 0.60 and the specificity was 0.98 for all combinations of the GLIM criteria.[40] Furthermore, Kang-Ping Zhang et al revealed that the GLIM criteria had a sensitivity of 0.71 and a specificity of 0.88.[41] Although one study had a significantly higher specificity,[40] the parameters acquired through the BLCM for the GLIM criteria are much higher when compared to those obtained through concurrent validation. The sensitivity difference ranged from 9 to 24.9% whereas the specificity ranged from 8 to 15%. With the exception of studies conducted by Wang et al,[40] and Khang-Ping Zhang et al,[41] the specificity of the GLIM criteria was always higher than the sensitivity.

The diverse approaches to the GLIM criteria account for the differences in diagnostic estimations between research. The method's validation and standardization are hampered by the current diversity of these criteria. It is noteworthy, however, that the GLIM criteria are already being employed to examine the concurrent validity of several methods in the cancer-associated malnutrition setting.[38]

The GLIM criteria exhibited a greater sensitivity and specificity than the NRS-2002 (Se: 0.74, Sp: 0.85). The PG-SGA, on the other hand, has a higher sensitivity and specificity (Se: 0.96, Sp: 0.89) than the GLIM criteria. Several validation studies have confirmed that it is a suitable tool for assessing malnutrition in cancer patients.[24,27]

The strength of this study lies in the method used to assess the diagnostic performance of these tools. In the ab-

Table 2. Characteristics of the study population

Characteristics	Overall	GLIM diagnosis			*p*
		Normal (n=1003)	Moderate malnutrition (Stage I) (n=211)	Severe malnutrition (Stage II) (n=170)	
Age, years, median (IQR)	62.0 (55.0-67.0)	61.0 (54.0-67.0)	63.0 (56.0-70.0)	63.0 (55.8-70.0)	0.001
Age ≥70 years, yes, n (%)	249 (18.0)	150 (15.0)	56 (26.5)	43 (25.3)	<0.001
Sex, male, n (%)	993 (71.7)	721 (71.9)	158 (74.9)	114 (67.1)	0.856
Family cancer history, yes, n (%)	214 (15.5)	155 (15.5)	33 (15.6)	26 (15.3)	0.988
Cancer stage, n (%)					0.079
I	65 (4.7)	53 (5.3)	7 (3.3)	5 (2.9)	
II	73 (5.3)	57 (5.7)	10 (4.7)	6 (3.5)	
III	133 (9.6)	97 (9.7)	20 (9.5)	16 (9.4)	
IV	163 (11.8)	106 (10.6)	28 (13.3)	29 (17.1)	
Other	950 (68.6)	690 (68.8)	146 (69.2)	114 (67.1)	
BMI, kg/m^2, median (IQR)	22.6 (20.6-24.9)	23.3 (21.5-25.4)	20.5 (18.8-22.6)	19.8 (17.5-21.5)	<0.001
Mid-arm circumference, cm, median (IQR)	27.0 (25-29.0)	27.5 (25.8-29.5)	25.0 (23.0-27.5)	24.6 (22.0-26.0)	<0.001
Hand grip strength, kg, median (IQR)	25.8 (19.1-32.7)	26.7 (20.6-33.8)	24.1 (16.5-32.1)	20.6 (13.5-27.3)	<0.001
Hand grip strength/weight ratio, median (IQR)	0.4 (0.3-0.5)	0.4 (0.3-0.5)	0.4 (0.3-0.5)	0.4 (0.3-0.5)	0.060
Upper arm muscle circumference, cm, median (IQR)	22.2 (20.0-24.4)	22.7 (20.6-24.8)	21.3 (19.5-23.2)	20.4 (18.5-22.5)	<0.001
Left calf circumference, cm, median (IQR)	33.0 (31.0-35.5)	33.8 (32.0-36.0)	31.0 (29.0-33.0)	31.0(28.0-33.0)	<0.001
Urea nitrogen, mmol/L, median (IQR)	5.0 (4.0-6.2)	5.1 (4.1-6.2)	5.1 (4.1-6.4)	4.7 (3.7-6.0)	0.367
Pre albumin, mg/dL, median (IQR)	212 (166-259)	227 (180-270)	200(142-240)	164(108-210)	<0.001
WBC, 10^9, median (IQR)	6.3 (4.9-8.2)	6.2 (4.9-7.9)	6.7 (5.1-8.9)	7.1 (4.9-9.8)	0.001
Neutrophil count, 10^9, median (IQR)	4.1 (2.9-5.9)	3.9 (2.9-5.5)	4.5 (3.2-6.6)	4.8 (3.2-7.4)	<0.001
Lymphocyte count, 10^9, median (IQR)	1.5 (1.1-1.9)	1.5 (1.1-1.9)	1.4 (1.0-1.8)	1.3 (0.9-1.7)	<0.001

GLIM: Global Leadership Initiative on Malnutrition; IQR: interquartile range; BMI: body mass index; NRS-2002: Nutritional Risk Screening 2002; PG-SGA: Patient Generated Subjective Global Assessment; WBC: white blood cells. Statistical differences were obtained using Pearson's Chi square (X^2) test/Fisher's exact test for categorical variables and the Mann Whitney test for continuous variables.

Table 2. Characteristics of the study population (cont.)

Characteristics	NRS-2002			PG-SGA			
	No risk (n=1073)	Nutritional risk (n=311)	*p*	Well-nourished (n =377)	Moderate malnutrition (n=777)	Severe malnutrition (n=230)	*p*
Age, years, median (IQR)	61.0 (54.0-67.0)	63.0 (56.0-70.3)	<0.001	58.0 (52.0-62.0)	64.0 (56.0-69.0)	63.0 (56.5-70.0)	<0.001
Age ≥70 years, yes, n (%)	161 (15.0)	88 (28.3)	<0.001	0 (0.0)	190 (24.5)	59 (25.7)	<0.001
Sex, male, n (%)	772 (71.9)	221 (71.1)	0.760	275 (72.9)	558 (71.8)	160 (69.6)	0.545
Family cancer history, yes, n (%)	170 (15.8)	44 (14.1)	0.466	46 (12.2)	131 (16.9)	37 (16.1)	0.040
Cancer stage, n (%)			0.017				0.055
I	57 (5.3)	8 (2.6)		14 (3.7)	49 (6.3)	2 (0.9)	
II	55 (5.1)	18 (5.8)		23 (6.1)	43 (5.5)	7 (3.0)	
III	102 (9.5)	31 (10.0)		39 (10.3)	75 (9.6)	19 (8.3)	
IV	112 (10.4)	51 (16.4)		30 (8.0)	84 (10.8)	49 (21.3)	
Other	747 (69.6)	203 (65.3)		271 (71.9)	526 (67.7)	153 (66.5)	
BMI, kg/m^2, median (IQR)	23.1 (21.2-25.3)	20.4 (18.1-22.6)	<0.001	23.4 (21.5-25.5)	22.8 (20.7-25.0)	20.9 (18.8-22.9)	<0.001
Mid-arm circumference, cm, median (IQR)	27.0 (25.0-29.2)	25.0 (23.0-27.0)	<0.001	28.0 (26.0-30.0)	27.0 (25.0-29.0)	25.5 (23.0-27.3)	<0.001
Hand grip strength, kg, median (IQR)	26.8 (20.1-33.5)	22.5 (16.3-28.9)	<0.001	29.6 (23.0-36.0)	25.5 (19.5-32.0)	20.1 (13.6-28.3)	<0.001
Hand grip strength/weight ratio, median (IQR)	0.4 (0.3-0.5)	0.4 (0.3-0.5)	0.033	0.5 (0.4-0.6)	0.4 (0.3-0.5)	0.4 (0.3-0.5)	<0.001
Upper arm muscle circumference, cm, median (IQR)	22.6 (20.4-24.7)	21.0 (19.0-23.0)	<0.001	23.2 (20.7-25.0)	22.0 (20.1-24.1)	21.3 (18.9-23.3)	<0.001
Left calf circumference, cm, median (IQR)	33.3 (31.5-36.0)	31.0 (29.0-33.1)	<0.001	34.0 (32.0-36.0)	33.0 (31.0-35.0)	31.5 (29.0-33.5)	<0.001
Urea nitrogen, mmol/L, median (IQR)	5.0 (4.1-6.2)	4.9 (3.9-6.2)	0.327	4.9 (4.1-6.0)	5.2 (4.1-6.3)	4.9 (3.8-6.3)	0.314
Pre albumin, mg/dL, median (IQR)	224 (180-265)	171 (120-223)	<0.001	231.8 (198-277)	211.4 (161.5-259.8)	170.0 (110.0-221.3)	<0.001
WBC, 10^9, median (IQR)	6.2 (4.9-7.9)	6.9 (5.2-9.6)	<0.001	6.0 (4.9-7.6)	6.3 (4.9-8.1)	7.2 (5.3-9.8)	0.005
Neutrophil count, 10^9, median (IQR)	3.9 (2.9-5.5)	4.7 (3.4-7.4)	<0.001	3.7 (2.8-5.1)	4.1 (2.9-5.7)	5.3 (3.4-7.9)	<0.001
Lymphocyte count, 10^9, median (IQR)	1.5 (1.1-1.9)	1.4 (1.0-1.8)	0.001	1.6 (1.2-2.0)	1.5 (1.1-1.9)	1.2 (0.9-1.8)	<0.001

GLIM: Global Leadership Initiative on Malnutrition; IQR: interquartile range; BMI: body mass index; NRS-2002: Nutritional Risk Screening 2002; PG-SGA: Patient Generated Subjective Global Assessment; WBC: white blood cells. Statistical differences were obtained using Pearson's Chi square (X^2) test/Fisher's exact test for categorical variables and the Mann Whitney test for continuous variables.

Table 3. Diagnostic performance according to the Bayesian latent class model

Tools and parameters	Mean	SD	MC error	Median	95% CrI
GLIM criteria					
Sensitivity	0.85	0.04	0.000594	0.85	0.76, 0.92
Specificity	0.88	0.06	0.000804	0.89	0.73, 0.97
NRS-2002					
Sensitivity	0.74	0.03	0.000465	0.74	0.68, 0.80
Specificity	0.85	0.02	0.000320	0.85	0.81, 0.89
PG-SGA					
Sensitivity	0.96	0.02	0.000276	0.96	0.91, 0.99
Specificity	0.89	0.04	0.000626	0.90	0.81, 0.96
Prevalence	0.56	0.13	0.00185	0.56	0.30, 0.80

GLIM: Global Leadership Initiative on Malnutrition; NRS-2002: Nutritional Risk Screening 2002; PG-SGA: Patient Generated Subjective Global Assessment; CrI: credible interval; SD: standard deviation; MC: Monte Carlo.

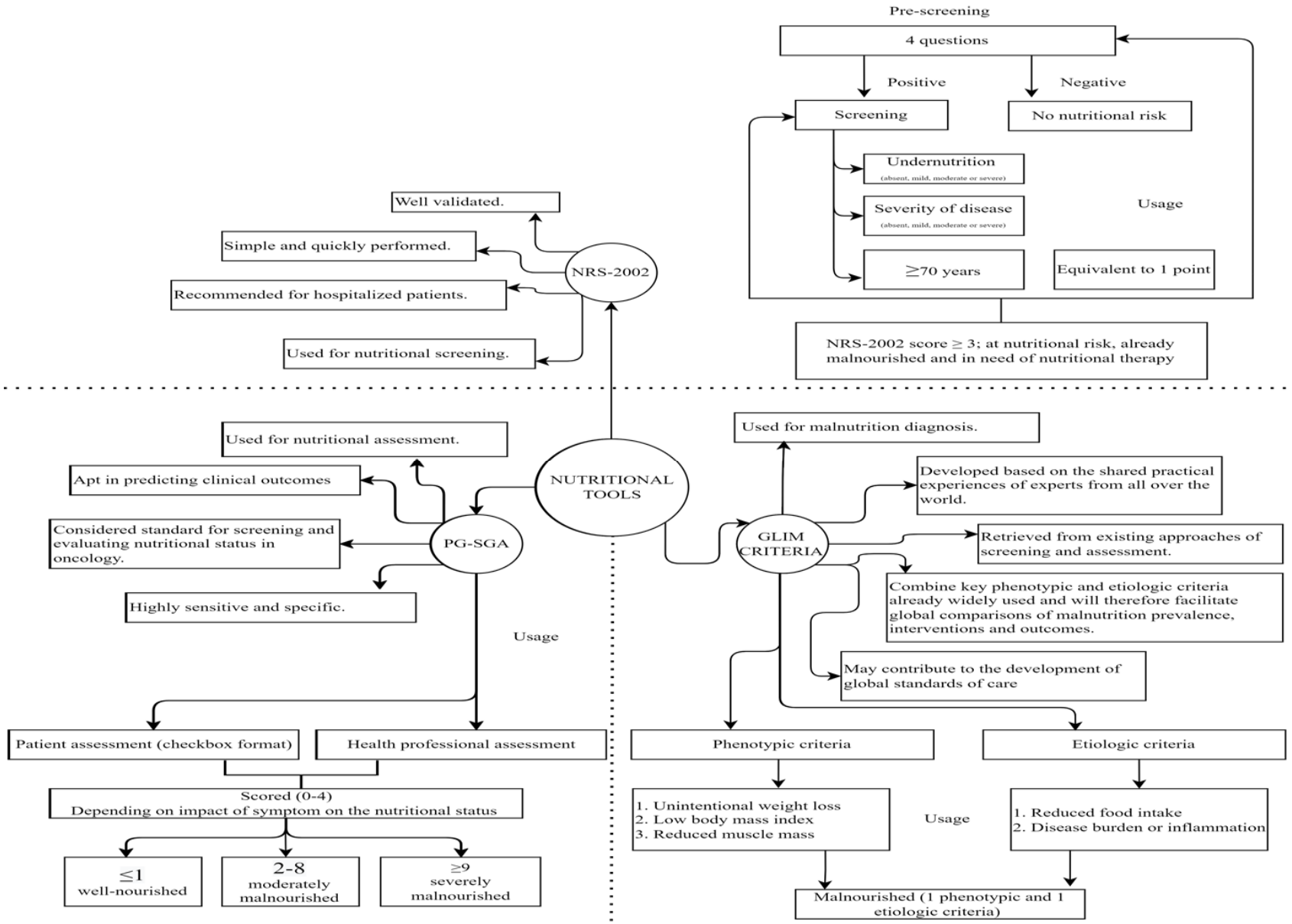

Figure 2. Conceptual diagram of the evaluated nutritional tools. NRS-2002: Nutritional Risk Screening 2002; PG-SGA: Patient Generated Subjective Global Assessment; GLIM: Global Leadership Initiative on Malnutrition.

sence of a gold standard, the BLCM has been shown to be an acceptable approach for validation. This is because inferring measures of test accuracy or prevalence in the target population does not require knowledge of the true disease condition of the sampled individuals.[37] Additionally, the large sample size ensures that the margin of error is minimized and an ideal approach for determining RMM (CC and HGS/W) was applied as previously described.[8] Furthermore, reporting partly adhered to the 2015 Standards for Reporting Diagnostic Accuracy Studies (STARD-BLCM) requirements and will therefore facilitate future systematic reviews and meta-analyses.[42]

When evaluating these findings, the following limitations should be considered. RMM was assessed using anthropometric measurements rather than body composition analyses, which might have contributed to misclassification.[8] Furthermore, because there have been few investigations on the validation statistics of the GLIM criteria in lung cancer patients, interstudy comparisons were somewhat more challenging.

For more accurate diagnostic performance results, we advocate for the establishment of prospective studies developed exclusively for evaluating these tools utilizing the BLCM. The findings of this study could serve as a foundation for future research in low- and middle-income nations like Uganda, where cancer-associated malnutrition is not well reported.

Conclusion

In conclusion, the PG-SGA remains the best instrument for assessing cancer-associated malnutrition. Furthermore, the GLIM criteria met the needed sensitivity (> 80%) and specificity (> 80%), implying that the GLIM criteria are likewise suitable for identifying well-nourished or malnourished persons in this patient group,43 and may thus be useful for malnutrition diagnosis. The NRS-2002 was best suited to screen out patients who were not at nutritional risk.

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AUTHOR DISCLOSURES

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