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Observational Study

The relation between force production at different hip angles and functional capacity in older women

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ABSTRACT

Although hip muscles are related to activities of daily living (ADLs) in older adults, there is a lack of evidence concerning the extensor–flexor hip torque–angle. A shift of the torque–angle relationship is caused by the aging process (increasing or reducing the range of motion) affecting the force production in a given muscular length during ADLs. Thus, the relationship between hip extensor–flexor muscles' force production and their association with functional capacity tests in elderly women were evaluated. Seventeen elderly women performed timed up and go, timed up and down stairs, and 30-s chair stand tests. Hip extensor–flexor isometric peak torques at 15°, 60°, 90°, and 100° (0° = full extension) were also assessed. Hip flexors produced the highest absolute and relative peak torque at a 15° angle and hip extensor muscles at 100°. A large and significant correlation ($r = 0.62$, $p = 0.008$) was observed only between absolute hip extensor peak torque at 90° and the 30-s chair stand test. When peak torque was normalized by body mass, the hip extensor–flexor muscles' peak torque obtained at all measured angles presented significant correlation with the 30-s chair stand test. The results indicate that for older women there is an optimum torque–angle for the hip flexor and extensor muscles. Furthermore, although the hip torque–angle relationship was measured under isometric contractions, there was a correlation with the 30-s chair stand test, which could indicate the presence of the isometric component during this movement.

1. Introduction

The torque–angle relationship is one of the musculoskeletal characteristics related to the mechanical functions of the body due to its adaptive response by functional demands (Kitai and Sale, 1989). Although the torque–angle relationship is well described in joints such as the ankle (Kitai and Sale, 1989; Maganaris, 2001) and knee (Herzog, 2008; Murray et al., 1980), there is no evidence involving this muscular property with respect to the hip joint in older adults. The changes caused by aging, such as the reduction of tendon stiffness and/or sarcopenia (Narici et al., 2008), affect the torque–angle relationship and lead to reduction in the range of motion, influencing force production on a given muscular length.

According to previous studies, muscle force production is related to functional capacity (FC), which is the ability to perform independently activities of daily living (ADLs), such as gait, sitting down and rising from a chair, climbing up and down the stairs, among others (Neumann, 2010), in older adults (Puthoff and Nielsen, 2007). In this sense, isometric muscle force production has been commonly measured at previously known optimal angles (Baroni et al., 2013; Maganaris, 2001). However, there is no data about the hip torque–angle relationship among older adults and there is no evidence about the association between hip extensor–flexor muscles' isometric torque and performance during FC tests (Butler et al., 2009; Jones and Rikli, 2002; Rikli, 2000). Thus, this torque–angle relationship in the elderly needs to be further explored.

Thereby, the aims of this study were: i) to evaluate the torque–angle relationship of hip extensor–flexor muscles in older women, and ii) to verify the association between hip

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extensor–flexor muscles' isometric peak torque in different angles and FC tests. The main hypothesis of this study was that at greater hip flexion joint angles, the extensor muscles would produce greater isometric peak torque, while at smaller hip flexion joint angles, the flexor muscles would produce greater isometric peak torque (0° = full extension). The secondary hypothesis was that there is a positive association between the hip extensor–flexor muscles' isometric peak torque at angles of greater force production and FC tests.

2. Methods

2.1. Participants

In order to determine the sample size, G*Power 3.1 (Düsseldorf, Germany) was used. A large effect size of 0.40, α 0.05, and a power (1-β error probability) for four groups (four different angles) were used to calculate the sample size, which revealed 20 participants (Cohen, 1992). In order to obtain the sample size to analyze the Pearson correlation between peak torques of each measured angle and FC, a large effect size of 0.5 and a power of 0.8 was used, which revealed 29 participants (Cohen, 1992). However, due to the difficulty of finding participants willing to volunteer for this study, 25 healthy women volunteered to participate in the present study, three of them were excluded and five withdrew. Hence, 17 participants finished the study (65.06 ± 5.17 years, 1.58 ± 0.07 m, 71.34 ± 13.60 kg). Nine of them practiced water aerobics twice a week for 50 min sessions, four practiced gymnastics for seniors twice a week for 50 min sessions and two performed strength training twice a week for 60 min sessions. These physical activities were part of a project at the Federal University of Santa Catarina where this study was conducted. Only two participants were sedentary; however, they were physically independent. It is worth mentioning that women of the region are encouraged to be physically active, ensuring that participants of this study might represent the average of this population.

This study was approved by the local Human Research Ethics Committee (number 44972915.9.0000.0110), and the protocol was written in accordance with the standards set by the Declaration of Helsinki. Participants were recruited in a non-probabilistic and intentional way. Once the consent form was signed, participants answered a questionnaire concerning age, address, health insurance, personal and family coronary medical history, neurological illnesses, skeletal muscle diseases (osteoarthritis, arthrosis, rheumatoid arthritis, and disc hernia), history of falls, fractures, physical activity practice and its frequency. The scale of depression (Yesavage and Sheikh, 1986) and mini-mental cognition test (Almeida, 1998; Folstein et al., 1983), which indicates the presence of dementia due to memory decline, were assessed. In order to be included in the study, the participants had to be physically healthy, pass all tests (scale of depression and mini-mental cognition test), be 60 years old or older, participate in the familiarization of the isokinetic tests, be able to return to the laboratory after 48 h of the familiarization and take part in all FC tests. Participants who achieved less than 19 points in the Mini Mental Examination, scored more than five points in the depression scale, which indicated a possible depression, were diagnosed with Alzheimer's, Parkinson's, Multiple Sclerosis, or skeletal muscle illnesses (previously cited) and with a history of hip fracture were excluded.

2.2. Study design

Participants visited the laboratory on three occasions. In the first visit, body mass, height, and FC tests (timed up and go, timed up and down stairs, and 30-s chair stand) were performed. Body mass and height were measured using an electronic scale (Pharo 200, Soehnle, Nassau-Germany) and a wall stadiometer (Sani, São Paulo, Brazil), with 100 g and 1 mm resolution, respectively. On the second visit, participants underwent a familiarization test with the isokinetic dynamometer (Biodex System 4 Pro, Biodex Medical Systems, Shirley, New York, USA) at submaximal effort. On the third visit, approximately 48 h after the second one, torque–angle tests were performed with maximal effort on the preferred lower limb defined by the Waterloo Footedness Questionnaire revised by Elias et al. (1998).

2.2.1. Measures

2.2.1.1. Torque–angle assessment. Participants lay down on the dynamometer chair in dorsal decubitus position following the recommendations of the manufacturer, which was the best way to stabilize the body during the assessment. The greater trochanter was aligned with the dynamometer axis. The trunk was attached by two crossed belts and another one on the pelvis. The lower limb tested was fixed in the dynamometer lever arm with straps around the thigh. The reference angle of the dynamometer was at 90° of hip flexion (hip extension = 0°). To set the baseline value as zero, the passive baseline torque value was considered with the limb weight at 45° of hip flexion and then subtracted from the signal. The knee of the tested limb remained flexed to avoid compensation during the test. The contralateral lower limb remained extended and was stabilized with a belt around the tibia. Before both the familiarization and torque–angle tests, a global warm-up was performed in a cycle ergometer at 50 W, for 5 min, followed by dynamic hip extensor–flexor concentric contractions at $120^\circ \cdot s^{-1}$ to warm up at the isokinetic dynamometer.

To estimate the hip extensor–flexor muscles' optimal angle of force production, participants performed 3 sets of 5-s hip extension–flexion maximal isometric voluntary contractions, at four different and randomly distributed hip angles (15°, 60°, 90°, and 100°) with 2 min' rest between contractions. When the coefficient of variation was higher than 5% among contractions, a fourth isometric contraction was performed (Walker et al., 2014). The highest peak torque produced at each hip angle was selected for analysis. The absolute peak torque and normalized peak torques by the participant's body mass ($N \cdot m \cdot kg^{-1}$) were analyzed.

2.2.1.2. Functional capacity assessments

2.2.1.2.1. Timed up and go. This test evaluates functional mobility and dynamic balance in elderly people. The participant had to stand up without the help of their hands, walk 3 m in a straight line as fast as they could without running, turn around a cone, return and sit again. In this study three attempts were performed, the first one as a familiarization, with 1 min intervals between them. The best score was registered (Bennell et al., 2011).

2.2.1.2.2. Timed up and down stairs. This test measures the lower limbs' functional mobility, motor control (Zaino et al., 2004) strength, power, and coordination (Bennell et al., 2011). The test was separated into two moments (go up stairs and go down stairs). Participants had to go up eight steps, of 15.5 cm each. After 1 min rest, participants went down the same number of steps, during going up and down the stairs, they were allowed to use the handrail. The stopwatch was stopped when the feet were on the last step. The test was performed twice and the best score was registered (Butler et al., 2009).

2.2.1.2.3. 30-s chair stand. This test evaluates the ability to sit down and stand up not only from chairs but also from sofas or beds. Participants started sitting on a chair of 43 cm height, their feet in contact with the floor and both arms crossed on the chest. They stood up and sat down as many times as possible during 30 s.

Participants were allowed to try a few repetitions before the test to check possible mistakes during execution (Bennell et al., 2011; Butler et al., 2009).

2.2.1.2.4. Statistical analysis. The data were presented as mean and standard deviation. Data normality was checked through the Shapiro–Wilk test. All variables presented parametric distributions. One-way ANOVA was used to analyze the hip flexor and extensor muscles' peak torque and Levene's test was used to verify the variance homogeneity. The Bonferroni post hoc test was applied to verify if there were significant differences between the flexor and extensor muscles' peak torque among angles. The correlation between FC tests and peak torque was calculated through a linear regression using the Pearson correlation coefficient (r). All statistics were analyzed with SPSS 18.0 (Statistics for Windows IBM Corp., Armonk, USA) software. A significance level of 0.05 was assumed for all the tests.

3. Results

The hip extensor–flexor muscles' torque–angle relationship is shown in Table 1. Regarding the absolute peak torque, the highest peak torque for the hip flexor muscles was observed at 15°. There was a significant difference of peak torque between 15° and 90° ($p = 0.001$), 15° and 100° ($p = 0.001$), 60° and 90° ($p = 0.047$), and between 60° and 100° ($p = 0.001$). No difference was observed between 15° and 60° ($p = 1.000$), or 90° and 100° ($p = 0.490$). The hip extensor muscles presented the highest peak torque at 100°. There was a significant difference of peak torque between 15° and 90° ($p = 0.008$), 15° and 100° ($p = 0.001$), and between 60° and 100° ($p = 0.023$). No difference was observed between 15° and 60° ($p = 1.000$), 60° and 90° ($p = 0.222$), and between 90° and 100° ($p = 1.000$).

When normalized by body mass, the peak torque showed similar results. The hip flexor muscles produced greater peak torque at 15° compared to the other joint angles. There was also a significant difference of peak torque between 15° and 90° ($p = 0.001$), 15° and 100° ($p = 0.001$), 60° and 90° ($p = 0.047$), and between 60° and 100° ($p = 0.001$). No difference was observed between 15° and 60° ($p = 0.490$), or 90° and 100° ($p = 1.000$). The same was observed for the hip extensor muscles' peak torque when normalized by body mass compared to the absolute values. The highest peak torque was obtained at 100°. There was a significant difference of peak torque between 15° and 90° ($p = 0.033$), 15° and 100° ($p = 0.001$), and between 60° and 100° ($p = 0.008$). No difference was observed between 15° and 60° ($p = 1.000$), 60° and 90° ($p = 0.222$), or 90° and 100° ($p = 1.000$).

Regarding the correlation analyses between the FC tests and the absolute hip extensor–flexor muscles' peak torque for each angle, a large significant correlation only between the hip extensor muscles' peak torque at 90° and the 30-s chair stand test was observed ($r = 0.617$, $p = 0.008$). Nevertheless, when the peak torques were normalized by body mass, the hip extensor–flexor muscles' peak torque had significant correlation for all angles measured with the 30-s chair stand test (see Table 2).

4. Discussion

The aims of this study were to evaluate the torque–angle relationship of hip extensor–flexor muscles, and to verify the association between the hip extensor–flexor muscles' peak torque at different hip joint angles and FC tests in older women. Results on the torque–angle relationship confirmed the first hypothesis of this study. The highest isometric absolute and relative hip extensor muscles' peak torque was observed at the greatest joint angle (100°); whilst for the absolute and relative hip flexor muscles it was observed at the smallest joint angle (15°). Regarding the secondary hypothesis, it was partially confirmed since an association between the hip extensor muscles' absolute peak torque at 90° and the 30-s chair stand test was observed. However, when peak torques were normalized by body mass there were associations between the hip extensor–flexor muscles' peak torques at all measured angles and the 30-s chair stand.

These findings are related to the torque–angle relationship, where muscles will produce a given amount of force according to the muscle length, which depends on the joint angle (Marginson and Eston, 2001). Thus, there is an optimal joint angle and

Table 1
Mean and standard deviations of absolute peak torque (N·m) and peak torque normalized by body mass ($N \cdot m \cdot kg^{-1}$) for hip flexor and extensor muscles in the four angles evaluated.

Hip Angles	15°	60°	90°	100°	*f*	p
Flexor Muscles						
PT(N·m)	79 ± 18	73 ± 13	59 ± 15*#	50 ± 14*#	13.97	0.001
PT(N·m·kg1)	1.14 ± 0.26	1.04 ± 0.20	0.83 ± 0.15*#	0.71 ± 0.19*#	14.65	0.001
Extensor Muscles						
PT(N·m)	73 ± 27	89 ± 27	117 ± 36*	127 ± 55*#	7.13	0.001
PT(N·m·kg1)	1.08 ± 0.51	1.32 ± 0.57	1.74 ± 0.74*	1.90 ± 0.98*#	4.53	0.006

$p < 0.05$; * significant difference from 15°, # significant difference from 60°, *f* (experimental effect ratio), p (intervention significance effect) of ANOVA's Greenhouse-Geisser.

Table 2
Correlation between functional capacity tests and hip extensor–flexor muscles' peak torques normalized by body mass ($N \cdot m \cdot kg^{-1}$) at the different measured angles.

Functional Capacity Tests	Mean ± SD		Flexion				Extension			
			15°	60°	90°	100°	15°	60°	90°	100°
Timed up and go (s)	9.42 ± 3.35	*r*	−0.124	−0.253	−0.423	−0.285	−0.244	−0.246	−0.312	−0.256
		p-value	−0.256	0.327	0.091	0.267	0.345	0.341	0.222	0.322
Timed up stairs (s)	3.93 ± 0.76	*r*	−0.186	−0.194	−0.174	0.038	−0.239	−0.324	−0.359	−0.376
		p-value	0.475	0.456	0.504	0.885	0.356	0.205	0.156	0.137
Timed down stairs (s)	3.71 ± 1.01	*r*	0.016	0.003	0.172	0.229	0.017	−0.088	−0.200	−0.239
		p-value	0.950	0.991	0.508	0.379	0.949	0.738	0.442	0.112
30-s Chair Stand (rep)	15 ± 2.64	r	0.601	0.572	0.651	0.631	0.537	0.566	0.720	0.601
		p-value	0.001*	0.016*	0.005*	0.007*	0.026*	0.018*	0.001*	0.011*

s = seconds; rep = repetitions; r = Pearson Correlation Coefficient; *statistical significance < 0.05.

muscle length at which the muscle can exert the maximal isometric force (Baroni et al., 2013; Herzog, 2008). The aging process can cause shortening of the hip muscles due to the necessity to lower the center of gravity to maintain balance during gait (Prince et al., 1997). This might influence the hip torque–angle relationship. Hip muscle shortening could be related to the decrement of knee and hip isometric muscles' force production (Dean et al., 2004).

Furthermore, the muscle adaptability property of training at different lengths was demonstrated (Kitai and Sale, 1989). Kitai and Sale (1989) assessed the effects of isometric strength training in young women at only one joint angle (90°) for plantar extensor–flexor muscles. After 6 weeks of training, 3 times per week, the isometric force production increased significantly at the trained angle and at the two adjacent angles. Therefore, muscle adaptability to training at specific joint angles could reduce or increase the range of motion (Herzog, 2008; Kitai and Sale, 1989). Despite the fact that most participants were physically active, none of them trained at a specific joint angle that could have affected the hip extensor–flexor torque–angle relationship in comparison with the sedentary ones.

Murray et al. (1980) assessed the torque–angle relationship in men's knee extensor–flexor muscles during isometric contraction in three different age groups (20–35, 50–65, and 70–86 years). The highest isometric peak torque values occurred between 30° and 40° for flexor muscles, and at 60° for extensor muscles in all age groups. These results might indicate that, regardless of the muscle group, there is an optimum angle of force production. Moreover, for older participants a decrease in the peak torque at all angles for both muscle groups assessed was observed, implying the necessity to strengthen skeletal muscles in this population. A similar study investigating the extensor–flexor hip torque–angle relationship, however, at a short range of motion of hip flexion (0°, 30°, and 45°) in three different age groups of older adults (60–69, 70–79 and $\geq$ 80 years, females and males) also observed that the peak torque decreased with increasing age (Samuel and Rowe, 2009). Our results when compared with all age groups, whether or not separated by gender, were similar to Samuel and Rowe (2009). For hip extensor muscles the highest peak torque was obtained at greater joint angles, whilst for hip flexor muscles the highest peak torque was observed at smaller joint angles, suggesting that our results could be extrapolated to other age groups.

Another interesting finding of the present study was the high correlation between the hip extensor muscles' absolute peak torque at 90° and the 30-s chair stand test. Moreover, when the hip extensor–flexor muscles' peak torques were normalized by body mass, there was significant correlation for all measured angles with the 30-s chair stand test. This could be due to well-documented force production and body mass. Furthermore, rising from a chair could be related to body size (Jaric, 2015). On the other hand, this result may be associated with the fact that during the movement of rising from a chair there is a great contribution of hip extensor muscles and knee extensor muscles. Flexor muscles, mainly iliopsoas, play an important role in stabilizing the trunk when returning to a sitting position (Butler et al., 2009). Despite the fact that the 30-s chair stand test is a dynamic movement involving concentric and eccentric contractions, Roebroeck et al. (1994) suggest that during muscular dynamic actions, isometric contractions could also occur. Even though rising from a chair is a common movement, its functional anatomy is much more complicated (Bieryla et al., 2009; Butler et al., 2009).

Ranisavljev et al. (2014) showed moderate and significant correlation between isometric hip flexor muscles' peak torque and the run to walk transition speed test ($r = 0.340$; $p < 0.005$), which indicates the importance of this muscle group during daily tasks. Differently from the present study, Ranisavljev et al. (2014) measured both isometric hip extensor and flexor muscles' peak torque in the standing position at 20° of hip flexion. Greater joint angles for extensor muscles could have been assessed in the standing position, which could have produced more force and therefore have found a correlation between extensor muscles' isometric peak torque and the tests assessed by these authors.

It is important to emphasize that the hip muscles have relevant functions since they are in the central region of the body, acting as a base for the lower limbs, pelvis, and trunk (Neumann, 2010). Dean et al. (2004) observed that this joint showed a decrement in the maximum isometric hip muscle force and has an important role in moving the entire leg and preventing falls. Unlike eccentric force production, the isometric and concentric force production capacity decreases equally and significantly in older people (Power et al., 2012). Thereby, the increase and/or maintenance of hip muscle force could provide greater balance, independence to perform ADLs, and reduced fall risk.

Despite the high participation of the hip muscles extension–flexion movements during the timed up and go (Dean et al., 2004) and timed up and down stairs tests (Protopapadaki et al., 2007), there were no significant correlations between the hip extensor–flexor muscles' peak torques assessments in all the measured hip angles. These findings may be due to the predominantly dynamic characteristics of muscle contraction during the performance of these tests compared to the isometric measurements at the dynamometer. According to what we know so far, there are no other studies associating isometric force production with dynamic FC tests.

Despite the relevance of the present findings, a limitation of this study is related to the configuration of the participant in the dynamometer. Due to the high abdominal circumference of some participants, it was not possible to evaluate force production at angles above 100° of hip flexion. Additionally, it was not possible to assess hip flexor force production at smaller angles than 15° flexion due to the lying down position (dorsal decubitus) being limited by the dynamometer chair. Nonetheless, this position was used due to the recommendations of the dynamometer manufacturer for better stabilization of the upper body. Other limitations should be mentioned, such as the non-probabilistic recruitment technique, the low number of participants, all of whom were female and the majority of whom participated in training programs.

Although this study has some limitations, we emphasize that this is the first study to demonstrate the hip torque–angle relationship in a wide range of motion (15° to 100°) when compared to Samuel and Rowe (2009), which tested the hip extensor–flexor muscle torque–angle relationship from 0 to 45° of hip flexion. Future studies at intermediate angles, with a different range of ages and sex, as well as in the standing position, might be of interest to assess. The results of this study also suggest that when training older adults, it is important to take into consideration hip joint angles to avoid undesired and negative functional muscular adaptations that could affect ADLs. It is also important to highlight that hip muscles' assessments are infrequent (Dvir, 2002). Additionally, investigating the hip joint is essential because of its role in balance during gait, running, and other movements related to older adults' ADLs (Morcelli et al., 2016).

5. Conclusions

In conclusion, this study is the first to demonstrate the hip torque–angle relationship in older women in a wide range of motion. It was found that older women produce higher muscle force at the smallest angle for hip flexors (15°) and at the greatest angle for hip extensors (100°), even when the peak torque is normalized by body mass. Moreover, we also observed a large significant positive association between hip extensor muscles' absolute peak torque at 90° and the 30-s chair stand test. When normalized by body mass, there was a significant correlation between hip extensor–flexor muscles' peak torques at all measured angles and the 30-s chair stand test.

Conflicts of interests' statement

On behalf of all authors, the corresponding author declares there are no conflicts of interest and/or financial interests.

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