Elasticity of Leg Muscles and Risk of Falls İn Older Adults: a Prospective Cohort Analysis

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Abstract

Background: Aging impacts muscle strength and elasticity, which in turn influence dynamic balance, walking speed, and physical performance. We aimed to evaluate the relationship between the elasticity of leg muscles and the incidence of falls in older adults.

Methods: We conducted a prospective cohort analysis with outpatients from a geriatric clinic. Participants underwent comprehensive geriatric assessments and timed up and go tests. Any history of fall in the past year was recorded. Elasticities of the gastrocnemius medialis and rectus femoris muscles were evaluated using shear wave elastography. All patients were asked to record their falls in a diary and additional phone calls were made each month. A regression analysis was performed to identify parameters associated with fall incidence during the follow-up period.

Results: The median age of the included patients (n = 55) was 75 years (66–89); 72 % were women. The gastrocnemius muscle showed significantly lower elasticity in patients with a history of fall in the past year than in those without (8.08 kpa [3.90–16.17] vs. 9.70 kpa [4.99–20.95]; p = 0.028). A similar negative correlation between gastrocnemius elasticity and fall incidence was noted among those with additional falls during the follow-up period (6.96 kpa [3.90–12.41] vs. 9.13 kpa [4.99–20.95]; p = 0019). Gastrocnemius muscle elasticity was significantly correlated with the timed up and go test score (r = -0.612, p < 0.001), handgrip strength (r = 0.384, p = 0.015), and muscle thickness (r = 0,232, p = 0.049). No such associations were observed for the rectus femoris muscles.

Conclusions:

Gastrocnemius muscle elasticity is associated with alterations in muscle structure that may lead to falls in older adults; therefore, muscle elasticity may be a fall predictor in older adults.

Background

Falls are the second leading cause of death due to accidental or unintentional injury worldwide. One of three older adults have fallen once in their lifetime and 50% are likely to fall again [1, 2]. Falls lead to a significant increase in mortality with increasing age. Haagsma et al. reported that across 22 countries, the mortality rate of falls was 18 per 100,000 people in those aged 17–19 years and this rate increased to 75 per 100,000 people in those aged 70–74 years [3].

Falls have many causes, including advanced age, impaired cognition, multiple drug use, dependency in daily activities, impaired senses, balance disorders, and sarcopenia [4]. Both muscle mass and muscle quality play an essential role in the evaluation of balance and sarcopenia [5]. Muscle quality is independently and significantly associated with fall risk [6] and is considered a vital component of muscle function. The importance of muscle quality is becoming clearer as more research is being conducted on the subject [7]. Cruz et al. mentioned the technological difficulties in measuring muscle quality and the lack of a standard definition of quality [8]. Elasticity, which is the ability of a muscle to return to its initial state after contraction or relaxation, is an indicator of muscle quality and is assessed using elastography [5]. Muscle elasticity affects the active strength of dynamically active muscles and plays a vital role in body balance [9, 10]. Muscle elasticity is affected by age-related changes in the collagen structure and intramuscular adipose tissue [11]. Salto et al. indicated that leg muscle elasticity was associated with dynamic balance and walking capability in older women, independent of muscle stiffness [10]. Bastijins et al. found that muscle elasticity is associated with muscle elongation and flexibility and these characteristics may be related to falls [12]. Muscle stiffness is the most frequently used parameter to assess muscle elasticity in current studies and numerous methods are available to measure it. Elasticity can be examined using either muscle palpation or a myotonometer. However, for quantitative assessment, ultrasonography and magnetic resonance (MR) elastography are the most widespread methods. Although MR elastography is commonly used in sports medicine, ultrasound elastography is used more frequently in research because of its easy accessibility. In recent years, shear wave elastography (SWE) with ultrasound is the preferred method for evaluating muscle elasticity because it has less operator dependency and can provide stiffness values, such as Young's modulus (kPa) [12].

Several studies have investigated the relationship between sarcopenia, balance, and falls [13, 14] however, no study has prospectively evaluated the relationship between falls and muscle elasticity, which is a marker of muscle quality. This study aimed to prospectively investigate the relationship between falls and muscle elasticity by measuring the rectus femoris and gastrocnemius muscles, using SWE, as they play an essential role in maintaining balance.

Methods

Study design

Our study included 136 outpatients who visited the geriatric clinic in three months. To avoid confounding, 31 patients with known myositis, tendinitis, or disease in the muscle tendons, and a history of lower extremity surgery were excluded from the study. Additionally, 42 patients with advanced Alzheimer's disease, cerebrovascular disease, speech and language problems, systemic inflammatory disease, or lower extremity venous insufficiency were excluded. Of the remaining 63 patients, eight were lost to follow-up, and the final sample size was 55 patients. The patients' sociodemographic data were recorded and a comprehensive geriatric evaluation was performed. The comprehensive geriatric evaluation comprised of the following tests: activities of daily living (ADL), instrumental activities of daily living (IADL), Mini Nutritional Assessment Test Short Form (MNA-SF), Geriatric Depression scale-15 (GDS-15), Mini-Mental State Examination (MMSE), and (SARC-F). The incidence of falls during the follow-up period was recorded. The presence of comorbid diseases and the number of drugs used were recorded. A radiologist who specialized in elastography, was an expert on the subject, and had performed several elastographies in the last five years performed the SWE examinations in our study. The radiologist was blinded to the patients' details and fall history. After the baseline evaluations were performed, the patients were followed-up for six months. At the follow-up visit, the patients were interviewed in person and the number and incidence of falls during the six-month follow-up period was recorded. All patients were asked to record their falls in a diary and additional phone calls were made each month.

Components of the comprehensive geriatric assessment

1. Activities of daily living

This scale assigns one point for the adequate performance of each of six ADL functions including: bathing, dressing, toilet hygiene, mobility, incontinence, and feeding [15]. The overall ADL score between 0 and 6 is noted. The validity and reliability of the ADL scale in Turkish are reported by Gunes et al. [16].

2. Instrumental activities of daily living

The IADL scale measures an individual's activity levels regarding phone use, shopping, meal preparation, house cleaning, laundry washing, transport, timely consumption of medications, and money management. The overall test score varies between 0 and 8, with lower scores indicating greater dependency [17]. The Turkish version of the IADL scale is validated [18].

3. Mini Nutritional Assessment-Short Form

This test is used for malnutrition screening, and the validity and reliability of its Turkish version have been reported [19, 20]. An overall MNA-SF score varies between 0 and 14. Scores $\leq$ 11 points indicate a risk for malnutrition [20].

4. Mini-Mental State Exam

The MMSE is commonly used for cognitive screening in older adults. The validity and reliability of this scale in Turkish has been reported. The overall MMSE score ranges between 0 and 30 [21, 22]. Scores $\leq$ 24 points indicate cognitive impairment [22].

5. Geriatric Depression scale-15

The GDS-15 evaluates depressive symptoms in older adults. Responses are scored between 0 and 15 and an overall score $\geq$ 5 indicates a risk of depression [23]. Durmaz et al. reported the validity of the Turkish version [24].

6. SARC-F

This scale, validated in Turkish by Güliastan et al., was recommended in 2018 for sarcopenia screening [25, 26]. The responses are scored between 0 and 10; scores $\geq$ 4 indicate sarcopenia that requires further investigation [26].

Muscle measurements

1. Handgrip strength

A digital handheld dynamometer (T.K.K.5401; Takei Scientific Instruments, Tokyo, JAPAN) was used to assess muscle mass. The patients were instructed to sit on a chair, extend their arms parallel to the ground, and squeeze the dynamometer with their dominant hand. This process was repeated thrice and the highest handgrip strength value was recorded. In the Turkish population, the cutoff values for handgrip strength are 22 and 32 kg for women and men, respectively [27]. For handgrip strength values below the cutoff values, the possibility of sarcopenia was investigated.

2. Evaluation of muscle thickness and elasticity

A single radiologist performed all the SWE examinations using an ultrasound system (LOGIQ E9; GE Medical Systems, Wisconsin, USA) with a 9-MHz linear transducer. The radiologist examined only the medial heads of the gastrocnemius and rectus femoris muscles bilaterally, with the patient in the prone position. The tip of the linear transducer was sufficiently covered with ultrasound gel. First, the medial head of the gastrocnemius and rectus femoris were scanned using B-mode imaging. The linear transducer was placed parallel to the longitudinal axis of the medial heads of both muscles. The thickest portion of each muscle was measured in millimeters. Thereafter, elastography imaging was performed in the same position, and particular attention was given to avoid applying any pressure to the skin. Shear wave elastography imaging was performed at the thickest portion of the medial heads of the gastrocnemius and rectus femoris. Stiffness values in kilopascals (kPa) were measured for the selected portions of these two muscles, whilst the muscles were in a relaxed state [28]. The examination was repeated for the other leg.

3. Muscle function assessment

The timed up and go (TUG) test is recommended by the European Working Group on Sarcopenia in Older People (EWGSOP2) to evaluate muscle function [29]. It is beneficial in measuring mobility and dynamic balance, and evaluating falls among older adults [30]. In the test, patients are asked to wear regular shoes, walk 3 meters away from a chair, then return to the chair, and sit. The total time elapsed determines the test result [30]. Bischoff et al. determined the TUG cutoff value for older adults as 12 s, which was used in our study [29].

Ethical approval

This study was performed in accordance with the Declaration of Helsinki and approved by the relevant ethics committee. Verbal and written informed consent were obtained from all the patients participating in the study.

Statistics

Categorical variables are expressed as numbers and percentages (n, %). Histograms and coefficients of variation were used to determine the distribution of the numerical parameters. Normally distributed numerical parameters are shown as mean ± standard deviation. Non-normally distributed numerical parameters are shown as medians (minimum – maximum). Student's t-test was used to compare the numerical parameters showing a normal distribution between the two independent groups. Chi-square or Fisher's exact test was used to compare categorical variables. The comparison of non-normally distributed numerical data between the two groups was performed using the Mann–Whitney U test. Pearson's test was used to examine correlations between normally distributed numerical parameters, and Spearman's test was used for non-normally distributed numerical parameters. To interpret the Spearman or Pearson’s (r) coefficient, we used the following benchmarks: 0–0.20 = poor correlation; 0.21–0.40 = fair correlation; 0.41–0.60 = moderate correlation; 0.61–0.80 = substantial/strong correlation; and 0.81–1.0 = near-perfect correlation [30]. The parameters associated with the decline in handgrip strength within the six-month follow-up period were determined using univariate analysis, and those with $p < 0.05$ were included in the logistic regression analysis. The correlation matrix was evaluated and parameters with a high correlation were excluded from the regression analysis. The backward stepwise model was used; the omnibus test had $p < 0.005$, and the Hosmer-Lemeshow test had a p value of > 0.005.

Results

In the study cohort, the median age was 72 years (range: 66–86 years), 72 % were women, and 21.8 % lived alone. Hypertension, diabetes mellitus, and coronary artery disease were observed in 80 %, 31.5 %, and 29.6 % of the patients, respectively. A comparison of the general characteristics of the patients and the incidence of their falls in the year prior to the study and during the 6-month follow-up period is given in Table 1.

Overall, 45.5 % of the patients fell at least once in the year prior to the study, and 7.3 % fell at least once in the last 3 months. Among patients with a history of falls, 36 % fell again within the first six months of follow-up ($p < 0.001$). The 6-month incidence of falls during follow-up did not significantly differ according to sex. There was no significant relationship between sexes regarding muscle elasticity ($p > 0.05$). Probable sarcopenia was present in 78 % of the patients and these patients had a significantly lower gastrocnemius stiffness value than the patients without probable sarcopenia (7.89 kpa [3.90–15.36] vs. 11 kpa [4.99–15.90], respectively; $p = 0.006$). There was no significant difference in rectus femoris elasticity between patients with and without probable sarcopenia ($p > 0.05$). Both rectus femoris and gastrocnemius muscle stiffness values were lower in patients with a TUG test score > 12 s than in those with a TUG value < 12 s (rectus femoris stiffness value, 9.80 [5.94–22.51] vs. 11.52 [7.70–21.68]), $p = 0.035$; gastrocnemius stiffness value, 8.08 [3.90–16.17] vs. 10.34 [6.17–20.95], $p = 0.007$). The correlations between gastrocnemius and rectus femoris stiffness values and muscle-related parameters are shown in Table 2. Table 3 shows the independent factors associated with falls within the 6 month follow up period.

Table 1: General characteristics of the patients and the incidence of falls

	No falls	Falls in past year	p value	No fall in next 6 months	Falls in next 6 months	p value
Age	72 (66–86)	79 (68–89)	< 0.001	74 (66–89)	84 (7 2–89)	<0.001
ADL	6 (5–6)	5 (1–6)	< 0.001	6 (3–6)	4 (1–6)	< 0.001
IADL	8 (4–8)	6 (0–8)	< 0.001	8 (2–8)	4 (0–7)	< 0.001
MMSE	28 (16–30)	25.5 (10–30)	0.035	27 (14–30)	24 (10–30)	0.025
MNA-SF	12 (6–14)	11 (1–14)	0.027	11 (8–14)	11 (6–12)	0.032
GDS-15	2 (0–15)	6 (0–14)	0.196	2 (0–15)	7 (0–11)	0.029
Number of drugs used	4 (0–15)	5 (0–13)	0.199	4 (0–15)	5 (2–13)	0.064
SARC-F	0,5 (0–5)	5 (1–9)	< 0.001	2 (0–9)	7 (4–9)	< 0.001
TUG	10,8 (7–18)	15,33(9–67)	< 0.001	11.7 (7–23.9)	36.5 (16.8–67)	< 0.001
Handgrip strength	25.1 (14.9–36.7)	15.1 (8.9–22.2)	< 0.001	20.6 (10–36.7)	13.5 (8.9–22.2)	0.006
GSK stiffness	9,70 (4,99–20,95)	8,08 (3,90–16,17)	0.028	9.13 (4.99–20.95)	6.96 (3.90–12.41)	0.019
RF stiffness	10,54 (6,08–22,51)	10,03 (5,94–21,68)	0.679	10.54 (5.94–22,51)	8.02 (6.36–18.75)	0.232
GSK thickness	15.68 ± 2.72	13.50 ± 2.34	0.021	15.32 ± 2.62	13.60 ± 2.41	0.045
RF thickness	15.65 ± 3.13	13.71 ± 2.14	0.011	15.09 ± 3.13	13.14 ± 2.21	0.037

ADL: activities of daily living; IADL: instrumental activities of daily living; MMSE: Mini Mental State Examination; MNA-SF: Mini Nutritional Assessment- Short Form; GDS-15: Geriatric Depression scale-15; SARC-F, xxx; TUG: timed up and go; GSK: gastrocnemius; RF: rectus femoris

Table 2: Correlation between elasticities of the gastrocnemius and rectus femoris muscles and selected muscle-related parameters

	Gastrocnemius elasticity, rho coefficient (r)	p value
TUG	-0.612	<0.001
Handgrip strength	0.384	0.015
SARC-F	-0.512	< 0.001
GSK thickness	0.232	0.049
RF thickness		
	Rectus femoris elasticity rho coefficient (r)	
TUG	-0.412	0.032
Handgrip strength	0.243	0.056
SARC-F	-0.027	0.847
RF thickness	0.233	0.043

TUG: timed up and go; SARC-F, xxx; GSK: Gastrocnemius; RF: Rectus Femoris

Table 3: Factors independently associated with the incidence of falls during the 6-month follow-up

Parameters	Odds ratio	95 % confidence interval		p value
GSK Elasticity (kpa)	0.279	0.094	0.756	0.042
IADL	0.322	0.396	0.853	0.017

* indicates statistical significance. The backward stepwise model was used and the last model (step-5) is presented in this table. The role of GSK elasticity, age, handgrip strength, MMSE, IADL, TUG were evaluated in the logistic regression analysis. Nagelkerke R square: 0.739. GSK: Gastrocnemius; MMSE: Mini Mental State Examination; IADL: instrumental activities of daily living; TUG: timed up and go

Discussion

In this study, we showed the relationship between lower extremity muscle elasticity and falls, highlighting that muscle elasticity should be considered in the fall assessment of older adults. Some studies have examined the association between muscle elasticity and parameters such as muscle stiffness, walking speed, and TUG [10, 12, 31]. However, to the best of our knowledge, this is the first study to prospectively associate fall risk with muscle elasticity. Gadelha et al. examined the relationship between muscle quality and falls, however, they defined muscle quality as the ratio between muscle strength and mass [6]. Contrastingly, we quantified muscle quality using a direct indicator: elasticity.

We showed that falls were significantly associated with a reduction in gastrocnemius stiffness, both in patients with a history of falls and in those who experienced a fall within six months of follow-up. However, no significant association existed between rectus femoris muscle elasticity and falls. Owing to the different muscle physiology of the two muscle groups studied, including the differing muscle architecture as demonstrated by the differing fiber type ratios of the muscles and angle of pennation of the fibers, similar conclusions may not be drawn in terms of postural stability, and dynamic balance. The dissimilar findings between the muscle groups studied may also be attributed to the changes in compensatory muscle mechanisms caused by postural disorders, which are common in older adults [32-34].

A decrease in elasticity affects muscle flexibility and may disturb dynamic balance [35]. McGregor et al. stated that muscle quality might influence muscle function independent of muscle mass [36]. We investigated the effect of elasticity on dynamic balance using the TUG test, which is one of the best indicators of dynamic balance [37], and found a negative correlation between TUG duration and muscle elasticity. Kojima et al. demonstrated that the TUG duration was significantly and independently associated with future falls [38]. Hence, the association between elasticity and falls may partially explain how elasticity impacts fall risk, but the evidence for this inference is inconclusive in the literature. While Saito et al. found a positive correlation between strain elastography, TUG, and gastrocnemius and rectus femoris stiffness [10], we found a negative correlation. Furthermore, while Saito et al. reported that elasticity increased with age, we found a negative link between age and muscle stiffness [10]. Our findings corroborate those of Sendur et al. [39] and Akagi et al. [31], who used SWE to show that elasticity decreases with age. In contrast, Saito et al. employed strain elastography [10] which has several drawbacks. As there is no standard for the pressure applied with the probe during strain elastography, it may differ among individuals [40]. Thus, the tension index determined using strain elastography would indicate the deformation rate and not the absolute elasticity value [41]. Although SWE has fewer artifacts and better spatial resolution than strain elastography, it is a more expensive method and requires newer devices. In SWE, an individual compression force is not used; instead, a short-term, high, and strong acoustic repulsive force is applied to the tissue using the ultrasonography probe. To avoid inaccurate measurements, the person using the probe should not apply force to the tissue. This eliminates user variability and allows for an objective measurement of elasticity [42]. Considering its benefits, we used SWE to measure elasticity in our study. Nonetheless, further research is warranted to determine a standard diagnostic procedure for measuring muscle elasticity.

Muscle elasticity is an indicator of muscle quality; therefore, the link between muscle function and elasticity should be assessed. Saito et al. showed the relationship between elasticity and physical function [10]. Our study revealed a weak correlation between muscle elasticity and thickness. A similar weak correlation was reported by Sendur et al. [39]. Based on these studies, a negative correlation was found between SARC-F, a sarcopenia screening tool, and muscle elasticity, while a positive correlation was found between handgrip strength, a marker of probable sarcopenia, and muscle elasticity. Alfuraih et al. reported a positive correlation between handgrip strength and reduced muscle stiffness [43]. The correlation was weak in both studies. Furthermore, we showed that gastrocnemius stiffness was lower in patients with probable sarcopenia than in those without sarcopenia. Thus, an association may exist between muscle elasticity and sarcopenia. Furthermore, muscle strength may influence the association between elasticity and falls. Akagi et al. noted that lower extremity muscle elasticity has an impact on the explosive strength of the muscle, and this diminished strength may increase the risk of falls in older adults [31].

The gastrocnemius and rectus femoris muscles are the primary muscle groups associated with balance and function as antigravity muscles that actively work to overcome torque as they are behind the gravity line. We selected them for our study since they are actively engaged in postural sway and balance [32].

Various elements should be considered to prevent falls [5] because the risk of falling increases with age. Therefore a comprehensive geriatric evaluation that assesses dependency in daily and instrumental activities, cognition, nutritional status, mood, and sarcopenia, is essential to identify risk factors for falls in older adults [44]. In our study, a relationship between ADL, IADL, MMSE, GDS-15, SARC-F, and falls was expected as it has been frequently mentioned in the literature [5].

The strengths of our study are its prospective design with a 6-month follow-up period, the use of SWE instead of strain elastography, and the single-blinding of the data. Of note, our study's inference that muscle quality plays an important role in falls may contribute to the existing literature and propel future investigations into muscle elasticity. Examining the link between sarcopenia, measured using standard methods, and elasticity, measured in various muscle groups in larger populations, may provide additional insight into muscle pathophysiology and associated diseases. There is a need for a standard method that can more objectively measure elasticity and eliminate individual bias. It is also essential to identify cutoff values for assessing muscle elasticity through a standard method.

This study has certain limitations. First, only a small cohort was examined. Second, muscle elasticity was measured in the static state, though it is well known that falls are dynamic events. The inability to measure dynamic elasticity is a substantial limiting factor and highlights the need for technological advancements in the field. Third, although previous studies have evaluated a relationship between muscle stiffness and subcutaneous fatty tissue thickness, the muscle pennate angle, muscle density, and explosive muscle strength [12], we could not examine these parameters in our study. Fourth, as only one experienced radiologist performed the elastography measurement, we were unable to examine inter-rater reliability. Finally, the inability to measure sarcopenia using benchmark devices such as DEXA and computed tomography was a crucial limiting factor in the evaluation of the relationship between sarcopenia and muscle elasticity. Thus, large-scale studies should be planned in young, healthy populations to determine the cutoff values for muscle elasticity.

Conclusions

Our study showed that muscle elasticity should be assessed when analyzing falls in older adults and that muscle elasticity is critical for maintaining balance. Our findings indicate that a relationship exists between the objective stiffness value of the gastrocnemius and rectus femoris muscles, as determined using SWE, and muscle strength. Therefore, it is essential to remember that muscle quality may play a significant role in the pathophysiology and prevention of falls.

List Of Abbreviations

ADL, activities of daily living; EWGSOP2, European Working Group on Sarcopenia in Older People; GDS-15, Geriatric Depression scale-15 ; IADL, instrumental activities of daily living; MMSE, Mini-Mental State Examination; MNA-SF, Mini Nutritional Assessment Test Short Form; MR, magnetic resonance; SARC-F, xxx; SWE, Shear Wave Elastography; TUG , timed up and go.

Declarations

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Code availability

None.

Authors’ contributions

CC, RTD, BG equally contributed to the conception and design of the research; CC, II, FYB, BC, HNS ,MNC equally contributed to the acquisition and analysis of the data; CC, RTD, II and BG equally contributed to the interpretation of the data; HNS,MNC made muscle measurements and CC, HNS, and BG drafted the manuscript. All authors critically revised the manuscript, agree to be fully accountable for ensuring the integrity and accuracy of the work, and read and approved the final manuscript.

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Availability of data and materials

Data is kept confdential. The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study was approved by the Gazi University Ethics Committee for Clinical Research (reference no: 952). Research was carried out in accordance with the Declaration of Helsinki, taking into consideration local regulations and standards. All participants provided written informed consent to participate. We confrm that all methods were carried out in accordance with relevant guidelines and regulations under ethics approval, including participants' informed consent to participate.

All participants provided written informed consent for study publication.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests

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