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ORIGINAL ARTICLE

Utility of four sarcopenia criteria for the prediction of falls-related hospitalization in older Australian women

M. Sim[1,2] · R. L. Prince[2,3] · D. Scott[4,5] · R. M. Daly[6] · G. Duque[5,7] · C. A. Inderjeeth[2,8] · K. Zhu[2,3] · R. J. Woodman[9] · J. M. Hodgson[1,2] · J. R. Lewis[1,2,10]

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Abstract

Summary Numerous sarcopenia definitions are not associated with increased falls-related hospitalization risk over 5 years to 9.5 years in older community-dwelling Australian women. Measures of muscle strength and physical function, but not appendicular lean mass (measured by dual-energy X-ray absorptiometry) may help discriminate the risk of falls-related hospitalization.

Introduction The aim of this prospective, population-based cohort study of 903 Caucasian-Australian women (mean age 79.9 ± 2.6 years) was to compare the clinical utility of four sarcopenia definitions for the prediction of falls-related hospitalization over 9.5 years.

Methods The four definitions were the United States Foundation for the National Institutes of Health (FNIH), the European Working Group on Sarcopenia in Older People (EWGSOP), and modified FNIH (AUS-POP_F) and EWGSOP (AUS-POP_E) definitions using Australian population-specific cut points (< 2 SD below the mean of young healthy Australian women). Components of sarcopenia including muscle strength, physical function, and appendicular lean mass (ALM) were quantified using hand grip strength, timed-up-and-go (TUG), and dual-energy X-ray absorptiometry (DXA), respectively. Incident 9.5-year falls-related hospitalization were captured by linked data.

Results Baseline prevalence of sarcopenia according to FNIH (9.4%), EWGSOP (24.1%), AUS-POP_F (12.0%), and AUS-POP_E (10.7%) differed substantially. Sarcopenia did not increase the relative hazard ratio (HR) for falls-related hospitalization before or after adjustment for age (aHR): FNIH aHR 1.00 95%CI (0.69–1.47), EWGSOP aHR 1.20 95%CI (0.93–1.54), AUS-POP_F aHR 0.96 95%CI (0.68–1.35), and AUS-POP_E aHR 1.33 95%CI (0.94–1.88). When examining individual components of sarcopenia, only muscle strength and physical function but not ALM (adjusted for height^2 or BMI) were associated with falls-related hospitalization.

Conclusion Current definitions of sarcopenia were not associated with falls-related hospitalization risk in this cohort of community-dwelling older Australian women. Finally, measures of muscle strength and physical function, but not ALM

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✉ M. Sim
marc.sim@ecu.edu.au

[1] School of Medical and Health Sciences, Edith Cowan University, Joondalup, Western Australia, Australia

[2] Medical School, The University Western Australia, Perth, Western Australia, Australia

[3] Department of Endocrinology and Diabetes, Sir Charles Gairdner Hospital, Nedlands, Western Australia, Australia

[4] Department of Medicine, School of Clinical Sciences at Monash Health, Monash University, Clayton, Victoria, Australia

[5] Department of Medicine and Australian Institute of Musculoskeletal Science, Melbourne Medical School – Western Campus, The University of Melbourne, St Albans, Victoria, Australia

[6] Institute for Physical Activity and Nutrition, School of Exercise and Nutrition Sciences, Deakin University, Geelong, Victoria, Australia

[7] Department of Medicine-Western Health, The University of Melbourne, St Albans, Victoria, Australia

[8] North Metropolitan Health Service, Nedlands, Western Australia, Australia

[9] Flinders Centre for Epidemiology and Biostatistics, Flinders University, Adelaide, South Australia, Australia

[10] Centre for Kidney Research, Children's Hospital at Westmead, School of Public Health, Sydney Medical School, The University of Sydney, Sydney, New South Wales, Australia

(measured by DXA) may help discriminate the risk of falls-related hospitalization.

Keywords Falls-related hospitalization · Geriatrics · Muscle mass · Muscle strength · Physical function

Introduction

Age-related progressive loss of skeletal muscle mass in conjunction with compromised muscle strength and/or physical function has been termed sarcopenia [1–3]. Globally, the two most commonly adopted sarcopenia definitions are the United States Foundation for the National Institutes of Health (FNIH) and European Working Group on Sarcopenia in Older People (EWGSOP) [1, 4]. FNIH have provided evidence-based cutoffs for muscle weakness and low appendicular lean mass (ALM) using data from cohorts of community-dwelling older persons [4]. Additionally, EWGSOP identifies sarcopenic individuals as those presenting with low ALM in conjunction with reduced muscle strength and/or impaired physical function [1].

Falling propensity has been related to individual components of sarcopenia such as reduced muscle strength and physical function [5–7], which may or may not be present in conjunction with low muscle mass [8, 9]. While some previous research has shown that individuals classified as sarcopenic according to EWGSOP and/or FNIH criteria are at an increased risk for falls [10–12], most studies to date have generally considered self-reported falls as outcomes, which likely occur more frequently and are often less serious than injurious falls [13].

Falls-related injuries are the largest contributor to hospitalization rates for unintentional causes of injury for all age groups aged 65 and over [14]. This places substantial financial and resource strains on health care, especially with an aging population [14]. Underlying causes such as neuromuscular and cognitive function may differ between self-reported and injurious falls [15], suggesting the aforementioned type of falls should be examined separately. Presently, the role of sarcopenia on injurious falls resulting in hospitalization remains unclear. The aim of this study was to compare the clinical utility of four sarcopenia definitions for the prediction of falls-related hospitalization from linked data records over 9.5 years in older Australian women. The four definitions included the FNIH, EWGSOP, and two adapted criteria based on these definitions but using Australian population-specific cut points.

Methods

Study population

The Perth Longitudinal Study of Aging in Women (PLSAW) is an extension of a 5-year, double-blind, randomized controlled trial (RCT) of daily calcium supplementation to prevent fracture [Calcium Intake Fracture Outcome Study (CAIFOS) study] in 1500 participants that commenced in 1998. Participants were originally recruited from the Western Australian general population of Caucasian women aged ≥ 70 years by mail using the electoral roll. These community-dwelling women were included on the basis of an expected survival beyond 5 years and not receiving any medication (including hormone replacement therapy) known to affect bone metabolism as has been previously described [16]. The participants from CAIFOS were re-enrolled into two additional 5-year extension studies 2003–2009 and 2008–2013 [17]. The 903 community-dwelling women in the current study were included if they: (i) completed the CAIFOS study, (ii) agreed to participate in the extension study; and (iii) had measures of muscle strength (grip strength), physical function (timed-up-and-go; TUG), and ALM obtained in their 2003 clinical visit.

All participants provided written informed consent. Ethics approval was granted by the Human Ethics Committee of the University of Western Australia. Both studies were retrospectively registered on the Australian New Zealand Clinical Trials Registry (CAIFOS trial registration number ACTRN12615000750583 and PLSAW trial registration number ACTRN12617000640303) and complied with the Declaration of Helsinki. Human ethics approval for the use of linked data was provided by the Human Research Ethics Committee of the Western Australian Department of Health (project number 2009/24).

Falls outcome assessment

Linked falls-related hospitalization over 9.5 years were drawn from the Western Australia Hospital Morbidity Data Collection (HMDC), via the Western Australian Data Linkage System (Department of Health Western Australia, East Perth, Australia). These falls were considered injurious as it was serious enough to require hospitalization. HMDC records were obtained for each of the study participants from the date of their clinical visit in 2003. We had 9.5 years of follow-up for falls-related hospitalization and deaths for all women that remained in Western Australia over the study period. Falls-related hospitalization were identified using the international classification of external causes of injury codes and the international classification of diseases (ICD) coded discharge data pertaining to all public and private inpatient admissions in Western Australia. This allows ascertainment

of hospitalizations independent of self-report and avoids the problems of patient self-reporting. As described previously [17], falls from standing height or less, not resulting from external force were included (ICD-10 codes W01, W05–W08, W10, W18, and W19). Where ICD-10 coded death data were not yet available, we used parts 1 and 2 of the death certificate or all diagnosis text fields from the death certificate. Criteria for recurrent falls-related hospitalization included (i) admission dates for an inpatient falls-related hospitalization of more than 2 weeks apart and; (ii) were not currently undergoing rehabilitation procedures following an initial fall or fracture (Z50.9). Self-reported falls were assessed by asking participants during their baseline clinical visit (2003) if they had experienced a fall in the previous 3 months.

Baseline characteristic assessment

Body weight was measured to the nearest 0.1 kg using digital scales and height was assessed to the nearest 0.1 cm using a wall-mounted stadiometer, both while participants were wearing light clothes and without socks and shoes. Body mass index (BMI) (kg/m^2) was then calculated. ALM was assessed using a Hologic Acclaim QDR4500A (Hologic Corp, Waltham, MA) dual-energy X-ray absorptiometry (DXA) machine. This was then adjusted for BMI or height according to FNIH (ALM/BMI) [4] and EWGSOP (ALM/height^2) [1] guidelines, respectively. Grip strength and timed-up-and-go (TUG) were assessed at baseline (2003). A detailed description of test protocols are found under Supplementary Text S1.

Sarcopenia definitions

Sarcopenia criteria were based on FNIH [4] and EWGSOP [1] consensus reports, as well as modified FNIH (AUS-POP$_F$) and EWGSOP (AUS-POP$_E$) definitions we developed using Australian-specific population data. Australian cohort normative data for healthy young women aged 20–39 years were obtained from previous studies for grip strength [18], TUG [19], and ALM [20] to determine population-specific cut points for AUS-POP$_F$ and AUS-POP$_E$, which were set at 2 SD below the mean reference value as recommended previously [1, 21, 22]. For EWGSOP and AUS-POP$_E$, individuals were classified as sarcopenic if they presented with low height-adjusted ALM in the presence of slow TUG and/or poor grip strength [1]. Although the EWGSOP definition is generally applied using slow gait speed, their report states that TUG can similarly be used as a measurement of physical performance in geriatric assessment [1]. However, as no recommended cut point was provided for this measure, TUG reference values from a comparable European cohort were adopted for EWGSOP [23], and Australian population-specific values were adopted for AUS-POP$_E$. For the FNIH definition, grip strength and BMI-adjusted ALM were included. AUS-POP$_F$ represented an Australian equivalent of this. Specific cut points for each definition are reported in Table 1.

Statistical analysis

Differences in baseline characteristics were compared across sarcopenia categories using one-way analysis of variance (ANOVA) for normally distributed continuous variables and the chi-squared test for categorical variables. Non-normally distributed variables were assessed using the Mann-Whitney U Test. Spearman's rank test was used to determine the relationship between baseline ALM including height and BMI adjustment, grip strength, and TUG. The primary outcome of the study was falls-related hospitalization with the primary independent variable being sarcopenia (presence or absence according to FNIH, EWGSOP, and AUS-POP$_F$ and AUS-POP$_E$ definitions).

Each participant was followed until either 9.5 years after their clinic visit in 2003 or date of death. Follow-up of all 9.5 years was therefore available for all participants that remained resident in Western Australia, which is likely to be the majority of participants given their age. Kaplan-Meier curves and the log-rank test were used to assess univariate associations between sarcopenia definitions and falls-related hospitalization. Cox proportional hazards modeling was used to assess the unadjusted and age-adjusted associations between each sarcopenia definition and falls-related hospitalization over 5 years and 9.5 years. Individual components of sarcopenia (ALM adjusted for BMI or height^2, grip strength, and TUG) were also examined separately for their relationship with falls-related hospitalization over 5 years and 9.5 years using Cox proportional hazards modeling. Cox proportional hazards assumptions were tested using log-log plots, which were shown to be parallel indicating that proportional hazards assumptions were not violated. For the primary analysis, we treated deaths as censored. To evaluate the clinical utility or "usefulness" of adding the four sarcopenia definitions (present vs. absent) to age alone, we tested the model discrimination or predictive accuracy using the area under the receiver-operating characteristic (ROC) curve (AUC) in logistic regression models for falls-related hospitalization over 5 years and 9.5 years for each individual. Model calibration was tested using the Hosmer-Lemeshow goodness of fit test for logistic regression based on deciles of predicted risk vs. actual risk (all $p > 0.05$ indicating models were considered well calibrated). Statistical analysis was performed using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp., Armonk, NY, USA), and Stata software, version 14 (StataCorp LLC, College Station, Texas, USA). Statistical significance was set at a two-sided type one error rate of $p < 0.05$ for all tests. Descriptive statistics of normally and non-normally

Table 1 Specific cut points for the various components for sarcopenia as per (i) United States Foundation for the National Institutes of Health (FNIH), (ii) European Working Group on Sarcopenia in Older People (EWGSOP), and two Australian population specific criteria (AUS-POP_F and AUS-POP_E) adapted from FNIH and EWGSOP, respectively

	Sarcopenia criteria			
	FNIH	EWGSOP	AUS-POP_F	AUS-POP_E
Grip strength (kg)	< 16.0	< 20.0	< 17.1	< 17.1
Timed-up-and-go (sec)	–	> 8.30	–	> 8.51
Appendicular lean mass/BMI (kg/BMI)	< 0.512	–	< 0.517	–
Appendicular lean mass/height^2 (kg/m^2)	–	< 5.67	–	< 5.28

distributed continuous variables were expressed as mean ± standard deviation (SD) and median (interquartile range), respectively. Categorical variables were expressed as the number and proportion (%).

Additional analysis

Unadjusted and age-adjusted logistic regression was used to determine the association between sarcopenia definitions and self-reported falls in the previous 3 months and recurrent falls-related hospitalization. As FNIH does not include physical function but does highlight its importance, we developed and tested a separate definition (FNIH2; Supplementary Text S2).

Results

Baseline characteristics by the four sarcopenia definitions are displayed in Table 2. Mean ± SD age of participants ($n = 903$) was 79.9 ± 2.6 years. The proportion of women categorized as sarcopenic differed substantially by definition (Table 2). Spearman's rank correlation demonstrated ALM (including height and BMI-adjusted variants) was weakly correlated with grip strength and TUG. An inverse correlation between grip strength and TUG ($r = -0.26$, $p < 0.01$) was observed (Table 3). For every 1 SD decrease in grip strength or 1 SD increase in TUG, there were 27% and 38% higher relative hazards, respectively, for falls-related hospitalization over 5 years. These hazards remained similar over 9.5 years. ALM/BMI and ALM/height^2 were not associated with falls-related hospitalization over 5 years and 9.5 years (Supplementary Table S1).

Falls-related hospitalization

Over 9.5 years (6669 person-years) of follow-up (mean ± SD; 7.4 ± 2.8 years), 34.8% (314/903) of women experienced a falls-related hospitalization, while 108/903 (11.9%) had two or more falls-related hospitalizations. A total 1132 falls-related hospitalizations were recorded over 9.5 years, and the most common diagnostic category was musculoskeletal and connective tissue (37%; Supplementary Fig. S1). Seven individuals had a falls-related hospitalization that resulted in death. Falls risk did not differ for sarcopenic women compared with non-sarcopenic women for any of the four definitions of sarcopenia in Kaplan-Meier survival analysis (Fig. 1) or age-adjusted Cox proportional hazard regression over 5 years and 9.5 years (Fig. 2). The addition of sarcopenia definitions did not improve discriminative ability compared to age in ROC (Fig. 3).

Further analysis

Of the women who experienced a falls-related hospitalization, 34.4% (108/314) were identified as recurrent fallers (Table 2). For all sarcopenia definitions, there was no increase in unadjusted or age-adjusted odds ratios (aOR) for self-reported falls for 3 months prior to participants baseline clinical visit (aOR range: 0.62–0.82) or recurrent falls-related hospitalizations over 9.5 years (aOR range: 0.91–1.51) for individuals with versus without sarcopenia (all $p > 0.05$; Supplementary Table S2). However, for EWGSOP, a trend for a relationship with recurrent falls-related hospitalization was observed ($p = 0.06$). FNIH2 was not associated with greater hazards for falls-related hospitalization over 5 years and 9.5 years (Supplementary Text S2).

Discussion

The main finding from this study was that neither FNIH nor EWGSOP sarcopenia definitions were predictive of future falls-related hospitalization risk over and above age alone in this large cohort of older community-

Table 2 Baseline characteristics of participants according to the US Foundation for the National Institutes of Health (FNIH), European Working Group on Sarcopenia in Older People (EWGSOP) (2a) and two Australian population-specific criteria (AUS-POP_F and AUS-POP_E) (2b)

2a		FNIH sarcopenia		EWGSOP sarcopenia	
	All participants	Yes	No	Yes	No
Number (%)	903 (100)	85 (9.4)	815 (90.5)	218 (24.1)	685 (75.9)
Age, years	79.9 ± 2.6	*80.5 ± 2.8*	*79.8 ± 2.6*	80.1 ± 2.6	79.8 ± 2.6
Height (cm)	157.4 ± 5.9	*149.9 ± 5.9*	*158.2 ± 5.3*	157.5 ± 5.6	157.3 ± 6.0
Weight (kg)	66.6 ± 12.1	66.5 ± 11.8	66.6 ± 12.2	*56.4 ± 7.7*	*69.8 ± 11.5*
BMI (kg/m^2)	26.9 ± 4.6	*29.6 ± 5.1*	*26.6 ± 4.5*	*22.7 ± 2.8*	*28.2 ± 4.3*
Lean appendicular mass (kg)	15.5 ± 2.5	*13.8 ± 2.3*	*15.7 ± 2.4*	*13.0 ± 1.2*	*16.3 ± 2.2*
Grip strength (kg)[1]	17.8 ± 4.9	*12.5 ± 2.3*	*18.3 ± 4.8*	*16.3 ± 4.1*	*18.3 ± 5.0*
TUG (sec)[2]	10.2 (8.9–12.0)	*11.2 (9.8–13.7)*	*10.1 (8.9–11.8)*	10.2 (9.0–11.9)	10.2 (8.9–12.1)
Outcomes					
First falls-related hospitalization *n* (%)[3]	314 (34.8)	30 (35.3)	282 (34.6)	80 (36.6)	234 (34.2)
Recurrent falls-related hospitalization *n* (%)[3]	108 (11.9)	11 (10.2)	97 (11.9)	34 (15.5)	74 (10.8)
Self-reported falls *n* (%)[4]	150 (16.6)	10 (11.8)	139 (17.1)	31 (14.3)	119 (17.4)
2b		**AUS-POP_F sarcopenia**		**AUS-POP_E sarcopenia**	
		Yes	No	Yes	No
Number (%)		108 (12.0)	792 (88.0)	97 (10.7)	806 (89.3)
Age, years		80.3 ± 2.7	79.8 ± 2.5	80.0 ± 2.5	79.9 ± 2.6
;Height (cm)		*150.5 ± 5.8*	*158.3 ± 5.3*	157.4 ± 5.8	157.4 ± 5.9
Weight (kg)		66.7 ± 11.4	66.6 ± 12.2	*53.8 ± 7.0*	*68.1 ± 11.7*
BMI (kg/m^2)		*29.4 ± 4.8*	*26.5 ± 4.5*	*21.7 ± 2.5*	*27.5 ± 4.4*
Lean appendicular mass (kg)		*13.8 ± 2.2*	*15.8 ± 2.4*	*12.3 ± 1.1*	*15.9 ± 2.3*
Grip strength (kg)[1]		*13.4 ± 2.7*	*18.4 ± 4.8*	*15.5 ± 4.0*	*18.1 ± 4.9*
Timed-up-and-go (sec)[2]		*10.8 (9.6–12.8)*	*10.1 (8.9–11.8)*	9.9 (9.0–11.9)	10.2 (8.9–12.0)
Outcomes					
First falls-related hospitalization *n* (%)[3]		37 (34.3)	275 (34.7)	36 (37.1)	278 (34.5)
Recurrent falls-related hospitalization *n* (%)[3]		13 (12.0)	95 (12.0)	13 (13.4)	95 (11.8)
Self-reported falls *n* (%)[4]		14 (13.0)	135 (17.1)	14 (14.4)	136 (17.0)

Italicized numbers indicate a significant difference ($p < 0.05$)

[1] $n = 900$

[2] $n = 902$

[3] Over 9.5 years

[4] Over 3 months, $n = 899$

dwelling Australian women. Our results also suggest that adopting Australian population-specific criteria may not improve predictive ability of these sarcopenia definitions for falls-related hospitalization risk. The lack of association observed in this study for falls-related hospitalization has also been previously reported in studies examining self-reported falls as outcomes [7, 24].

There have been a number of studies which have investigated whether sarcopenia is associated with an increased risk of falling in community-dwelling older adults with mixed findings [7, 10, 11, 24]. In an old Italian cohort ($n = 260$, mean age ~ 85 years), sarcopenia according to EWGSOP was associated with increased self-reported falls risk (HR 3.25 95%CI [1.54–6.88]) over 2 years [10]. Similarly, in an older Japanese female cohort, sarcopenic women according to EWGSOP ($n = 738$, mean age = 73.3 years), had higher relative risk for a self-reported fall in the previous year (RR 1.46 95%CI [1.05–2.04]) [11]. Consistent with our findings, seven sarcopenia definitions (including EWGSOP OR 1.41 95%CI [0.53–3.81] and FNIH OR 0.71 95%CI [0.20–2.40]) were not associated with increased odds for a self-reported fall in older American women over 3 years ($n = 246$, mean age ~ 71 years) [7]. Finally, in an older British cohort ($n = 298$,

Table 3 Spearman's rank correlations between appendicular lean mass (ALM), ALM-height, and ALM-body mass index (BMI)–adjusted variants, grip strength, and timed-up-and-go (TUG)

	ALM	ALM/height^2	ALM/BMI	Grip strength	TUG
ALM (kg)	–	0.87**	0.31**	0.28**	0.05
ALM/height^2 (kg/m^2)	0.87**	–	0.03	0.14**	0.11**
ALM/BMI (kg/BMI)	0.31**	0.03	–	0.27**	− 0.14*
Grip strength	0.28**	0.14**	0.27**	–	− 0.26**
TUG	0.05	0.11**	− 0.14**	− 0.26**	–

**$p < 0.001$

mean age ~ 76 years), sarcopenia defined by the EWGSOP was not associated with increased risk for self-reported falls in the previous year (OR 1.32 95%CI [0.55–7.29]) [24].

A number of factors may explain these mixed findings, including the age, size, and gender of cohorts, as well as differences in the follow-up time. Findings are further complicated as ALM, muscular strength, and/or physical function have been quantified using a variety of methods and cut points. For example, in the aforementioned Japanese and Italian cohorts, muscle mass was estimated using bioelectrical impedance analysis [11] and mid-arm muscle circumference [10], respectively. Therefore, it is difficult to directly compare the findings across studies.

Another potential reason for the difference in findings across some studies utilizing self-reported falls is that this method is subject to recall bias [25], and occur more frequently than falls resulting in injury [13]. For example, only 5% of all falls (~ 60 out of 1195 falls) resulted in the faller being hospitalized in a cohort of older Australian women followed for 1.6 years ($n = 887$, mean age ~ 78 years). Additionally, neuromuscular and cognitive impairment differences as well as falls circumstances distinctions between injurious and non-injurious falls may exist [15]. Other falls propensity risk factors such as balance, coordination, muscle power, or vision [6] could also play an important role in relation to falls that result in injury. Such factors provide a strong rationale to examine both fall types separately.

In the current investigation, ALM adjusted for BMI or height^2 were poorly correlated with both grip strength and TUG. When components of sarcopenia were examined individually, both grip strength and TUG, but not ALM adjusted for BMI or height^2, were associated with falls-related hospitalization. This highlights the importance of muscle strength and physical function in reducing the risk of falls-related hospitalization. Previous studies indicate that age-related declines in muscle strength exceeds losses in lean mass [3], and it is the reduction in muscle strength that is more strongly associated with disability, falls, and institutionalization [26, 27]. This concept is supported by a meta-analysis of studies on older adults reporting individuals with reduced lower-limb muscle strength have increased odds for falling (OR 1.76 95%CI [1.31–2.37]) [28]. Upper-limb muscle strength was also associated with an increased risk for falling, but the strength association was less than that for lower-limb muscle strength (OR 1.53 95%CI [1.01–2.32]) [28]. Although we did not quantify muscle strength in the lower-limb, TUG relies on a combination of muscle strength and mobility. Specifically, lower-limb muscle power, or the ability to produce force rapidly, may be a more critical component of functional status in older women [29]. Given that the loss in muscle power occurs at an earlier age and exceeds that of muscle strength [29], this should be considered in future work.

Of interest, unlike measures of muscle function, no relationship was observed for DXA-derived ALM and falls-related hospitalization. Although DXA is commonly used to quantify lean mass, current gold standards for the non-invasive assessment of muscle mass, size, and/or quality include magnetic resonance imaging (MRI) and computed tomography (CT) [30]. In comparison to MRI and CT, DXA represents a quick low-radiation cost-effective method. However, DXA does have limitations. Specifically, DXA assumes segment constancy in relation to tissue composition, whereas both the lipid and water content vary in skin, adipose, muscle, and bone tissue [31]. Considering DXA cannot differentiate between bone-free lean mass and water content, lean mass may be overestimated in older populations who have higher extracellular fluid accumulation [32]. Therefore, the relationship between lean mass and falls may have been different if ALM (or muscle cross-sectional area) was quantified using MRI or CT. Finally, alternate ways to accurately quantify muscle mass such as the urinary creatine dilution test [33] and ultrasound [34] have been investigated. However, more work is required before such methods and associated cut points for low ALM can be recommended.

Limitations of the study include its observational nature, meaning causality cannot be established and we cannot exclude the possibility of bias due to residual confounding. Furthermore, as only falls resulting in hospitalization were examined here, this excludes falls where patients could have presented to hospital emergency departments with potentially less traumatic injuries (e.g., small lacerations and minor contusions) and were consequently sent home. It is possible that the inclusion of these non-hospitalized falls may have produced different results.

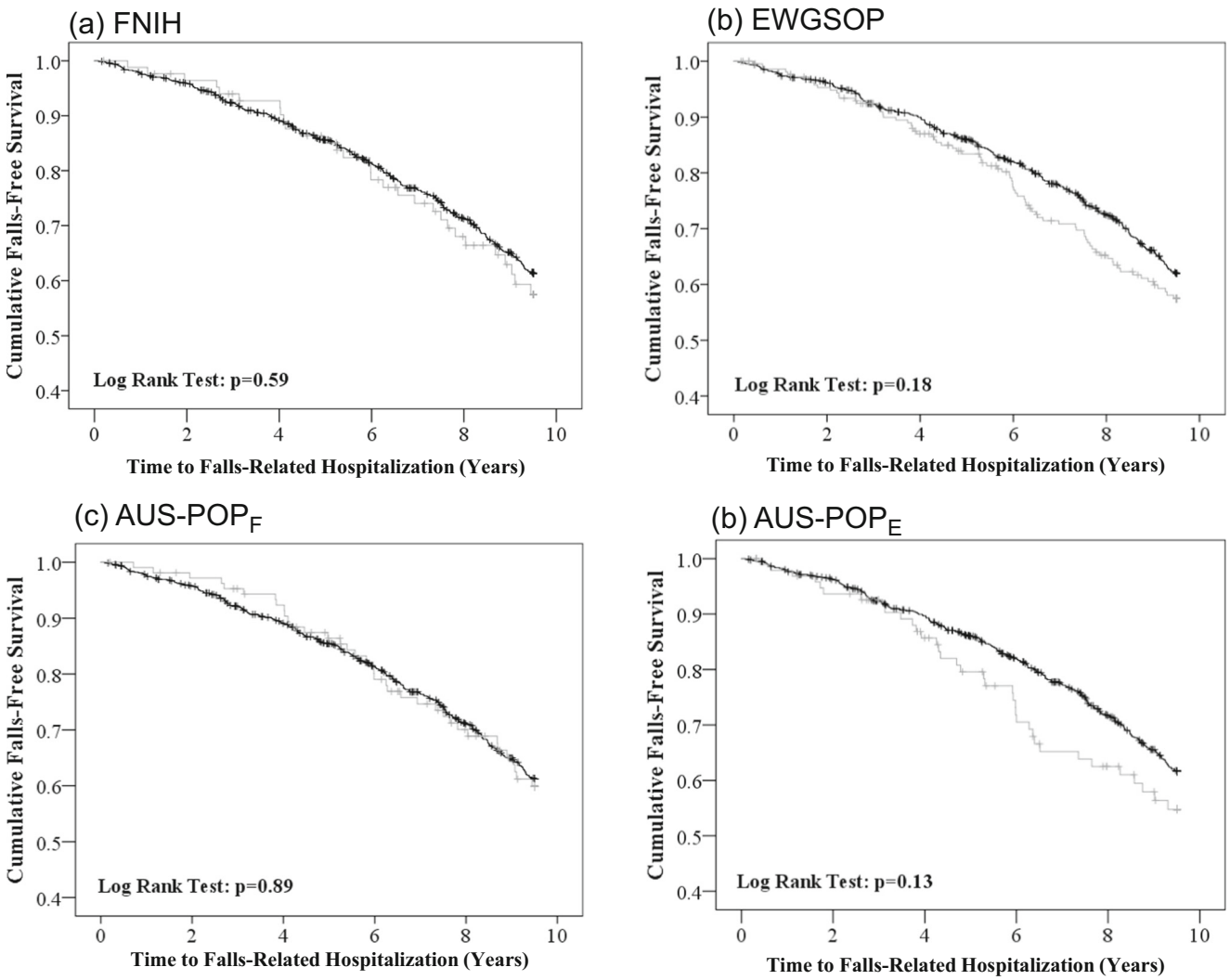

Fig. 1 Kaplan-Meier survival curves for FNIH (**a**), EWGSOP (**b**), AUS-POP_F (**c**), and AUS-POP_E (**d**) sarcopenia definitions for falls-related hospitalization over 9.5 years. Gray and black lines represent individuals with or without sarcopenia, respectively. AUS-POP_F and AUS-POP_E represent Australian population-specific criteria adapted from FNIH and EWGSOP, respectively

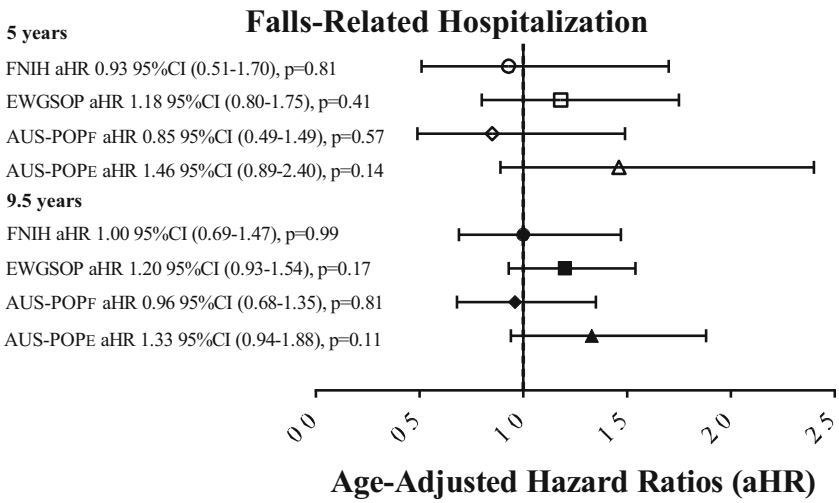

Fig. 2 Age-adjusted hazard ratios (aHR) with 95% confidence intervals (CI) for falls-related hospitalization over 5 years and 9.5 years according to FNIH, EWGSOP, AUS-POP_F, and AUS-POP_E sarcopenia definitions. The referent group was participants without sarcopenia according to the respective definition. AUS-POP_F and AUS-POP_E represent Australian population-specific criteria adapted from FNIH and EWGSOP, respectively

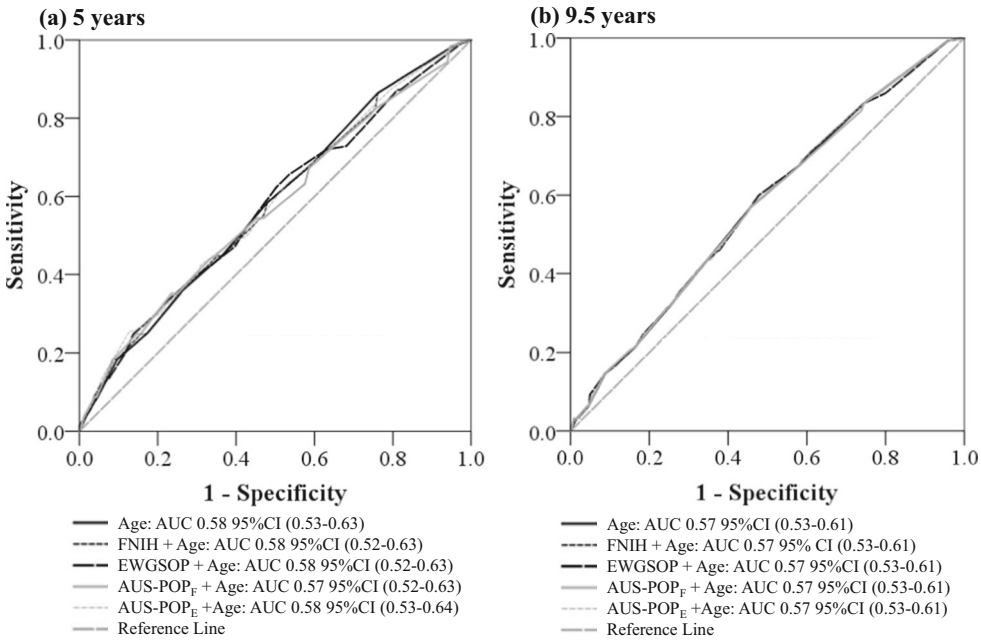

Fig. 3 ROC analysis for age and age-adjusted FNIH, EWGSOP, AUS-POP_F, and AUS-POP_E sarcopenia definitions for falls-related hospitalization over 5 years (**a**) and 9.5 years (**b**). AUS-POP_F and AUS-POP_E represent Australian population-specific criteria adapted from FNIH and EWGSOP, respectively

Nonetheless, our data provides a unique opportunity to examine the most serious type of falls, which are rarely reported in the literature. Secondly, as gait speed was unavailable in PLSAW, TUG was used as an assessment of physical performance for EWGSOP and AUS-POP_E. It is possible that definitions using gait speed may perform differently for falls-related hospitalization prediction to those using TUG. Nonetheless, TUG represents a complex test–incorporating maneuvers typically used in daily life such as balance, gait speed, and functional abilities (e.g., sitting and standing) [35]. Furthermore, TUG is recommended by the EWGSOP as a physical function test (with reference values obtained from an appropriate cohort) and is associated with fractures [36], self-reported disability, and mortality in older individuals [5]. Third, because we were solely interested in the clinical utility of sarcopenia definitions, only an age-adjusted model was examined. Potential confounders such as lifestyle factors (diet and physical activity), medical history, and medication use, all of which are known to be associated with falls propensity and mortality, were not studied. Specifically, non-sarcopenic women may have experienced more falls due to lifestyle choices, such as greater levels of physical activity. Alternatively, sarcopenic women may limit such activities, thereby avoiding injuries related to falls. Fourth, there is the potential for a healthy survivor bias given the individuals enrolled in the initial RCT (CAIFOS) were selected based on greater than 5-year survival, and that women who withdrew or died in the first 5 years were not available for assessment of sarcopenia measures in 2003. Finally, results may not be generalized to other populations including older men or younger cohorts.

Strengths of the current study include the prospective design and population-based setting with ascertainment of verified falls-related hospitalization, including recurrent falls-related hospitalizations with almost no loss to follow-up in a large cohort of older community-dwelling women that were representative of older Australian female population [37]. We also quantified ALM using DXA, hand grip strength, and TUG using standardized assessment. Additionally, we explored population-specific sarcopenia definitions derived from FNIH and EWGSOP guidelines. This included obtaining ALM, BMI, height, grip strength, and TUG reference values from young healthy Australian women.

In conclusion, current sarcopenia definitions may not identify older Australian women at higher risk of falls that result in hospitalization. This is supported by (i) the low proportion of women who experienced a falls-related hospitalization that were captured by the different sarcopenia definitions (9.5% to 27.1%), and (ii) the lack of association between sarcopenia definitions and falls-related hospitalization. Future work should consider the importance of muscle strength and physical function as opposed to ALM (measured by DXA) when considering risk models for falls-related hospitalization in this population.

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Author contributions M. S., R. L. P., D. S., R. M. D., G. D., C. A. I, K. Z., R. J. W., J. M. H., and J. R. L. conceived and designed the study. J. R. L, K. Z., and R. L. P. collected the data. M. S., J. M. H, J. R. L., and R. L. P. prepared the manuscript; all authors reviewed the manuscript; M. S. had the primary responsibility for the final content. All authors read and approved the final manuscript.

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Compliance with ethical standards

Conflict of interest None.

Ethics statement All participants provided written informed consent. Ethics approval was granted by the Human Ethics Committee of the University of Western Australia. Both studies were retrospectively registered on the Australian New Zealand Clinical Trials Registry (CAIFOS trial registration number ACTRN12615000750583 and PLSAW trial registration number ACTRN12617000640303) and complied with the Declaration of Helsinki. Human ethics approval for the use of linked data was provided by the Human Research Ethics Committee of the Western Australian Department of Health (project number 2009/24).

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