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Assessment of maximum isometric, isotonic and isokinetic leg extensor strength in young adult females

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For many years strength has been recognized as a major factor contributing to success in athletic performance. For this reason, the development and assessment of muscular strength have been of vital interest to athletes, exercise physiologists, and individuals involved in rehabilitation programs. However, much of the available literature has concentrated on the study of male subjects (5, 6, 7, 9, 10, 25, 26, 33, 34). A comparatively small number of studies have examined muscular strength in females (1, 23, 36). Conclusions derived from studies utilizing male subjects are often applied to female subjects without reservation. The basis for this practice is the assumption that male and female musculature exhibit similar strength characteristics (e.g., contractile properties, force velocity curves). However, a review of the literature would suggest this may not be a valid assumption.

Wilmore (36) has reported that when strength values are corrected for size of the lean body mass, little, if any, difference exists between genders. In contrast, Asmussen (3) has reported that, even when height and weight of subjects are equated, males are stronger than females. Hoffman, Stauffer and Jackson (15) have indicated that while relative differences exist between males and females in upper body strength, there are not demonstrable differences in lower body strength. However, college women have been reported having 50% less arm and shoulder strength, and approximately 30% less leg strength than college men (30). Ikai et al. (16) found strength relative to the cross-sectional surface area of the muscle to be the same for males and females. However, Morris (22) found males stronger than females even when accounting for muscular size. Kroll et al. (19, 20) have reported differences in strength between genders and have suggested that differences in muscle fiber composition may account for the differences observed in muscular strength when comparing specific muscle groups.

The observed differences also may in part be related to the use of different assessment techniques. Isotonic (IT), isometric (IM), and isokinetic (IK) methods have each been utilized in research to assess strength. Several factors may influence the maximum force potential of the different types of contractions (i.e., the pattern of motor-unit recruitment). Rosentswieg and Hinson (29) have examined the electromyographical patterns (EMG) of three types of contraction and have shown IK contractions elicit the greatest EMG activity. While Rasch and Pierson (28) have shown that greater force can be developed in an IM contraction than an IT contraction, Thorstensson (33, 34) has shown maximum IM force is greater than IK derived strength values.

In view of the confusing data, it seems apparent that the similarities (or differences) in the muscular strength characteristics of males and females may be an unresolved issue. For this reason additional study of the strength characteristics of females appears warranted. Therefore, the purpose of this study was to investigate the interrelationships of isotonically, isometrically, and isokinetically derived measures of maximum force development in the quadricep femoris muscle group of females, and, to compare the strength characteristics of females with those of males as previously reported in the literature.

Methods

Subjects

Physical characteristics (age, height and weight) and strength measures were collected from 63 active, healthy volunteer female subjects. Subjects were informed of any risk associated with participation in the study and signed letters of informed consent prior to participation in the study. The subjects' medical records were reviewed to ensure that the type of maximum exertion required in this study was not contraindicated for any reason.

Testing sessions

Each of the three assessment methods were duplicated on separate days with the mean of the two greatest determinations serving as the score for subsequent statistical analysis (31). All testing was conducted on the quadriceps femoris muscle group of the left leg because of the ease of measurement and the availability of comparative data (32, 33, 34).

A testing session consisted of a warm-up period followed by one of the three treatments, an 18 minute rest period, a second treatment, an 18 minute rest period, and the final treatment (11, 21). The order of treatments were determined by a Latin square design with test sessions separated by a minimum of 24 hours of recovery.

Each subject reported to the appropriate testing area in gym shoes, shorts and exercise shirt. Subjects were allowed a ten minute flexibility warm-up session. After being positioned for the test, further warm-up was allowed appropriate to the test apparatus. This additional warm-up consisted of five leg extension/flexion movements against a sub-maximal resistance.

Isotonic testing procedures

Isotonic assessments were made on a Universal Gym Centurion Leg Extension Machine (model 9335, Kiddle Co.). The apparatus was equipped with an adjustable lifting arm to suit the subject's leg length. Weight increments were in 2.24 N (10 lbs). A weight locking device was attached so that smaller increments could be selected. The procedure used to determine the one repetition maximum (1 RM) was a modification of that suggested by Berger (5). Following the standard warm-up activities each subject was positioned for the test. The lever arm of the apparatus was adjusted to rest on the tibia just above the ankle. The subject was then verbally encouraged to extend her left leg in an attempt to overcome the resistance provided by the attached load. The load was then increased by 2.24 N after each successful effort until the load became difficult. A 1.12 N load increment was subsequently utilized until the subject was not successful in achieving at least 90 degrees of extension as suggested by Berger (5). Inter-trial rest was maintained at 3 minutes (5, 17). The maximum load successfully lifted served as the score for statistical analysis. Care was exercised to determine the 1 RM within three trials in an effort to enhance the validity of comparisons between assessments, however, several subjects (n=6) did require a fourth trial.

Isometric testing procedures

A Cybex II (Lumex, Inc.) was used to conduct all IM and IK strength assessments. For the purposes of this study, the apparatus consisted of a supportive chair with thigh-securing strapping, an adjustable dynamometer with an adjustable lever arm with strapping for securing to the tibia. Subjects were positioned in the right chair of the testing apparatus. The subject's left leg was secured at the thigh by a Velcro strap. The dynamometer was adjusted to be in alignment with the subject's left knee joint axis of rotation. The lever arm of the dynamometer was secured on the tibia just above the ankle joint by another Velcro strap. Following the prescribed warm-up, the subject's knee joint was placed in a position of 115 degrees extension, as determined by use of a gonimeter (9), and held in position by setting the speed selector control at zero degrees per second (°/sec). The subject was verbally encouraged to attempt extension of the leg as forcefully as possible against the lever arm for six seconds as described by Muller (24), while the torque generated was simultaneously recorded. Three trials to determine maximum torque were given with inter-trial rest of 3 minutes (5, 17). The highest torque value of the three trials served as the score used for statistical analysis.

Isokinetic testing procedures

For assessment of the maximum IK strength the testing apparatus was used in the same manner as during IM testing, with the exception that the speed setting was set at 30, 180, and 300°/sec. Subjects were then positioned in a manner similar to that described for assessment of maximum IM strength. Following the prescribed warm-up, the subject performed three maximal leg extensions in succession. The movement was made through the full range of motion utilizing the protocol described by others (21, 33). A three minute inter-test rest period was provided between the assessments made at the three different speeds. Peak torque generated at each speed served as the score for statistical analysis.

Statistical analysis

Statistical analysis involved bivariate regression analysis, as well as a repeated measures ANOVA for statistical comparison of the two strength measures expressed in terms of torque (i.e., IK and IM). Significance of the statistical analysis was interpreted at the 0.05 level of significance.

Result

The subjects were composed of a relatively homogeneous group of females. The mean (±S.D.) age, height and weight were 21.8 ± 3.0 years; 166.2 ± 7.0 cm; and 59.3 ± 8.9 kg, respectively and compare favorably to other samples of active healthy college-age females (18).

The strength data were expressed initially in absolute terms and subsequently relative to body weight (Table 1). The IT strength measure was expressed in Newtons (N) while the other strength measures were expressed as Newton-meters (N·m). The absolute value for IM force development differed significantly ($p < 0.05$) from the IK at 180°/sec (IK180) and the IK300 scores; however, no significant difference was observed between the IM and IK30 score. All IK strength values differed significantly ($p < 0.05$) from each other and decreased in magnitude with increasing speed of movement.

The relative IM and IK scores mirror the trend observed in the data expressed without regard for body weight. The greatest force development was observed at IK30 with IM slightly less ($p > 0.05$). As well as differing significantly from each other, the faster IK values (180 and 300°/sec) differed significantly from the IK30 and IM values. In addition, it might be noted that with increasing speed of movement torque values decreased.

Correlation coefficients were computed for all measures (Table 2). The correlation coefficients indicate that IM and relatively slow contraction speeds (i.e., IT to determine the 1 RM and IK30) have higher correlations with each other than with the faster contraction speeds (i.e., IK180 and IK300). This pattern was evident irrespective of the manner of expressing the strength score (absolute or relative to body weight) while the faster speeds of contraction showed significant relationships among themselves. The data of Table 2 would indicate that quantification of strength in absolute terms or relative to body weight reflect a tendency of scores employing similar methods of assessment and movement speeds to correlate more highly with each other than with scores derived from assessment methods utilizing extreme movement speeds (i.e., IM and IK300).

Regression analyses were performed to determine the feasibility of predicting various strength scores from others derived by a different method. These results appear in Table 3 for variable(s) accounting for the largest variance.

The IM strength scores and strength scores derived from slow movement speed assessment techniques (IT, IK30) accounted for the greatest variance between each other, while strength scores derived from fast movement speed assessment techniques (IK180, IK300) accounted for the greatest variance between each other. These observations were apparent for both the absolute and relative equations. All equations produced relatively high correlation coefficients while the standard errors of estimate ranged from 12.5 to 17.7 percent. Correlation coefficients between the dependent and independent variables ranged from +0.69 to +0.81, indicating all independent variables account for approximately 50 percent, or greater, of the variance in the dependent measures.

Discussion

The literature regarding strength presents conflicting data and thus it was the purpose of the present study to examine the strength characteristics of young adult females and to compare the relationships between various methods of strength assessment to those relationships previously observed in male subjects.

In the present study, sixty-three adult females were tested for maximal IM, IK and IT strength of the left leg extensors. Maximum IK torque (absolute and relative) decreased with increasing speed of movement and differed significantly from maximum IM torque except for IK30 which did not differ significantly from IM. In addition, it was apparent that IT force development had a significant relationship only with the IM and IK30 values.

Anderson et al. (1) demonstrated that females exhibit the same IK force velocity characteristics as males; with increased speed of movement eliciting a decreased force production. Force development was reduced by approximately 68% as the speed of movement progressed from IK30 to IK300 °/sec. A comparable decrease was observed in the present data (61%). However, Anderson et al. (1) expressed strength relative to the lean body weight rather than total body weight. In addition, males were observed to produce greater relative force at higher velocities. Thorstensson et al. (33) as well as Grimby et al. (12) have reported similar results in force production in studies involving males and females. Therefore, it appears that males and females do exhibit similar IK force velocity curves, but males generally produce greater force at all velocities.

Thorstensson et al. (33), Grimby et al. (12), and Osternig et al. (25) have each reported IM leg extension scores for males (15 through 90 degrees of the range of motion) which exceed maximal IK force development (speed of movement ranging from 30 to 300°/sec). Kroll (19) and Anderson et al. (1) have reported similar findings for females. However, results of the present study do not support these findings. Asmussen (3), Hettinger (14) and Wilmore (36) have each suggested there should be greater similarity between genders in the lower extremities than in other parts of the body due to the similarity of use of the involved musculature relative to maintaining posture and walking. However, the present data demonstrate different force development characteristics at least in these female subjects.

Unfortunately, the reason why the maximal IM torque did not exceed IK at 30°/sec cannot be determined from the present data. Possible differences in the muscle fiber composition, the patterns of muscle fiber recruitment, or inherent contractile properties of the involved musculature may each be considerations in accounting for the observed differences. Morris (22) indicated that even with equal cross-sectional surface area, and leverage, females could only develop approximately 78% of the force developed by males. Morrow and Hosier (23) found untrained males to have greater relative upper and lower body strength than trained females. In addition, Morris (22) reporting work completed by Wendler suggested that the total body strength of males is approximately 40% greater than that of females.

Kroll et al. (19,20) have investigated the maximal IM strength and muscle fiber composition of the leg extensors of males and females. Male subjects generally produced greater force and contained a greater percentage of slow twitch fibers than females. This suggests that a difference in fiber type composition may in part account for the difference in the force velocity relationships observed in the present study. Unfortunately, without assessment of the fiber type composition of the present subjects and a representative sample of male subjects this consideration cannot be addressed.

Any assumption that male and female musculature at the same anatomical site display the same strength characteristics is not supported by the literature. This study also suggests that such an assumption may be invalid. However, more definitive research may be required to determine the significance of such findings with respect to strength training. Generally, the relationships observed for IT strength with IM and IK strength assessments are in agreement with the literature. Rasch and Pierson (28) and Astrand and Rodahl (4) have reported correlations of +0.69 to +0.80 between maximal IM and IT strength measures and suggest that dynamic strength can be roughly predicted from simple measures of IM strength. Asmussen et al. (2) have shown that the correlation between force development as measured by IM and dynamic IT methods to be +0.80. Correlations in the present study ranged from +0.10 to +0.73, with the lower correlations involving dynamic movements (i.e., IK180, IK300). Clarke (8), Henry and Whitley (13), Rasch (27), and Whitley and Smith (35) found these relationships (IT to IM, IT to IK) to increase as the dynamic load increased, i.e., simulating an effort more static in nature. Their findings indicating the similarity of the relationships of IT to both IM and IK between genders is supported by the present study.

While data from the present study indicate very similar strength characteristics between genders in relationship to the development of maximum force, the findings of greater force development with IK30 as opposed to IM may suggest a unique characteristic which may be important to consider, particularly when assessing potential force development of females. Whether these findings have implications for the design of strength training programs for women remains to be seen. Further research is need to more specifically identify the force-velocity curves of females. From the present data, it appears that females may possibly be capable of greater force development with some degree of movement than a truly isometric effort.

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Table 1:

Strength scores $\left(\overline{X} \pm S.E.\right)$ as a function of method assessment[a]

Assessment Method	Absolute	Relative
IK300	48.7 ± 1.6 N·m	0.84 ± 0.03 N·m/kg
IK180	71.5 ± 1.8 N·m	1.23 ± 0.04 N·m/kg
IK30	125.8 ± 3.5 N·m	2.14 ± 0.06 N·m/kg
IM	120.8 ± 3.8 N·m	2.06 ± 0.07 N·m/kg
IT	214.5 ± 6.9 N	3.65 ± 0.11 N

[a] n = 63: Statistically significant differences for absolute ($F_{3,186} = 288.3$) and relative strength measures ($F_{3,186} = 303.4$) with subsequent post hoc analysis (Scheffe) revealing IM and IK30 > IK180 > IK300.

Table 2:

Correlation matrices of selected strength assessment scores[a]

	IT	IM	IK30	IK180	IK300
With scores expressed in absolute terms (N or N·m)					
IT	–	+0.62[☼]	+0.73[☼]	+0.23	+0.11
IM	–	–	+0.81[☼]	+0.17	+0.23
IK30	–	–	–	+0.32[☼]	+0.31[☼]
IK180	–	–	–	–	+0.75[☼]
IK300	–	–	–	–	–
With scores expressed relative to body weight (N/kg or N·m/kg)					
IT	–	+0.60[☼]	+0.69[☼]	+0.23	+0.10
IM	–	–	+0.80[☼]	+0.24	+0.27[☼]
IK30	–	–	–	+0.38[☼]	+0.36[☼]
IK180	–	–	–	–	+0.81[☼]
IK300	–	–	–	–	–

[a] n = 63:

[☼] significant at *a* = 0.05.

Table 3:

Linear regression equations for prediction of various strength scores[a]

Criterion Variables	Equation	SEE	r	% Error
With scores expressed in absolute terms (N or N·m)				
IK300	= 0.651 × IK180 + 2.11	8.27	+0.75	17.0%
IK180	= 0.880 × IK300 + 28.66	9.62	+0.75	13.4%
IK30	= 0.753 × IM + 34.78	16.30	+0.81	12.9%[☼]
IM	= 0.873 × IK30 + 11.03	17.50	+0.81	14.5%
IT	= 1.442 × IK30 +33.10	37.60	+0.73	17.5%
With scores expressed relative to body weight (N/kg or N·m/kg)				
IK300	= 0.674 × IK180 + 0.00	0.14	+0.81	16.8%
IK180	= 0.987 × IK300 + 0.41	0.17	+0.81	13.8%
IK30	= 0.691 × IM + 0.72	0.27	+0.80	12.5%
IM	= 0.930 × IK30 + 0.07	0.31	+0.80	16.1%
IT	= 1.399 × IK30 + 0.65	0.64	+0.69	17.7%

[a] n = 63

[☼] significant at *a* = 0.05.