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Original Article

Relative validity of surrogate measures within the global leadership initiative on malnutrition (GLIM) phenotypic criteria for diagnosing adult malnutrition in resource-constrained settings

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ABSTRACT

Background and aim: Implementing the Global Leadership Initiative on Malnutrition (GLIM) diagnostic criteria may improve adult malnutrition identification. Some GLIM parameters are challenging to obtain in resource-constrained settings. We assessed the relative validity of accessible surrogates in substituting accepted phenotypic diagnostic criteria within GLIM.
Methods: In a prospective diagnostic accuracy study, adult ambulatory patients with diverging diagnoses from five South African hospitals were consecutively sampled. The Malnutrition Universal Screening Tool (MUST score$\geq$1) and GLIM diagnostic criteria determined malnutrition risk and diagnosis respectively. Surrogates investigated for appendicular skeletal muscle mass index (ASMMI), measured by multifrequency bio-electrical impedance, were mid-upper arm circumference (MUAC) and body mass index-adjusted calf circumference (CC). Pearson correlation coefficients, receiver operating characteristics curve analysis, Youden's index, sensitivity (Se), specificity (Sp), and Cohen's kappa were used.
Results: Among 480 patients screened (51% male; mean age: 47.03 years, SD 14.87), 73% ($n = 350$) were at malnutrition risk. Of these,

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54% ($n = 189$) were malnourished (GLIM criteria). MUAC and CC moderately correlated with ASMMI ($r = 0.645$; $P<0.001$ and $r = 0.515$; $P<0.001$ respectively). Optimal cut-offs for surrogates, with corresponding diagnostic accuracy, were: MUAC for ASMMI: 24.9 cm (area under the curve (AUC) = 0.857, Se = 85%, Sp = 74%) and CC for ASMMI: 29.1 cm (AUC = 0.819, Se = 73%, Sp = 83%). Substituting MUAC and CC for ASMMI at study-specific cut-offs - within the GLIM phenotypic criteria - was relatively valid (MUAC: kappa = 0.925, Se = 100%, Sp = 91%; CC: kappa = 0.849, Se = 100%, Sp = 91%).

Conclusion: Within GLIM and using the reported cut-offs, MUAC reflects ASMMI. BMI-adjusted CC can replace low skeletal muscle mass. Valid, easy-to-use surrogates may enhance the feasibility of the GLIM diagnostic framework, particularly where resources are constrained.

Introduction

The severity and prevalence of disease-related malnutrition (DRM) have been identified as significant parameters in disease outcomes [1–4]. Yet the diagnosis thereof remains a considerable challenge across healthcare settings, particularly among non-nutritional healthcare professionals and in settings with constrained resources [2,5,6]. It is therefore likely that many malnourished patients remain unidentified, thus not receiving the necessary nutritional care, intensifying their risk of increased morbidity, mortality, and a decreased quality of life [7].

The Global Leadership Initiative on Malnutrition (GLIM) has proposed a diagnostic framework to standardise the global diagnosis of adult malnutrition (undernutrition) and enable the comparison across clinical and geographical settings [8]. This diagnostic framework consists of a two-step process, starting with nutritional screening using any validated screening tool. A more comprehensive assessment follows in those identified to be at risk of malnutrition. A malnutrition diagnosis requires at least one phenotypic criterion and one etiologic criterion. The severity grading is determined using pre-defined cut-off values of the phenotypic criteria [8].

A recent scoping review [9] found that hospital malnutrition prevalence in Africa (8–85%) or the risk thereof (23–74%) falls at the upper end of the global range (20–50%) [10]. The wide variation in reported prevalence has been attributed to factors such as differences in patient populations, diagnostic tools, and cut-off values used for anthropometric and other measures [9,11,12]. Despite challenges in directly comparing studies—and the overall scarcity of data on hospital malnutrition in Africa—it is clear that a significant proportion of hospitalized patients remain vulnerable to its adverse clinical outcomes.

In resource-constrained settings, like South Africa, the lack of implementation of valid screening and diagnostic tools for adult malnutrition poses a significant risk to the health and well-being of patients. Failure to adopt and implement these may lead to the presence of malnutrition being undetected, depriving individuals of the essential nutritional support required. This not only heightens the probability of negative outcomes associated with malnutrition, but also infringes upon patients' fundamental rights to food, health and nutritional care [13,14]. The systematic use of a malnutrition diagnostic framework could lead to timely detection and treatment of malnourished patients, assist with the compilation of a reliable adult malnutrition registry, a more robust comparison with regional and global adult malnutrition prevalence data, as well as evaluating outcomes from malnutrition intervention studies [15].

However, aspects required for the GLIM criteria have previously been reported as problematic to obtain owing to limited resources which may hamper their implementation, particularly by non-nutritional healthcare professionals. This includes, but is not limited to the availability of equipment such as scales and stadiometers, shortage of staff to obtain and record measurements, and competency in basic anthropometrical skills [16–18]. Obtaining BMI is often challenging due to the lack of weight and height measurements at ward level, poor documentation in medical files, and reduced mobility or mental status of patients [16–19]. Identifying a low skeletal muscle mass (SMM) has also been reported challenging to obtain, especially in settings that lack access to skilled clinical nutrition practitioners and specialised body composition methods [20]. The GLIM body composition working group recommends the use of bioelectrical impedance analysis (BIA), dual-energy x-ray absorptiometry (DXA), and computerized tomography (CT) for its measurement [20]. Should these methods not be available, the use of anthropometric measures like calf circumference and mid-upper arm circumference (MUAC) is supported [20].

In resource-constrained settings, easy-to-use, surrogate measures within the GLIM criteria, which can be quickly performed and do not require specialized equipment, may assist in the implementation of malnutrition screening and diagnosis, particularly by non-nutritional healthcare professionals. The aim of this study was therefore to determine the relative validity of MUAC and BMI-adjusted CC as surrogates for a low SMM within the GLIM phenotypic criteria.

Material and methods

Study design and population

A prospective diagnostic accuracy study was conducted in five urban hospitals within the Eastern Cape province, South Africa. Consecutive sampling was used in all patients above 18 years of age admitted to the medical, surgical and oncology wards, who were conscious, able to communicate, and could stand unassisted for anthropometrical measurements. Exclusions included pregnancy, severe psychological or neurological disorders, fluid imbalances, pacemakers, joint prostheses, or admission to critical care, orthopaedic, or burns units. Assuming a 30% malnutrition risk [5], 5% margin of error, and 95% confidence level, a minimum sample of 336 participants was required; 350 were recruited to allow for attrition. The sample reflected national hospital utilization (84% public, 16% private) [21]. Ethical approval was obtained from Stellenbosch University (S19/10/201), and institutional permissions and written informed consent were secured.

Data collection

Between March 2020 and February 2022, three trained dietitians collected data using standardized procedures and researcher-administered questionnaires on demographic, clinical, and nutritional variables. Malnutrition risk was assessed with the Malnutrition Universal Screening Tool (MUST) [22]; participants at risk (MUST >1) underwent a full GLIM-based malnutrition diagnostic assessment. Phenotypic criteria included BMI, muscle mass, and weight loss; etiologic criteria included reduced intake/assimilation and inflammation. Anthropometry followed NHANES protocols [22] using SECA (Hamburg, Germany) calibrated equipment (scale: SECA 876; stadiometer: SECA 213, and BIA for SMM: SECA mBCA 525). Mid-upper arm (MUAC) and calf circumference (CC) were measured to 0.1 cm using non-stretchable tape. MUAC was taken at the midpoint between the acromion and olecranon with the arm relaxed; CC was measured at maximal girth while seated. Measurements were taken twice (or thrice if discrepant), with the mean recorded [23].

A clinical exam identified oedema, ascites, or amputations. Dietary intake was recorded as a self-reported proportion of the prescribed diet, including oral, enteral, or parenteral nutrition. Inflammatory markers included C-reactive protein (CRP), body temperature, and white cell count (WCC) [24,25], which were collected prior to the publication of the GLIM guidance paper on the assessment of the inflammation etiologic criterion [26].

Data management

Malnutrition was diagnosed as per GLIM when ≥1 phenotypic and ≥1 etiologic criterion were present. BMI was calculated as weight (kg)/height^2 (m^2)^{a,b}, and appendicular skeletal muscle mass index (ASMMI) as ASMM (kg)/height^2 (m^2). Adjustments were made for mild oedema (−1 kg) and ascites (−2.2 kg) [27]. Inflammation was defined by elevated CRP, body temperature, or WCC (Table 1).

To account for adiposity, CC was adjusted for BMI [30]: −3 cm for BMI 25–29.9 kg/m^2, −7 cm for BMI 30–39.9 kg/m^2, and −12 cm for BMI ≥ 40 kg/m^2. No adjustment was applied to normal or underweight BMI. For the severity grading of malnutrition, patients were classified as either moderately or severely malnourished, using GLIM criteria [8]. Only BMI and weight loss were used, as cut-offs for low muscle mass severity remain undefined [8].

Statistical analysis

Microsoft® Excel® and IBM® SPSS® Advanced Statistics 28.0 were used to capture and analyse the data, respectively.

Associations between continuous response variables (e.g. BMI, MUAC, CC, ASMMI) and nominal input variables (e.g. sex) were assessed using independent t-tests, contingency tables, and Pearson chi-square tests. Significance was set at $P < 0.05$.

Pearson correlation coefficients (r) quantified associations between MUAC and BMI-adjusted CC for ASMMI with correlation values interpreted as follow: 0.9–1: very high, 0.7–0.9: high, 0.5–0.7: moderate, 0.3–0.5: low, and 0.0–0.3: negligible [32]. Receiver operating characteristic (ROC) analyses assessed the accuracy of these surrogates against ASMMI as reference standard. Area under the curve (AUC) >0.8 denoted very good accuracy [33]. Optimal cut-offs were identified using Youden's index, and validation statistics [sensitivity (Se), specificity (Sp), positive (PPV) and negative predictive values (NPV)] were reported as percentages, with >80% considered strong [34]. Both the optimal cut-off derived (to the closest 0.1 cm) and its corresponding rounded value (RV) (to the nearest whole number) are reported.

GLIM-based malnutrition diagnosis substituting each surrogate individually (MUAC, BMI-adjusted CC) was compared to the original GLIM diagnosis using cross-tabulations and corresponding validation statistics. Cohens kappa determined the extent of convergence between the alternative and original malnutrition classifications.

Table 1
Cut-off points used in the study

Indicator	Cut -off points
Low BMI	<20 kg/m^2 if <70 years <22 kg/m^2 if ≥70 years [8]
Low ASMMI	<7 kg/m^2 in males <5.7 kg/m^2 in females [28]
Significant weight loss	>5% within the past 6 months or >10% beyond 6 months [8].
Low MUAC	<23 cm [16,29]
Low BMI-adjusted CC	<33 cm in males <32 cm in females [30,31]
Reduced dietary intake	≤50% of prescribed diet for more than a week, or any reduction beyond 2 weeks [8]
Increased CRP	≥10 mg/l [24,25]
Increased body temperature	≥37.5 °C [25]
Increased WCC	≥11 x 10^9/l [24]

Abbreviations used: BMI: body mass index; ASMMI: appendicular skeletal muscle mass index; MUAC: mid-upper arm circumference; CC: calf circumference; CRP: C-reactive protein; WCC: white cell count. a.GLIM cut-offs were applied for the diagnosis of malnutrition). [8] b. WHO cut-offs were used to describe anthropometric characteristics. [35].

Results

Study population and sample

A total of 697 participants were evaluated for eligibility for the study. Of these, 217 participants were ineligible or did not provide consent. This left 480 participants to be screened for malnutrition risk. Of these, 350 (73%) had a score of $\geq$1 (MUST score = 1: n = 160, 33%; MUST score $\geq$2: n = 190, 40%) and included in the final study sample (Figure 1). According to the GLIM criteria, more than half of the final sample (n = 189, 54%) were diagnosed with malnutrition, with no significant difference between males (56%, n = 101) and females (51%, n = 88; P = 0.352). However, over one-third (35%, n = 121) met the threshold for severe malnutrition, with a significantly higher prevalence among males (43%) compared to females (26%; P<0.001).

The mean age of participants was 47.03 years (SD 14.87, range 18–80); 51% (n = 179) were male, and majority (n = 294, 86%) admitted to public hospitals. Most participants in the final study sample were from medical wards (n=183, 53%), followed by surgical wards (n = 140, 40%), while 27 (7%) were from oncology wards. The most common diagnosis categories were gastroenterology (13%), infectious diseases (tuberculosis and HIV) (13%), oncology (including haematology) (13%) and respiratory disease (11%). Oedema was present in 42 participants (12%), of whom two also presented with ascites. A further three participants (<1%) had ascites without evidence of oedema, and seven participants (2%) had lower limb amputations. Weight adjustments were applied accordingly.

Anthropometric characteristics

The anthropometric characteristics of the final study sample, stratified by sex, are summarized in Table 2. Males had significantly lower mean BMI, MUAC, and calf circumference compared to females. Overall, more than a quarter of the sample (n = 94; 27%) was underweight, while 36% (n = 128) were classified as overweight or obese.

Males had a significantly higher mean ASMMI than females and nearly a third of the sample (30%, n = 52) had low ASMMI values. ASMMI measurements were obtainable in only half of the final study sample (n = 175). Of these, 24 (14%) presented with oedema or ascites (mild oedema: n = 20, moderate oedema: n=2, mild oedema and ascites: n=1, and ascites only: n=1). Oedema (mild: n=3, moderate: n=1) was present in four participants (2%) with a low ASMMI. The primary reasons for missing data were BIA error readings (n = 61; 35%) and the inability to access patients' hands or feet for electrode placement (n = 63, 36%), i.e., it being covered with bandages or plasters. Additional patient-related factors included reported discomfort or pain (n = 11), the presence of a pacemaker (n = 1), drowsiness (n = 2), or patients leaving the ward for medical procedures or investigations (n = 2).

Relative validity of MUAC and calf circumference (CC) as surrogates for a low ASMMI

A moderate positive correlation (r = 0.645, P<0.001, n = 175) existed between MUAC and ASMMI. From the ROC curve analysis, MUAC displayed a very good diagnostic accuracy as a surrogate for a low muscle mass compared to ASMMI, with the area under the curve (AUC) determined at 0.86 as illustrated in Figure 2.

Based on Youden's' index of 0.594, the optimal MUAC cut-off values to identify a low muscle mass in the final study sample was 24.9 cm (rounded value 25 cm), with a Se of 85% and Sp of 74%, as summarized in Table 3. The optimal cut-off for males was 24.9 cm and 24.7 cm for females, with a rounded value of 25 cm suggested for both groups.

A moderate level of correlation was also found between BMI-adjusted CC as an indicator of low muscle mass, and ASMMI (r = 0.515, P <0.001, n = 174). The BMI-adjusted CC as a surrogate for a low ASMMI displayed a very good diagnostic accuracy, with the AUC under the ROC curve determined at 0.82 (males: 0.84, females: 0.79) as shown in Figure 2 and Table 3. Based on the Youden's Index of 0.560, the optimal BMI-adjusted CC cut-off value to identify a low muscle mass was calculated at 29.1 cm (rounded value 29 cm). This cut-off corresponded with a Se of 73%, a Sp of 83%, PPV of 64% and NPV of 88% when compared with a low ASMMI. For males, the optimal CC cut-off point was determined at

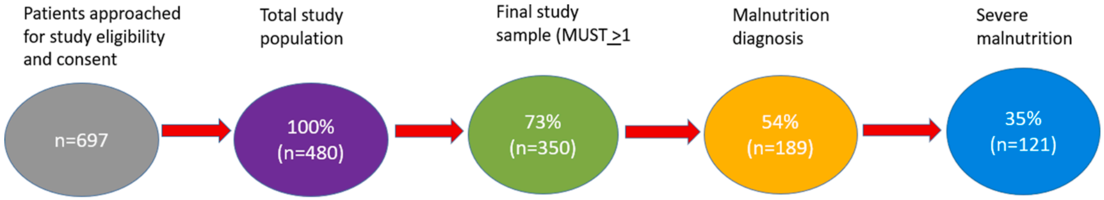

Figure 1. Malnutrition risk and diagnosis according to the Global Leadership Initiative on Malnutrition (GLIM) criteria
Abbreviation used: MUST: Malnutrition Universal Screening Tool.

Table 2
Anthropometric characteristics of the final study sample by sex

	Final study sample	Sex		*P*-value sex
		Males	Females	
BMI ($kg/m^{2)}$) Mean (±SD) n = 350	23.7 ±7.2	21.5±5.4	26.20±8.0	**<0.001**[a]
Underweight[c] *n* (%)	94 [27]	62 (35)	32 (19)	**<0.001**[b]
Normal weight[c] *n* (%)	128 [37]	73 (41)	55 (32)	
Overweight and obese[c] *n* (%)	128 [36]	44 (25)	84 (49)	
MUAC (cm) Mean (±SD) n = 347	27.2±5.8	26.1±4.8	28.5 ±6.4	**<0.001**[a]
Low MUAC[d] (cm) *n* (%)	87 [25]	48 (27)	39 (23)	0.403[b]
Normal MUAC[d] *n* (%)	262 (75)	131 (73)	131 (77)	
Measured CC (cm) Median [95% CI] n = 349	32.3 [32.0, 33.2]	31.3 [30.9, 32.5]	33.6 [32.7, 34.5]	**0.002**[a]
Low measured CC[e] *n* (%)	176 (50)	90 (50)	86 (50)	0.998[b]
Normal measured CC[e] *n* (%)	174 (50)	89 (50)	85 (50)	
BMI-adjusted CC (cm) Median [95% CI] n = 349	30.4 [30.2, 31.1]	30.6 [30.0, 31.2]	30.8 [30.1, 31.4]	0.706[a]
Low BMI-adjusted CC[e] *n* (%)	221 (63)	111 (62)	110 (64)	0.653[b]
Normal BMI-adjusted CC[e]; *n* (%)	129 [37]	68 (38)	61 (36)	
ASMM (kg) Mean (±SD) n = 175	21.1±13.2	22.7 ±6.6	17.4±5.8	**<0.001**[a]
ASMMI (kg/m^2) Mean (±SD) n = 175	7.4 ±2.2	7.9±2.2	6.9±2.1	**0.002**[a]
Low ASMMI[f] *n* (%)	52 [30]	28 (31)	24 (28)	0.607[b]
Normal ASMMI[f] *n* (%)	123 (70)	61 (69)	62 (72)	

Abbreviations: ASMM: appendicular skeletal muscle mass, ASMMI: appendicular skeletal muscle mass index BMI: body mass index; CC: calf circumference MUAC: mid-upper arm circumference; SD: standard deviation.
Bold values: $P<0.05$.

[a] Independent t-test.

[b] Pearson χ^2.

[c] Classification of BMI: Underweight <18.5 kg/m^2, normal weight 18.5–24.9 kg/m^2, overweight 25–29.9 kg/m^2, obese >30 kg/m^2 [35]. *Cut-offs*.

[d] low mid-upper arm circumference: <23 cm [16,29].

[e] low calf circumference: males<33 cm; females<32 cm [20,30]).

[f] low ASMMI: males<7 kg/m^2, females <5.7 kg/m^2 [28].

29.4 cm with a Se of 75% and a Sp of 84%. For females, the optimal cut-off point was only slightly lower at 29.1 cm, with a Se 75%, and Sp 80%, with a rounded value of 29 cm for both groups.

Relative validity of adapted GLIM using surrogates at optimally determined cut-offs for its phenotypic criteria, in comparison with the original GLIM criteria

The relative validity of using surrogates for a low muscle mass, including MUAC and CC, at the respective cut-offs determined, within the GLIM phenotypic criteria, was evaluated against the use of ASMMI, to diagnose malnutrition (Table 4). The adapted GLIM, substituting ASMMI with a MUAC cut-off value of 24.9cm to indicate low muscle mass, identified 58% ($n = 202$) of the sample with malnutrition, compared with 54% ($n = 189$) using the original GLIM criteria. A substantial agreement was found between these two methods (Cohen's kappa = 0.925), with a Se = 100%, Sp = 92%, PPV = 94% and NPV = 100%. Substituting ASMMI with CC (cut-off value, adjusted for BMI, of 29.1 cm), identified 61% ($n = 215$) of the sample as malnourished, also with a substantial level of agreement (Cohen's kappa = 0.849). This method resulted in Se = 100%, Sp = 84% PPV = 88% and NPV = 100%. Neither method resulted in any false negative results.

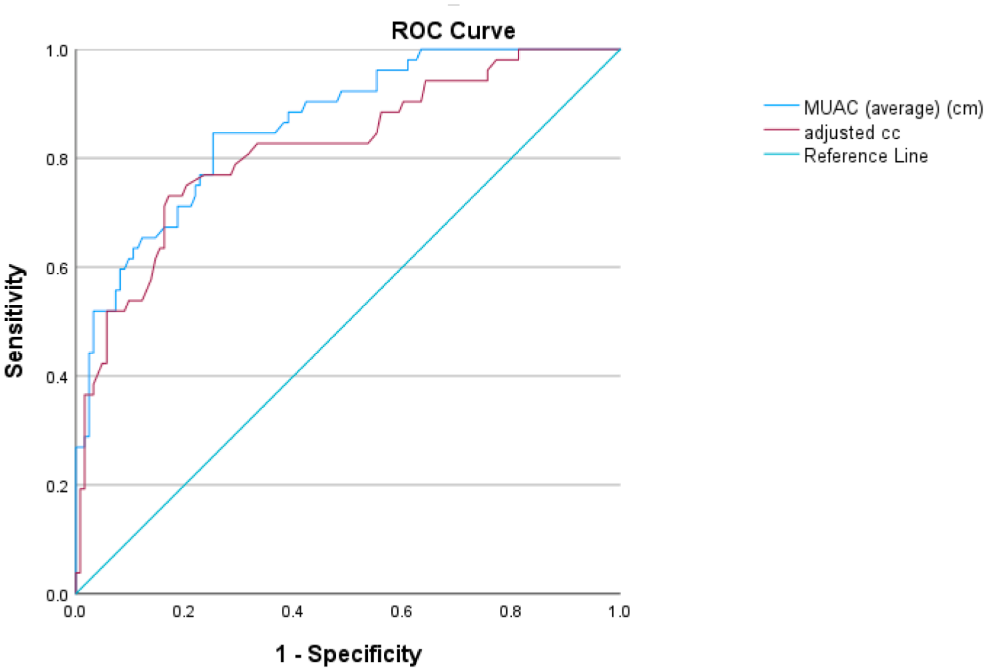

Figure 2. ROC curves for MUAC and BMI-adjusted CC to identify a low appendicular skeletal muscle mass index (ASMMI)
Abbreviations used: ROC: receiver operating curve; MUAC: mid-upper arm circumference; CC: calf circumference, AUC: area under the curve.

Table 3
Optimal cut-off values determined for mid-upper arm circumference (MUAC) and BMI-adjusted calf circumference to identify a low appendicular skeletal muscle mass index (ASMMI) stratified by sex

	Optimal cut-offs (cm)	Se (%) [95% CI]	Sp (%) [95% CI]	PPV (%) [95% CI]	*NPV (%) [95% CI]*	YI	AUC
MUAC							
Final study sample (n = 175)	24.9 RV 25	85 [71, 93]	74 [65, 81]	58 [46, 69]	92 [84, 96]	0.594	0.857
Male (n = 89)	24.9 RV 25	89 [71, 97]	70 [57, 81]	58 [42, 73]	93 [81, 98]	0.598	0.848
Female (n = 86)	24.7 RV 25	79 [57, 92]	79 [66, 88]	59 [41, 76]	91 [79, 97]	0.582	0.867
Calf circumference (BMI-adjusted in overweight or obese individuals)							
Final study sample (n = 174)	29.1 RV 29	73 [59–84]	83 [75–89]	64 [51–76]	88 [80–93]	0.560	0.819
Male (n = 89)	29.4 RV 29	75 [55–89]	84 [71–91]	68 [49–83]	88 [76–95]	0.586	0.843
Female (n = 86)	29.1 RV 29	75 [53–89]	81 [68–89]	60 [41–77]	89 [77–96]	0.582	0.793

Optimal cut-offs determined with ROC analysis and Youden's index representing an ASMMI <7 kg/m^2 in males, and <5.7 kg/m^2 in females [28].
Abbreviations used: RV: rounded value, PPV: positive predictive values, NPV: negative predictive values, YI: Youden's index; AUC: area under the curve, ROC: receiver operating curve, Se: sensitivity, Sp: specificity, cm: centimetre.

Table 4
Relative validity of an adapted GLIM employing surrogates at optimally determined cut-offs for its phenotypic criteria, in comparison with the original GLIM criteria

	Cohen's kappa	Malnourished (adapted GLIM) *n* (%)	Tp *n*	Fp *n*	Fn *n*	Tn *n*	Se (%) [95% CI]	Sp (%) [95% CI]	PPV (%) [95% CI]	NPV (%) [95% CI]
Substituting ASMMI with MUAC[a] (*n* = 350)	0.925	202 (58)	189	13	0	148	100 [98, 100]	92 [86, 95]	94 [89, 96]	100 [97, 100]
Substituting ASMMI with BMI-adjusted CC[b] (*n* = 350)	0.849	215 (61)	189	26	0	135	100 [98, 100]	84 [77, 89]	88 [83, 92]	100 [97, 100]

Optimal cut-offs used determined in study.
Abbreviations used: ASMMI: appendicular skeletal muscle mass index; BMI: body mass index; MUAC: mid-upper arm circumference; CC: calf circumference; GLIM: Global Leadership Initiative on Malnutrition; Se: sensitivity, Sp: specificity, PPV: positive predictive values, NPV: negative predictive values, Tp: true positive, Fp: false positive, Fn: false negative, Tn: true negative.
[a] MUAC to substitute low ASMMI: <24.9 cm.
[b] BMI-adjusted CC: <29.1 cm.

Discussion

Drawing on data from a South African hospitalized adult sample, this study demonstrates good diagnostic accuracy when ASMMI is replaced with surrogate markers within the GLIM phenotypic criteria, findings that should be interpreted within this local clinical context. We found that MUAC can accurately replace a low ASMMI within the GLIM context. The MUAC cut-off value of 24.9 cm slightly exceeds the proposed MUAC cut-off of 23.5 cm by Azman *et al.* [36]. The lower positive predictive value (PPV) may be explained by the slightly higher proportion of patients identified by MUAC as having a low SMM, compared with the reference method (ASMMI measured by BIA) [37]. In addition, PPVs may also be influenced by the prevalence of the disease (i.e., malnutrition) in the study population [33]. MUAC is relatively easy to measure, requires little equipment and few calculations, is transportable and inexpensive [29]. Furthermore, MUAC is less affected by fluid retention, compared with the lower extremities [38], which makes this surrogate an attractive option to identify a low muscle mass in the clinical setting. To facilitate ease of use in the clinical setting, the MUAC rounded value of 25 cm is proposed to identify a low muscle mass within the GLIM phenotypic criteria.

The moderate correlation observed between BMI-adjusted CC and ASMMI, concurs with the findings of Santana *et al.* ($r = 0.592$) [39], Gonzales *et al.* (males: $r = 0.84$, females: $r = 0.86$) [30] and Kawakami *et al.* (males: $r = 0.81$, females: $r = 0.73$) [40]. Notably, measured CC was used in their studies, and not BMI-adjusted CC as was done in this study. Similar to MUAC, BMI-adjusted CC, at a cut-off of 29.1 cm (males 29.4. cm, females 29.1 cm) demonstrated a very good diagnostic accuracy as a surrogate for a low ASMMI. The optimal CC cut-offs in our study are similar to those determined by Gonzalez *et al.* (males: 32 cm; females: 31 cm; based on -2 SD for severely low muscle mass) [30], Erdoğan *et al.* (males: 31 cm; females: 30 cm; based on classification for severely low muscle mass) [41], as well as the recommended 31 cm cut-off point recommended by the World Health Organi**z**ation (WHO) for older people [42]. The cut-off is however lower than those proposed by the Asian Working Group for Sarcopenia (2019) (males<34cm; females<33cm) [28]; Kawakami *et al.* (males<35 cm; females<33 cm) [40], Gonzalez *et al.* [(-1SD) males<34 cm; females<33 cm] [30] and Champaiboon *et al.* (males: 34 cm; females: 33 cm) [43]. The lower CC cut-off points observed in this study compared with the latter studies may be attributed to various factors, including differences in study design and populations under study. Notably, all the aforementioned studies relied on normative population data generally characterised by a lower prevalence of low muscle mass, and focused on cohorts from Asian regions and the United States. As this study was conducted in hospitalized patients, the lower CC cut-off points may also reflect a lower muscle mass attributed to factors previously referred to, i.e., immobility, disease-related inflammation and a poor dietary intake. The use of BMI-adjusted CC to minimize the impact of obesity, as opposed to measured CC, may further explain the lower cut-offs points in this study compared with some other studies. As a lower extremity, the use of CC is gaining popularity as a marker for SMM. The calf region is composed of a skinfold, subcutaneous fat, and bone in addition to muscle. A notable advantage of CC is its relatively lower proportion of fat compared with upper extremities like MUAC, thereby mitigating the impact of fat mass on its utility as a surrogate for SMM [41]. Nevertheless, CC is more susceptible to the effects of fluid retention than MUAC [38]. Although oedema was present, it affected only a small minority of participants (12%); however, its occurrence may still have contributed to overestimation of BMI-adjusted CC in this subgroup and could partly account for the lower diagnostic accuracy of CC compared with MUAC.

Similar to MUAC, measuring CC is simple, cost-effective, and minimally invasive, requiring little to no undressing [40,44]. To enhance the practicality of use in the clinical setting, the BMI-adjusted CC rounded value of 29 cm for both males and females is proposed to identify a low muscle mass within the GLIM phenotypic criteria.

All the above surrogate measures led to a somewhat overdiagnosis of malnutrition, when used within the GLIM phenotypic criteria, compared to the original proposed criteria, which is attributed to the slightly higher false positives identified with each of these methods. Nevertheless, considering clinical, cost-effective, and ethical considerations, it may be better to adopt a more inclusive approach, erring on the side of caution by identifying patients who may have been incorrectly diagnosed with malnutrition, rather than overlooking malnourished patients and the adverse outcomes they may face as a result.

Female patients had a significantly higher mean MUAC and median CC compared with males, which may be explained by the higher BMIs observed in the females, generally associated with higher levels of adiposity. To minimize the impact of adiposity on CC as an indicator of muscle mass, measurements were adjusted for BMI as per the recommendations by Gonzalez *et al.* [30], after which the difference between males and females was no longer significant. The proportion of patients with a low CC became notably distinct when CC was adjusted for BMI. Similar adjustments to minimize the impact of adiposity on MUAC as a marker of muscle mass may also be beneficial, though this requires further investigation. A low SMM was observed in almost a third of the final study sample, which is similar to the 32% reported by Brito *et al.*, using CC or adductor pollicis muscle thickness of the dominant hand [45]. It was slightly lower than the 39% reported by Clark *et al.* [46] measured with BIA, which is likely attributed to the higher cut-offs used in their study (females<6.76 kg/m^2 and males<10.75 kg/m^2), proposed by Janssen *et al.*, in 2004 [47]. Since only mobile patients were included in this study, the proportion of the sample that presented with a low muscle mass might be lower than if immobile patients were also included, owing to the negative impact of immobility on muscle mass [48].

In accordance with prior African research findings, this study found a high proportion of the study population to be malnourished, or at risk thereof [6,16]. As with a low muscle mass, the occurrence of malnutrition may be even higher in the population studied, considering the exclusion of certain vulnerable demographics such as unconscious or bedridden individuals, who may inherently face an elevated risk of malnutrition. This underscores the importance of timely detection and treatment of malnourished patients to uphold their fundamental right to health and nutritional care. However, the effective implementation of globally accepted malnutrition frameworks, such as the GLIM criteria, may be challenging in resource-constrained settings. In such contexts, the use of valid surrogate measures within diagnostic frameworks can play a complementary role, facilitating malnutrition screening and diagnosis when standard measurements are not feasible. Notably, the surrogate cut-offs in this study were derived from hospitalised patients in five South African hospitals in the Eastern Cape province and may not be generalisable to other settings or populations. The proposed surrogates are intended for use by non-nutritional healthcare professionals, but their reliability and validity in this context require further verification through larger studies.

Conclusion

The use of MUAC and BMI-adjusted CC as surrogates for low SMM presents opportunities for implementing the GLIM in comparable resource-constrained hospital settings where many patients are at risk of malnutrition amid a high prevalence of overweight/obesity and limited availability of staff skilled in nutrition assessment.

Author contributions

E. van Tonder: Conceptualization, methodology, investigation, data curation, writing - original draft, project administration, funding acquisition.

R. Blaauw: Conceptualization, methodology, writing - review & editing, supervision.

F.A.M. Wenhold: Conceptualization, methodology, writing - review & editing, supervision.

T.M. Esterhuizen: Formal analysis, validation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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