AN INEXPENSIVE METHOD TO MEASURE KNEE EXTENSORS' POWER IN OLDER ADULTS

MÉTODO ACESSÍVEL PARA MEDIÇÃO DE POTÊNCIA DE EXTENSÃO DE JOELHO EM IDOSOS

MÉTODO ACCESIBLE PARA MEDIDA DE POTENCIA EN LA EXTENSIÓN DE LA RODILLA EN ANCIANOS

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João Pedro Pinho[1] (Educador Físico)
Bruno Mezêncio[1] (Educador Físico)
João Gustavo Oliveira Claudino[1] (Educador Físico)
Rafael Soncin[1] (Educador Físico)
Arnaldo José Hernandez[2] (Médico)
Júlio Cerca Serrão[1] (Educador Físico)
Alberto Carlos Amadio[1] (Educador Físico)

1. Universidade de São Paulo, Escola de Educação Física e Esporte, Laboratório de Biomecânica, São Paulo, SP, Brasil.
2. Universidade de São Paulo, Faculdade de Medicina, Hospital das Clínicas, Instituto de Ortopedia e Traumatogia, São Paulo, SP, Brasil.

Correspondência:
Avenida Professor Mello Moraes, 65 - Cidade Universitária. 05508-030, São Paulo, Brasil.
pinhojp@usp.br

ABSTRACT

Introduction: Measuring knee extensors' power in elderly population is crucial but not accessible to everyone. Objective: To provide a method to calculate knee extensors' power in a conventional knee extension machine. Method: Thirteen sedentary elderly women (69.3±4.1 years) performed six knee extensions as fast as possible. Kinematic data, an anthropometric model and Newtonian mechanics was used to write movement equations that allowed calculating knee extensors' power and work. The reliability was assessed by variables' coefficient of variation, intraclass correlation coefficient and standard measurement error. Results: Knee extensors' peak power and work values obtained were in agreement with the literature. We found high intraclass ICC values for both variables (93% and 97%, respectively) and low normalized SEM (10.13% and 2.09%, respectively). Conclusion: We provided an inexpensive method to assess a major physical dysfunction indicator in older adults which can also be used to evaluate the progression of an intervention.

Keywords: aged, muscle strength, quadriceps muscle, knee.

RESUMO

Introdução: Avaliar a potência de extensão de joelhos na população idosa é crucial, porém não acessível a todos. Objetivo: Propor um método para calcular a potência de extensão de joelhos em uma cadeira extensora convencional. Métodos: Treze idosas sedentárias (69.3±4.1 anos) realizaram seis extensões de joelho na maior velocidade possível. Dados cinemáticos, um modelo antropométrico e mecânica Newtoniana foram aplicados para elaborar as equações do movimento que permitiram o cálculo do trabalho e da potência de extensão de joelhos. A confiabilidade foi avaliada pelo coeficiente de variação, pelo coeficiente de correlação intra-classe e pelo erro padrão de medida. Resultados: Os valores do trabalho e do pico de potência de extensão de joelhos encontrados corroboram com os relatados na literatura. Foi encontrado uma alta correlação intra-classe para ambas variáveis (97% e 93%, respectivamente) e baixo erro padrão de medida (2.09% e 10.13%, respectivamente). Conclusão: Foi proposto um método acessível para avaliar o principal indicador de disfunção física de idosos, que pode ser utilizado igualmente para o acompanhamento dos resultados de uma intervenção.

Palavras-chave: *idoso, força muscular, músculo quadríceps, joelho.*

RESUMEN

Introducción: Evaluar el poder de la extensión de rodilla en los ancianos es fundamental, pero no es asequible para todos. Objetivo: Desarrollar un método para calcular la potencia de la extensión de rodilla en una extensión convencional pierna. Métodos: Trece mujeres mayores sedentarias (69,3 ± 4,1 años) realizaron seis extensiones de rodilla con la mayor velocidad posible. Datos cinemáticos, un modelo antropométrico y la mecánica newtoniana fueron aplicados para derivar las ecuaciones de movimiento que permitieron el cálculo del trabajo y la potencia de la extensión de rodilla. La fiabilidad se evaluó mediante el coeficiente de variación, el coeficiente de correlación intraclase y el nivel de error de medición. Resultados: Los valores encontrados para el trabajo y la potencia máxima en la extensión de rodillas corroboran con los reportados en la literatura. Un alto ICC para ambas variables fue encontrado (97% y 93%, respectivamente) y un bajo EPM (2,09% y 10,13%, respectivamente). Conclusión: Se demostró un método económico para evaluar el indicador primario de la disfunción física en los ancianos, que puede ser utilizado tanto para el monitoreo de la disfunción como para la intervención.

Palabras clave: *anciano, fuerza muscular, músculo cuádriceps, rodilla.*

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INTRODUCTION

The aging process has a profound deteriorative effect in the elderly's ability to perform everyday tasks such as those that ensure an independent life (e.g., walking, sitting/lying down, working activity, recreation/sports/entertainment, up and down stairs). Indeed, the main cause of death in this population is due to falls; event that frequently happens during the performance of those tasks[1]. Additionally, muscle power loss in one of the most striking features in this population and the ability to produce knee extensors' power seems to be related with the elderly's inefficient gait and increased risk of fall[2].

Therefore, measuring knee extensors' power is crucial to identify the older adults that have greater risk of fall. For this purpose, isokinetic dynamometer has been widely used[3,4]. However, its use has been questioned due to its lack of resemblance to the limbs' acceleration and deceleration patterns of everyday movements. Even its use in the sports performance field has been questioned[5-7]. Furthermore, the use of an isokinetic dynamometer to measure this dysfunction indicator is restricted to major clinical facilities not affordable to everyone who needs.

Therefore, our purpose was to obtain knee extensors' power in a conventional knee extension machine as well as to verify its reliability.

MATERIALS AND METHODS

The sample was selected among the female older adults that replied to the study's public advertising. Twenty five candidates signed up to participate in the project although 12 were excluded based in the study functional inclusion criteria. Participants reported absence of cardiac and musculoskeletal problems like knee or hip osteoarthritis diagnosticated, as well as absence of arterial hypertension. Thus, 13 sedentary elderly women aged between 65 and 75 years old (69.3 ± 4.1 years) and homogeneous Body Mass Index (26.1 ± 2.5 Kg/m^2) took part in the study. The participants were previously informed of all of the operational procedures and gave their Written Consent informing that their involvement in the study was voluntary. The study was approved by the local Ethics Committee (31199114.0.000.539). Baecke questionnaire[8] modified and validated for older adults[9] was used to assess their physical activity level ensuring that all were sedentary.

The experiments were conducted in a conventional knee extensors machine (Gervasport Fitness Equipment - Pleven, Bulgaria) (figure 1) and a digital video camera (Casio EX-ZR10) with a sample rate of 240Hz and a shutter speed of 1/2000s recorded the trials. The sample rate allowed recording 138,240 pixels (432X320 pixels) per frame.

Experimental procedures: ensuring that the participants' trunk and thigh remained immovable, with the knee axis aligned with the leg extensor machine axis, a sub-maximal test was conducted in order to estimate the participants' maximum knee extensors load. After estimating the maximum load effort by Brzycki[10] equation 50% of that maximum was calculated and used (equation 1).

Figure 1. Conventional knee extensors machine (Gervasport Fitness Equipment - Pleven, Bulgaria).

Equation 1: 1RM = m · 36/((37-reps))

Where *1RM* is the estimated maximum load (kilograms), is the mass lifted in the trial (kilograms) and *reps* is the number of repetitions that the participant was able to produce with that load.

This maximum load estimation protocol was conducted so that the number of repetitions was below ten. Indeed, all participants were able to achieve that goal within two trials, being given 10 minutes rest between trials. The participants executed 6 repetitions with the concentric phase of the knee extension movement as quickly as possible. Between each repetition 30 to 45 seconds rest were given. Reflexive markers (20 millimeters diameter) were attached to the participants' lateral malleolus of the ankle and lateral condyle of the knee. Such markers allowed assessing knee angle in relation to the machine's initial position. These data were used to calculate knee concentric angular velocity and acceleration as well as to determine the eccentric cam axis position.

All mathematical procedures were performed in MatLab v.R2010a (Mathworks, Inc - Natick, Massachusetts, U.S.A.). SkillSpector 1.3.2 (Video4Coach, Inc - Odense, Denmark), a free available motion analysis software, was used to digitize the two markers. After the digitalization process, the spatial coordinates were smoothed with an 8Hz low-pass Butterworth filter. The knee extension machine used, as well as the ones commonly found, had an eccentric cam. His purpose is to impose different efforts along the knee angular excursion to attend to the muscle length/tension demand. To calculate the machine's radius a high resolution photo (12.1 Megapixels) of the cam was taken and a hundred equidistant virtual markers were placed along the cam's edge (where the machine's belt passed). A general Fourier series model was used to adjust the data (equation 2).

Equation 2: $r_{KE} = 0.21 + 0.01 \cdot \cos(x \cdot 0.03) + 0.01 \cdot \sin(x \cdot 0.03)$

Where is the machine's radius given by the distance in meters between the eccentric cam axis and the tangent point of the machine's belt and is the angle in relation to the initial position.

Net knee extensors torque was calculated assuming the knee extensor machine's torque equality (equation 3).

Equation 3: $\tau_{net} = \tau_{KEm}$

Where is the net knee extensors' torque and is the knee extension machine's torque, given in N·m (Newton·meter).

Therefore, to calculate the knee extensors' torque equation 4 was used.

Equation 4: $\tau_{net} = m_{KE} \cdot r_{KE} \cdot (\alpha_{KE} + g) + w_a \cdot r_a \cdot cos\Phi_a + m_{S\&F} \cdot \omega_a \cdot I^2_{S\&F} + w_{S\&F} \cdot r_{S\&F} \cdot cos\theta_{S\&F}$

Where is the mass lifted by the subject, is the mass's linear acceleration, is the gravitational constant (9.81 m·s^{-2}), is the machine's arm weight, is the distance between the machine's axis and the center of mass of the machine's arm, is the cosine of the angle formed by the horizontal, the machine's axis and the machine's arm center of mass, is the shank and foot's mass, is the machine's arm angular acceleration, is square distance of the proximal radius of gyration in relation to the knee axis, is the shank and foot weight, is the distance in meters between the knee axis and the shank and foot's center of mass and is the sine of the angle formed by the horizontal, the knee axis and the shank and foot's center of mass. Information about the segment parameters was provided by Dempster's anthropometric model[11].

It should be noticed that the equation's first term corresponds to the machine's load torque; the second term corresponds to the machine's arm torque and the third and fourth terms corresponds to the shank and foot's torque. Finally, to calculate the knee extensors' power and work equation 5 and 6 were used.

Equation 5: $P_o = 2 \cdot \pi \cdot RPS_{KE} \cdot \tau_{net}$

Where is the knee extensors' power output given in w (Watts) and is the number of the machine's arm revolutions per seconds.

Equation 6: $W_m = \int_i^f P_o dt$

Where is the mechanical work done by the knee extensors in the movement's concentric phase expressed in joules (J) and is the integral of the power output curve between the initial and final moments of the movement's concentric phase. This mechanical work cannot be related to the total work performed by the subject due to the impossibility to assess the mechanics efficiency of the muscle contraction[12].

Statistical Procedures

SigmaStat 3.5 (Dundas Software, Ltd - Toronto, Canada) was used to conduct all statistical procedures. Initially, individual trials' coefficient of variation (CV) of the two variables was calculated. Then, an analysis of variance with participants and trials as factors was conducted in order to obtain the factors' mean squares. Intraclass correlation coefficient (ICC) was calculated according to Weir[13] (equation 7). Standard error of measurement (SEM) was obtained by taking the square root of the ANOVA's residual mean square. Normalized standard error of measurement (SEM_{norm}) was calculated dividing the SEM by the mean.

Equation 7: $ICC= \dfrac{MS_{participant} - MS_{residual}}{MS_{participant} + (k\text{-}1)MS_{residual}}$

Where is the mean square due to the participants' variation, is the mean square error and is the number of participants.

RESULTS

We found total knee extensors' peak power output values around 221.4 ± 87.1 W with a total range interval of 85.1 – 427.8 W and an interquartile range of 153.2 – 280.8 W; and total knee extensors' mechanical work around 76.9 ± 26.3 J with a total range interval of 38.5 – 122.8 J and an interquartile range of 56.5 – 102.7 J. Individual distributions' box-plots are presented in figure 2.

Plotted in figure 3 are the individual coefficients of variation. Whereas six out of thirteen knee extensors' peak power output CVs were above 10% all of the knee extensors' mechanical work CVs were under 7.2%.

The reliability indicators used are expressed in table 1.

DISCUSSION

Our main purpose was to develop an inexpensive way to calculate knee extensors' power output in older women. Applying basic Newtonian mechanics to knee kinematics in a conventional knee extension machine we were able to reliably calculate knee extensors' power output and mechanical work. To the best of our knowledge this is the first study to propose such method as well as the first study to show the selected variables' reliability in it.

The validity of our method is given by the assumptions made by Newtonian mechanics and the anthropometric models used. It is our belief that the movement equations formulated for this particular purpose attended all demands, making unnecessary a gold standard comparison. Furthermore, based in concentric knee isokinetic power's predictive equations proposed by Neder et al.[14] we found that our values are similar to the ones presented in that study. Adjusted for sex, age, height and weight of our sample such equations showed a total mechanical work of 86.32 J, close to what we found (76.9 J).

Being able to measure knee extensors' power output in the elderly population is an essential condition to assess the older adult's risk of fall and, in a general way, their functional level[15]. Furthermore, assessing an individual knee extensors' power output over time allows making inferences about the employed intervention protocol. Therefore, a physical education teacher or a physiotherapist would be able to conduct their intervention based on this fundamental physical function indicator without needing expensive or inaccessible clinical evaluations.

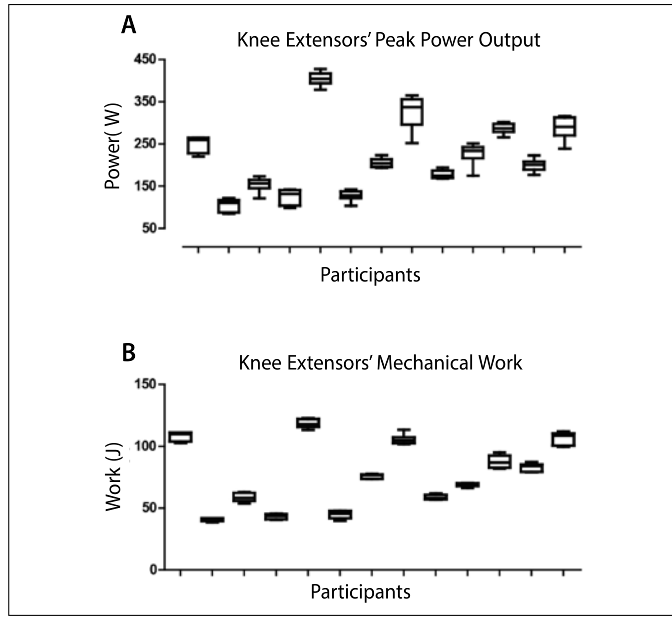

Figure 2. Box-plots representing Knee extensors' peak power output (A) and mechanical work (B) individual distributions.

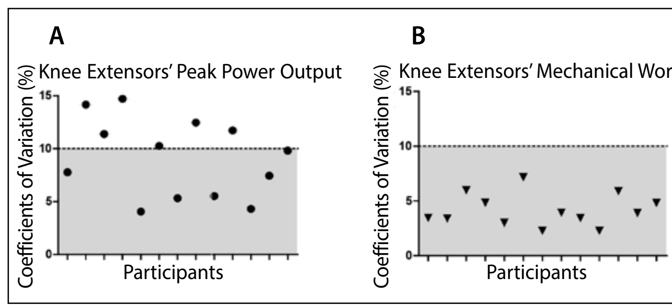

Figure 3. Graphical representation of knee extensors' peak power output (A) and mechanical work (B) individual coefficients of variation.

Table 1. Mains results of the reliability statistics used: intraclass coefficient correlation (ICC), standard error of measurement (SEM) and the mean normalized standard error of measurement (SEM_{norm}).

	ICC (%)	SEM	SEM_{norm}(%)
Knee extensors' peak power output	0.93	16.6 W	10.13
Knee extensors' mechanical work	0.97	3.3 J	2.09

In order to trust the obtained results and use them as progression or functional indicators it is imperative that such measures are highly reliable. We found that individual coefficients of variation were under 15% when assessing peak power output and under 8% when assessing mechanical work. Although not able to compare those values with ones from another study due to the method's originality we believe that they are indeed reliable. This statement is partially supported by intraclass correlation coefficients' high values founded. Similarly, Hartmann et al.[16] found an ICC of 0.94 when measuring intrarater knee extensors torque reliability in an isokinetic dynamometer at 120⁰/s of 24 independently living elderly subjects (18 women). Symons et al.[17] found a knee extensors' mechanical work ICC of 0.93 when measuring 25 older women without a familiarization session also in an isokinetic dynamometer.

An ICC of 0.93 could be interpreted as: the proportion of variance between total knee extension trials that is attributed to the true individual trial variance is 93%. Thus, only 7% is attributed to error. However, Weir[13] call attention to the fact that between-subjects variability could mask ICC values. Therefore, high ICC values could be obtained even in the presence of low reliability if a heterogenic sample was taken, in other words if between-subjects' variability is high[13]. Although high ICC values were found we believe our sample was not homogeneous (figures 1 and 2) making us unsure about making reliability inferences.

Conversely, the typical error of measurement (SEM) quantifies the precision of individual trials, in other words, the reliability within individual subjects. We found the knee extensor's peak power output normalized typical error of measurement value (SEM_{norm}) similar to the SEM_{norm} values of knee extensors' peak torque obtained by Hartmann et al.[16] and Symons et al.[17] - 10.1% in contrast with 9.3% and 9.24%, respectively. However, regarding knee extensor's mechanical work SEM_{norm} we observed a significantly lower value – 2.1% in contrast with 9.0% and 20.50%. This means that knee extensor's peak power measured by our method is as reliable as the knee extensor's peak torque measured by isokinetic dynamometer.

Nevertheless, knee extensor's mechanical work reliability measured by our method is higher suggesting it as a feasible indicator to assess differences between time spaced trials. High individual variability would be expected for a peak variable making even more reasonable to expect larger inter-subject variability. Therefore, it was no surprise to find lower reliability in knee extensor's peak power output than in knee extensor's mechanical work. Being less variable the knee extensor's mechanical work true value would lay within a short confidence interval (small typical error) making small changes easy to be detected and, consequently, a best intervention progression indicator.

Notwithstanding, it is the knee extensors' peak power output that have a strong association with functional performance and disability[18,19]. Indeed, to evaluate older adults' physical function knee extensors' power output should be assessed as a prime indicator. The proposed method showed that without an isokinetic dynamometer, in a conventional knee extension machine and in a 6 repetitions' protocol with 30 seconds rest it was possible to reliable measure knee extensors' power output. Furthermore, we strongly believe that assessing knee extensors' power without controlling movement's velocity is a more functional evaluation.

Isokinetic dynamometer allows safely measuring muscle strength and power in older adults because the speed and range of motion are computer-controlled[17]. Although it is indeed a safe measure procedure in the elderly's everyday life rarely or never a constant angular velocity is required. For instance, the elderly's gait cycle velocity curve is far from being constant, with velocity changing by the millisecond. After the initial contact the older adult has about 0.161 seconds to generate an eccentric muscle contraction to decelerate more than his entire body weight (1.2 times their body weight), with a knee flexion velocity of 145⁰/s. Afterwards, in the stance phase, he has about 0.193 seconds to generate a quadriceps contraction to propel is body weight with a knee extension velocity of 85⁰/s[20]. Not accounting for movement specificity makes the power value obtained by the isokinetic dynamometer, in our point of view, misleading. We believe that although not able to fully reproduce the functional ability needed in everyday life our method is closely related with the elderly functional tasks.

CONCLUSION

The results of this study showed that in order to evaluate elderly's knee extensors' power output one does not need expensive or inaccessible instruments. Our method provided knee extensors' power output and mechanical work values close to the ones showed in related literature. Moreover, we found high intra-subjects reliability in both variables studied suggesting this approach's feasibility.

All authors have declared there is not any potential conflict of interests concerning this article.

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