# Isokinetic Strength Characteristics of the Quadriceps Femoris and Hamstring Muscles in High School Students

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**The purpose of this study was to determine the isokinetic strength of the quadriceps femoris and hamstring muscles in high school-aged students. Forty-seven 15- to 18-year-old high school volunteers served as subjects. Data were gathered on each subject by a questionnaire, lower extremity musculoskeletal assessment, and isokinetic testing of the two muscle groups at 60°/sec and 180°/sec. This study found no age effect on peak torque and no significant differences in peak torque between dominant and nondominant limbs. Significant differences ($p < .001$) occurred between the isokinetic strength of male and female subjects. The average hamstring muscle to quadriceps femoris muscle torque ratio was 57 percent at 60°/sec and 70 percent at 180°/sec. A value of foot pounds of torque per kilogram of body weight was provided as a guideline for clinicians. This investigation supports several findings already reported for other age groups.**

**Key Words:** *Knee, Muscle contraction, Physical therapy.*

Over the last 15 years, the use of isokinetic exercise devices has steadily increased. Such devices have been used in the rehabilitation and assessment of musculoskeletal injuries. The advantages, indications, and efficacy of isokinetic exercise and isokinetic assessment of strength have been well-documented.[1-7] Additionally, the establishment of the reliability and validity of the isokinetic testing device for the measurement of torque has facilitated its use as a clinical research tool.[1]

Although an isokinetic assessment can be made of any major muscle group in the body, the knee is probably the most commonly tested joint. Usually, when assessing the results of an isokinetic test, the involved knee is compared with the uninvolved knee. Should a patient have bilateral knee problems, however, determining reasonable rehabilitation goals may be difficult because of the lack of data from uninvolved knees. Therefore, normative isokinetic strength data on knee musculature are needed.

Establishing normative isokinetic strength values is not a new idea. A great deal of normative isokinetic data for quadriceps femoris and hamstring muscle strength have been established for athletes in a variety of sports and age groups. Isokinetic testing has been conducted on professional football players[8] and football players at the high school level.[9,10] Other published reports include isokinetic strength of the knees of hockey players,[11] professional baseball players,[12] and a variety of collegiate athletes.[13]

Isokinetic strength values have also been reported on non-athletes. During the development of the isokinetic concept, Moffroid et al conducted a series of tests on quadriceps femoris and hamstring muscles in men and women who were 18 to 31 years old.[1] Other researchers have now studied isokinetic strength of knees in relation to age,[14-19] height,[14-16] weight,[14-16,18] sex,[14-16,19] and isometric strength.[19,20] Goslin and Charteris provided more extensive isokinetic analysis on knee extensor and flexor strength in college-aged subjects.[7] Wyatt and Edwards extended normative isokinetic data on knee strength by testing and thoroughly assessing men and women who were 25 to 34 years old.[21] A review of the literature revealed a paucity of information on isokinetic strength data of healthy high school-aged students. The purpose of this study was to provide clinicians with descriptive data on the isokinetic strength and endurance of knee extensor and flexor muscles in these students.

## METHOD

### Subjects

Forty-nine subjects, 17 male and 32 female high school students, volunteered for this study. Their ages ranged from 15 to 18 years. All of the subjects were engaged in a recreational or interscholastic sport. One male and one female student were disqualified for not meeting all of the criteria for inclusion. The remaining 47 subjects had 1) no reported

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history of any hip, knee, or ankle surgery; 2) no reported history of any known knee pathology; 3) no reported history of hip or ankle pathology that interfered with their function; 4) no hip, knee, or ankle pathology based on musculoskeletal examination; and 5) no current use of medication with known cardiac or musculoskeletal side effects.

## Procedure

We gathered the data in one day for each subject. We obtained informed consent from each subject before study participation began. On the day of testing, the subjects completed a questionnaire that inquired about their medical history (primarily musculoskeletal injuries), exercise activity level, and lower extremity limb dominance. We defined limb dominance as the preferred kicking leg. The subjects were then measured for height and weight. We performed a lower extremity musculoskeletal examination composed of inspection, palpation, ligamentous examination of the knee, range of motion measurements, and a manual muscle test of the quadriceps femoris and hamstring muscles.

Isokinetic testing using the Cybex ®II isokinetic dynamometer and dual channel recorder* completed the procedures. Before this test, we gave each subject uniform instructions regarding the apparatus and procedure. One investigator administered all Cybex® tests. We tested the subjects in the seated position using the three principles of positioning described by Goslin and Charteris: 1) parallel alignment of the limb with the lever arm of the dynamometer, 2) alignment of the anatomical axis of rotation of the knee joint with the rotational axis of the dynamometer, and 3) proper stabilization.[7] Because the subjects sat at 20 degrees from a vertical line, we provided stabilization by thigh, ankle, and chest straps. We encouraged the subjects to use the handles on either side of the chair to provide further stabilization.

The testing protocol was strictly adhered to for each subject. Approximately five minutes before testing, each subject passively stretched their quadriceps femoris and hamstring muscles. Each subject was allowed three to five repetitions of reciprocal knee contractions at 60°/sec and 180°/sec for warm-up. The testing sequence was 1) five repetitions at 60°/sec with the last two repetitions recorded with paper speed at 25 mm/sec, 2) three repetitions at 180°/sec, and 3) endurance test[22] of number of repetitions to quadriceps femoris muscle fatigue at 180°/sec. A 30-second rest separated the test segments. The subjects were allowed to walk around for about three minutes before we tested the contralateral limb. The order of limb testing was randomized to eliminate any learning effect. We gave verbal encouragement throughout the testing procedure to facilitate a maximum performance by each subject.

## Data Analysis

Peak torque of each subject's best effort and number of repetitions to quadriceps femoris muscle fatigue were manually interpreted from the recording paper. From these values, we derived dominant and nondominant leg data, hamstring to quadriceps femoris muscle torque ratios, and foot pounds of torque per kilogram of body weight for each muscle and speed. Pearson product-moment correlations were calculated on mean peak torque and body weight. Means and standard deviations were calculated for all recorded values. We determined levels of significance by paired $t$ tests.[23]

*Cybex, Div of Lumex, Inc, 2100 Smithtown Ave, Ronkonkoma, NY 11779.

**TABLE 1**
**Age, Height, Weight, and Leg Dominance of Students**

| Variables | Males (n = 16) | Females (n = 31) |
|---|---|---|
| Age (yr) ($\bar{X} \pm s$) | 16.9 ± 0.72 | 16.3 ± 0.78 |
| Height (in) ($\bar{X} \pm s$) | 69.9 ± 1.60 | 65.3 ± 1.90 |
| Weight (kg) ($\bar{X} \pm s$) | 70.2 ± 12.0 | 56.0 ± 4.90 |
| Leg Dominance (n) (%) | | |
| right leg dominant | 16 (100) | 26 (83.9) |
| left leg dominant | 0 (0) | 4 (12.9) |
| both legs dominant | 0 (0) | 1 (3.2) |

## RESULTS

Table 1 lists age, height, weight, and leg dominance of the subjects in this study. Comparisons of mean peak torque and of endurance between dominant and nondominant limbs for male students are given in Table 2 and for female students in Table 3. No differences existed between dominant and nondominant limbs at 60°/sec and 180°/sec or between endurance

**TABLE 2**
**Comparison of Mean Peak Torque and Endurance Between Dominant and Nondominant Limbs for Male Students (n = 16)**

| Variables | Dominant Limb (ft lb) | | Nondominant Limb (ft lb) | | $t$ | $p$ |
|---|---|---|---|---|---|---|
| | $\bar{X}$ | $s$ | $\bar{X}$ | $s$ | | |
| 60°/sec | | | | | | |
| quadriceps femoris | 151.00 | 25.98 | 146.06 | 25.20 | 1.48 | NS |
| hamstrings | 86.56 | 18.66 | 86.31 | 21.32 | 0.15 | NS |
| 180°/sec | | | | | | |
| quadriceps femoris | 88.13 | 11.45 | 84.94 | 13.50 | 1.48 | NS |
| hamstrings | 61.94 | 13.14 | 60.69 | 14.44 | 0.98 | NS |
| Endurance | | | | | | |
| (no. repetitions to quadriceps femoris fatigue at 180°/sec) | 25.19 | 4.64 | 25.25 | 4.10 | 0.07 | NS |

**TABLE 3**
**Comparison of Mean Peak Torque and Endurance Between Dominant and Nondominant Limbs for Female Students (n = 31)**

| Variables | Dominant Limb (ft lb) | | Nondominant Limb (ft lb) | | $t$ | $p$ |
|---|---|---|---|---|---|---|
| | $\bar{X}$ | $s$ | $\bar{X}$ | $s$ | | |
| 60°/sec | | | | | | |
| quadriceps femoris | 100.19 | 15.57 | 99.68 | 16.0 | 0.30 | NS |
| hamstrings | 55.19 | 8.65 | 55.71 | 7.87 | 0.75 | NS |
| 180°/sec | | | | | | |
| quadriceps femoris | 56.71 | 11.45 | 56.90 | 11.11 | 0.20 | NS |
| hamstrings | 38.52 | 7.47 | 38.00 | 6.74 | 0.83 | NS |
| Endurance | | | | | | |
| (no. repetitions to quadriceps femoris fatigue at 180°/sec) | 25.32 | 4.85 | 25.84 | 4.84 | −0.76 | NS |

**TABLE 4**
**Comparison of Mean Peak Torque and Endurance by Sex for Dominant Limb of Students**

| Variables | Males (n = 16) (ft lb) | | Females (n = 31) (ft lb) | | *t* | *p* |
|---|---|---|---|---|---|---|
| | X̄ | *s* | X̄ | *s* | | |
| 60°/sec | | | | | | |
| quadriceps femoris | 151.00 | 25.98 | 100.19 | 15.57 | 8.39 | .001 |
| hamstrings | 86.56 | 18.66 | 55.19 | 8.65 | 7.91 | .001 |
| 180°/sec | | | | | | |
| quadriceps femoris | 88.13 | 11.45 | 56.71 | 11.45 | 8.91 | .001 |
| hamstrings | 61.94 | 13.14 | 38.52 | 7.47 | 7.82 | .001 |
| Endurance | | | | | | |
| (no. repetitions to quadriceps femoris fatigue at 180°/sec) | 25.19 | 4.64 | 25.32 | 4.85 | 0.09 | NS |

for male or female students. Because we found no differences between dominant and nondominant limbs, the remaining data will be reported for dominant limbs only.

Significant differences ($p < .001$) occurred in isokinetic strength between male and female students (Tab. 4). As the speed of isokinetic contractions increased, mean peak torque decreased for both sexes. No differences occurred in number of repetitions to fatigue between the two groups.

Because of the small sample size in this investigation, we decided to combine 15 and 16 year olds and 17 and 18 year olds to make age group comparisons. As shown in Table 5, no differences existed in the isokinetic strength of the quadriceps femoris and hamstring muscles between the two age groups.

For the male students, a significant correlation occurred between total body weight and mean peak torque of the quadriceps femoris muscles ($r = .60$; $p < .05$) and hamstring muscles ($r = .81$; $p < .001$) at 60°/sec. At 180°/sec, the correlation coefficients were $r = .63$ ($p < .01$) and $r = .77$ ($p < .001$) for the quadriceps femoris and hamstring muscles, respectively. The female students demonstrated correlation coefficients of $r = .47$ ($p < .01$) for the quadriceps femoris and $r = .59$ ($p < .001$) for hamstring muscles at 60°/sec. At the faster testing speed, the correlations were significant ($p < .001$), with coefficients of $r = .56$ and $r = .55$ for the quadriceps femoris and hamstring muscles, respectively. Based on the relationship between total body weight and isokinetic torque, we constructed Table 6 to depict means, standard deviations, and ranges for foot pounds of torque per kilogram body weight for male and female students.

The relationship between hamstrings and quadriceps femoris muscle strength is presented in Table 7. The hamstring to quadriceps femoris muscle torque ratio increased as the speed of contraction increased. Male and female students demonstrated similar ratios at both 60°/sec and 180°/sec.

## DISCUSSION

The purpose of this study was to provide clinicians with isokinetic strength data on healthy high school-aged students. The study design, which called for volunteers, led to a sample containing a combination of athletes and nonathletes. This study provides data unique to the literature because previous studies describing teenage isokinetic strength tested the subjects at faster velocities[17] or involved just athletes.[9,10]

### Isokinetic Strength

No differences in isokinetic strength occurred between the 15- to 18-year-old male or female students in this study. This finding is in contrast to that reported by Miyashita and Kaneshisa who tested a large group of healthy 13 to 17 year olds.[17] Their data demonstrated a linear increase in isokinetic knee-extensor muscle strength for boys aged 13 to 16 years old. For girls, significant strength differences were noted only between ages 13 and 14 years old. Other investigators have reported similar age-related differences in isokinetic strength of knee extensors and flexor muscles in high school football players.[9,10] Other studies have noted isokinetic knee-strength differences in children aged 7 to 15 years old[14–16] and men aged 20 to 86 years old.[19] The reasons for the discrepancies between data from this study and the other studies are not readily apparent. These differences, however, may reflect the small sample size in this investigation.

**TABLE 5**
**Comparison of Peak Torque by Age for Dominant Limbs in Male and Female Students**

| Variables | Age 15–16 Years (ft lb) | | Age 17–18 Years (ft lb) | | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|
| | X̄ | *s* | X̄ | *s* | | | |
| Males | (n = 5) | | (n = 11) | | | | |
| 60°/sec | | | | | | | |
| quadriceps femoris | 143.60 | 23.4 | 154.36 | 27.4 | 0.76 | 14 | NS |
| hamstrings | 84.40 | 20.5 | 87.55 | 18.7 | 0.30 | 14 | NS |
| 180°/sec | | | | | | | |
| quadriceps femoris | 88.80 | 11.9 | 87.82 | 11.8 | 0.15 | 14 | NS |
| hamstrings | 61.40 | 15.0 | 62.18 | 13.0 | 0.11 | 14 | NS |
| Females | (n = 20) | | (n = 11) | | | | |
| 60°/sec | | | | | | | |
| quadriceps femoris | 98.95 | 15.4 | 102.45 | 16.4 | 0.59 | 29 | NS |
| hamstrings | 54.65 | 8.0 | 56.18 | 10.0 | 0.47 | 29 | NS |
| 180°/sec | | | | | | | |
| quadriceps femoris | 57.00 | 12.0 | 56.18 | 11.0 | 0.19 | 29 | NS |
| hamstrings | 38.45 | 6.7 | 38.64 | 9.0 | 0.07 | 29 | NS |

**TABLE 6**
**Comparison of Mean Peak Torque per Mean Kilogram of Body Weight for Dominant Limb in Male and Female Students**

| Test Speed and Muscle Group | Males (n = 16) (ft lb) | | | Females (n = 31) (ft lb) | | |
|---|---|---|---|---|---|---|
| | X̄ | s | Range | X̄ | s | Range |
| 60°/sec | | | | | | |
| quadriceps femoris | 2.17 | 0.18 | 1.46 – 2.58 | 1.79 | 0.24 | 1.33 – 2.37 |
| hamstrings | 1.23 | 0.15 | 1.02 – 1.49 | 0.99 | 0.13 | 0.71 – 1.28 |
| 180°/sec | | | | | | |
| quadriceps femoris | 1.27 | 0.15 | 0.90 – 1.48 | 1.01 | 0.17 | 0.68 – 1.36 |
| hamstrings | 0.88 | 0.12 | 0.69 – 1.10 | 0.69 | 0.11 | 0.48 – 0.94 |

**TABLE 7**
**Comparison of Mean Peak Torque Ratio Between the Hamstring and Quadriceps Femoris Muscles in Dominant Limbs for Male and Female Students**

| Age | Males (Ratio %) | | | | Females (Ratio %) | | | |
|---|---|---|---|---|---|---|---|---|
| | 60°/sec | | 180°/sec | | 60°/sec | | 180°/sec | |
| | X̄ | s | X̄ | s | X̄ | s | X̄ | s |
| 15 | | ... | | ... | 60 | 7 (n = 4) | 72 | 9 (n = 4) |
| 16 | 59 | 9 (n = 5) | 69 | 1 (n = 5) | 55 | 6 (n = 16) | 67 | 7 (n = 16) |
| 17 | 57 | 11 (n = 8) | 71 | 12 (n = 8) | 56 | 7 (n = 9) | 69 | 7 (n = 9) |
| 18 | 57 | 8 (n = 3) | 69 | 9 (n = 3) | 58 | 10 (n = 2) | 66 | 17 (n = 2) |
| TOTAL | 58 | 9 (n = 16) | 70 | 10 (n = 16) | 55 | 7 (n = 31) | 68 | 7 (n = 31) |

Significant differences existed in strength between male and female students at both test speeds. Previous investigators have also shown strength differences between boys and girls, 7 to 15 years old[15] and 13 to 17 years old.[17] In a study of 70 year olds, Aniansson and co-workers concluded that women were, on the average, 56 percent as strong as men.[18]

Numerous studies have reported a decrease in torque output with increasing speeds of contraction.[1,8,10,11,18–21] Data from our study showed a similar pattern. Wyatt and Edwards found a significant decrease in torque when a 120°/sec separation in testing velocity existed.[21] We agree with Wyatt and Edwards that more research is needed to determine velocity-spectrum differences in torque output.[21]

The hamstring to quadriceps femoris muscle torque ratio is a key value to look at when evaluating the results of a knee isokinetic test. Coplin suggested that a 60 percent ratio was needed to maintain a normal muscle balance around the knee for college-aged athletes.[24] A study of high school football players reported ratios of approximately 56 percent at a 54°/sec test speed.[9] Gilliam et al also tested 15- to 17-year-old football players and reported ratios of 60 percent at 30°/sec and 77 percent at 180°/sec.[10] Davies et al, testing at 45°/sec and 180°/sec, found similar ratios in professional football players.[8] Highly skilled hockey players, however, had ratios between 80 percent and 85 percent at 180°/sec.[11]

More discrepancies seem to appear in healthy nonathletic groups. Early investigations reported that mean flexor muscle torque was approximately half that of the extensor muscles.[1,2] Scudder reported a ratio of 60 percent, which did not vary with speed of testing.[20] In a group of 7- to 13-year-old boys and girls, the ratio ranged from 40 to 70 percent.[16] Wyatt and Edwards reported ratios for men and women of approximately 70 percent at 60°/sec and 80 percent at 180°/sec.[21] In a study of university-aged students, Goslin and Charteris concluded that the normal extension to flexion muscle torque ratio should be 2.25:1.[7] The ratios in our study ranged from 55 to 60 percent at 60°/sec and were approximately 70 percent at 180°/sec. The differences in the literature regarding hamstring to quadriceps femoris muscle torque ratios may be attributed to investigators testing at different slow velocities. Future isokinetic research should be conducted using consistent testing velocity protocols so that meaningful comparisons can be made between different groups. With reference to athletes, current published data suggest that sport-specific ratios may exist. Hockey players exhibited a ratio up to 85 percent at 180°/sec,[11] and football players at various levels of skill had a ratio of approximately 77 percent at the same test velocity.[8,10]

## Dominant and Nondominant Leg Strength

No differences in strength occurred between the dominant and nondominant legs for male and female students in this study. Gilliam et al reported the same findings in young male athletes.[10] Studies involving 7 to 15 year olds[14,15] and young adults,[7] however, demonstrated significant differences between dominant and nondominant limbs. Wyatt and Edwards found limb-strength differences in men but not women.[21] These discrepancies may result from the definition of dominance by various authors. Some researchers define it as the leg preferred for kicking,[21] others describe it as the stronger limb,[7] and some do not specify how dominance was determined.[14,15] Consistent definitions of dominance should be established to make future research findings meaningful.

## Body Weight and Peak Muscle Torque Output

Previous studies have consistently demonstrated a relationship between total body weight and peak quadriceps femoris and hamstring muscle torque output.[8–10, 13, 16, 18] In professional football players, Davies et al, testing at 45°/sec, calculated an average quadriceps femoris muscle to body weight ratio of 107 percent.[8] The data from our study also produced significant correlations between mean peak quadriceps femoris and hamstring torque and body weight for male and female students. The values for the male students in our study are similar to those reported by Parker et al.[9] Because the correlation of peak quadriceps femoris and hamstring muscle torque to body weight is well established, we chose to express this relationship by calculating values of foot pounds of torque per kilogram of body weight. These values may be useful to the clinicians who are seeing individuals with bilateral knee involvement. Obviously, because of the small sample size in our study, more data need to be collected to ensure the validity of these values.

## Endurance

Endurance was not different between male and female students in our study. Additionally, endurance in the dominant limb was not different from the nondominant limb. Davies et al have investigated muscular endurance in football players.[25] They concluded that the total number of repetitions to quadriceps femoris muscle fatigue may not truly represent muscular endurance. They suggested that total work done may be a more important indicator of muscular endurance. No other study has fully addressed the issue of isokinetic muscular endurance. More research is needed in this area.

## CONCLUSIONS

The information provided by our study should be useful to clinicians who have considerable contact with high school-aged patients. This study demonstrated the following results:

1. No significant age effect on peak torque of quadriceps femoris or hamstring muscles.
2. Significant differences in quadriceps femoris and hamstring muscle strength between male and female students.
3. Torque ratio of hamstring to quadriceps femoris muscle increased with increasing testing velocity.
4. No differences in quadriceps femoris and hamstring muscle strength between dominant and nondominant limbs for male and female students.
5. Significant correlations between total body weight and peak quadriceps femoris and hamstring muscle torque.
6. Establishment of a value of foot pounds of peak torque per kilogram of body weight for male and female students.
7. Similarity of quadriceps femoris muscle endurance in male and female students.

We believe that more clinical research in isokinetic knee testing involving a larger sample size needs to be conducted in this age group. We hope this study provided some useful guidelines for establishing rehabilitation and training goals for high school-aged patients.

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