Accepted Article

Journal of Frailty, Sarcopenia and Falls

Short Communication

Bioimpedance-Estimated Metabolic Age in a Falls Clinic: Associations with Multimorbidity and Physical Frailty

Nicolás Martínez-Gómez[1,2], Nicolás Martínez Velilla[2,3], Eoin Duggan[1,4], Román Romero Ortuño[1,4]

[1]Discipline of Medical Gerontology, School of Medicine, Trinity College Dublin, Ireland;
[2]School of Medicine, University of Navarra, Spain;
[3]University Hospital of Navarra, Spain;
[4]Falls and Syncope Unit, Mercer's Institute for Successful Ageing, St James's Hospital, Dublin, Ireland

Abstract

Bioelectrical impedance analysis (BIA) is a non-invasive method used to assess body composition and estimate metabolic age (MA). However, the clinical significance of BIA-estimated MA remains poorly understood. We explored the associations of MA with chronological age (CA), multimorbidity, and physical frailty (PF) in falls clinic attendees. Participants aged ≥50 years were assessed for multimorbidity using the Cumulative Illness Rating Scale-Geriatric, PF using the SHARE Frailty Instrument for Primary Care, and underwent BIA. Among 107 participants (mean age 69.8 years, 57% women), MA showed a moderate correlation with CA (r=0.62, p<0.001). On bivariate analysis, participants with MA>CA were younger, had higher multimorbidity, and were frailer compared to those with MA<CA. Multivariate linear regression analyses revealed that MA was independently associated with CA and BIA-estimated fat mass in both sexes, BIA-estimated muscle mass in men, and PF in women, but not with multimorbidity. BIA-estimated MA mostly reflects CA and BIA's own body composition estimates, but was significantly associated with PF in women. Research should externally validate this finding and investigate the responsiveness of BIA-estimated MA to interventions.

Keywords: Bioelectrical impedance analysis, Metabolic age, Body composition, Frailty, Multimorbidity

As the number of community-dwelling older adults continues to increase and falls presentations become more common in clinical practice, there is a pressing need for strategies to assess risk and implement evidence-based interventions[1]. However, advancing chronological age (CA) does not always reflect unhealthy ageing; instead, an individual's biological age is more influenced by factors such as metabolism, morbidities[2], frailty, and body composition[3].

In the falls clinic, alongside the evaluation of factors such as comorbidities, frailty, and functionality, assessing body composition could be important because muscle mass, fat distribution, and sarcopenia can influence balance, strength, and overall falls risk[1,4]. Bioelectrical impedance analysis (BIA) is a non-invasive method used in some clinical and research settings to estimate body composition and also readily provides a BIA-based estimate of an individual's metabolic age (MA)[5]. BIA-estimated MA has been associated with factors such as: waist-to-height ratio[6]; physical activity, adherence to the Mediterranean diet, and socioeconomic class[7]. However, the clinical significance of this MA estimate remains poorly understood in the falls clinic and it is not clear if it should be used for patient feedback in clinical practice.

To address this gap, this study investigated the clinical associations of BIA-estimated MA in older attendees of a falls clinic. Specifically, it examined differences between

The authors have no conflict of interest.

Corresponding author: *Román Romero Ortuño, Discipline of Medical Gerontology, Mercer's Institute for Successful Ageing (MISA), St James's Hospital, James's Street, Dublin 8, Ireland*

ORCID: *0000-0002-3882-7447*

E-mail: *romeroor@tcd.ie*

Edited by: *Jagadish K. Chhetri*

Accepted *19 April 2025*

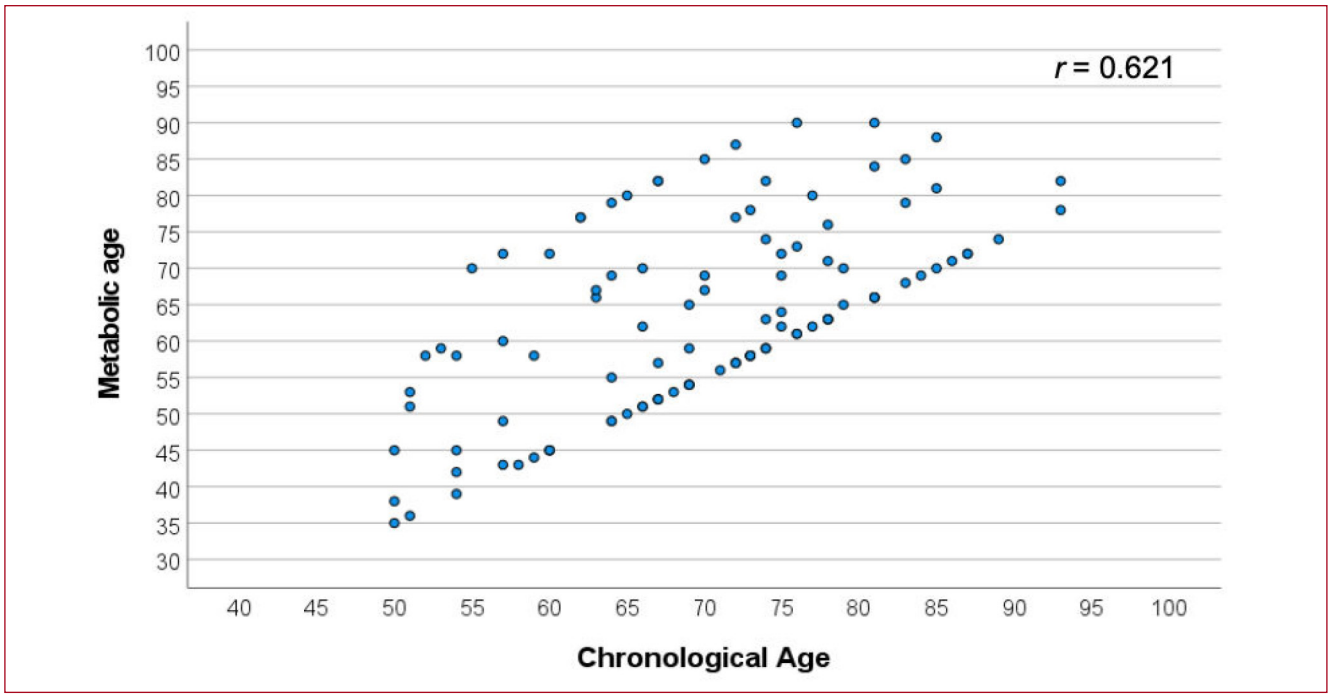

Figure 1. Scatter plot between chronological age (X axis) and metabolic age (Y axis), n = 107.

individuals with MA greater than CA (MA>CA) and those with MA less than CA (MA<CA), as well as the independent sex-specific associations of MA with CA, BIA-estimated body composition (muscle and fat mass), multimorbidity, and physical frailty (PF).

Adults aged ≥50 years were prospectively recruited from January to November 2022 at the Falls and Syncope Unit (FASU) at St. James's Hospital, Dublin, Ireland. The clinical research environment has been detailed elsewhere[8,9]. Inclusion criteria required participants to provide written informed consent, mobilise independently (with or without aid), and transfer with minimal assistance from lying to standing. Exclusion criteria included contraindications to BIA, such as having an indwelling electronic device (e.g., cardiac pacemaker).

BIA was conducted using the TANITA DC-430 MAP Body Composition Analyser (Tanita Europe, Amsterdam, The Netherlands), measuring weight (kg), muscle mass (kg), fat mass (kg), and MA. Additional patient data included CA (years), sex, self-reported alcohol consumption (units per week), and smoking status (current, former, or never). Height, measured to the nearest 0.01m with footwear, used a Seca 222 Stadiometer (Seca Ltd., Birmingham, UK). Body mass index (kg/m^2) was calculated. Multimorbidity was evaluated with the Cumulative Illness Rating Scale-Geriatric (CIRS-G)[10], a tool that evaluates severity of disease across 14 organ systems, scoring each from 0 (no problem) to 4 (severe problem), with higher scores indicating higher severity (maximum 56 points). PF was measured with the continuous score from the SHARE Frailty Instrument for Primary Care[11], which is based on self-reported exhaustion, reduced appetite, walking/stair difficulties, low physical activity, and grip strength. We also recorded the number of falls reported over the past year.

Statistical analyses were conducted using IBM SPSS Statistics version 27 (IBM Corp., Armonk, NY). Descriptive statistics were displayed as mean and standard deviation (SD) for normally distributed continuous variables, and median and interquartile range (IQR) for non-normally distributed variables. Normality was evaluated using the Kolmogorov-Smirnov test. Categorical variables were shown as counts and percentages (%). A scatter plot depicted the relationship between CA and MA. Pearson's coefficient assessed the correlation between normally distributed variables.

The sample was divided into three groups: MA<CA, MA=CA, and MA>CA. The independent samples t-test compared normally distributed variables between MA<CA and MA>CA groups, while the 2-sided Mann-Whitney U test compared non-normally distributed variables. Categorical variables were compared using the Chi-squared test or Fisher's exact test.

Multivariate linear regression analyses were conducted separately for men and women to identify predictors of MA

	MA < CA	MA > CA	p	n
	n=76	n=29		
	71.0%	27.1%		
Mean age, years (SD)	71.2 (10.3)	66.4 (9.7)	0.032	105
Female sex (%)	63.2	44.8	0.089	105
Median BMI, kg/m^2 (IQR)	24.8 (4.1)	29.1 (6.0)	<0.001	105
Mean muscle mass, kg (SD)	45.1 (9.7)	54.0 (8.9)	<0.001	105
Median fat mass, kg (SD)	20.6 (8.6)	31.3 (13.3)	<0.001	105
Median CIRS-G score (IQR)	5.0 (6.0)	8.0 (4.0)	0.002	105
Median SHARE-FI score (IQR)	0.2 (2.0)	1.0 (3.1)	0.022	105
Median alcohol intake, units/week (IQR)	0.0 (8.0)	6.0 (16.0)	0.763	105
Current smoker (%)	8.0	17.2	0.176	104
Median number of falls in the past year (IQR)	1 (1)	1 (2)	0.168	105

Table 1. Comparison between MA < CA (metabolic age lower than chronological age) and MA > CA (metabolic age greater than chronological age) groups. SD: standard deviation; IQR: interquartile range; BMI: body mass index; CIRS-G: cumulative illness rating scale-geriatric; SHARE-FI: Survey of Health, Ageing and Retirement in Europe Frailty Instrument.

		B	95% CI lower bound	95% CI upper bound	p	VIF
Men	CA	0.39	0.27	0.50	<0.001	1.91
	Muscle mass	-1.01	-1.22	-0.81	<0.001	3.05
	Fat mass	1.94	1.72	2.16	<0.001	2.46
	CIRS-G	0.05	-0.29	0.38	0.785	1.40
Women	CA	0.75	0.59	0.90	<0.001	1.47
	Muscle mass	-0.23	-0.53	0.08	0.148	3.02
	Fat mass	1.01	0.82	1.20	<0.001	2.69
	CIRS-G	0.002	-0.37	0.37	0.990	1.39

Table 2. Results of the linear regression by sex predicting MA on the basis of chronological age (CA), muscle mass, fat mass, and multimorbidity score (CIRS-G). CI: confidence interval; VIF: variance inflation factor. The adjusted R-squared values for the regression models were 0.85 for women and 0.95 for men.

as a continuous variable. In the initial models, independent variables included CA, BIA-estimated muscle mass, BIA-estimated fat mass, and CIRS-G score, with additional models built replacing the CIRS-G score with the SHARE-FI score. Additionally, sex-specific models were computed to predict MA solely based on CA, CIRS-G score, and SHARE-FI score. Unstandardised B regression coefficients, 95% confidence intervals (CI), and p-values were reported for each independent variable. Multicollinearity was assessed using variance inflation factors (VIF), with values exceeding 4 indicating major collinearity issues. Statistical significance was defined as $p<0.05$.

A total of 107 patients were included, with a mean age of 69.8 years (SD 10.4), ranging from 50 to 93 years. The mean BIA-estimated MA was 64.5 years (SD 14.7), ranging from 36 to 90 years. The sample consisted of 57% women.

The Pearson correlation coefficient between CA and MA was 0.62 ($p<0.001$). A scatter plot depicting this relationship is shown in Figure 1.

Two participants had MA=CA, while 29 had MA>CA and 76 had MA<CA. Table 1 compares the characteristics

		B	95% CI lower bound	95% CI upper bound	p	VIF
Men	CA	0.39	0.27	0.51	<0.001	1.85
	Muscle mass	-1.03	-1.23	-0.82	<0.001	2.93
	Fat mass	1.95	1.74	2.16	<0.001	2.25
	SHARE-FI	-0.04	-0.78	0.71	0.919	1.12
Women	CA	0.77	0.62	0.91	<0.001	1.49
	Muscle mass	-0.10	-0.38	0.19	0.507	2.96
	Fat mass	0.92	0.75	1.08	<0.001	2.39
	SHARE-FI	1.14	0.31	1.97	0.008	1.20

Table 3. Results of the linear regression by sex predicting MA on the basis of chronological age (CA), muscle mass, fat mass, and physical frailty score (SHARE-FI). CI: confidence interval; VIF: variance inflation factor. The adjusted R-squared values for the regression models were 0.87 for women and 0.95 for men.

		B	95% CI lower bound	95% CI upper bound	p	VIF
Men	CA	0.76	0.48	1.05	<0.001	1.30
	SHARE-FI	-1.00	-3.58	1.60	0.441	1.54
	CIRS-G	1.09	-0.03	2.21	0.056	1.81
Women	CA	0.58	0.32	0.84	<0.001	1.03
	SHARE-FI	1.95	0.14	3.76	0.035	1.22
	CIRS-G	0.72	-0.01	1.43	0.051	1.25

Table 4. Results of the linear regression by sex predicting MA on the basis of chronological age (CA), physical frailty score (SHARE-FI), and multimorbidity score (CIRS-G). CI: confidence interval; VIF: variance inflation factor. The adjusted R-squared values for the regression models were for 0.38 women and 0.53 for men.

of the MA<CA and MA>CA groups. Participants in the MA>CA group were chronologically younger (66.4 vs. 71.2 years, p=0.032), had a higher BMI (29.1 vs. 24.8 kg/m^2, p<0.001), a greater burden of multimorbidity (median CIRS-G score: 8 vs. 5, p=0.002), and were frailer (median SHARE-FI score: 1.0 vs. 0.2, p=0.022). Significant differences were also observed in BIA-estimated body composition, with higher fat mass and muscle mass in the MA>CA group (p<0.001). Although the MA>CA group included a higher proportion of men, this difference was not statistically significant. Similarly, there were no significant differences in smoking status, alcohol intake, or the number of falls reported in the past year between the two groups.

The initial multivariate linear regression analyses stratified by sex (61 women and 46 men) are summarized in Tables 2 and 3. All variance inflation factor (VIF) values were below 4, but some were close to or slightly above 3. These findings suggested that MA was independently associated with CA and fat mass in both sexes, as well as with muscle mass in men. Additionally, the SHARE-FI score was independently associated with MA in women but not in men. No significant association was observed between MA and the CIRS-G score in either sex. As shown in Table 4, when BIA-estimated muscle and fat mass were not included in the models to avoid multicollinearity, in men, CA was the only significant predictor of MA. In women, both CA and physical frailty significantly predicted MA. These models had lower VIFs than the previous models, and their adjusted R2 values were more modest.

To discuss the findings, at first glance in the bivariate analysis (Table 1), participants with MA>CA were chronologically younger than those with MA<CA. This suggests that, despite being chronologically younger, BIA estimated their metabolism to function as if they were older. These MA>CA participants appeared to have higher multimorbidity and frailty. This would align with previous

research suggesting that MA can predict future metabolic syndrome[12] and worsening frailty status[13]. However, the loss of this association in multiple regression analyses suggests that the relationship between MA and multimorbidity may not be of great clinical significance. Instead, BIA-estimated MA appeared to primarily reflect CA and, most notably, its own measurements of body composition. Illustrating this, in the initial linear regression models for men, each additional year of CA was associated with a 0.4-year increase in MA, while each kilogram of muscle mass was associated with a 1-year decrease in MA, and each kilogram of fat mass was associated with a 2-year increase in MA. In women, the SHARE-FI score ranges from approximately -4 (robust) to 6 (frail) (9), with each 1-unit increase in frailty independently linked to a 1-year increase in MA.

The association between muscle mass and MA in women was not significant. However, according to BIA, muscle mass includes not only muscle tissue, but also all other non-fat and non-bone components of the body, such as body water[14], which can be subject to sex differences. Furthermore, the SHARE-FI score incorporates a measure of maximum handgrip strength, which is related to muscle mass and may provide a more nuanced assessment of muscle status in women. The additional multivariate regression analyses, excluding BIA-estimated muscle and fat mass, suggested that CA is a consistent predictor of MA across both sexes and reinforced the independent association of PF (SHARE-FI) with MA in women but not in men. Multimorbidity (CIRS-G) showed no statistically significant associations in this small sample, although in both sexes the associations were close to significance.

Based on our findings, if used for patient feedback, BIA-estimated MA should be interpreted as mostly reflecting CA, BIA-estimated fat mass in both sexes, BIA-estimated muscle mass in men, and PF in women, rather than as an indicator of multimorbidity. The association between BIA-estimated MA and PF in women but not in men may reflect sex-specific differences in body composition, muscle mass distribution, or the impact of adiposity on PF risk. However, further research is needed to externally validate this finding and enable the informed use of this parameter in clinical practice. For instance, future studies should explore how physical activity and weight management interventions might influence MA over time. Evidence suggests that in men, moderately vigorous physical activity can reduce adiposity and improve metabolic health[15]. Additionally, physical activity interventions totalling three or more hours per week, including balance and functional exercises, have demonstrated a 42% reduction in falls compared to controls[16]. Although limited, the existing literature on BIA-estimated MA supports its relevance; one study found that higher levels of physical activity were associated with improved BIA phase angle at one-year follow-up, in a linear dose-response manner[17].

Limitations of our study include its cross-sectional design, which means causality cannot be established and the relatively small sample size, which may have led to underpowering, as indicated by Table 1, where potentially clinically significant differences in sex, alcohol intake and smoking status did not achieve statistical significance. The linear regression analyses were stratified by sex, and since the sample size for men was n = 46, following the rule of thumb of at least 10 observations per independent variable, CIRS-G and SHARE-FI were entered in two separate but otherwise equal models to ensure comparability of results between men and women. However, with a larger sample size, simultaneous inclusion could have been considered. Even in Table 4, including CIRS-G and SHARE-FI simultaneously, the non-significant association between MA and multimorbidity may be due to limited statistical power in this small sample, as well as its heterogeneous nature as global measure of multimorbidity. Additionally, the sample was drawn from a falls clinic, which may impact the generalisability of the findings and possibly explains the lack of differences in falls history between the groups in Table 1. The validity and reliability data specifically for the TANITA DC-430 MAP device are not published, which limits the interpretability of its MA estimate. Even though muscle and fat mass were also estimated by the device, the objective of the initial regression models, while acknowledging this circularity, was to gain insight into the relative relevance of the internal BIA muscle and fat measurements in men and women for calculating the MA estimate, while controlling for non-BIA-measured multimorbidity and PF. Since the MA algorithm is proprietary, our results may offer researchers indirect insights into how MA is derived when using this Tanita device.

In conclusion, BIA-estimated MA reflects CA, BIA-estimated fat mass in both sexes, BIA-estimated muscle mass in men, and PF in women, rather than multimorbidity. While BIA-estimated MA shows potential as a clinical marker, further research involving larger, more diverse populations and longitudinal interventional studies is necessary to validate its clinical use (e.g., for patient feedback) and evaluate the impact of interventions on MA over time.

Ethics approval

The study received ethical approval from the Tallaght University Hospital (TUH)/ St. James's Hospital (SJH) Joint Research Ethics Committee (Project ID: 0221; approval date: 4 May 2021). Approval was also granted by St. James's Hospital Research & Innovation Office (Reference: 6567, approval date: 26 July 2021). The study adhered to the World Medical Association Declaration of Helsinki on ethical principles for medical research involving human subjects.

Consent to participate

All participants provided written informed consent for inclusion in the study.

Funding

This research was funded by Research Ireland, grant number 18/FRL/6188.

Authors' contributions

Nicolás Martínez Gómez conducted data analysis and drafted the manuscript. Nicolás Martínez Velilla interpreted the data and critically revised the manuscript. Eoin Duggan acquired and interpreted data and critically revised the manuscript. Roman Romero-Ortuno conceived and designed the study and critically revised the manuscript. All authors approved the final version and agree to be accountable for all aspects of the work, ensuring that questions related to its accuracy or integrity are appropriately investigated and resolved.

References

1. Montero-Odasso M, van der Velde N, Martin FC, Petrovic M, Tan MP, Ryg J, et al. World guidelines for falls prevention and management for older adults: a global initiative. Age Ageing. 2022;51(9):afac205.
2. Jylhava J, Pedersen NL, Hagg S. Biological Age Predictors. EBioMedicine. 2017;21:29-36.
3. Muller MJ, Bosy-Westphal A, Later W, Haas V, Heller M. Functional body composition: insights into the regulation of energy metabolism and some clinical applications. Eur J Clin Nutr. 2009;63(9):1045-56.
4. Zhang K, Ju Y, Yang D, Cao M, Liang H, Leng J. Correlation analysis between body composition, serological indices and the risk of falls, and the receiver operating characteristic curve of different indexes for the risk of falls in older individuals. Front Med (Lausanne). 2023;10:1228821.
5. TANITA-EU. What is my metabolic age and what does it mean? Available online: https://tanita.eu/blog/what-is-my-metabolic-age (accessed 8 September 2024). 2024.
6. Elguezabal-Rodelo R, Ochoa-Précoma R, Vazquez-Marroquin G, Porchia LM, Montes-Arana I, Torres-Rasgado E, et al. Metabolic age correlates better than chronological age with waist-to-height ratio, a cardiovascular risk index. Med Clin (Barc). 2021;157(9):409-417.
7. Ramírez-Gallegos I, Marina-Arroyo M, López-González ÁA, Vallejos D, Martínez-Almoyna-Rifá E, Tárraga López PJ, et al. Associations Between Metabolic Age, Sociodemographic Variables, and Lifestyle Factors in Spanish Workers. Nutrients. 2024;16(23):4207.
8. O'Donoghue PJ, Claffey P, Rice C, Byrne L, Cunningham C, Kenny RA, et al. Association between gait speed and the SHARE Frailty Instrument in a Falls and Syncope Clinic. Eur Geriatr Med. 2021;12(5):1101-5.
9. Duggan E, Knight SP, Romero-Ortuno R. Relationship between sarcopenia and orthostatic blood pressure recovery in older falls clinic attendees. Eur Geriatr Med. 2023;14(3):439-46.
10. Linn BS, Linn MW, Gurel L. Cumulative illness rating scale. J Am Geriatr Soc. 1968;16(5):622-6.
11. Romero-Ortuno R, Walsh CD, Lawlor BA, Kenny RA. A frailty instrument for primary care: findings from the Survey of Health, Ageing and Retirement in Europe (SHARE). BMC Geriatr. 2010;10:57.
12. Vasquez-Alvarez S, Bustamante-Villagomez SK, Vazquez-Marroquin G, Porchia LM, Perez-Fuentes R, Torres-Rasgado E, et al. Metabolic Age, an Index Based on Basal Metabolic Rate, Can Predict Individuals That are High Risk of Developing Metabolic Syndrome. High Blood Press Cardiovasc Prev. 2021;28(3):263-70.
13. Zanforlini BM, Trevisan C, Bertocco A, Piovesan F, Dianin M, Mazzochin M, et al. Phase angle and metabolic equivalents as predictors of frailty transitions in advanced age. Exp Gerontol. 2019;122:47-52.
14. Khalil SF, Mohktar MS, Ibrahim F. The theory and fundamentals of bioimpedance analysis in clinical status monitoring and diagnosis of diseases. Sensors (Basel). 2014;14(6):10895-928.
15. Jefferis BJ, Parsons TJ, Sartini C, Ash S, Lennon LT, Wannamethee SG, et al. Does duration of physical activity bouts matter for adiposity and metabolic syndrome? A cross-sectional study of older British men. Int J Behav Nutr Phys Act. 2016;13:36.
16. Sherrington C, Fairhall N, Kwok W, Wallbank G, Tiedemann A, Michaleff ZA, et al. Evidence on physical activity and falls prevention for people aged 65+ years: systematic review to inform the WHO guidelines on physical activity and sedentary behaviour. Int J Behav Nutr Phys Act. 2020;17(1):144.
17. Uemura K, Kamitani T, Okamoto H, Yamada M. Longitudinal association of objectively measured physical activity and bioimpedance phase angle in older adults. Clin Nutr ESPEN. 2024;63:631-4.