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Comparison of Isokinetic Hip Abduction and Adduction Peak Torques and Ratio Between Sexes

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Abstract

Objective—To evaluate hip abductor and adductor peak torque outputs and compare their ratios between sexes.

Design—A cross-sectional laboratory-controlled study.

Setting—Participants visited a laboratory and performed an isokinetic hip abductor and adductor test. All participants performed 2 sets of 5 repetitions of concentric hip abduction and adduction in a standing position at 60 degrees per second. Gravity was determined as a function of joint angle relative to the horizontal plane and was corrected by normalizing the weight of the limb on an individual basis.

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Participants—A total of 36 collegiate athletes.

Independent Variable—Sex (20 females and 16 males).

Main Outcome Measures—Bilateral peak hip abductor and adductor torques were measured. The 3 highest peak torque values were averaged for each subject.

Results—Independent *t* tests were used to compare sex differences in hip abductor and adductor peak torques and the abductor:adductor peak torque ratios. Males demonstrated significantly greater hip abductor peak torque compared with females (males 1.29 ± 0.24 Nm/kg, females 1.13 ± 0.20 Nm/kg; $P = 0.03$). Neither hip adductor peak torque nor their ratios differed between sexes.

Conclusions—Sex differences in hip abductor strength were observed. The role of weaker hip abductors in females deserves further attention and may be a factor for higher risk of knee pathologies.

Keywords

gravity; correction; strength training; body position

INTRODUCTION

It has been documented that approximately 100 000 to 250 000 individuals suffer an anterior cruciate ligament (ACL) injury annually in the United States alone¹ and females have 2-fold to 4-fold higher risk to suffer ACL injury compared with the male counterparts in sports of soccer and basketball.² In addition to females' higher risk for ACL injuries, they are more likely to develop patellofemoral pain syndrome (PFPS).^{3,4} In fact, one retrospective case-control study that analyzed running injuries reported that female runners have 1.7 times more PFPS incidents compared with male runners.⁴ A common biomechanical risk factor for both ACL and PFPS was knee abduction motion and torque.^{5,6} Via examination of a total of 205 young female athletes, a prospective cohort study concluded that knee abduction moment is a strong predictor for future ACL injury with high sensitivity (78%) and specificity (73%).⁵ Similarly, another prospective study that investigated 240 young female athletes found that knee abduction moment is an indicator for future knee PFPS development.⁶

Recent studies have discussed a sex-specific influence of the lumbo-pelvic-hip complex,⁷ which includes trunk, pelvis, and thigh segments, on the knee abduction and lower extremity pathologies. Reviewing previously published studies, Mendeigchia et al⁸ summarized that females tend to have less trunk and hip flexion during dynamic movements compared with males, which may lead to a decreased energy absorption and consequently increased knee and ankle loads. Another study that compared video images of professional female and male basketball players revealed that female athletes who suffered an ACL injury landed with greater lateral trunk flexion and knee abduction angles compared with male basketball players.⁹ Similarly, a 3-year prospective study examining 277 college female and male athletes reported that trunk neuromuscular control deficits, especially lateral trunk flexion, were a predictive variable for future knee ligamentous injuries, including ACL injuries for females, but not for males.¹⁰ Finally, a cross-sectional study assessing knee kinematics in a

drop-landing task found that fatigued hip abductor musculature is associated with elevated knee abduction in females, but not in males.¹¹

A few studies investigated the role of hip abductor strength in knee pathologies and found weak hip abductor strength in a PFPS population compared with non-PFPS population.^{12,13} However, little is known about the contribution of the hip adductors, especially in relation to knee abduction (Figure 1). The knee abduction position or “knee valgus” refers to an angle that can be influenced by voluntary motion of the hip. As the position of the pelvis changes relative to the distal segments, a lack of adduction muscular control can result in the knee abduction or valgus positions that increase the risk of knee injuries, including ACL and PFPS in female population. Therefore, hip adductor strength may potentially play a critical role in knee abduction kinematics in dynamic movements. More precisely, the strength ratio between hip abductors and adductors may be an important factor for the determination of injury predisposition because hip abductor strength may be responsible for counterbalancing against the hip adduction strength in dynamic movements. In addition, hip adductor strength may be different between sexes, which may explain the higher rates of knee pathologies in female population compared with the male counterparts because if hip adductor strength differences exist between sexes, it may influence frontal plane knee biomechanics. Specifically, higher hip adductor strength may potentially contribute to excessive knee valgus.

Of interest methodologically, there are various methods to control for gravity correction when assessing hip strength. Specifically, documentation of the methodology for gravity correction has often not been reported. Thus, the primary purpose of the current study was to investigate isokinetic concentric hip abductor and adductor peak torques and abductor:adductor peak torque ratios between sexes. It was hypothesized that sex differences in isokinetic hip abductor and adductor peak torques and abductor:adductor peak torque ratios would be observed. More precisely, females demonstrate higher hip adductor peak torque in relation to hip abductor compared with that of males. The secondary purpose was to demonstrate the importance of gravity correction when assessing hip abduction and hip adduction and to compare gravity correction methods in the literature.

METHODS

Participants

With institutional review board approval, 36 healthy college-aged athletes signed an informed consent and voluntarily participated in this study (16 males: age = 20.5 ± 1.6 years, height = 1.89 ± 0.09 m, mass = 86.2 ± 9.9 kg; 20 females: age = 19.4 ± 1.1 years, height = 1.79 ± 0.05 m, mass = 72.3 ± 8.2 kg). Included subjects were engaged with sports of volleyball, basketball, baseball, and tennis. The exclusion criteria were as follows: (1) any previous knee surgery within 6 months from test date, (2) any previous hip surgery that limited full hip abduction and adduction range of motion, (3) any acute, subacute, and chronic hip injury and condition that caused pain and limited full hip abduction and adduction range of motion, and (4) current pregnancy in female subjects. Any subject with hip and pelvic dysfunction that would potentially influence the outcome of the current study was treated as a confounding variable and excluded from this study.

Instrumentation

Isokinetic concentric hip adductor and abductor strengths were assessed using the Biodex System 3 Isokinetic dynamometer (Biodex Medical System, Shirley, New York). Gravity correction was performed before testing each subject. Details of the gravity correction were described at the end of Procedure.

Testing Procedures

Subjects were tested while standing, and the test leg was placed in approximately 5 degrees of hip flexion. The approximately 5 degrees of hip flexion was selected because the gluteus medius functions primarily as a hip abductor when the hip was flexed below 30 degrees. However, once the hip flexion passes greater than 30 degrees flexion, gluteus medius starts acting as a hip internal rotator.¹⁴ Additionally, when the hip was extended more than 15 degrees, the line of pull is changed and it becomes an external rotator.¹⁴ The subject stood facing the dynamometer with the hip joint axis of rotation aligned with the dynamometer axis of rotation at frontal plane. The hip joint axis of rotation was defined as the intersection of an imaginary line directed inferiorly from the anterior superior iliac spine down the midline of the thigh and a second imaginary line medially directed from the greater trochanter of the femur toward the midline of the body. An attachment arm was placed over the middle one-third of the lateral thigh, and a resistance pad was applied at the same level of the medial thigh. The hip was securely restrained by a supporting strap to stabilize hip and torso movements during testing. Leg testing order was counterbalanced throughout the study.

Procedure

The investigator sets the subject's range of motion by assigning 0 degree of adduction as the position when the hip was in a neutral alignment. The subject was instructed to abduct the hip to approximately 45 degrees of abduction (Figure 2). At that time, the subject was asked to be relaxed, and the subject's limb was weighed to calculate the gravitational factor (Figure 2). The tested range of motion was approximately 45 degrees of hip abduction to 0 degree of hip adduction motion. The subject was tested at 60 degrees per second for 2 sets of 5 repetitions per leg. This particular velocity was used because it has been reported that slower velocities can reproduce greater concentric forces in isokinetic testing.¹⁵

Each subject was given 5 minutes to warm-up and stretch. The subject was given several pretrial submaximal repetitions before performing the actual trial. For each trial, subjects were asked to "push in" as hard and fast as possible to the end of the range of motion and then to "pullout" as hard and fast as possible until they returned back to the neutral hip (starting) position. Subjects initiated testing after a verbal start command from the investigator, and verbal encouragement was given to the subjects throughout the testing session to employ maximal efforts. After one limb was tested, the subject received a few minutes of rest to prevent muscular fatigue of the contralateral hip, as pelvic stabilization during this activity results in bilateral co-contraction of the hip musculature. The same process was repeated with the opposite limb.

The dependent variables were hip abductor and adductor peak torques and hip abductor:adductor peak torque ratio. The independent variable was sex. A difference was not observed between right and left limbs so that the bilateral peak torque values were combined to produce a single measure. Three highest peak torque values were obtained from 5 peak torque repetitions and were extracted for statistical analyses. The hip abductor:adductor peak torque ratio was defined as the hip adductor peak torque divided by hip abductor peak torque. The 3 highest peak torque units were converted from Foot-pound (ft-lb) to Newton meters (Nm), and the values were normalized by mass (kilograms). Although gravity correction was executed before each trial by the Biodex System 3, potential contribution of the upper body gravity, because the testing position was standing, was a concern. Thus, gravity correction was once removed, and the data without gravity compensation were obtained (Figure 3). Segmental percentages of mass and length of upper leg, lower leg, and foot were referenced from previous studies^{16,17} and applied to each subject's upper leg, lower leg, and foot based on their mass and height. Then, gravity compensation was recalculated solely for the lower extremities (Figure 3). A series of calculations was applied for the above gravity correction procedure (Table 1), and these values were used for statistical analyses.

Statistical Analyses

The concentric abductor and adductor peak torques and the abductor:adductor peak torque ratios were analyzed by a series of independent *t* tests to compare differences between male and female subjects. Alpha level (α) was set at <0.05 before the analysis.

RESULTS

Descriptive values (mean and SD) for the concentric abductor and adductor peak torques and the abductor:adductor peak torque ratios are displayed in Table 1. There was a significant difference in hip abductor peak torques between male (1.29 ± 0.24 Nm/kg) and female (1.13 ± 0.20 Nm/kg) athletes. Males produced 0.16 Nm/kg higher concentric abductor peak torques than that of females ($P = 0.03$, Table 2).

In contrast, concentric hip adductor peak torque was not different between sexes ($P = 0.79$, Table 1). The concentric adductor peak torques were 0.75 ± 0.32 and 0.72 ± 0.27 Nm/kg for male and female athletes. The concentric adductor peak torque difference between male and female athletes was only 0.03 Nm/kg (Table 2). There were no statistical differences in abductor:adductor peak torque ratios between sexes ($P = 0.32$, Table 2). The abductor:adductor peak torque ratios were 0.64 ± 0.21 for male and 0.57 ± 0.18 for female athletes.

DISCUSSION

The primary purpose of this study was to compare isokinetic concentric hip abductor and adductor peak torques and the abductor:adductor peak torque ratios between males and females. The tested hypothesis was that there would be a sex difference in isokinetic concentric hip abductor and adductor peak torques and the abductor:adductor peak torque ratios. A difference in isokinetic concentric hip abductor peak torque was observed between

male and female populations (Table 2). However, no difference in concentric hip adductor peak torque and abductor: adductor peak torque ratios was observed. Therefore, one of the 3 variables in our hypothesis was supported, but the other 2 variables within our hypothesis were not supported.

Specific hypothesis was that females show higher hip adductor peak torque relative to hip abductor compared with that of the male counterparts. The hip adductor peak torque did not demonstrate a difference between the sexes; however, because greater hip abductor peak torque was noted in the males compared with the females, the abductor: adductor peak torque ratio demonstrated slight disparity; yet, it was not statistically significant (Table 2). The higher hip adductor peak torque in relation to hip abductor in female population was hypothesized because the imbalanced hip musculature strength may exist in the female population, which may potentially link to higher ACL and PFPS rates in female population. However, this study did not find a difference in the hip abductor: adductor peak torque ratio between sexes.

There was no difference in hip adductor peak torque between male and female athletes. Instead, the normalized adductor peak torque values were actually fairly comparable between groups. The abductor: adductor peak torque ratios also did not differ between sexes. Comparing these results with the previously published studies, the role of the hip abductor peak torque seems to be critical for distal segments, especially knee joint pathologies and kinematics.^{12,13,18,20–24} For example, several cross-sectional studies identified that females with PFPS had lower hip abductor torque compared with females without PFPS.^{12,13,22} Similarly, a laboratory-controlled study that measured running kinematics between PFPS patients and uninjured controls found that PFPS patients had significantly lower isometric hip abductor peak torque and exhibited increased hip adduction angles during running, especially toward the end of the running.²³ Another laboratory-controlled study demonstrated that knee abduction angles were increased in a running task in subjects with weak isometric hip abductors compared with the subjects who had stronger hip abductors.²⁴ A study that examined the effects of knee kinematics in cutting, jumping, and running maneuvers after hip abductor fatigue protocol reported greater knee abduction angles as well.¹⁸ Furthermore, females with greater eccentric hip abductor torque showed less femur adduction, medial rotation, and greater knee adduction excursion compared with the male population.²¹ Because female's pelvis is wider compared with their male counterparts, decreased hip abductor peak torque may lead to greater kinematic alteration in female population. In short, the previously published studies reported consistent evidence that decreased hip abductor peak torque may influence knee kinematics, resulting in an increase in knee abduction, especially in the coronal/frontal plane.^{18,23,24} The application of an intervention to strengthen the hip abductors has been recently reported. A series of lumbo–pelvic–hip complex exercises were instituted to young female athletes for 8 weeks and resulted in an increase in eccentric hip abductor peak torque and a decrease in knee abduction angles performing a single-leg squat when posttesting was compared with pretesting values.²⁰ Therefore, the role of the hip abductors may be important for controlling the knee joint at coronal/frontal plane. Future studies to determine if differences exist between sexes for both strength and kinematics are warranted.

In our study, subjects generated higher isokinetic hip abductor torque (males 1.29 ± 0.24 Nm/kg, females 1.13 ± 0.20 Nm/kg; Table 2) than hip adductor torque (males 0.75 ± 0.32 Nm/kg, females 0.72 ± 0.27 Nm/kg; Table 2). In contrast, previous studies have reported higher isokinetic peak torque values in hip adductors rather than hip abductors.^{25–27} For example, Donatelli et al²⁵ reported greater adductor values (males 152.6 ± 54.1 , females 108.2 ± 24.5) than abductor values (males 63.8 ± 17.1 , females 42.6 ± 8.2 ; units were unrecorded, Tables 3 and 4). The reported abductor:adductor ratios for males and females were 1:2.09 and 1:2.46, which implied that the adductors are 2.09 and 2.46 stronger in males and females relative to abductors. Poulmedis²⁶ also reported higher isokinetic peak torque values for the hip adductors at 3 different speeds (160 ± 17 Nm at 30 degrees per second, 137 ± 24 Nm at 90 degrees per second, 109 ± 22 Nm at 180 degrees per second) compared with the hip abductors (119 ± 24 Nm at 30 degrees per second, 88 ± 19 Nm at 90 degrees per second, 66 ± 17 Nm at 180 degrees per second; Tables 2 and 3) isometrically. Similarly, isokinetic concentric peak torque values reported by Tippet²⁷ were higher in the hip adductors in 2 different speeds bilaterally (stance leg: 104 ± 39.0 ft-lb at 30 degrees per second and 96 ± 38.6 ft-lb at 180 degrees per second; kicking leg: 107 ± 32.8 ft-lb at 30 degrees per second and 97 ± 33.4 ft-lb at 180 degrees per second) compared with the hip abductors (stance leg: 80 ± 26.5 ft-lb at 30 degrees per second and 48 ± 17.5 ft-lb at 180 degrees per second; kicking leg: 87 ± 28.8 ft-lb at 30 degrees per second and 44 ± 18.0 ft-lb at 180 degrees per second; Tables 3 and 4).

One likely reason for this discrepancy in the literature may be the inclusion or exclusion of gravity correction. Our comparison with and without gravity correction found 28% and 32% of differences in hip abductor and adductor peak torque values (Figure 3), and gravity compensation was not documented in the several studies.^{25,27–29} In the studies performed by Donatelli et al²⁵ and Tippet,²⁷ the side-lying position was chosen for assessing hip abductor and adductor strengths. Because a gravity correction was not employed, the effect of gravity would artificially inflate the hip adduction values and artificially result in a depression of hip abduction values. In fact, our data display the impact of gravity correction (Figure 2). Hip adductor peak torque showed higher values when gravity effects were not compensated. Conversely, hip abductor peak torque values seemed to be deflated when gravity compensation was not incorporated.

The importance of correction for the influence of gravity has also been identified by several authors.^{19,30,31} Winter et al³¹ reported 26% to 43% and 55% to 510% of mechanical work errors associated with gravity in the isokinetic knee extension and flexion tests in 3 different speeds (20, 40, and 60 degrees per second). Using knee flexion as an example, the author explained that if subjects' efforts to engage with the knee flexion were low, gravity significantly assisted the knee flexion motion, which increased the mechanical errors. The author also pointed out that this might account for the greater mechanical work error margins in knee flexion compared with knee extension. Another study performed by Edouard et al³⁰ examined 33 healthy volunteers' dominant shoulder internal and external rotations concentrically and found 12% to 15% and 24% to 28% peak torque differences in shoulder internal and external rotations with and without gravity correction. Greater influences of gravity were observed on internal and external shoulder rotation ratio calculation, and 39% to 42% of the ratio differences were documented with and without

gravity correction. The author concluded that gravity correction has a significant impact on isokinetic peak torque measurements.

Limitations

Several limitations to this study should be stated. Although absence of gravity correction was suspected as a potential reason for inflated isokinetic peak torque values in the hip adductor muscle group, 2 studies^{22,26} that actually compensated for gravity in the isokinetic testing reported higher isokinetic peak torque values in hip adduction compared with hip abduction. One study that used a side-lying position for isokinetic peak torque measurement for eccentric hip abductor and adductor demonstrated higher isokinetic peak torque values in hip adductor (10 adults: 197.4 ± 12.1 Nm/kg at 30 degrees per second, 10 adults with PFPS: 171.0 ± 13.4 Nm/kg at 30 degrees per second) compared with hip abductor (10 adults: 123.4 ± 5.9 Nm/kg at 30 degrees per second; 10 adults with PFPS: 88.9 ± 10.3 Nm/kg at 30 degrees per second; Tables 3 and 4).²² Therefore, it is difficult to conclude that the gravity compensation is the only potential cause of higher peak torque values in the hip abductors.

A few studies employed a side-lying position to measure hip abduction peak torque.^{12,13,15,18,22,23} However, the current study chose a standing position to measure hip abductor and adductor peak torques simultaneously. Application of gravity correction for the standing testing position for hip abductors potentially involves upper body segments. As it was explained above, gravity correction gives a substantial influence on the torque values. Thus, although there is no gold standard for hip peak torque measurement, testing position and gravity correction method might have influenced the current results.

When the tested leg was transitioning from abduction to adduction directions, the torque values demonstrated counter directional values (Figure 3). It was suspected that when the attachment arm, which was securely placed over the middle one-third of the lateral thigh, hits preprogrammed hip abduction range of motion (approximately 45 degrees), the force transition was not smooth, which in turn generated counter directional values before actual transition to hip adduction direction. However, peak torque values of hip abductor and adductor were used for the data reduction; thus, it does not alter results of this study.

Both hip abductor and adductor peak torques were measured concentrically. From the suggested ACL and PFPS mechanisms, measuring eccentric hip abductor peak torque would have been ideal. Recently published studies^{15,20–22} measured eccentric hip abductor peak torque, which may be more applicable from functional standpoint. Also, because of the concentric contraction, slight hip internal rotation might have contributed to the peak torque values although hip and distal thigh were securely stabilized. Additionally, because we eliminated subjects with previous hip surgery and any acute, subacute, and chronic hip injury, this study results are only applicable for athletic population without low back dysfunction. Those limitations are warranted for future studies.

CONCLUSIONS

In summary, the current cross-sectional study demonstrated reduced isokinetic concentric hip abductor peak torque in college-aged females compared with college-aged males.

Another finding from the current project, which is contradictory to previous studies, is higher peak torque values in hip abduction compared with hip adduction values in both male and female subjects. Possible explanation for this finding is a status of gravity correction. Absence of gravity correction may result in inflated adductor and decreased abductor peak values and is important to consider when reviewing studies that did employ a gravity correction procedure. For future isokinetic research, implementation of gravity correction is warranted for accurate isokinetic hip abductor and adductor measurements.

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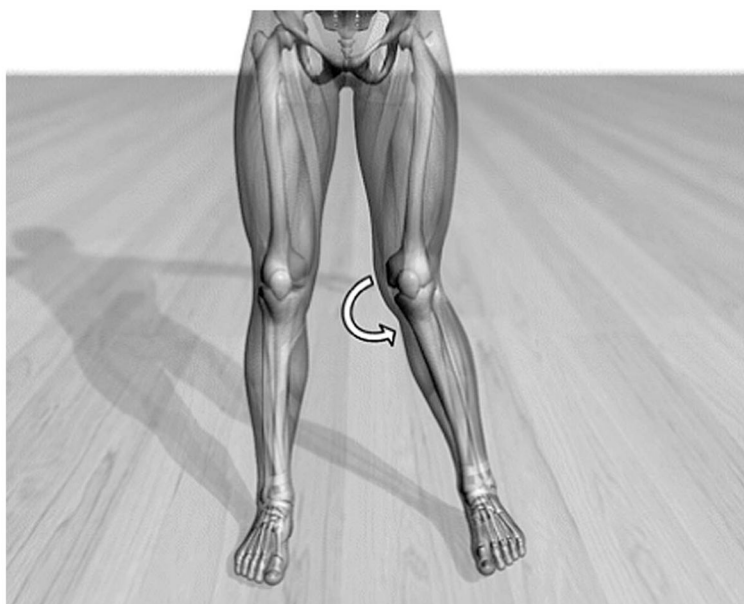


FIGURE 1.
Knee abduction in the frontal plane (left knee).



FIGURE 2.
Positioning for standing hip abduction and adduction testing.

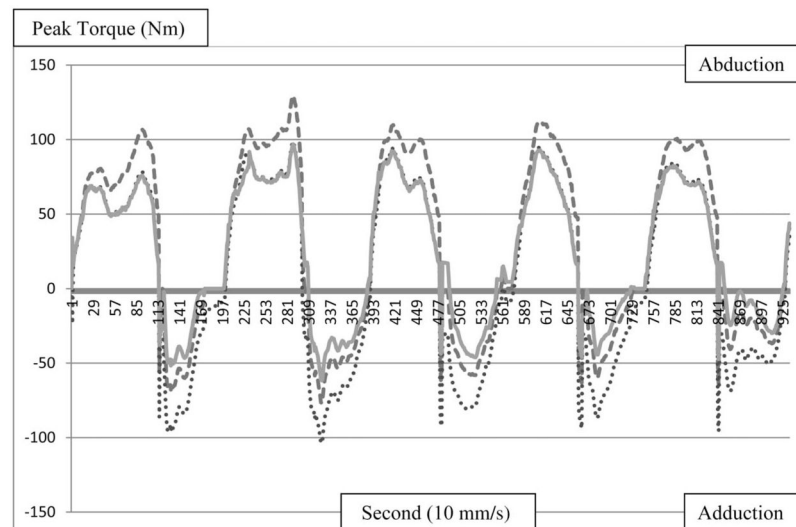


FIGURE 3.

Example of a torque of 5 repetitions of hip abduction and adduction motions at 60 degrees per second. The dotted line indicates an original torque with gravity correction from the Biodex. The dashed line displays a torque when gravity was removed from the Biodex. The solid line illustrates a torque with gravity correction based on recalculation of lower extremities.

TABLE 1

A Series of Equations Were Applied to Calculate the Gravity Correction

Equations	Equation Content	Purpose
Equation 1	Gravity compensated by the Biodex/sin [radian (starting position) – 90 degrees]	Gravity removal from the Biodex machine
Equation 2	–Cos [radian (moving angles)] × sin	Adjustment of gravity direction with hip abduction and adduction motions for equation 5
Equation 3	Subject's mass × relative mass (upper leg, shank, and foot)	Calculation for the application of equation 5
Equation 4	Subject's upper leg length × relative length (shank and foot)	Calculation for the application of equation 5
Equation 5	(Upper leg + shank + foot) × sin + (equation 2) × [gravity compensated by the Biodex/radian (starting position/90 degrees)]	Gravity adjustment with calculated body segments throughout performed range of motion

For equations 3 and 4, references^{18,19} were used for the relative mass and length calculations.

TABLE 2

Mean (\pm SD) Peak Torques of Hip Abductor and Adductor and Abductor:Adductor Peak Torque Ratios for 36 subjects (20 Females and 16 Males)

Isokinetic Strength	Male	Female	Significance (<i>P</i>)
Abductor Peak Torque (Nm/kg)	1.29 \pm 0.24	1.13 \pm 0.20	0.03*
Adductor Peak Torque (Nm/kg)	0.75 \pm 0.32	0.72 \pm 0.27	0.79
Abductor:Adductor Peak Torque Ratios	0.64 \pm 0.21	0.57 \pm 0.18	0.32

* Significant $P < 0.05$.

TABLE 3
Comparisons of Isokinetic Peak Torque of the Hip Abductor at Varying Velocities and Several Previous Studies

Study	Subjects	Units	Abduction			
			30 Degrees per Second	60 Degrees per Second	90 Degrees per Second	180 Degrees per Second
Poulmedis ²⁶	18 males	Nm	119 ± 24	—	88 ± 19	66 ± 17
Tippett ^{27, *}	16 males stance leg	Nm	109 ± 35.9	—	—	65 ± 23.7
	16 males kicking leg	Nm	118 ± 39.1	—	—	60 ± 24.4
Cahalan et al ^{28, *}	18 younger males	Nm	103 ± 26	—	79 ± 20	—
	21 younger females	Nm	66 ± 19	—	54 ± 20	—
	17 elderly males	Nm	75 ± 18	—	63 ± 19	—
	16 elderly females	Nm	48 ± 14	—	38 ± 13	—
Donatelli et al ^{25, *}	28 males	— [†]	—	63.8 ± 17.1	—	—
	56 females	— [†]	—	42.6 ± 8.2	—	—
Johnson et al ^{29, *}	38 young	Nm	—	96.4 ± 18.8	—	—
	38 elderly	Nm	—	53.6 ± 16.2	—	—
Baldon et al ²²	10 adults	Nm/kg	123.4 ± 5.9	—	—	—
	10 adults with PPPS	Nm/kg	88.9 ± 10.3	—	—	—

Values were expressed with mean ± SD.

* No gravity compensation stated.

[†] No units stated.

TABLE 4
Comparisons of Isokinetic Peak Torque in Hip Adductor at Varying Velocities and Several Previous Studies

Study	Subjects	Units	Adduction			
			30 Degrees per Second	60 Degrees per Second	90 Degrees per Second	180 Degrees per Second
Poulmedis ²⁶	18 males	Nm	160 ± 17	—	137 ± 24	109 ± 22
Tippett ^{27,*}	16 males stance leg	Nm	141 ± 52.9	—	—	130 ± 52.3
	16 males kicking leg	Nm	145 ± 44.5	—	—	132 ± 45.3
Cahalan et al ^{28,*}	18 younger males	Nm	121 ± 26	—	103 ± 32	—
	21 younger females	Nm	82 ± 26	—	62 ± 32	—
	17 elderly males	Nm	99 ± 18	—	83 ± 28	—
	16 elderly females	Nm	63 ± 17	—	44 ± 19	—
Donatelli et al ^{25,*}	28 males	— [†]	—	152.6 ± 54.1	—	—
	56 females	— [†]	—	108.2 ± 24.5	—	—
Johnson et al ^{29,*}	38 young	Nm	—	105.6 ± 26.8	—	—
	38 elderly	Nm	—	46.9 ± 22.6	—	—
Baldon et al ²²	10 adults	Nm/kg	197.4 ± 12.1	—	—	—
	10 adults with PPPS	Nm/kg	171.0 ± 13.4	—	—	—

Values were expressed with mean ± SD.

* No gravity compensation stated.

[†] No units stated.