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Martin Vigorimeter assesses muscle fatigability in older adults better than the Jamar Dynamometer

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ABSTRACT

INTRODUCTION

Muscle fatigability can be measured based on sustained handgrip performance, but different grip strength devices exist and their relationship to frailty remains unclear. We aimed to compare muscle fatigability obtained by Martin Vigorimeter and Jamar Dynamometer in older women across levels of frailty.

METHOD

53 community-dwelling women living in Greece (63–100y), categorized according to tertiles on the Frailty Index score (FI) as: low-frail (FI<0.19), intermediate-frail (FI 0.19–0.36), and high-frail (FI>0.36). Fatigue resistance (FR, time for maximal grip strength to decrease to 50% during sustained contraction) was measured with both Martin Vigorimeter and Jamar Dynamometer, and grip work (GW, reflecting the area under the time-force curve) was calculated.

RESULTS

FR, when measured with the Martin Vigorimeter, was approximately double in low-frail (44.3±24.6s) compared to high-frail participants (23.9±12.7s, p=0.011), whereas FR was similar across frailty groups when measured with the Jamar Dynamometer. In logistic regression models, FR (OR=0.94 [0.90-0.99]) and GW (OR=0.90 [0.82-0.99) were significantly related to high frailty when measured with the Martin Vigorimeter but not when measured with Jamar Dynamometer. There is a significantly proportional difference in FR measured with both devices (R^2 =0.364, p<0.001), highlighting that the longer the participant could sustain the FR test, the higher the difference in FR measured with both devices.

CONCLUSION

Our results suggest that the Martin Vigorimeter is a more appropriate handgrip device compared with the Jamar Dynamometer to assess muscle fatigability for older women across levels of frailty. When measured with the Martin Vigorimeter, high-frail participants show twice the level of fatigability compared to low-frail, whereas no difference was observed when using the Jamar Dynamometer. Older participants might stop the FR test prematurely when using the Jamar Dynamometer, before muscle fatigue is reached, indicating that the Jamar Dynamometer is unable to identify those participants with higher levels of muscle endurance. Martin Vigorimeter assessed muscle fatigability might be a good additional marker to include in frailty tools.

KEY WORDS: frailty; fatigue resistance; strength, force

1. INTRODUCTION

Frailty has a devastating impact on older people, their family and society[1]. Recently, Azzopardi et al[2] established an extensive list of the available frailty instruments and linked their items to the codes of the International Classification of Functioning, Disability and Health to analyze the overlap and gaps. They showed that self-reported fatigue is a central component in several frailty assessment tools. In these studies, as well as in clinical practice, fatigue is usually measured by a subjective estimation of tiredness by the patient[2]. This sensation of tiredness may indeed characterize frailty by reflecting depletion of physiological reserve capacity. Even so, muscle fatigability, a reduced tolerance for muscular work may be also an important indicator of frailty[3,4]. Remarkably, none of the frailty tools reported in the literature include a direct assessment of muscle fatigability.

Previously[5-14] we have validated a new assessment method for determining muscle fatigability (fatigue resistance, FR): during a rapid and simple test, suitable for bedside evaluation, where patients are instructed to sustain maximal handgrip effort as long as possible, and FR is expressed as the time during which grip strength (GS) drops to 50% of its maximum[7]. This FR test also allows the calculation of grip work ($GW=0.75*GS_{max}*FR$)[6] which is a parameter reflecting the work output delivered by the muscles during testing. Our previous work demonstrated that FR and GW are significantly related to dependency for basic activities of daily living, self-perceived fatigue and circulating markers of inflammation within groups of community-dwelling older persons[6,15,16], older nursing home residents[10], hospitalized geriatric patients[5,9,14-16] and patients following abdominal surgery[8].

This FR test has been well validated for the Martin Vigorimeter (KLS Martin Group, Tuttlingen, Germany), a device consisting of a rubber bulb connected via a rubber airtight junction to a manometer. Since this device is comfortable and allows performing a dynamic contraction (the rubber bulb is compressible), it is highly suitable to assess sustained maximal contractions, even in frail and/or ill people. When using the Martin Vigorimeter, FR is highly reproducible in older people with ICC-values between 0.91-0.94 and 0.88-0.91 respectively for intra- and inter-observer reliability[7]. However, many researchers and clinicians are using more classic devices for GS_{max} evaluation such as the Jamar Dynamometer (Sammons Preston, Rolyon, Bolingbrook, IL) which is designed to measure isometric GS and is characterized by its rigid iron handle. GS_{max} measures obtained by the Martin Vigorimeter have been shown to be well correlated with those obtained with the Jamar Dynamometer[17]. However, no studies have yet compared whether FR measured by both the Martin Vigorimeter and Jamar Dynamometer differs across levels of frailty. This limits the implementation of the FR test across settings as a clinical indicator of frailty. Therefore, the aim of this study was to compare muscle fatigability values obtained by the Martin Vigorimeter and Jamar Dynamometer, and to evaluate the relationship with the degree of frailty in older women.

2. METHOD

2.1. Participants

A detailed description of the participants and their recruitment is published elsewhere[18]. Briefly, 53 community-dwelling women (age range: 63-100 years) who were living in Greece participated. The study was approved by the human ethical research committee of Western University, London Ontario Canada, and all participants provided written informed consent.

2.2. Measurements

Participants did a GS_{max} and a FR handgrip performance test using a Martin Vigorimeter (KLS Martin Group, Tuttlingen, Germany) and Jamar Dynamometer (Sammons Preston, Rolyon, Bolingbrook, IL). To be sure that the order for the devices did not affect the handgrip performance test results, they were applied in a random order for the consecutively tested subjects. The Martin Vigorimeter is provided with 3 different sizes of compressible rubber bulbs, but as recommended by Bautmans et al[7] we used the largest bulb for all participants. The Jamar Dynamometer is a rigid iron handle, which can be adjusted according to the individual's hand size. For all participants GS_{max} and FR were assessed in the second handle position (counting from the handle outward), since this was the most comfortable position for the participant's hand. Supplementary figure S1A and S1B shows the set-up for each handgrip device. All tests were performed with the self-reported dominant hand with both devices on the same day, in a random order.

2.2.1. Maximal grip strength, fatigue resistance and grip work

After 2 to 3 practice trials, 3 maximal measurements were performed for each hand with both instruments. The shoulder was adducted and neutrally rotated, elbow flexed at 90°, forearm in a neutral position, and wrist in slight extension (0°-30°). Briefly, participants were asked to squeeze 3 times the large rubber bulb or rigid handle as hard as possible. The inter-trial rest interval was one minute. The highest score of the 3 attempts was registered as GS_{max} in kPa and kg, respectively for Martin Vigorimeter and Jamar Dynamometer. Afterwards, the participants were asked to squeeze the bulb again or handle as hard as possible, and to maintain this maximal effort as long as possible, under continuously standardized verbal stimulation by the investigator. The time in seconds (s) during which GS dropped to 50% of its maximum was recorded as FR. The researcher verified that the starting GS corresponded to their established GS_{max}. GW, a parameter reflecting the total effort produced during the FR test, represents the physiologic work delivered by the handgrip flexor muscles, corresponding to the area under the strength drop decay curve, when assuming a linear decrease of the GS during the FR test. GW was calculated by multiplying the FR in seconds (s) by 75% of the GS_{max} reported as either kPa or kg[6]. We corrected GW for body mass (GW/body mass in kg) since heavier or more obese participants will have to engage more strength and sustain that effort over time in order to execute daily tasks , such as transfers and carrying or moving objects compared to their lighter or leaner counterparts[11].

2.2.2. The Borg Scale of Perceived Exertion (RPE)

Immediately after the FR test the Borg scale was assessed in order to obtain RPE scores. RPE is widely used to reliably monitor and guide physical performance intensity. The women were asked to subjectively rate their level of exertion during the FR test, with both devices, going from 0 = “nothing at all” to 10 = “extremely strong/maximal”[19].

2.2.3. Frailty Index

A Frailty Index was constructed based on the accumulation of deficits approach where a deficit can be any symptom, sign, disease, disability, or laboratory abnormality that accumulates with age and is associated with adverse events[20]. A detailed description of the FI used in this study is published elsewhere[18] Briefly, the FI was derived from 56 measures from 13 domains that were assessed through a health history questionnaire (adapted from Rogers 2005)[21]; performance-based measures were excluded. The number of recorded deficits was divided by the total number of measures (56 measures) to give FI score. The FI does not give a cut-off that identifies someone as frail; rather, it is graded so that the greater the score (closest to 1), the more likely it is that someone is vulnerable to adverse events associated with frailty. The FI predicts declining health, institutionalization, and death, and is validated in both community and institutionalized older adults[22]. Prior studies have shown that the FI, even when different deficits are collected, has remarkably similar measurement properties and substantive results, especially when a minimum of 30 variables are included[22]. In this study, participant scores for the FI were split into tertiles. Various cut-points have been suggested for the Frailty index. Based on Hoover et al.[23] the first tertile includes the “non-frail/pre-frail” group, the second tertile includes the “frail and more-frail” groups and the last tertile includes the “most frail” group. Here, as described previously[18], terminology was simplified and we defined the lowest FI tertile as “low-frail” (<0.19 FI), the intermediate FI tertile as “intermediate-frail” (0.19–0.36 FI) and the highest FI tertile as “high-frail” (>0.36 FI) (table 1).

Table 1: Descriptive characteristics

	Low-frail[a] N=17	Intermediate-frail[b] N=18	High-frail[c] N=18	p-value[d]
Age (y)	71 ± 4	76 ± 6	**82 ± 7**$^{*\$}$	**<0.001**
Frailty index	0.09	**0.26***	**0.47**$^{*\$}$	**<0.001**
Body mass (kg)	68.5 ± 9.4	76.9 ± 11.5	72.7 ± 16.9	0.175
BMI (kg/m^2)	28.7 ± 3.3	31.9 ± 4.6	31.8 ± 6.9	0.122
GS_{max} MV (kPa)	57.8 ± 10.9	**46.4 ± 12.0***	**38.4 ± 11.0***	**<0.001**
GS_{max} JD (kg)	27.3 ± 4.8	**22.1 ± 6.1***	**18.2 ± 6.7***	**<0.001**
GW MV (kPa*s/kg)[e]	28.4 ± 17.6	**17.1 ± 12.2***	**10.1 ± 7.0***	**0.001**
GW JD (kg*s/kg)[e]	7.2 ± 3.8	**4.1 ± 3.0***	**3.5 ± 2.7***	**0.003**

*[a] Corresponds to the lowest FI tertile (<0.19 FI); [b] corresponds to the intermediate FI tertile (0.19 – 0.36 FI); [c] corresponds to the highest FI tertile (>0.36 FI); [d] One-way ANOVA; [e] GW corrected for body mass; * significantly different from the low-frail group; $ significantly different from the intermediate-frail group; all Tukey post hoc tests p<0.05; MV = Martin Vigorimeter; JD = Jamar Dynamometer; bold font = p-value <0.05.*

2.3. Statistical analyses

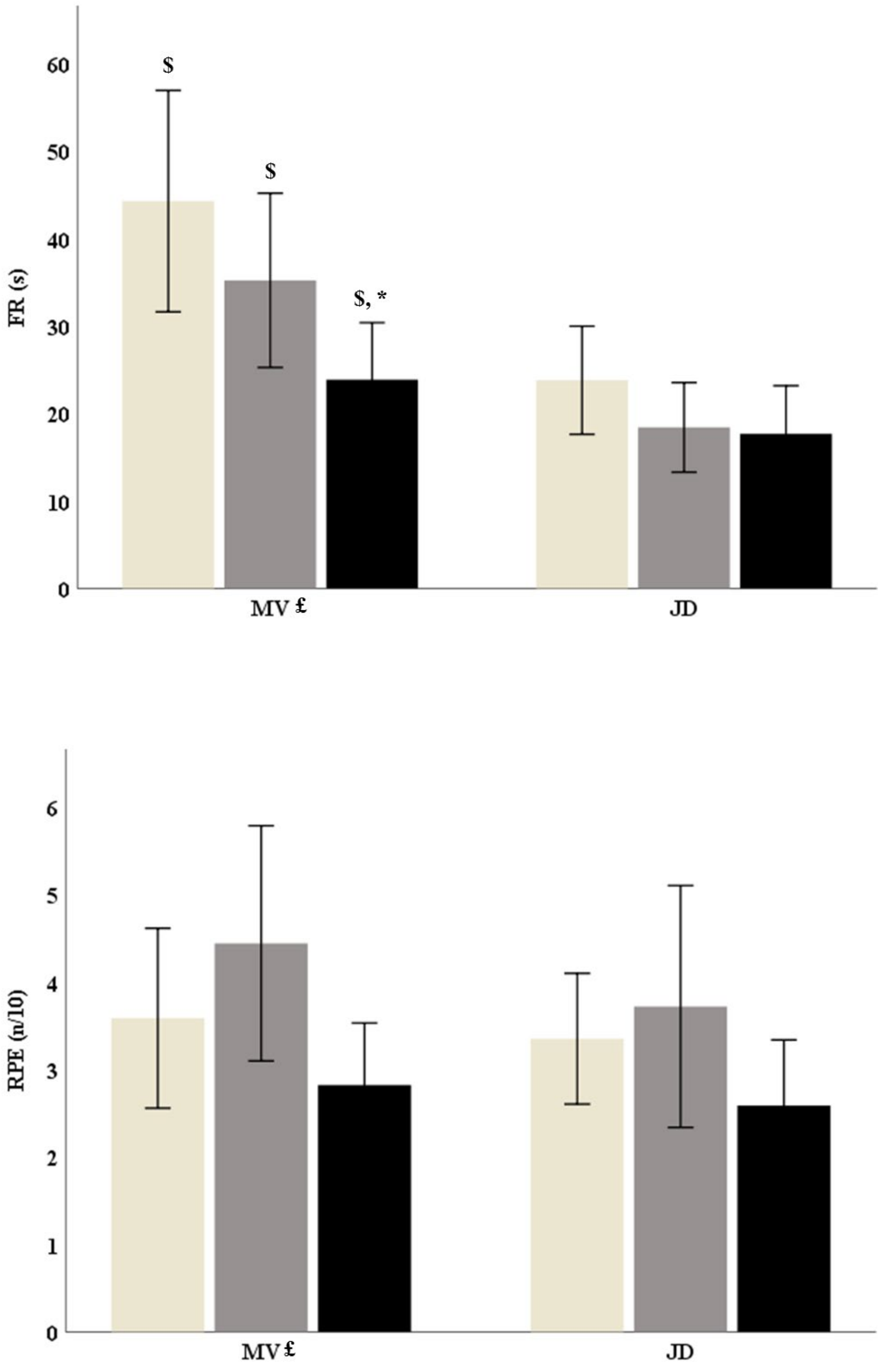
The Statistical Package for the Social Sciences (SPSS version 24; Chicago, Ill., USA) was used for this analysis. One-way analysis of variance (ANOVA) was performed to determine whether descriptive characteristics differed between the FI tertile groups. Tukey post-hoc tests were run when there was a significant (p<0.05) main effect for frailty. Differences between devices in FR results were analyzed using the Paired Samples T-test. Partial correlation coefficients (corrected for age and BMI) were computed to examine the association between FI score and muscular handgrip performance (GSmax, FR, GW corrected for body mass). Then logistic regressions were conducted to assess whether the 3 predictor variables (age, BMI and handgrip performance expressed as either GS_{max}, FR or GW corrected for body mass; independent factors) significantly predicted whether or not a participant belonged to the high frailty group (i.e. dependent factor) and odds ratios were calculated. A Bland–Altman plot was made to visualize the relationship between the mean FR and the difference in FR when measured with Martin Vigorimeter and Jamar Dynamometer. A regression line was plotted in the Bland-Altman graph to verify for proportional differences. Significance was set *a priori* at $p<0.05$.

3. **RESULTS**

Among the 53 women, one belonging to the high-frail group (FI=0.61) refused to perform the FR test by using the Martin Vigorimeter, because she thought that she was too old and weak; however, we included her in all statistical analyses except those involving FR or GW corrected for body mass assessed by the Martin Vigorimeter (since these data were missing). Table 1 presents the descriptive characteristics of the participants. High-frail participants were significantly older than the 2 other frailty groups. We found that participants who belonged to the low-frail group were the strongest, irrespective whether their GS_{max} was measured by the Martin Vigorimeter or Jamar Dynamometer device. For both devices we also found that the low-frail group had better GW corrected for body mass scores than the intermediate- and high-frail group. There was no significant difference in muscular handgrip performance found between intermediate- and high-frail groups for either device. Figure 1 shows that overall the FR scores were higher ($p<0.001$) when measured with Martin Vigorimeter compared to Jamar Dynamometer (respectively 34.5±21.1s and 19.9±11.2s). When participants were divided into FI tertiles, those in the low-frail group were able to sustain the grip effort with the Martin Vigorimeter approximately twice as long as the high-frail group (FR 44.3±24.6s versus 23.9±12.7s, $p=0.011$). No significant differences between the 3 FI tertiles for the FR scores were reported when using the Jamar Dynamometer device. Furthermore, no significant differences between the 3 FI tertile groups in perceived exertion (RPE) during the FR test were found for the devices (see figure 1). However, the RPE scores were overall significantly higher ($p<0.001$) following the FR test measured with Martin Vigorimeter compared to Jamar Dynamometer (respectively 3.6±2.2 and 3.2±2.0). Figure 2 (Bland-Altman plot) also shows that there is a significantly proportional difference in FR measured with both devices ($R^2=0.364$, $p<0.001$), highlighting that the longer the participant could sustain the FR test, the higher the difference in FR measured with both devices.

The FI was not related to FR as measured with the Jamar Dynamometer and to RPE scores (table 2). However, a higher FI was significantly related to a weak GS_{max} score, lower FR (only when measured with the Martin Vigorimeter), and low GW score corrected for body mass.

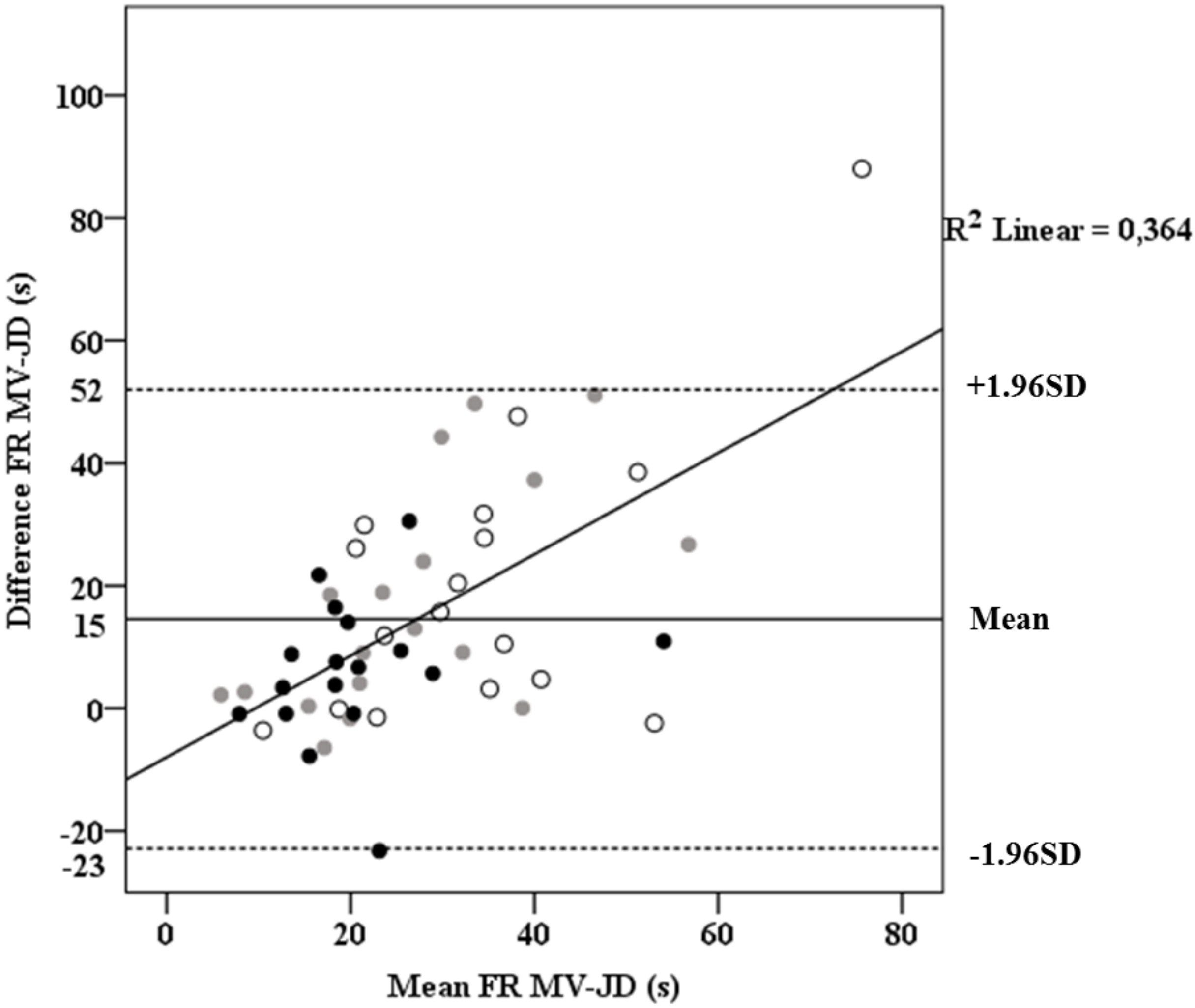
Figure 1: FR (measured with Martin Vigorimeter and Jamar Dynamometer) and RPE scores after FR testing



*Light gray = low-frail, dark gray = intermediate-frail, black = high-frail; * significantly different from the low-frail group (p<0.05); significantly different from Jamar Dynamometer £*

$p<0.001$ and [$] $p<0.05$; error bars: 95% CI; MV = Martin Vigorimeter; JD = Jamar Dynamometer.

Figure 2: Bland–Altman plot for FR measured with Martin Vigorimeter and Jamar Dynamometer



White = low-frail; gray = intermediate-frail; black = high-frail; the horizontal plain line represents the mean difference in FR between both devices. The dotted lines show the upper and lower limits of agreement. The plain line represents the linear regression showing that there is a significantly proportional difference in FR measured with both devices (R^2=0.364, p<0.001), indicating that the longer the participant could sustain the FR test, the higher the difference in FR measured with both devices.

Table 2: Relationship between frailty index, age, BMI, muscular handgrip performance and the Borg Scale of Perceived Exertion

	FI	
	r[a]	p-value
Grip strength$_{max}$ MV (kPa)	**-0.39**	**0.005**
Grip strength$_{max}$ JD (kg)	**-0.39**	**0.004**
Fatigue resistance MV (s)	**-0.33**	**0.019**
Fatigue resistance JD (s)	0.02	0.883
Rate of Perceived Exertion MV (n/10)	-0.22	0.124
Rate of Perceived Exertion JD (n/10)	-0.01	0.921
Grip work MV (kPa*s/kg)[b]	**-0.37**	**0.009**
Grip work JD (kg*s/kg)[b]	**-0.28**	**0.048**

[a] Partial correlation coefficients corrected for age and BMI; [b] GW corrected for body mass; MV = Martin Vigorimeter; JD = Jamar Dynamometer; Rate of Perceived Exertion, score ranging from 0 = "nothing at all" to 10 = "extremely strong/maximal"; p-value <0.05 = bold font.

Muscle fatigability (FR: OR=0.94 [0.90-0.99] and GW: OR=0.90 [0.82-0.99] as independent predictors) were significantly related to high frailty when measured with the Martin Vigorimeter, but not when measured with the Jamar Dynamometer (table 3). Older age was also significantly related to high levels of frailty but neither BMI nor muscle endurance, as measured with Jamar Dynamometer, were significant predictors of higher frailty, in any of the 3 models (table 3).

Table 3: Logistic regression models for predicting high frailty level

	MV						JD					
	B	SE	Odds ratio	95% CI		p-value	B	SE	Odds ratio	95% CI		p-value
				Lower	Upper					Lower	Upper	
FR	**-0.06**	**0.03**	**0.94**	**0.90**	**0.99**	**0.027**	-0.00	0.03	1.00	0.95	1.05	0.924
Age	**0.21**	**0.07**	**1.23**	**1.08**	**1.41**	**0.002**	**0.20**	**0.06**	**1.23**	**1.08**	**1.38**	**0.001**
BMI	0.08	0.07	1.08	0.95	1.23	0.246	0.07	0.06	1.07	0.94	1.21	0.295
	χ^2 = 23.77, df = 3, N = 52, p<0.001						***χ^2 = 17.65, df = 3, N = 53, p=0.001***					

	MV						JD					
	B	SE	Odds ratio	95% CI		p-value	B	SE	Odds ratio	95% CI		p-value
				Lower	Upper					Lower	Upper	
GW	**-0.10**	**0.05**	**0.90**	**0.82**	**0.99**	**0.029**	-0.18	0.13	0.84	00.65	1.09	0.184
Age	**0.19**	**0.07**	**1.21**	**1.06**	**1.37**	**0.005**	**0.20**	**0.07**	**1.23**	**1.08**	**1.39**	**0.002**
BMI	0.05	0.07	1.05	0.92	1.19	0.487	0.04	0.07	1.04	0.92	1.18	0.533
	χ^2 = 24.34, df = 3, N = 52, p<0.001						***χ^2 = 19.75, df = 3, N = 53, p=0.001***					

MV = Martin Vigorimeter; JD = Jamar Dynamometer; BMI = body mass index; FR = fatigue resistance; GW = grip work corrected for body mass; B = exponent; SE = standard error; bold font = p-value <0.05.

4. DISCUSSION

In this study, we have investigated the relation of muscle fatigability, which was obtained by two devices, with the degree of frailty in 53 older women. Our results suggest that Martin Vigorimeter is a more appropriate handgrip device compared with Jamar Dynamometer to assess muscle strength and fatigability in the context of frailty. The FR, when measured with Martin Vigorimeter, was two times shorter in the high-frail group compared to the low-frail group, whereas no significant difference was found in FR when measured with Jamar Dynamometer. In logistic regression models, reduced muscle strength and fatigability were significantly related to high frailty when measured with Martin Vigorimeter but not when measured with Jamar Dynamometer.

Previously, fair to good correlations for GS_{max} were reported between Martin Vigorimeter and Jamar Dynamometer[17,24,25]. In a recent study, Sipers et al. concluded that Martin Vigorimeter is a more practical tool than the Jamar Dynamometer to measure GS_{max} in geriatric hospitalized patients[24]. The Martin Vigorimeter allows a dynamic contraction and a softer external resistance on the hand joints since the rubber bulb is compressible. This device has been specifically designed for patients with arthritis to allow proper GS assessment while avoiding excess stress on weak or painful joints[26,27]. Since the Martin Vigorimeter is more comfortable, older people may maintain the sustained grip effort for a longer time during the FR testing, thus allowing muscle fatigue to occur. Conversely, older participants might stop the FR test prematurely when using the Jamar Dynamometer, before muscle fatigue is reached and thus this device may be unable to discriminate levels of muscle endurance. This assumption is strengthened by the significantly proportional differences that we found in FR with both devices, showing that the longer the participant could sustain the FR test, the higher the difference in FR measured with both devices. This observation could suggest a certain 'ceiling effect' for FR when using the Jamar Dynamometer. Future studies including simultaneous recording of forearm muscle activity (e.g. by surface EMG) during the FR test might help to confirm or reject this hypothesis. Unfortunately, we did not quantify the level of discomfort that the participants experienced during the FR test in our study. It is possible that participants experienced more pain by using the Jamar Dynamometer, a presumption that is based on earlier studies about perceived pain when using the Jamar Dynamometer[28-30].

There are several reasons to hypothesize a physiologically based association between frailty and muscle fatigability since they share common biomedical determinants[3]. In addition, the key elements of the vicious cycle of frailty, as proposed by Fried and colleagues[1], include both physiological determinants (sarcopenia, neuroendocrine dysregulation and immunological dysfunction) and clinical markers of frailty (muscle weakness, subjective fatigue, reduced physical activity, low gait speed and weight loss)[3]. Interestingly, the group of Westerblad et al. showed that muscle fatigue occurs before the onset of muscle weakness in a mouse model of premature ageing[31]. This supports the hypothesis that muscle fatigue might be a good early marker for frailty and therefore potentially highly relevant in identifying people who are progressing towards frailty but in whom reduced GS_{max} is not yet clinically apparent. Our results indicate that muscle fatigability measured with the Martin Vigorimeter is more suitable for this purpose than the Jamar Dynamometer. Interestingly, although distinctively higher scores were obtained compared to the high-frail women, a substantial spread of performance among the women with low frailty is seen for the FR measured with the Martin Vigorimeter (mean [min-max] = 44.3s [8.7-119.6s]). This lets us assume that there is no tendency to ceiling effects for the muscle fatigability measured with the Martin Vigorimeter. In addition, previously[16,32] we studied the muscle fatigability in 51 older community-dwelling women in whom found a mean FR score of 93±52s when using a Martin Vigorimeter pointing towards the potential of this measure to discriminate very robust older persons from those in early stages of frailty. Furthermore, the slightly but significantly higher RPE scores support the assumption that the FR test performed with the Martin Vigorimeter was able to push the participants closer to their fatigue level compared to the Jamar Dynamometer. Martin Vigorimeter-based muscle fatigability should be included in assessment frailty and might contribute to the standardization of the frailty concept and its operationalization[2,33].

This study has certain limitations. Firstly, this study is based on a relatively small population (53 women). To minimize potential bias, the study population was recruited among older women who were living in the same community and who has similar lifestyle. Nevertheless, the sample size was sufficient to identify differences in handgrip performance obtained by Martin Vigorimeter and Jamar Dynamometer in relation to the participants' degree of frailty. Secondly, despite the fact that the same test conditions were used to minimize bias, we were unable to fully standardize the test environment, since all measurements were performed inside the participants' home. Even so, measures obtained in frail older persons are a better reflection of their physical capacity when assessed in a safe and well-known environment rather than in a laboratory. However, because we did not quantify the level of discomfort that the participants experienced during the FR test in our study it is possible that difference in pain between devices might have contributed to reduced FR test with the Jamar Dynamometer compared with the Martin Vigorimeter. As a final point, except for FR (for both devices expressed in seconds) the units of measurement are different between Jamar Dynamometer and Martin Vigorimeter, making direct comparisons for GW between the two devices difficult.

5. CONCLUSION

Our results suggest that Martin Vigorimeter is a more appropriate handgrip device compared with Jamar Dynamometer to assess muscle fatigability in women across levels of frailty. When measured with the Martin Vigorimeter, participants with higher levels of frailty show twice the level of fatigability compared to participants with lower frailty levels, whereas no difference is observed when using the Jamar Dynamometer. Older participants might stop the FR test prematurely when using the Jamar Dynamometer, before muscle fatigue is reached, indicating that the Jamar Dynamometer is unable to identify those participants with higher levels of muscle endurance. Martin Vigorimeter-based muscle fatigability might be a good additional marker to include in frailty assessment instruments.

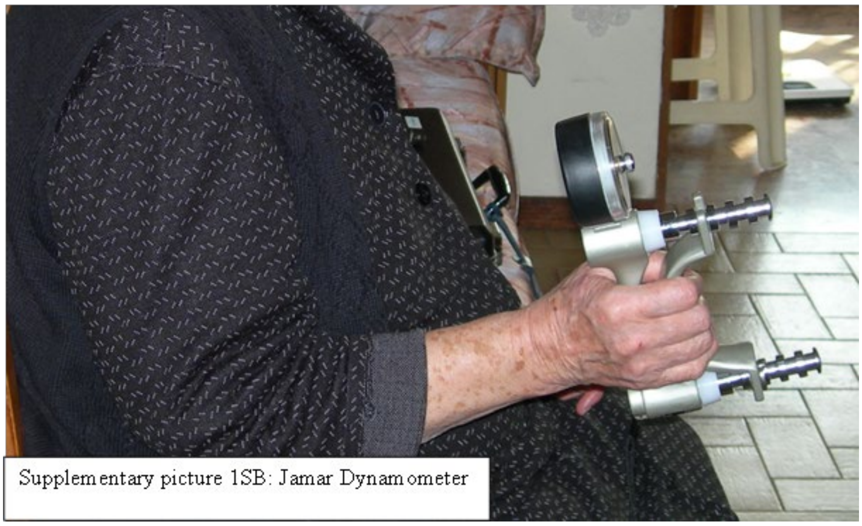
6. DECLARATIONS OF INTEREST

None of the authors have any conflict of interest with any entity with regard to this study.

7. SUPPLEMENTARY MATERIAL

Supplementary picture S1A and S1B: The set up for respectively Martin Vigorimeter and Jamar Dynamometer during the handgrip performances.

Supplementary picture S1A: Martin Vigorimeter



Supplementary picture 1SB: Jamar Dynamometer

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