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Original article

Low relative sit-to-stand power is associated with history of falls and fractures, prospective hospitalization, and all-cause mortality in older adults from the Toledo study for healthy aging

Mikel Garcia-Aguirre [a,b,c,d], Ivan Baltasar-Fernandez [a,b,c,d,e], Julian Alcazar [a,b,c,d], Ana Alfaro-Acha [b,c,d,f], Fabio A. Quiñonez-Bareiro [b,c,d,f], Ignacio Ara [a,b,c,d], Leocadio Rodriguez-Mañas [b,g], Francisco J. Garcia-Garcia [b,c,d,f,*], Luis M. Alegre [a,b,c,d,*]

[a] *GENUD Toledo Research Group, Faculty of Sport Sciences, University of Castilla-La Mancha, Toledo 45071, Spain*
[b] *Centro de Investigación Biomédica en Red Fragilidad y Envejecimiento Saludable (CIBERFES), Instituto de Salud Carlos III, Madrid 28029, Spain*
[c] *Instituto de Investigación Sanitaria de Castilla-La Mancha (IDISCAM), Junta de Comunidades de Castilla-La Mancha (JCCM), Toledo 45004, Spain*
[d] *Grupo Mixto de Fragilidad y Envejecimiento Exitoso Universidad de Castilla-La Mancha-Servicio de Salud de Castilla-La Mancha (UCLM-SESCAM), Toledo 45007, Spain*
[e] *Faculty of Health Sciences, University of Castilla-La Mancha, Talavera de la Reina 45600, Spain*
[f] *Geriatrics Department, Hospital Universitario de Toledo, Toledo 45071, Spain*
[g] *Geriatrics Department, Getafe University Hospital, Getafe 28905, Spain*

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Abstract

Background: Low relative sit-to-stand (STS) power has emerged as a critical predictor of adverse health outcomes, such as frailty and disability, in older adults. However, its impact on falls, fractures, hospitalizations, and all-cause mortality remains unclear. Therefore, this longitudinal study aimed to investigate the potential associations between low relative STS power and these adverse health outcomes in older adults.

Methods: A total of 1876 older adults (aged ≥65 years, 56.4% women) were included from the Toledo Study for Healthy Aging. Relative STS power was assessed using the 30-s STS test and the Alcazar equation. Participants were categorized as having low relative STS power based on previously established cut-off points (2.53 W/kg for men and 2.01 W/kg for women). Falls and fractures (hip and all-type) within the previous year were recorded. Hospitalizations and all-cause mortality were obtained during a follow-up of 6.8 ± 3.1 years (mean ± SD; median = 7.8 years; interquartile range: 3.9−10.1 years) and 9.7 ± 3.5 years (median = 10.9 years; interquartile range: 8.2−12.5 years), respectively. Generalized linear mixed models, binary logistic regression, and proportional hazards regression adjusted for age, educational level, and comorbidities were used.

Results: In men, low relative STS power was significantly associated with an increased likelihood of history of falls (odds ratio (OR) = 1.73, 95% confidence interval (95%CI): 1.08−2.75, $p = 0.022$) and all-type fractures (OR = 1.86, 95%CI:1.21−2.84, $p = 0.004$) in the previous year. In women, low relative STS power was associated with a higher probability of hip fractures within the previous year (OR = 3.25, 95%CI: 1.07−9.86, $p = 0.038$). Low relative STS power predicted hospitalizations in women (hazard ratio (HR) = 1.29, 95%CI: 1.06−1.58, $p = 0.012$) and longer hospital stays in both men ($p = 0.020$) and women ($p = 0.033$). Low relative STS power significantly increased all-cause mortality in both men (HR = 1.57, 95%CI: 1.26−1.97, $p < 0.001$) and women (HR = 2.04, 95%CI: 1.51−2.74, $p < 0.001$).

Conclusion: Low relative STS power was associated with history of hip fractures in women, whereas in men it was associated with history of falls and all-type fractures. Low relative STS power predicted hospitalizations in women but not in men. In both men and women, low relative STS power was associated with longer hospital stays and increased risk of all-cause mortality.

Keywords: Adverse outcomes; Muscle power; Hospitalization stay; Frailty; Disability

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* Corresponding authors.
E-mail addresses: franjogarcia@telefonica.net (F.J. Garcia-Garcia), luis.alegre@uclm.es (L.M. Alegre).

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1. Introduction

The musculoskeletal system undergoes significant changes with aging, particularly muscle mass, strength (peak force a muscle can generate), and power (the product of force and velocity).[1] Among these parameters, relative muscle power—defined as muscle power (W) normalized by body mass (kg)—deteriorates at a faster rate than muscle mass, performance, and strength,[1–3] with declines starting after the age of 30 years and accelerating significantly in people aged 65 years and over.[4] This decline has profound health implications for older adults, as low relative muscle power is strongly associated with adverse health outcomes, including frailty,[5] disability,[6] and cognitive impairment.[5] These conditions increase vulnerability to external stressors, such as falls and fractures,[7] and increase the risk of hospitalizations[8] and mortality.[9] Among these outcomes, falls are particularly concerning[10,11] as they often lead to severe injuries, including fractures.[12] Hip fractures, in particular, place a high burden on patients, resulting in disability,[13] decreased quality of life,[14] and increased all-cause mortality.[15] With the rising prevalence of osteoporosis and sarcopenia in aging populations,[10,11] the combined risk of falls and fractures places a significant strain on both individuals and healthcare systems.

Among these challenges, low relative muscle power emerges as a key factor, affecting more than 45% of individuals aged 65 years and older, with higher rates observed in women compared to men.[5] Furthermore, longitudinal studies have shown that low muscle power predicts the incidence of frailty as well as hospitalizations and all-cause mortality in older adults.[9,16] However, these studies have primarily classified low muscle power using the lowest sex-specific tertiles or quintiles. While this approach helps identify higher-risk individuals within a population, it may be less suitable for standardized comparisons across studies. In contrast, employing sex-specific standardized cut-off points offers a more uniform and clinically meaningful approach, providing actionable thresholds that can be directly applied in practice to identify individuals at risk of adverse outcomes.[17]

In this context, recent research has proposed sex-specific cut-off points for identifying older people with low relative muscle power.[5] In that study, relative muscle power was evaluated using the 30-s sit-to-stand (STS) test and the Alcazar equation,[18] allowing for simple, low-cost, and efficient evaluation of relative muscle power in the clinical setting. Compared to the 5-repetition STS test, the 30-s version offers greater applicability across a broader range of functional capacities as it enables muscle power estimation even in individuals unable to complete 5 STS repetitions,[19] which makes the 30-s version especially suitable for frailer populations and for monitoring functional trajectories over time. Importantly, these cut-off points for low 30-s relative STS power (2.53 W/kg for men and 2.01 W/kg for women) have been associated with an increased risk of frailty and disability in activities of daily living.[5] However, it remains unknown whether these thresholds are sensitive enough to identify individuals with a history of falls and fractures and to predict hospitalization and all-cause mortality over time.

Therefore, the aim of this longitudinal study was to evaluate whether low relative STS power would be associated with an increased risk of falls, fractures, hospitalizations, and all-cause mortality in older adults. By doing so, we sought to extend the external validity of these recently proposed cut-off points and to support their use as clinically meaningful thresholds for early risk stratification in geriatric populations.

2. Materials and methods

2.1. Study design and participants

The present study includes longitudinal data from the Toledo Study for Healthy Aging (TSHA)[20] collected between 2006 and 2019. Participants were recruited by two-stage random sampling. In the 1st stage, a random selection was conducted in 6 strata according to sex, age, and town-size groups. In the 2nd stage, a subsample of individuals from the 1st-stage selection were randomly drawn again to be included in the study sample. A total of 2488 older adults agreed to participate in the study. Of these, 1876 participants aged 65 years and older (75.4 ± 6.1 years (mean ± SD), 817 men and 1059 women) successfully completed the 30-s STS test and were included in the analysis (Fig. 1). All the participants signed an informed consent, and the Clinical Research Ethics Committee of the Toledo Hospital (Spain) approved the study protocol (30/03/2005; reference number 22). All the evaluations were conducted according to the Helsinki Declaration.

2.2. Anthropometry

Body mass was measured using a scale with a precision of 0.1 kg (Seca 711; Seca, Hamburg, Germany), and height was measured with a portable stadiometer with a precision of 1 mm (Medizintechnikseit 1890; KaWe, Asperg, Germany). Participants were measured while wearing light clothing and no shoes. Body mass index (BMI) was calculated by dividing body mass by height squared (kg/m^2).

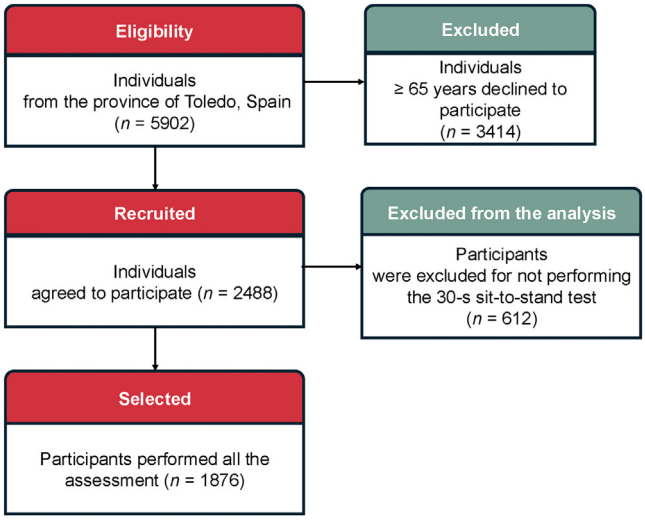

Fig. 1. Flow chart of study participants.

2.3. Relative STS power

Relative STS power was assessed using the 30-s STS test and the Alcazar equation.[21] Participants were instructed to complete the maximum number of STS repetitions within 30 s after the cue "ready, set, go!" on a 0.43 m standardized chair without armrests. Participants had to perform the test with their arms crossed over their chest, and the STS repetitions were considered valid when the participant achieved a full standing position (full knee and hip extension) and at least touched the chair with their buttocks when sitting. The maximum number of repetitions completed in the 30-s STS test was recorded, and the Alcazar equation was used to estimate relative STS power:[21]

$$\text{Relative STS power (W/kg)} = (0.9 \times g) \times \frac{(\text{Body height (m)} \times 0.5 - \text{Chair height (m)})}{\left(\frac{30\ \text{s}}{\text{Number of STS repetitions}}\right) \times 0.5}$$

Low relative STS power was defined as a value ≤2.53 W/kg in men and ≤2.01 W/kg in women,[5] while the remaining participants were categorized as having normal relative STS power. Participants unable to perform a single STS repetition were also classified as having low relative STS power.

2.4. Falls and fractures

Falls and fractures were retrospectively assessed using the TSHA questionnaire.[20] This tool gathers information on the number of falls experienced and the occurrence of hip fractures or fractures in other bones (i.e., all-type fractures) in the previous year.

2.5. Hospitalizations and all-cause mortality

Hospitalization data were obtained from the National Hospital database for each participant during a mean follow-up of 6.8 ± 3.1 years (median = 7.8 years; interquartile range: 3.9−10.1 years), while all-cause mortality data were retrieved from the Spanish National Death Index (Ministry of Health, Consumer Affairs, and Social Welfare) during a mean follow-up of 9.7 ± 3.5 years (median = 10.9 years; interquartile range: 8.2−12.5 years). Follow-up time was calculated from the date of the baseline assessments to the date of hospitalization, death, or censoring (December 2019).

2.6. Covariates

Age, educational level, and comorbidities were evaluated and included as covariates in the analyses. Educational level was categorized into 4 groups: illiterate, primary education, secondary education, and university education. Comorbidities were assessed using the Charlson Comorbidity Index, which evaluates the presence and severity of 19 comorbid conditions.[22]

2.7. Statistical analysis

Descriptive data are shown as mean ± SD for continuous variables and frequencies (*n*) and percentages (%) for categorical variables. Kolmogorov-Smirnov and Levene's tests were used to evaluate the normality distribution and the homoscedasticity of the sample, respectively. Student's *t* tests and χ^2 tests were used to evaluate baseline differences between men and women in continuous and categorical variables, respectively. General linear models adjusted for age, educational level, and comorbidities were used to analyze differences between older adults with low relative STS power and normal relative STS power in terms of the number of falls collected in the previous year, number of hospitalizations, and mean duration of each hospitalization. Binary logistic regression and Cox proportional hazards regression, adjusted for age, educational level, and comorbidities were used to evaluate the association of low relative STS power with the history of falls and fractures as well as with the risk of hospitalizations and all-cause mortality during the follow-up. Hospitalizations and deaths within the first year were excluded to minimize bias from reverse causation. All statistical analyses were performed using SPSS V21 (IBM Corp., Armonk, NY, USA), and the significance level was set at $\alpha = 0.05$.

3. Results

The baseline characteristics of the study sample are shown in Table 1. Compared to men, older women presented lower body mass and height, and higher BMI. In addition, older women exhibited lower relative STS power, higher prevalence of low relative STS power, higher Charlson index, higher prevalence of falls, higher prevalence of all-type fractures, lower length and prevalence of hospitalizations, and lower mortality rate compared to older men (all $p < 0.05$). There were no significant differences between sexes in terms of age, number of falls and prevalence of hip fractures.

3.1. Comparison of falls and fractures within the previous year between older adults with low and normal relative STS power

Older women with low relative STS power exhibited a higher prevalence (27.0% *vs.* 17.6%; $p < 0.001$) (Fig. 2A) and frequency of falls (1.3 ± 0.4 *vs.* 1.2 ± 0.4 falls; $p < 0.001$) (Fig. 2B), higher prevalence of hip fractures (4.5% *vs.* 1.0%; $p = 0.001$) (Fig. 2D) and higher prevalence of all-type fractures (26.0% *vs.* 17.0%; $p < 0.001$) (Fig. 2E) compared to those with normal relative STS power. In older men, the prevalence of falls (17.3% *vs.* 9.4%; $p < 0.001$), the frequency of falls (1.2 ± 0.4 *vs.* 1.1 ± 0.3 falls; $p < 0.001$), and the prevalence of hip fractures (3.5% *vs.* 1.3%; $p = 0.046$) were higher in those with low relative STS power than in those with normal relative STS power (Fig. 2A, 2B, and 2D). The prevalence of all-type fractures was similar between older men with low and normal relative STS power (19.3% *vs.* 15.0%; $p = 0.103$) (Fig. 2E). When considering only individuals who had experienced a fall, no significant differences were found in the number of

Table 1
Baseline characteristics of study participants (mean ± SD or *n* (%)).

	All participants (*n* = 1876)	Men (*n* = 817)	Women (*n* = 1059)
Age (year)	75.4 ± 6.1	75.2 ± 5.9	75.5 ± 6.3
Body mass (kg)	71.3 ± 14.8	76.0 ± 12.0	69.2 ± 12.4*
Height (m)	1.56 ± 0.11	1.64 ± 0.11	1.52 ± 0.08*
BMI (kg/m^2)	29.2 ± 4.7	28.2 ± 3.9	30.0 ± 5.1*
Relative STS power (W/kg)	2.38 ± 0.88	2.75 ± 0.94	2.07 ± 0.69*
Low relative power	1077 (57.4)	433 (53.0)	644 (60.8)*
Charlson index (points)	1.79 ± 1.83	1.67 ± 1.8	1.87 ± 1.85*
Falls (yes)	360 (19.2)	111 (13.6)	249 (23.5)*
Number of falls	1.98 ± 1.97	1.84 ± 1.81	2.04 ± 2.04
All-type fractures (yes)	375 (20.2)	140 (17.3)	235 (22.4)*
Hip fractures (yes)	53 (2.8)	20 (2.4)	33 (3.1)
Hospitalization (yes)	1054 (56.2)	488 (59.7)	566 (53.4)*
Time to hospitalization (year)	4.7 ± 2.5	4.7 ± 2.5	4.8 ± 2.5
Number of hospitalizations	2.09 ± 1.72	2.09 ± 1.66	2.10 ± 1.79
Hospitalization length (day)	2.86 ± 6.14	2.86 ± 6.14	2.49 ± 5.68*
Deceased (yes)	762 (40.6)	397 (48.6)	365 (34.5)*
Time to deceased (year)	6.9 ± 3.3	6.6 ± 3.3	7.3 ± 3.2

* $p < 0.05$ denotes significant differences compared to men.
Abbreviations: BMI = body mass index; SD = standard deviation; STS = sit-to-stand.

falls among older men with low relative STS power and those with normal relative STS power (2.0 ± 1.1 *vs.* 1.6 ± 1.0 falls; $p = 0.143$) (Fig 2C). In contrast, among older women with a history of falls, those with low relative STS power had a significantly higher number of falls than those with normal relative STS power (2.2 ± 2.3 *vs.* 1.6 ± 1.1 falls; $p = 0.002$) (Fig. 2C).

3.2. Associations of low relative STS power with falls and fractures within the last year

The unadjusted analysis showed that low relative STS power was associated with falls in the previous year in both men and women (both $p < 0.05$) (Supplementary Table 1). Low relative STS power was associated with hip fractures and all-types of fractures in women (both $p < 0.05$) but not in men ($p = 0.055$ and $p = 0.103$, respectively) (Supplementary Table 1). After adjusting for covariates, there was a significant association between low relative STS power and falls (odds ratio (OR) = 1.73, 95% confidence interval (95%CI): 1.08−2.75; $p = 0.022$) and all-types of fractures (OR = 1.86, 95%CI: 1.21−2.84; $p = 0.004$) but not hip fractures (OR = 2.40, 95%CI: 0.83−6.98; $p = 0.107$) in men (Fig. 3A). In women, there was a significant association between low relative STS power and hip fractures (OR = 3.25, 95%CI: 1.07−9.86; $p = 0.038$), and a strong trend towards an association with falls (OR = 1.38, 95%CI: 0.98−1.95; $p = 0.065$) and all-types of fractures (OR = 1.40, 95%CI: 0.98−1.99; $p = 0.061$) (Fig. 3B).

3.3. Comparison of hospitalizations and all-cause mortality between older adults with low and normal relative STS power

Older men with low relative STS power showed a tendency towards a higher cumulative hospitalization incidence compared to those with normal relative STS power (62.6% *vs.* 56.5%, respectively; $p = 0.077$) (Fig. 4A). In women, a significantly higher cumulative hospitalization incidence was observed in those with low relative STS power compared to those with normal relative STS power (59.6% *vs.* 43.9%, $p < 0.001$) (Fig. 4A). Both men and women with low relative STS power experienced a greater number of hospitalizations compared to those with normal relative STS power (men: 0.89 ± 1.60 *vs.* 0.51 ± 1.10 hospitalizations, $p = 0.037$; women: 0.64 ± 1.5 *vs.* 0.37 ± 0.9 hospitalizations, $p = 0.004$) (Fig. 4B). Hospital length was longer in those older adults with low relative STS power compared to those with normal relative STS power (men: 4.0 ± 7.7 *vs.* 2.5 ± 5.1 days, $p = 0.020$; women: 2.7 ± 6.4 *vs.* 1.9 ± 4.0 days, $p = 0.033$) (Fig. 4C). The cumulative incidence of mortality was significantly higher among men and women with low relative STS power compared to those with normal relative STS power (men: 59.6% *vs.* 36.2%, $p < 0.001$; women: 46.6% *vs.* 15.7%, $p < 0.001$) (Fig. 4F). Furthermore, when considering only individuals who had been hospitalized, no significant differences were found in hospitalization frequency (2.2 ± 1.8 *vs.* 1.8 ± 1.6 hospitalizations; $p = 0.286$) or hospitalization stay between older women with low relative STS power and those with normal relative STS power (10.1 ± 7.8 *vs.* 8.8 ± 6.2 days of hospitalization; $p = 0.326$) (Fig 4D and 4E). However, older men with low relative STS power showed significantly longer hospitalization stays (10.5 ± 8.9 *vs.* 8.7 ± 6.6 days of hospitalization; $p = 0.012$) but similar hospitalization frequency (2.2 ± 1.8 *vs.* 1.9 ± 1.4 hospitalizations; $p = 0.222$) than those with normal relative STS power (Fig. 4D and 4E).

3.4. Risk of hospitalization and all-cause mortality in older people with low vs. normal relative STS power

The unadjusted analysis showed that low relative STS power was associated with a higher risk of hospitalization in women ($p < 0.001$) but not in men ($p = 0.063$) (Supplementary Table 2). In contrast, low relative STS power was associated with a higher risk of all-cause mortality in both men and women (both $p < 0.001$) (Supplementary Table 2). After adjusting for covariates, no increased risk of hospitalization was observed in men with low relative STS power compared to those with normal relative STS power (HR = 1.14, 95%CI: 0.93−1.39; $p = 0.209$) (Fig. 5A), whereas women with low relative STS power exhibited an elevated risk of hospitalization compared to women with normal relative STS power (HR = 1.29, 95%CI: 1.06−1.58; $p = 0.012$) (Fig. 5B). In terms of all-cause mortality, a significantly increased risk of all-cause mortality was observed in both men (HR = 1.57, 95%CI: 1.26−1.97; $p < 0.001$) and women (HR = 2.04, 95%CI: 1.51−2.74; $p < 0.001$) with low relative STS power compared to those with normal relative STS power (Fig. 5C and 5D).

4. Discussion

The current study found that older adults with a previous history of falls and fractures had higher probabilities of having low relative STS power. Additionally, older adults with low

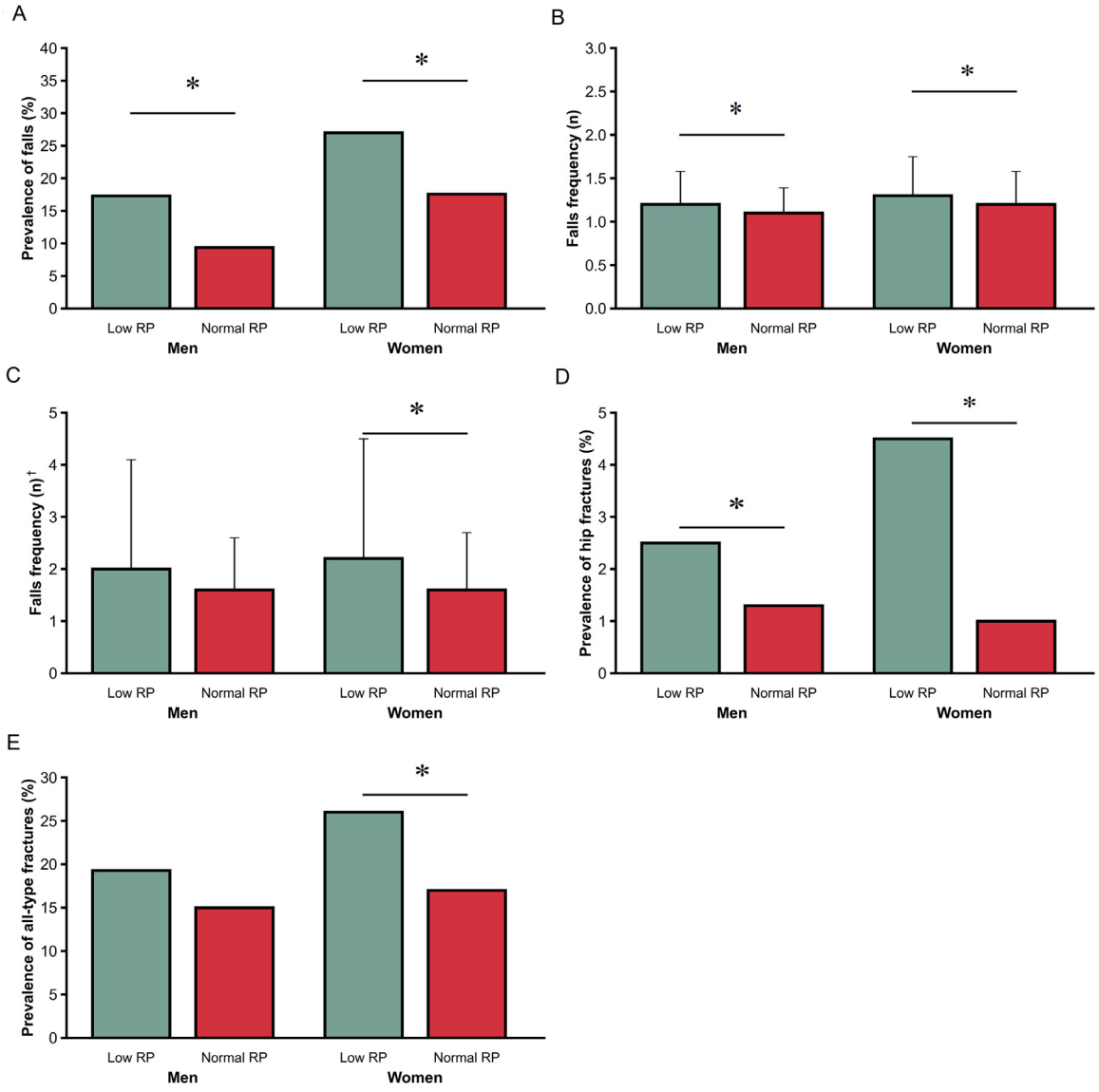

Fig. 2. Comparison between older adults with low and normal relative STS power in falls and fractures experienced in the previous year. (A) Prevalence of falls; (B) frequency of falls; (C) frequency of falls in individuals with history of falls in the previous year; (D) prevalence of hip fracture; (E) prevalence of all-type fracture. The analysis was adjusted by age, educational level, and comorbidities. * $p < 0.05$, significantly different compared to older adults with normal RP. † Denotes that these panels include only participants who experienced falls. RP = relative power; STS = sit-to-stand.

relative STS power experienced a higher prevalence of frequent hospitalizations, with longer stays compared to their counterparts with normal relative STS power. While no increased risk of hospitalization was observed in men with low relative STS power, such a risk was evident in women. Finally, both older men and women with low relative STS power faced a significantly higher risk of all-cause mortality compared to those with normal relative STS power.

Falls, fractures, and their associated consequences, such as functional decline and mortality, have become major concerns for health systems worldwide, particularly among older adults.[14,23] Previous studies have reported that 26.5% of older adults experience falls,[24] with women presenting a higher prevalence.[25] Our findings reveal that older adults with a history of falls had higher risk of presenting low relative STS power compared to those that did not have a fall in the previous year. Thus, the prevalence of history of falls reached 27% in women and 19% in men with low relative STS power.

Furthermore, given the increasing prevalence of osteoporosis[26] and sarcopenia[27] with aging, the risk of falls becomes particularly concerning, as they can lead to severe outcomes such as fractures, especially hip fractures.[28] Our study further confirmed that older women with low relative STS power had a higher incidence of hip fractures compared to those with normal relative STS power (4.5% *vs.* 1.0%), with women experiencing a significantly greater incidence than men (4.5% *vs.* 3.5%). Moreover, when considering all types of fractures, the prevalence among women rises to 19.3%, while men exhibit a 17.3% prevalence. These findings highlight the associations between prior fractures and low relative STS power,

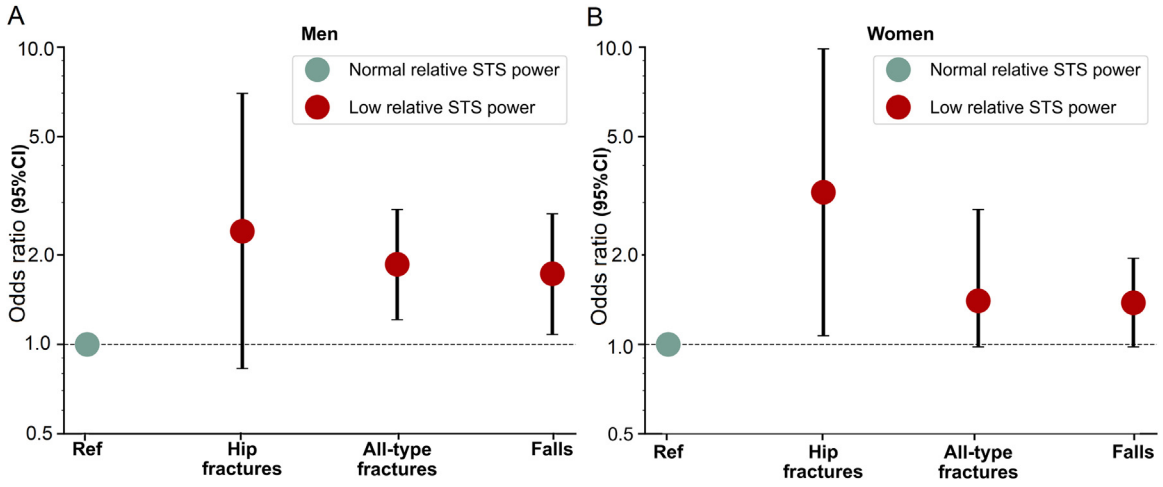

Fig. 3. Association of low baseline relative STS power with falls, hip fractures, and all-type fractures within the previous year in older (A) men and (B) women. The analysis was adjusted by age, educational level, and comorbidities. 95%CI = 95% confidence interval; STS = sit-to-stand.

particularly in women. The post-menopausal decline in bone mineral density driven by hormonal changes significantly increases fracture susceptibility in areas such as the intertrochanteric region and forearms, especially after a fall.[29] This aligns with our results, which revealed that women with low relative STS power were 3.25 times more likely to have reported hip fractures in the previous year. In men, our findings confirm a significant relationship between low relative STS power and the probability of having reported falls and all-types of fractures in the previous year, with odds ratios of 1.73 and 1.86, respectively. This could mean that, unlike in women, fractures in men are not concentrated in specific skeletal regions but could be distributed across a broader range of anatomical sites. Previous research supports these observations, demonstrating that reduced strength in hip abductors and knee flexors is a strong predictor of falls in older men.[30] These sex-specific differences in fracture patterns and associated risks likely stem from distinct biomechanical and physiological factors. The interplay between low muscle power, frailty, and other adverse health outcomes reinforces the importance of evaluating relative STS power in older adults. Evidence suggests that relative STS power is strongly associated with frailty and disability,[5] even more than sarcopenia.[31] Frailty syndrome, which affects 4 out of 10 older adults in our cohort,[20] likely amplifies the risk of both falls and fractures.[7] Collectively, these findings emphasize the necessity of early identification of individuals with low relative STS power to mitigate the risk of falls, fractures, and their cascading consequences.

Our study highlighted the critical role of relative STS power in predicting hospitalizations and all-cause mortality among older adults. Hospitalization poses a significant burden on healthcare systems, particularly in aging populations.[32] In our study, using previously established cut-off points,[5] older women but not older men with low relative STS power demonstrated an increased risk of future hospitalization compared to those with normal relative STS power (HR = 1.29). This is consistent with prior research[9] reporting elevated hospitalization risk in older women with very low relative power. Unlike men, women tend to make greater use of preventive health care services[33] and are often hospitalized at more advanced stages of functional decline, when their physical capacity is significantly compromised.[33–35] Therefore, since hospitalized women typically present with low functional reserves, low relative muscle power may serve as a more sensitive predictor of hospitalization in women than in men.

Moreover, our study revealed that low relative STS power was associated with higher incidence of cumulative hospitalizations and prolonged hospital stays in both men and women. This aligns with evidence showing that individuals with low relative STS power are significantly more likely to be frail,[5] and that frail individuals, in turn, are more susceptible to extended hospitalizations.[8]

The association between low relative STS power and mortality is particularly noteworthy. Although sarcopenia is a recognized risk factor for mortality,[36] low relative STS power predicts mortality just as effectively, as shown in our study. However, low relative STS power is considerably more prevalent, affecting ~45% of older adults compared to 10%–16% for sarcopenia.[37] This disparity underscores the importance of prioritizing low muscle power as a target for intervention in clinical and public health settings. Studies have consistently shown that low relative STS power is associated with an elevated risk of mortality independent of obesity (BMI, waist circumference, and body fat), hypertension, smoking status, and physical activity.[38] In our study, men with low relative STS power exhibited a 1.57-fold increased risk of all-cause mortality, while women had a 2.04-fold increased risk. Similarly, Losa-Reyna et al.[9] identified an increased mortality risk in men with very low relative STS power, although no significant association was observed in women. One key difference is that Losa-Reyna et al.[9] employed sex-specific tertiles to categorize relative STS power levels. In contrast, our research utilized sex-specific cut-off points.[5] Using sex-specific cut-off

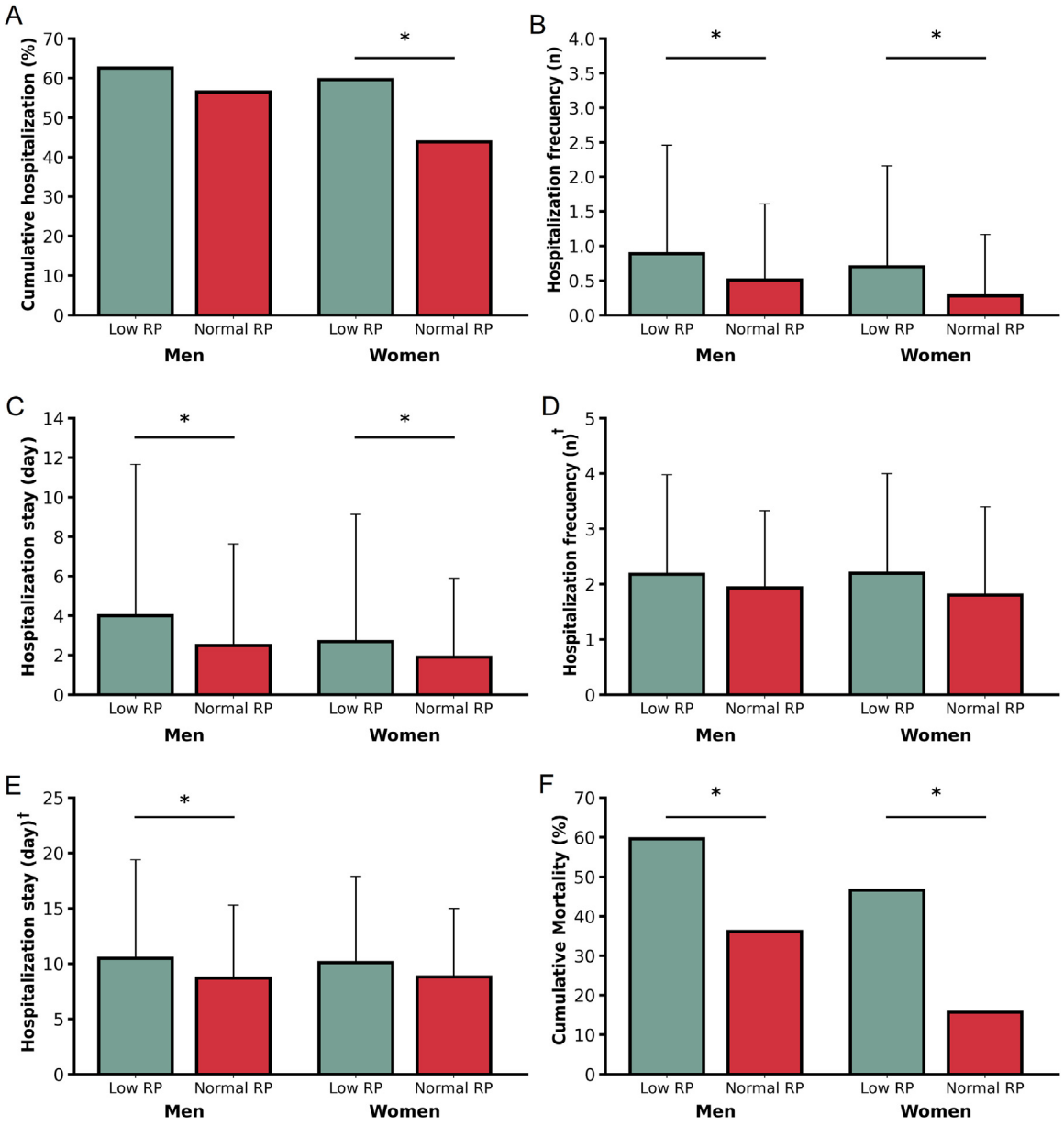

Fig. 4. Comparison between older adults with low and normal relative STS power in hospitalizations and mortality. (A) Cumulative hospitalization incidence; (B) frequency of hospitalizations; (C) mean hospitalization stay; (D) frequency of hospitalizations in participants that were hospitalized; (E) mean hospitalization stay in participants that were hospitalized; (F) cumulative mortality incidence. The analysis was adjusted by age, educational level, and comorbidities. * $p < 0.05$, significantly different compared to older adults with normal RP. † Denotes that these panels include only participants who were hospitalized. RP = relative power; STS = sit-to-stand.

points may offer distinct advantages over tertiles or quartiles by enhancing clinical applicability through tailored risk identification for men and women while improving precision by avoiding arbitrary thresholds that may not reflect clinically meaningful distinctions. Furthermore, another possible explanation might be the shorter follow-up period of the study of Losa-Reyna et al.[9] Overall, the significant hospitalization and mortality risk associated with low relative STS power highlights its potential as a standalone predictor and an essential component of preventative strategies. Given its high prevalence and strong predictive value, low relative STS power represents a critical focus for interventions aimed at reducing hospitalizations and mortality and improving health outcomes in older adults.

Finally, although various clinical assessments have been proposed to measure muscle power in older adults (e.g., the stair climbing test,[39] vertical jump test,[23] or the Nottingham Power Rig,[40] among others), these methods present considerable limitations. Specifically, they require specialized equipment, controlled environments, and qualified evaluators, and they pose challenges for older adults with impairments, which substantially limits their applicability in clinical practice. In

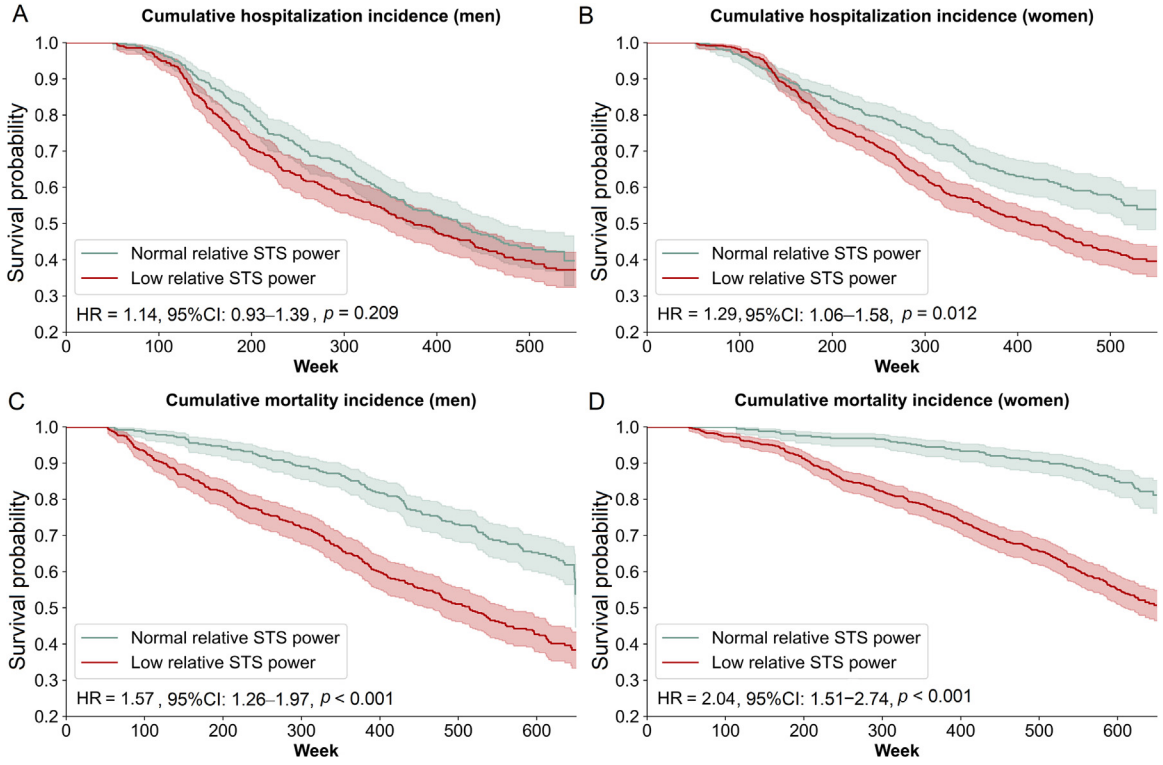

Fig. 5. Hospitalization and survival probability for older men and women with low *vs.* normal relative STS power. The first hospitalization probabilities for men and women are shown in panels (A) and (B), respectively, while the survival probabilities for men and women are displayed in panels (C) and (D). In each panel, the HRs and 95%CIs adjusted for age, educational level, and comorbidities are displayed, with the HRs reflecting the risk in comparison to the normal relative STS power group. 95%CI = 95% confidence interval; HR = hazard ratios; STS = sit-to-stand;

contrast, the 30-s STS test offers a simpler, safer, and more practical choice.[18] This test requires little space, no specialized tools, and can be administered effectively to older adults across various functional levels, including those with severe impairments, while reducing the ground and ceiling effects of the 5 repetitions STS test.[19] Furthermore, while tools such as the Stopping Elderly Accidents, Deaths, and Injuries (STEADI) guideline proposed by the Centers for Disease Control and Prevention,[41] which focuses on repetition counts in the STS test, are valuable for initial screening, they rely on a more simplistic approach that may fail to capture the complexities of neuromuscular performance. The use of relative STS power provides a more accurate reflection of functional capacity, accounting for individual differences in body mass and height, which significantly influence test performance.[42] Moreover, the 30-s STS muscle power test has shown strong sensitivity in detecting meaningful clinical changes, with minimal clinically important differences established at 0.42 W/kg for men and 0.33 W/kg for women.[43] Additionally, the Powerfrail App,[44] which is freely accessible, enables clinicians to easily calculate relative STS power and categorize individuals using validated sex-specific thresholds. This enhances the feasibility and clinical integration of the 30-s STS muscle power test, supporting its routine incorporation into comprehensive geriatric assessments to identify at-risk older adults early and guide targeted preventive measures.

5. Study limitations

This study has several limitations. First, muscle power was assessed using the 30-s STS muscle power test,[21] which is not the gold standard for evaluating muscle power. However, this tool has been validated in various older adult populations, demonstrating minimal bias compared to gold standard methods.[45] Furthermore, it is a low-cost, simple, and clinically practical tool strongly associated with adverse health outcomes in older adults.[5] Second, falls and fractures were assessed retrospectively, which precludes establishing a causal relationship between low relative STS power with adverse outcomes and can introduce bias when older adults are asked to recall their falls over the previous year. Third, our results are derived from an older Spanish population, limiting the generalization to other populations. Future studies should employ prospective designs to better elucidate the directionality and mechanisms underlying the association between low relative STS power, falls, and fractures.

6. Conclusion

Older adults with low relative STS power at baseline had a significantly higher prevalence of falls and fractures in the previous year. Additionally, older women with low relative STS power had a higher risk of hospitalizations, but this association was not observed in men. However, both men and women with low relative STS power had a higher number of

hospitalizations, longer hospital stays per admission, and a higher risk of all-cause mortality compared to those with normal relative STS power.

Declaration of competing interest

The authors declare that they have no competing interests.

Authors' contributions

FJGG, LMA, LRM, and IA conceived and designed the study, and secured funding; IBF conducted data collection, performed data analysis, and interpreted the results; JA, FABQ, and AAA conducted data collection; MGA performed data analysis, interpreted the results, and drafted the original manuscript. All authors critically revised, contributed to, and have approved the final version of the manuscript, and agree with the order of presentation of the authors.

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Supplementary materials

Supplementary materials associated with this article can be found in the online version at doi:10.1016/j.jshs.2025.101080.

References

1. Alcazar J, Rodriguez-Lopez C, Delecluse C, Thomis M, Van Roie E. Ten-year longitudinal changes in muscle power, force, and velocity in young, middle-aged, and older adults. *J Cachexia Sarcopenia Muscle* 2023;**14**:1019–32.
2. Bean JF, Leveille SG, Kiely DK, Bandinelli S, Guralnik JM, Ferrucci L. A comparison of leg power and leg strength within the InCHIANTI study: Which influences mobility more? *J Gerontol A Biol Sci Med Sci* 2003;**58**:M728-33.
3. Reid KF, Fielding RA. Skeletal muscle power: A critical determinant of physical functioning in older adults. *Exerc Sport Sci Rev* 2012;**40**:4–12.
4. Alcazar J, Aagaard P, Haddock B, et al. Assessment of functional sit-to-stand muscle power: Cross-sectional trajectories across the lifespan. *Exp Gerontol* 2021;**152**:111448. doi:10.1016/j.exger.2021.111448.
5. Garcia-Aguirre M, Baltasar-Fernandez I, Alcazar J, et al. Cut-off points for low relative 30-s sit-to-stand power and their associations with adverse health conditions. *J Cachexia Sarcopenia Muscle* 2025;**16**:e13676. doi:10.1002/jcsm.13676.
6. Baltasar-Fernandez I, Alcazar J, Mañas A, et al. Relative sit-to-stand power cut-off points and their association with negatives outcomes in older adults. *Sci Rep* 2021;**11**:19460. doi:10.1038/s41598-021-98871-3.
7. Fang X, Shi J, Song X, et al. Frailty in relation to the risk of falls, fractures, and mortality in older Chinese adults: Results from the Beijing longitudinal study of aging. *J Nutr Health Aging* 2012;**16**:903–7.
8. Khandelwal D, Goel A, Kumar U, Gulati V, Narang R, Dey AB. Frailty is associated with longer hospital stay and increased mortality in hospitalized older patients. *J Nutr Health Aging* 2012;**16**:732–5.
9. Losa-Reyna J, Alcazar J, Carnicero J, et al. Impact of relative muscle power on hospitalization and all-cause mortality in older adults. *J Gerontol A Biol Sci Med Sci* 2022;**77**:781–9.
10. Kirk B, Zanker J, Duque G. Osteosarcopenia: Epidemiology, diagnosis, and treatment-facts and numbers. *J Cachexia Sarcopenia Muscle* 2020;**11**:609–18.
11. Yeung SSY, Reijnierse EM, Pham VK, et al. Sarcopenia and its association with falls and fractures in older adults: A systematic review and meta-analysis. *J Cachexia Sarcopenia Muscle* 2019;**10**:485–500.
12. Harvey NC, Odén A, Orwoll E, et al. Falls predict fractures independently of FRAX probability: A meta-analysis of the Osteoporotic Fractures in Men (MrOS) Study. *J Bone Miner Res* 2018;**33**:510–6.
13. Johnell O, Kanis JA. An estimate of the worldwide prevalence and disability associated with osteoporotic fractures. *Osteoporos Int* 2006;**17**:1726–33.
14. Tosteson AN, Gabriel SE, Grove MR, Moncur MM, Kneeland TS, Melton 3rd LJ. Impact of hip and vertebral fractures on quality-adjusted life years. *Osteoporos Int* 2001;**12**:1042–9.
15. Sing CW, Lin TC, Bartholomew S, et al. Global epidemiology of hip fractures: secular trends in incidence rate, post-fracture treatment, and all-cause mortality. *J Bone Miner Res* 2023;**38**:1064–75.
16. Burbank CM, Branscum A, Bovbjerg ML, Hooker K, Smit E. Muscle power predicts frailty status over four years: A retrospective cohort study of the National Health and Aging Trends Study. *J Frailty Sarcopenia Falls* 2023;**8**:1–8.
17. Rhim HC, Ward RE, Travison TG, Latham N, Bean JF. Defining clinically meaningful cut points for leg power impairment using physical performance in older adults: A secondary analysis from Boston RISE. *Arch Phys Med Rehabil* 2024;**105**:690–5.
18. Alcazar J, Losa-Reyna J, Rodriguez-Lopez C, et al. The sit-to-stand muscle power test: An easy, inexpensive and portable procedure to assess muscle power in older people. *Exp Gerontol* 2018;**112**:38–43.
19. Alcazar J, Alegre LM, Suetta C, et al. Threshold of relative muscle power required to rise from a chair and mobility limitations and disability in older adults. *Med Sci Sports Exerc* 2021;**53**:2217–24.
20. Garcia-Garcia FJ, Gutierrez Avila G, Alfaro-Acha A, et al. The prevalence of frailty syndrome in an older population from Spain. The Toledo Study for Healthy Aging. *J Nutr Health Aging* 2011;**15**:852–6.
21. Alcazar J, Kamper RS, Aagaard P, et al. Relation between leg extension power and 30-s sit-to-stand muscle power in older adults: Validation and translation to functional performance. *Sci Rep* 2020;**10**:16337. doi:10.1038/s41598-020-73395-4.
22. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis* 1987;**40**:373–83.
23. Fujita Y, Nakamura Y, Hiraoka J, et al. Physical-strength tests and mortality among visitors to health-promotion centers in Japan. *J Clin Epidemiol* 1995;**48**:1349–59.
24. Salari N, Darvishi N, Ahmadipanah M, Shohaimi S, Mohammadi M. Global prevalence of falls in the older adults: A comprehensive systematic review and meta-analysis. *J Orthop Surg Res* 2022;**17**:334. doi:10.1186/s13018-022-03222-1.
25. Gale CR, Cooper C, Aihie Sayer A. Prevalence and risk factors for falls in older men and women: The English Longitudinal Study of Ageing. *Age Ageing* 2016;**45**:789–94.
26. Moradell A, Rodríguez-Gómez I, Fernández-García ÁI, et al. Associations between daily movement distribution, bone structure, falls, and fractures in older adults: A compositional data analysis study. *Int J Environ Res Public Health* 2021;**18**:3757. doi:10.3390/ijerph18073757.

27. Petermann-Rocha F, Ferguson LD, Gray SR, et al. Association of sarcopenia with incident osteoporosis: A prospective study of 168,682 UK biobank participants. *J Cachexia Sarcopenia Muscle* 2021;**12**:1179–88.
28. Paulin TK, Malmgren L, McGuigan FE, Akesson KE. Osteosarcopenia: Prevalence and 10-year fracture and mortality risk—A longitudinal, population-based study of 75-year-old women. *Calcif Tissue Int* 2024;**114**:315–25.
29. Ettinger B, Pressman A, Sklarin P, Bauer DC, Cauley JA, Cummings SR. Associations between low levels of serum estradiol, bone density, and fractures among elderly women: The study of osteoporotic fractures. *J Clin Endocrinol Metab* 1998;**83**:2239–43.
30. de Almeida Nagata C, Hamu TCDDS, Pelicioni PHS, Durigan JLQ, Garcia PA. Influence of lower limb isokinetic muscle strength and power on the occurrence of falls in community-dwelling older adults: A longitudinal study. *PLoS One* 2024;**19**:e0300818. doi:10.1371/journal.pone.0300818.
31. Bahat G, Kilic C, Eris S, Karan MA. Power sarcopenia: Associations with functionality and physical performance measures. *J Nutr Health Aging* 2021;**25**:13–7.
32. Moreland BL, Legha JK, Thomas KE, Burns ER. Hip fracture-related emergency department visits, hospitalizations and deaths by mechanism of injury among adults aged 65 and older, United States 2019. *J Aging Health* 2023;**35**:345–55.
33. Veronese N, Siri G, Cella A, et al. Older women are frailer, but less often die then men: A prospective study of older hospitalized people. *Maturitas* 2019;**128**:81–6.
34. Almagro P, Ponce A, Komal S, et al. Multimorbidity gender patterns in hospitalized elderly patients. *PLoS One* 2020;**15**:e0227252. doi:10.1371/journal.pone.0227252.
35. Corrao S, Santalucia P, Argano C, et al. Gender-differences in disease distribution and outcome in hospitalized elderly: Data from the REPOSI study. *Eur J Intern Med* 2014;**25**:617–23.
36. Benz E, Pinel A, Guillet C, et al. Sarcopenia and sarcopenic obesity and mortality among older people. *JAMA Netw Open* 2024;**7**:e243604. doi:10.1001/jamanetworkopen.2024.3604.
37. Yuan S, Larsson SC. Epidemiology of sarcopenia: Prevalence, risk factors, and consequences. *Metabolism* 2023;**144**:155533. doi:10.1016/j.metabol.2023.155533.
38. Alcazar J, Navarrete-Villanueva D, Mañas A, et al. "Fat but powerful" paradox: Association of muscle power and adiposity markers with all-cause mortality in older adults from the EXERNET multicentre study. *Br J Sports Med* 2021;**55**:1204–11.
39. Meulemans L, Van Roie E, Seghers J, Delecluse C. Older adults' lower-limb muscle power production throughout a full flight of stairs: Reliability and comparison between different stair models. *PLoS One* 2024;**19**:e0296074. doi:10.1371/journal.pone.0296074.
40. Suetta C, Haddock B, Alcazar J, et al. The Copenhagen Sarcopenia Study: Lean mass, strength, power, and physical function in a Danish cohort aged 20—93 years. *J Cachexia Sarcopenia Muscle* 2019;**10**:1316–29.
41. Johnson 2nd TM, Vincenzo JL, De Lima B, et al. Updating STEADI for primary care: Recommendations from the American Geriatrics Society Workgroup. *J Am Geriatr Soc* 2025;**73**:2019–28.
42. Alcazar J, Ara I, García-García FJ, Alegre LM. Number of chair stands should not be considered a muscle function measure, but a physical performance measure. What can we do then? *J Frailty Aging* 2022;**11**:245–6.
43. Alcazar J, Alegre LM, Van Roie E, et al. Relative sit-to-stand power: Aging trajectories, functionally relevant cut-off points, and normative data in a large European cohort. *J Cachexia Sarcopenia Muscle* 2021;**12**:921–32.
44. Alcazar J., Lopez-Moranchel I., Losa-Reyna J., et al. *App review: PowerFrail for the assessment of relative muscle power and frailty in older people*. Available at: https://blogs.bmj.com/bjsm/2021/02/04/app-review-powerfrail-for-the-assessment-of-relative-muscle-power-and-frailty-in-older-people/.[accessed 04.02.2021].
45. Meulemans L, Alcazar J, Alegre LM, et al. Sensor- and equation-based sit-to-stand power: The effect of age and functional limitation. *Exp Gerontol* 2023;**179**:112255. doi:10.1016/j.exger.2023.112255.