AIWW: a new nutrition-screening tool for the oncologic population

Yi-Zhong Ge[1,2,3,4,5†], Zhen-Ming Fu[6†], Qi Zhang[1,4,5,7†], Meng-Meng Song[1,3,4,5], Guo-Tian Ruan[1,3,4,5], Xi Zhang[1,3,4,5], Xiao-Wei Zhang[1,3,4,5], Xiang-Rui Li[1,3,4,5], Kang-Ping Zhang[1,3,4,5], Meng Tang[1,3,4,5], Xiao-Yue Liu[1,3,4,5], Ming Yang[1,3,4,5], Tong Liu[1,3,4,5], Hai-Lun Xie[1,3,4,5], He-Yang Zhang[1,3,4,5], Zi-Wen Wang[1,3,4,5], Chun-Lei Hu[1,3,4,5], Shi-Qi Lin[1,2,3,4,5], Rui Zhang[6], Hong-Xia Xu[8], Wei Li[9], Chun-Hua Song[10], Ming Liu[11], Jun-Qiang Chen[12], Kun-Hua Wang[13,14], Li Bo[15], Ming-Hua Cong[16], Zeng-Ning Li[17], Zeng-Qin Guo[18], Xiao-Bin Wang[19], Bin-Yan Wang[20], Benjamin Xu[21], Xian-Hui Qin[22], Xi-Ping Xu[22,23], Rocco Barazzoni[24], Qing-Hua Yao[25], Min Weng[26], Xian Shen[27], Han-Ping Shi[1,2,3,4,5*] & The Investigation on Nutrition Status and Clinical Outcome of Common Cancers (INSCOC) Group

[1]*Department of Gastrointestinal Surgery/Department of Clinical Nutrition, Beijing Shijitan Hospital, Capital Medical University, Beijing 100038, China;*
[2]*The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, Wenzhou 325000, China;*
[3]*National Clinical Research Center for Geriatric Diseases, Xuanwu Hospital, Capital Medical University, Beijing 100053, China;*
[4]*Beijing International Science and Technology Cooperation Base for Cancer Metabolism and Nutrition, Beijing 100038, China;*
[5]*Key Laboratory of Cancer FSMP for State Market Regulation, Beijing 100038, China;*
[6]*Cancer Center, Renmin Hospital of Wuhan University, Wuhan 430060, China;*
[7]*Department of Colorectal Surgery, Cancer Hospital of University of Chinese Academy of Sciences, Zhejiang Cancer Hospital, Hangzhou 310022, China;*
[8]*Department of Clinical Nutrition, Daping Hospital, Army Medical University (Third Military Medical University), Chongqing 400042, China;*
[9]*Cancer Center of the First Hospital of Jilin University, Changchun 130021, China;*
[10]*Department of Epidemiology, College of Public Health, Zhengzhou University, Zhengzhou, 450001, China;*
[11]*Department of Colorectal Surgery, the Second Affiliated Hospital of Harbin Medical University, Harbin 150081, China;*
[12]*Department of Gastrointestinal Surgery, First Affiliated Hospital of Guangxi Medical University, Nanning 530021, China;*
[13]*Yunnan University, Kunming 650091, China;*
[14]*General Surgery Clinical Medical Center of Yunnan Province, Kunming 650032, China;*
[15]*Affiliated Hospital of Yunnan University, Kunming 650091, China;*
[16]*Comprehensive Oncology Department, Cancer Hospital, Chinese Academy of Medical Sciences, Beijing 100021, China;*
[17]*Department of Clinical Nutrition, The First Hospital of Hebei Medical University, Shijiazhuang 050031, China;*
[18]*Department of Medical Oncology, Fujian Cancer Hospital, Fujian Medical University Cancer Hospital, Fuzhou 350014, China;*
[19]*Department of Population, Family and Reproductive Health, Johns Hopkins University Bloomberg School of Public Health, Baltimore MD 21228, USA;*
[20]*Shenzhen Evergreen Medical Institute, Shenzhen 518052, China;*
[21]*Department of Epidemiology, Harvard T.H. Chan School of Public Health, Boston MA 02115, USA;*
[22]*National Clinical Research Center for Kidney Disease, State Key Laboratory for Organ Failure Research, Renal Division, Nanfang Hospital, Southern Medical University, Guangzhou 510515, China;*
[23]*Beijing Advanced Innovation Center for Food Nutrition and Human Health, College of Food Science and Nutritional Engineering, China Agricultural University, Beijing 100193, China;*
[24]*Department of Medical, Surgical and Health Sciences, University of Trieste, Trieste 34127, Italy;*

†Contributed equally to this work
*Corresponding author (email: shihp@ccmu.edu.cn)

[25]*Department of Integrated Chinese and Western Medicine, Cancer Hospital of University of Chinese Academy of Sciences, Zhejiang Cancer Hospital, Hangzhou 310022, China;*
[26]*Department of Clinical Nutrition, The First Affiliated Hospital of Kunming Medical University, Kunming 650091, China;*
[27]*Department of Gastrointestinal Surgery, the Second Affiliated Hospital of Wenzhou Medical University, Wenzhou 325000, China;*

Malnutrition is a common comorbidity among patients with cancer. However, no nutrition-screening tool has been recognized in this population. A quick and easy screening tool for nutrition with high sensitivity and easy-to-use is needed. Based on the previous 25 nutrition-screening tools, the Delphi method was made by the members of the Chinese Society of Nutritional Oncology to choose the most useful item from each category. According to these results, we built a nutrition-screening tool named age, intake, weight, and walking (AIWW). Malnutrition was defined based on the scored patient-generated subjective global assessment (PG-SGA). Concurrent validity was evaluated using the Kendall tau coefficient and kappa consistency between the malnutrition risks of AIWW, nutritional risk screening 2002 (NRS-2002), and malnutrition screening tool (MST). Clinical benefit was calculated by the decision curve analysis (DCA), integrated discrimination improvement (IDI), and continuous net reclassification improvement (cNRI). A total of 11,360 patients (male, n=6,024 (53.0%) were included in the final study cohort, and 6,363 patients had malnutrition based on PG-SGA. Based on AIWW, NRS-2002, and MST, 7,545, 3,469, and 1,840 patients were at risk of malnutrition, respectively. The sensitivities of AIWW, NRS-2002, and MST risks were 0.910, 0.531, and 0.285, and the specificities were 0.768, 0.946, and 0.975. The Kendall tau coefficients of AIWW, NRS-2002, and MST risks were 0.588, 0.501, and 0.326, respectively. The area under the curve of AIWW, NRS-2002, and MST risks were 0.785, 0.739, and 0.630, respectively. The IDI, cNRI, and DCA showed that AIWW is non-inferior to NRS-2002 (IDI: 0.002 (−0.009, 0.013), cNRI: −0.015 (−0.049, 0.020)). AIWW scores can also predict the survival of patients with cancer. The missed diagnosis rates of AIWW, NRS-2002, and MST were 0.09%, 49.0%, and 73.2%, respectively. AIWW showed a better nutrition-screening effect than NRS-2002 and MST for patients with cancer and could be recommended as an alternative nutrition-screening tool for this population.

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INTRODUCTION

Patients with cancer often experience poor physiological and biological functioning, reduced food intake, aging, frailty, and psychological distress. Malnutrition is a common condition among patients with cancer (Hu et al., 2021). Approximately 40%–80% of patients with cancer suffer from malnutrition (Gabrielson et al., 2013; Song et al., 2019). Malnutrition affects treatment effectiveness and is associated with increased morbidity and mortality, longer hospital stays, higher hospital costs, and a poor quality of life (Gellrich et al., 2015). Meanwhile, nutritional therapy reduces the risk of mortality, improves function, and promotes the quality of life of patients with cancer who are at risk of malnutrition (Bargetzi et al., 2021; Cai and Liu, 2021).

Nutrition screening is a step ahead of nutrition assessment and should be performed for all patients with cancer (Lacey and Pritchett, 2003). Approximately 32 screening tools have been established for different purposes, each one with its advantages and disadvantages (van Bokhorst-de van der Schueren et al., 2014). A quick and easy nutrition-screening tool with high sensitivity and appropriate specificity is needed in the cancer population. The patient-generated subjective global assessment (PG-SGA) is widely used in patients with cancer and is recognized as the gold standard assessment tool for patients with cancer by the Oncology Nutrition Dietetic Practice Group of the Academy of Nutrition and Dietetics (Boléo-Tomé et al., 2012; Jager-Wittenaar and Ottery, 2017). However, the PG-SGA requires skilled professionals and takes approximately 30 min, limiting its popularity as a screening tool. The newly launched Global Leadership Initiative on Malnutrition (GLIM) criteria for the diagnosis of malnutrition has fewer items and takes less time than PG-SGA but requires an initial risk screening by validated tools (Cederholm et al., 2019).

According to the Academy of Nutrition and Dietetics, malnutrition risk could be identified based on dietary history, detailed nutrient intake, anthropometric and biochemical measurements, physical and clinical conditions, physiological and disease status, and functional and behavioral status (Rabito et al., 2017), which could be components of a nutrition-screening tool. Based on the contents of the existing nutrition-screening tools and assessment items of PG-SGA, we tried to create a useful screening tool for patients with cancer and then verify it in a multicenter prospective study.

RESULTS

Item selection

Of the 140 members of Chinese Society of Nutritional Oncology (CSNO), 83 returned their questionnaires. Table S1 in Supporting Information shows the results of the expert selection. Weight loss (76/83), eating less (51/83), activities and function (75/83), and >65 years old (64/83) were the most representative items of weight change, eating problems, life and physical problems, and aging, respectively. According to the reply of the members, four of the most representative questions formed the new nutrition-screening tool named the age, intake, weight, and walking (AIWW) tool—Q1: Age (A): are you over 65 years old? Q2: Intake (I): have you noticed a decrease in appetite or food intake in the past month? Q3: Weight (W): did you lose weight involuntarily over the past month? Q4: Walking (W, for activities and function): did your walking pace, walking steps, or walking distance decrease involuntarily over the past month?

Considering that the screening tool should be easy-to-use, we set the responses to the four questions as "yes" or "no" (Table 1). Malnutrition risk was defined as one or more AIWW items (AIWW risk).

Reliability

Reliability was investigated in 72 patients, which included 24 patients for internal consistency and 48 for test-retest reliability. No significant difference and strong correlations were observed in AIWW between two measurements by the same professional (Spearman correlation coefficient=0.995) and two independent raters (Spearman correlation coefficient=0.990).

Patient characteristics

In total, 11,360 patients (male, n=6,024 (53.0%)) were included in the final analysis. For all patients, the median follow-up time was 24.15 months, and the median follow-up time of the malnutrition group was 21.06 months. The baseline characteristics of the participants are shown in Table S2 in Supporting Information. The mean (standard deviation, SD) age of all patients was 57.23 (13.25) years, and the mean (SD) age of the malnutrition group was 59.69 (11.65) years. Among the participants, 2,511 (22.1%) had lung cancer; 1,904 (16.8%), colorectal cancer; 1,824 (16.1%), breast cancer; 1,296 (11.4%), gastric cancer; 1,064 (9.4%), nasopharynx cancer; 859 (7.6%), esophagus cancer; 437 (3.8%), cervical cancer; 315 (2.8%), liver cancer; and 1,150 (10.1%), other cancers. A total of 1,039 (9.1%) patients had tumor stage I; 2,399 (21.1%), tumor stage II; 2,686 (23.6%), tumor stage III; 3,477 (30.6%), tumor stage IV; and 1,759 (15.9%), unknown tumor stage.

Characteristics of patients with malnutrition risk

The population distribution in the AIWW assessment was similar to that in the PG-SGA assessment. The AIWW malnutrition risk group had a lower body mass index (BMI) than the no-risk group (Table S3 in Supporting Information). The malnutrition risk groups screened using AIWW and nutritional risk screening 2002 (NRS-2002) had a worse quality of life, higher hospitalization cost (COST), and longer length of stay (LOS) than the no-risk groups. The NRS2002 malnutrition risk group had a higher BMI, lower COST, and shorter LOS than the NRS-2002 malnutrition risk group (Table S4 in Supporting Information). The malnutrition screening tool (MST) malnutrition risk group had comparable COST and LOS with the no-risk group (Table S5 in Supporting Information).

Questions of AIWW relative to malnutrition

The relationship between AIWW questions and malnutrition showed that Q2 (intake (I); Kendall tau coefficient=0.561), Q3 (weight (W); Kendall tau coefficient=0.505), and Q4 (walking (W); Kendall tau coefficient =0.374) had a nearly moderate or moderate correlation (Kendall tau coefficient>0.400) with malnutrition (Table S6 in Supporting Information). The decision curve analysis (DCA) revealed that AIWW, when compared with an all-or-none approach, yielded a superior net benefit for patients with low estimated risk, and NRS-2002 yielded a superior net benefit for patients with high estimated risk (Figure S1 in Supporting Information).

Table 1 AIWW screening questionnaire[a)]

AIWW screening questionnaire
Q1: age (A), are you over 65 years old?
Q2: intake (I), have you noticed a decrease in appetite or food intake in the past month?
Q3: weight (W), did you lose your weight involuntarily over the past month?
Q4: walking (W), did your walking pace, walking steps, or walking distance decrease involuntarily over the past month?

a) Yes (add 1 point) or No (0 points). A score of 1 or more=patient at risk of malnutrition.

Concurrent validity between malnutrition risk assessed using AIWW, NRS-2002, and MST and malnutrition

In total, 6,363 (56.0%) patients had malnutrition based on PG-SGA. Based on AIWW, 7,545 (66.4%) patients had malnutrition risk. Moreover, 3,815 (33.6%) patients had an AIWW score of 0, 3,222 (28.4%) had an AIWW score of 1, 2,261 (19.9%) had an AIWW score of 2, 1,556 (13.7%) had an AIWW score of 3, and 506 (4.5%) had an AIWW score of 4 (Figure 1). Based on NRS-2002, 3,469 (30.5%) patients had malnutrition risk. Based on MST, 1,840 (16.2%) patients were at risk of malnutrition; the missed diagnosis rates of AIWW, NRS-2002, and MST were 0.09%, 49.0%, and 73.2%, respectively (Figure 2).

The sensitivity and specificity values of malnutrition were 0.910 and 0.768, respectively, for AIWW≥1; 0.531 and 0.946, respectively, for NRS-2002; and 0.285 and 0.975, respectively, for MST. The Kendall tau coefficients were 0.588, 0.501, and 0.326 for AIWW, NRS-2002, and MST, respectively. The area under the curve (AUC) values of AIWW, NRS-2002, and MST were 0.785, 0.739, and 0.630, respectively. AIWW had the highest AUC and sensitivity for malnutrition risk among the three nutrition-screening tools. The integrated discrimination improvement (IDI) and continuous net reclassification improvement (cNRI) showed that AIWW is non-inferior to NRS-2002 (IDI: 0.002 (−0.009, 0.013), cNRI: −0.015 (−0.049, 0.020)). The sensitivity and specificity values of severe malnutrition were 0.882 and 0.570, respectively, for AIWW≥2; 0.745 and 0.820, respectively, for NRS-2002; and 0.278 and 0.871, respectively, for MST. The Kendall tau coefficients were 0.590, 0.556, and 0.218 for AIWW, NRS-2002, and MST, respectively. The AUC values of AIWW, NRS-2002, and MST were 0.835, 0.782, and 0.574, respectively. AIWW had the highest AUC and sensitivity for severe malnutrition among the three nutrition-screening tools (Table 2).

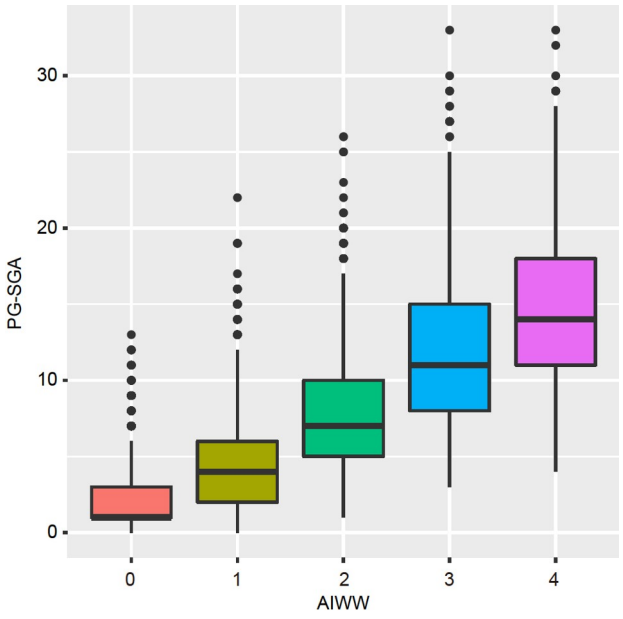

Figure 1 Box plot of PG-SGA and AIWW scores.

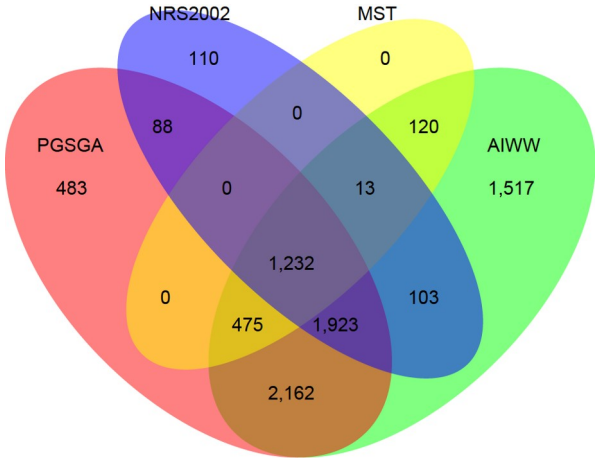

Figure 2 Venn plots of three screening tools and malnutrition defined by PG-SGA. Malnutrition was defined as a PG-SGA score of ≥4. The malnutrition risk in MST was defined as an MST score of ≥2. The malnutrition risk of NRS-2002 was defined as an NRS-2002 score of ≥3. The malnutrition risk in AIWW was defined as an AIWW score of ≥1. Severe malnutrition risk in AIWW was defined as an AIWW score of ≥2.

Assessment of the Global Leadership Initiative on Malnutrition (GLIM)

The GLIM malnutrition assessment using NRS-2002 included 3,013 patients, and that using AIWW included 4,446 patients (Figure 3). AIWW was more suitable for malnutrition risk screening in the oncologic population than NRS-2002.

Consistency metrics of AIWW with different questions about decreased physical function

We tested the questions about decreased physical function. Among the nine questions, the consistency metrics showed only weak-to-moderate correlation (Kappa=0.220–0.680, P<0.001), low sensitivity (sensitivity<0.600), and high specificity (specificity>0.650) between the questions and malnutrition risk (Table S7 in Supporting Information). The consistency metrics of AIWW with different questions about decreased physical function showed that patients had a moderate-to-strong concordance with malnutrition (Kappa>0.700, P<0.001). The sensitivity (0.888–0.938), specificity (0.486–0.687), and AUC (0.705–0.780) values of AIWW were comparable for various questions regarding decreased physical function (Table S8 in Supporting Information).

Table 2 Relation between characteristics and malnutrition defined by PG-SGA[a)]

	Sensitivity	Specificity	AUC	Kendall tau b with PG-SGA	kappa with PG-SGA	*P* value	IDI	*P* value	cNRI	*P* value
Malnutrition (PG-SGA≥4)										
MST	0.285	0.975	0.621	0.326	0.22	<0.001	−0.043 (−0.053, −0.034)	<0.001	−0.197 (−0.230, −0.162)	<0.001
NRS-2002 risk	0.531	0.946	0.732	0.501	0.437	<0.001	−0.009 (−0.019, 0.001)	0.09	−0.027 (−0.057, 0.007)	0.106
AIWW risk	0.910	0.768	0.780	0.588	0.574	<0.001	−0.008 (−0.017, 0.002)	0.136	−0.059 (−0.084, −0.033)	<0.001
AIWW *vs*. MST							0.036 (0.027,0.045)	<0.001	0.162 (0.130,0.194)	<0.001
AIWW *vs*. NRS-2002							0.002 (−0.009, 0.013)	0.747	−0.015 (−0.047, 0.021)	0.39
Severe malnutrition (PG-SGA≥9)										
MST	0.278	0.871	0.588	0.218	0.202	<0.001	−0.044 (−0.055, −0.034)	<0.001	−0.181 (−0.211, −0.150)	<0.001
NRS-2002 risk	0.745	0.820	0.781	0.556	0.556	<0.001	−0.011 (−0.021, −0.000)	0.056	−0.181 (−0.210, −0.147)	0.002
AIWW≥2	0.882	0.570	0.830	0.62	0.609	<0.001	−0.009 (−0.019, 0.002)	0.12	−0.023 (−0.055, 0.011)	0.174

a) Malnutrition was defined as a PG-SGA score of ≥4, and severe malnutrition was defined as a PG-SGA score of ≥9. The malnutrition risk in MST was defined as an MST score of ≥2. The malnutrition risk in NRS-2002 was defined as an NRS-2002 score of ≥3. The malnutrition risk in AIWW was defined as an AIWW score of ≥1. Severe malnutrition risk in AIWW was defined as an AIWW score of ≥2.

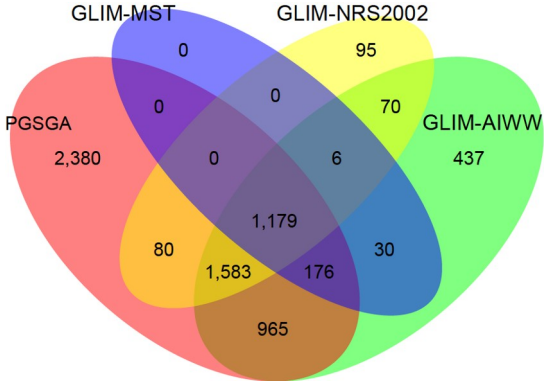

Figure 3 Assessment of GLIM. Notes: GLIM-NRS2002, malnutrition assessed by GLIM with NRS-2002; PGSGA, malnutrition assessment with PG-SGA; GLIM-AIWW, malnutrition assessed by GLIM with AIWW.

Association between the number of AIWW items and overall survival of patients with cancer

A comparison between the groups with different numbers of AIWW items was performed using the Kaplan-Meier curve (log-rank test, $P<0.001$). A dose-response increase was noted toward different numbers of AIWW items for mortality risk (Figure S2 in Supporting Information).

Weight analysis of AIWW

Moreover, we used AIWW items to construct the nomogram, which can be used as a quantitative tool to predict the malnutrition risk of patients in clinical practice (Figure S3 in Supporting Information), which also predicted survival quite well (Figure S4 in Supporting Information).

Sensitivity analyses of AIWW

Removing one or two items from AIWW, we can get different truncated versions of AIWW. Intake and weight loss had the highest AUC (0.822) but a low sensitivity (0.782). AIWW, with 2 as the tangent value, obtained the highest specificity (0.944) and the lowest sensitivity (0.641). Of the six AIWWs, the standard AIWW had the highest sensitivity (0.910), medium AUC (0.780), and correlation with PG-SGA (0.588). AIWW is more suitable as a screening tool (Table S9 in Supporting Information).

DISCUSSION

We developed a screening tool named AIWW for the oncologic population and validated it using the data from the Investigation on Nutrition Status and Clinical Outcome of Common Cancers (INSCOC), the largest prospective nutrition cohort of the oncologic population. AIWW takes approximately 20 s to complete, does not require professional training, and is more convenient than PG-SGA and PG-SGA SF. Additionally, AIWW is easy to answer. The good reliability of AIWW reflects the sound stability of the ques-

tionnaire. Compared with NRS-2002 and MST, AIWW had better sensitivity in the oncologic population and a similar discrimination effect to NRS-2002. AIWW has a very low missed diagnosis rate. An AIWW score of ≥2 indicated that patients are at high risk of severe malnutrition. AIWW can also predict the survival of patients with cancer.

In past decades, precision nutrition therapy has been valued, and the first step in precision nutrition therapy is the diagnosis of malnutrition (Lacey and Pritchett, 2003; Xu and Shi, 2022). The PG-SGA is widely used in patients with cancer and is recognized as the gold standard nutrition assessment tool for these patients by the Oncology Nutrition Dietetic Practice Group of the Academy of Nutrition and Dietetics (Boléo-Tomé et al., 2012; Jager-Wittenaar and Ottery, 2017). However, the PG-SGA requires skilled professionals and approximately 30 min of assessment. However, PG-SGA SF is not simple enough for patients to complete independently (Fu et al., 2022; Gabrielson et al., 2013), limiting its popularity as a screening tool. A simple nutrition-screening tool that allows for self-evaluation and not only helps reduce the workload of healthcare workers but also raises patients' awareness of malnutrition (Jager-Wittenaar et al., 2020). A quick and easy-to-use nutrition-screening tool with high sensitivity and appropriate specificity for the oncologic population is necessary.

In the creation of a nutritional screening tool, items with high sensitivity may be preferred over those with high specificity (Reber et al., 2021). First, we collected 25 nutrition-screening tools and classified the questionnaires of these screening tools (Bouillanne et al., 2005; Ferguson et al., 1999; Gabrielson et al., 2013; Gerasimidis et al., 2007; Kondrup et al., 2003; Kovacevich et al., 1997; Kruizenga et al., 2005; Laporte et al., 2001; Nakyeyune et al., 2021; Reilly et al., 1995; Rubenstein et al., 2001; Smith et al., 2009; Söderhamn and Söderhamn, 2001; Stratton et al., 2004; Tammam et al., 2009; Thorsdóttir et al., 1999; Vallén et al., 2011; Visvanathan et al., 2004; Weekes et al., 2004; Wolinsky et al., 1990; Woo et al., 2005). Their questions can be divided into seven categories. According to the Academy of Nutrition and Dietetics, patients were identified as being at risk of malnutrition based on dietary history, detailed nutrient intake, anthropometric and biochemical measurements, as well as physical and clinical, physiological and disease, and functional and behavioral status (Rabito et al., 2017). While helping patients better self-evaluate and reducing the time spent on screening for healthcare workers, questions for the screening tool must be readily available. Studies have shown that patients may experience significant weight gain because of ascites or edema after some treatment; thus, the weight or BMI does not respond well to the nutritional status (Um et al., 2014). Some researchers have pointed out that weight changes in recent months are not readily available, even though many nutritional assessment tools have this item (Miller et al., 2018). Based on our aim and expert panel discussion, we deleted anthropometry and biochemical measurements and excluded stress and disease because all patients have cancer. Among the remaining four items, we invited experts from the CSNO to select the most useful question for each category. The most expert-approved items make up AIWW. The items selected were approved by experts in the second inquiry. Therefore, we built AIWW, which included four categories for patients with cancer.

After its development, AIWW was tested. The European Society for Clinical Nutrition and Metabolism (ESPEN) guidelines recommend the following four tools for malnutrition screening in patients with cancer: NRS-2002, malnutrition universal screening tool (MUST), mini-nutrition assessment (MNA), and MST (Arends et al., 2017). MST and MUST were also recommended by the Academy of Nutrition and Dietetics (Thompson et al., 2017). Thus, we compared AIWW with NRS-2002 and MST, which are representative and widely used nutritional screening tools (Nakyeyune et al., 2021). Compared with NRS-2002 and MST, AIWW showed better sensitivity and better predictive value and a slightly lower specificity for malnutrition, which is an important characteristic because a high sensitivity is more important than a high specificity for a screening tool. With equivalent clinical benefits as NRS-2002, AIWW has an extremely low missed diagnosis rate, and previous studies have found that NRS-2002 as a screening tool leads to a higher missed diagnosis rate (38%) (Kyle et al., 2006).

MST mainly considers weight loss and appears to underestimate the effect of a decreased appetite. NRS-2002 was developed for screening patients who may benefit from nutritional support, which may explain its high specificity (Kondrup et al., 2003). A more demanding selection of NRS-2002 may help screen malnourished patients who can benefit from short-term efficacy. A study showed that MUST correlated better with the ESPEN criteria for the definition of malnutrition than NRS-2002 (Poulia et al., 2017). The widespread use of MNA-SF and multiple studies about MNA and other tools have shown that the nutritional status of older patients is influenced by various factors (Donini et al., 2016; Ju et al., 2022; Zhang et al., 2020). This illustrates the need for different populations when constructing different nutrition screening or assessment tools. A review reported that no single screening or assessment tool can adequately screen nutrition and predict poor nutrition-related outcomes (van Bokhorst-de van der Schueren et al., 2014). Our study shows that AIWW is not inferior to NRS-2002, whereas AIWW benefits patients with low estimated risk, and NRS-2002 is more stringent for screening malnourished people. To have a higher specificity, NRS-2002 has higher missed diagnosis rates than AIWW. Based on malnutrition assessed by PG-SGA, our study showed that AIWW could be the MST for patients with cancer.

Studies have shown that NRS-2002 could be an independent predictive factor for mortality; however, as an MST for the GLIM, MUST is better than NRS-2002 (Bellanti et al., 2020; Zhang et al., 2020). As the first step of GLIM, malnutrition risk screening, it appears that different screening tools should be used in different patient groups. In patients with cancer, a study showed that NRS-2002 may not be required for GLIM (Zhang et al., 2021). In our study, it is important to select a suitable tool for malnutrition risk screening of patients with cancer. By using AIWW, we can identify more patients with malnutrition, which is associated with increased mortality (Gellrich et al., 2015).

We conducted a sensitivity analysis to test various questions regarding physical function and found that each physical function question was independent of the other. By contrast, AIWW, which included various questions regarding physical function, had high consistency and good specificity for malnutrition. When we replaced this category (Q4: walking) with other similar items, the replacement scale had a high consistency with the original scale. This showed that even questions describing functional changes in different dimensions have a similar effect on screening. The above results show that at the screening stage, the questions on walking (for activities and function) can be appropriately replaced. The reliability analysis showed that AIWW has excellent consistency. The above results show that AIWW has a consistent effect when used by another person. AIWW has a strong universality. Patients' different understanding of the same entry does not affect the effectiveness of AIWW, which helps them better understand their state. Further analysis shows that the groups with different AIWW scores had a dose-response increase between different AIWW scores and mortality risk. AIWW scores can also predict the survival of patients with cancer.

The strength of this study is that AIWW was created in two rigorous steps and is validated. We first summarized 25 available nutrition-screening tools and then invited CSNO experts to make an expert selection. After AIWW development, it was validated in the current largest sample nutrition cohort of tumors (INSCOC). In addition, some of these issues can be replaced with the same type of question. The reliability analysis showed the excellent consistency of AIWW. The above results reveal that AIWW has a consistent effect when used by another person.

This study has some limitations. First, we only compared AIWW with NRS-2002 and MST. Approximately 32 nutrition-screening tools are available; however, we only compared AIWW to the two widely used tools because of limited data availability. Second, although our study had patients with different cancer types, the effect of the AIWW score on a single or special tumor type should be further examined.

In conclusion, we developed a novel nutrition-screening tool, i.e., AIWW, and validated it in a large cancer cohort. AIWW showed a better screening effect than NRS-2002 and MST on patients with cancer. We recommend AIWW as an alternative nutrition-screening tool in patients with cancer.

SUBJECTS AND METHODS

Item selection and development of nutrition-screening questionnaires

In this study, malnutrition was defined as a PG-SGA score of ≥4 points and severe malnutrition as ≥9 points. According to the Academy of Nutrition and Dietetics, the risk of malnutrition can be identified based on dietary history, detailed nutrient intake, anthropometric and biochemical measurements, and physical and clinical, physiological and disease, and functional and behavioral states. Based on clinical experience and 25 nutrition-screening tools, we categorized the items into anthropometry, weight change, biochemical measurements, eating, life and physical, age, stress, and disease (Table S10 in Supporting Information). To develop a better nutrition-screening tool for patients with cancer, the following criteria were used for selecting a nutrition-screening item: (i) convenient to use and easy to complete by nonprofessional staff, patients, or family members; (ii) makes use of routinely available, non-invasive, and inexpensive data; (iii) is applicable for use in adults with cancer; (iv) is valid and reproducible; (v) instrument-independent data, and (vi) have criterion validity comparable to the PG-SGA (Dent et al., 2019; Oh et al., 2019).

In line with the study aim, we deleted two categories of anthropometric or biochemical measurements that required additional tools or professional knowledge. Therefore, the items that require measurement tools were not included in the candidate items. We removed the burden of disease category because all patients had cancers. Then, we conducted a survey consisting of 13 questions from four categories on item selection among the tools. All questions were defined as "have" (1 point) or "don't have" (0 points) problems. Based on the Delphi method (Olsen et al., 2021), we created a working group including 140 members of the CSNO from 29 Chinese provinces. First, we sent a questionnaire containing the purpose of this study and the items of four categories to the members of the working group. After collecting their responses, we sent the results to all members of the working group and collected their revision opinions on the content. Four items were selected in the form of a question from each category to form the new screening tool.

Assessment of reliability and validity

For reliability, we analyzed the internal consistency and test-retest reliability of a new screening tool in consenting participants from the Beijing Shijitan Hospital. The same group

of patients was assessed twice within a week by the same investigator, and another group of patients was assessed multiple times by different investigators. The assessment days were at least 1 day apart.

Based on the malnutrition tool designed by PG-SGA, AIWW was compared with NRS-2002 and MST to assess their criterion validity through a prospective study. The GLIM with different screening tools was used to assess the validity of the malnutrition design. GLIM is a newly developed diagnostic tool for malnutrition based on a two-step approach: (i) screening to identify nutrition risk and (ii) assessment and grading of malnutrition. The ESPEN recommended NRS-2002 as the screening tool in the first step for the GLIM. We then combined MST with GLIM for analysis (Cederholm et al., 2019). The survival analysis showed the discriminant validity of AIWW.

Study population

This study used the data from the INSCOC Project of China (Registration NO. ChiCTR1800020329). The study population, which was fully described in existing reports (Song et al., 2019; Xu et al., 2020), consisted of patients aged ≥18 years with cancer. They were enrolled in 40 clinical centers throughout China from 2013 to 2020. This multicenter, large-scale, long-term follow-up prospective study aimed to investigate malnutrition in patients with cancer and identify the related risk factors associated with negative outcomes. The main outcome was long-term mortality, i.e., over a 5-year follow-up period, and the secondary outcomes were COST and LOS.

This study was approved by the medical ethical review committee of the registration hospital and was conducted in accordance with the Declaration of Helsinki. Patients completed the PG-SGA, NRS-2002, and MST, with guidance from health professionals who were fieldworkers in the study (Figure S5 in Supporting Information).

Patient characteristics

Demographic data, including age, sex, height, weight, primary tumor site, and TNM stage, were collected on admission. All questionnaires (PG-SGA, NRS-2002, and MST) were completed by health professionals within 48 h after admission and before the treatment. All pathological stages were defined according to the 8th edition of the American Joint Committee on Cancer TNM staging system (Amin et al., 2017). BMI was calculated using the following formula: BMI (kg m^{-2})=weight (kg)/height^2 (m^2).

Statistical analysis

Baseline characteristics are presented as mean±SD or median (interquartile range (IQR)) for continuous variables and as proportions for categorical variables. The baseline characteristics of the well-nourished and malnourished groups were compared using the two-sample *t*-test for continuous variables and the chi-squared test for categorical variables. Reliability was examined using the Spearman correlation coefficients. A nonparametric test of two related samples was used to compare the scores and time. Concurrent validity was evaluated by measuring the Kendall tau coefficient and kappa consistency between AIWW and NRS-2002 risk and malnutrition. Clinical benefit was calculated by the DCA, IDI, and cNRI. Survival analyses of AIWW scores were conducted using the Kaplan-Meier curve and univariate Cox regression models. The cutoff AIWW score was defined by the lowest combination.

Practically, an increase in the AUC of 0.025 per additional risk factor was considered clinically relevant (Apfel et al., 2001). In all analyses, a two-tailed *P*-value<0.05 was considered statistically significant. All analyses were performed using R software, version 4.0.2.

Data sharing

Data described in the manuscript, code book, and analytic code will be made available upon request, pending application and approval.

Compliance and ethics *The author(s) declare that they have no conflict of interest.*

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