Fair as a Percentage of Normal Using Manual Muscle Testing of Knee Extensor Strength

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Abstract. We explored the extent to which fair knee extensors might be judged to be weaker than the normal knee extensors of healthy young adults. To obtain quantitative data for normal strength of knee extensors, we recorded knee torque in 20 healthy young subjects using an isokinetic dynamometer, and calculated muscle strength equivalent to fair, including the effect of inertial force, using a rigid body model. The results showed that fair torque as a percentage of actual normal torque at 60 degrees per second was 4.8 ± 1.2% (mean ± standard deviation) among the men and 4.6 ± 1.0% among the women. This difference in per cent strength was not statistically significant between men and women. In manual muscle testing, the grade of fair for knee extensors is thus very far below the midpoint of the scale from no activity to normal. This means that the good range between grade fair and normal is too wide to connote one particular state of strength. We believe that other methods are needed, for example using a dynamometer, to evaluate intermediate muscle weakness in detail.

Key words: manual muscle testing, knee extensor strength, biomechanics

Manually muscle testing arose from the idea of being able to move against gravity, which forms the central idea of this form of evaluating muscular strength. The grade of fair, which signifies ability to move a given body part through its full available range of motion against gravity with no external resistance manually applied, does not simply express a certain degree of muscle weakness, but also bears a functional connotation about whether or not a certain minimum of work can be performed in everyday life. The language of the different stepwise grades of strength in manual muscle testing thus contains useful information other than simply degree of muscular weakness¹).

In spite of this functionally meaningful form of assessing muscular strength, the quantitative meaning of fair in relation, for example, to normal is vague. If a muscle has only fair strength, how much weaker is it than a muscle with normal strength?

Since fair is in the middle of the scale for this manual grading system, the examiner may misunderstand it to mean 50% of maximum strength²). Resnick et al.³) reported that the ratio of fair to normal means 4% for the biceps femoris, 17–22% for the hip abductors, and 2% for the supinator muscle. None of these values is close to half of maximum strength, thus posing a problem to the physical therapist, who should think of fair not simply as a grade, but also as an approximate quantity of muscle strength.

In the present study, we explored the extent to which fair knee extensors might be judged to be weaker than normal knee extensors of healthy young adults. The purpose of this study was to clarify the following: 1) How weak is fair strength as a percentage of normal strength in the knee extensors? 2) Is this ratio different between men and women?

Methods

Measuring muscle strength equivalent to normal

To obtain quantitative data for normal strength of knee extensors, we recorded knee torque in 20 physical therapy students (10 men and 10 women), whose physical characteristics are listed in Table 1. We used an isokinetic dynamometer (KinCom) at 60 degrees per second and at
180 degrees per second. The procedure was explained to each subject. During the measurements, the subject sat leaning against a backrest inclined 15 degrees from the vertical and was stabilized at the shoulders, waist, and distal portion of the thigh. All subjects performed the same series of tasks: four isokinetic contractions. The values were adjusted for gravity force on the leg. Maximum muscle force, equivalent to normal, was assessed by the mean peak torque.

Calculating muscle strength equivalent to fair

We sought to determine the muscle force equivalent to fair according to the definition “complete range of motion against gravity”\(^1\), which includes the effect of inertial force. To obtain a movement pattern for estimating the peak torque exerted by fair knee extensors during a manual muscle test, one of us (H.S.) performed a knee extension from 90 degrees of flexion to full extension. The time to perform the entire movement was approximately one second. Angular displacement was recorded via a potentiometer (Nihon Kohden) aligned to the sagittal axis of the knee joint, signal conditioning unit (Nihon Kohden), and analog-to-digital converter (MacLab), to a computer (Macintosh PowerBook 150). This history of angular displacement, recorded at 400 samples per second, was differentiated twice by calculus of finite differences, using a program supplied with the analog-to-digital converter, to estimate the history of angular acceleration during the knee extension.

Mass, center of gravity, and moment of inertia for the lower leg and foot of each of the 20 physical therapy students were determined from tabular data and equations made available in a textbook of biomechanics\(^4\). Figure 1 shows a rigid body model used in this connection, where \(I_0\) is anteroposterior moment of inertia for the moving segment, \(a\): distance between knee and center of gravity of lower leg and foot, \(g\): acceleration due to gravity, \(m\): mass of lower leg and foot, \(M\): knee extensor moment of force, \(\theta\): angle of knee extension.

\[
M(t) = I_0 \frac{d^2 \theta(t)}{dt^2} + mga \sin \theta(t) \quad \ldots \quad (1)
\]

To obtain a value for the dynamic moment \(M\) of the knee extensors, we needed to estimate angular acceleration.

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**Table 1** Physical characteristics of the subjects

<table>
<thead>
<tr>
<th>men</th>
<th>age</th>
<th>weight (kg)</th>
<th>height (m)</th>
<th>women</th>
<th>age</th>
<th>weight (kg)</th>
<th>height (m)</th>
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<td>subject a</td>
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<td>1.73</td>
<td>subject k</td>
<td>32</td>
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<td>l</td>
<td>21</td>
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<td>1.79</td>
<td>m</td>
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<tr>
<td>d</td>
<td>23</td>
<td>63.0</td>
<td>1.75</td>
<td>n</td>
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<td>1.52</td>
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<td>e</td>
<td>22</td>
<td>74.8</td>
<td>1.75</td>
<td>o</td>
<td>21</td>
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<td>1.58</td>
</tr>
<tr>
<td>f</td>
<td>22</td>
<td>74.8</td>
<td>1.76</td>
<td>p</td>
<td>22</td>
<td>49.9</td>
<td>1.54</td>
</tr>
<tr>
<td>g</td>
<td>20</td>
<td>64.9</td>
<td>1.69</td>
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<td>44.9</td>
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<tr>
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<td>28</td>
<td>54.9</td>
<td>1.67</td>
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<tr>
<td>i</td>
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<td>s</td>
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<tr>
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<td>61.2</td>
<td>1.64</td>
<td>t</td>
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<tr>
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of the knee joint. For this study, we hypothesized that each subject moved in the same pattern as that of the record of H.S., and the angular acceleration in equation 1 was set at the acceleration of the record. Mass, center of gravity, and moment of inertia were determined from equations based on height and weight of the individual subject.

We were able to consolidate the calculations to estimate fair knee extensor torque into a polynomial function of height and weight.

Statistical analysis

The fair-to-normal ratio was compared between men and women by a paired t-test.

Results

Estimating fair torque

Using equation 1, we estimated fair knee extensor torque. The following values were obtained from the textbook\(^4\): segment weight = 5.8% of body weight, segment length = 21.2% of height, center of gravity was located 47.5% from the proximal end, and moment of inertia \(I_0 = mr^2\), where \(r\) is radius of gyration whose value is 73.5% of segment length from the proximal end.

To search for the peak torque, we put the angular acceleration data derived from H.S. into equation 1. From the calculation it become clear that the point of peak torque was the peak of antigravity force, not the peak inertial force. We could thus estimate antigravity torque in fair knee extension as the static condition at 90 degrees, (full knee extension), and equation 1 could be changed to

\[ M = 5.73 \times 10^{-2}WH \]

where \(W\) is mass of the body in kilograms, \(H\) is height in meters, and \(M\) is expressed in Newton-meters (Nm). The mean and standard deviation of peak torque estimated by this method was 6.4 ± 0.9 (mean ± standard deviation) Nm for men and 4.8 ± 0.7 Nm for women.

Measuring normal torque

Table 2 presents the maximum torque values for all of the subjects. The mean and standard deviation of peak torque actually produced at 60 degrees per second was 136.8 ± 19.4 Nm for men and 106.2 ± 15.9 Nm for women. At 180 degrees per second, peak torque was 86.4 ± 14.0 Nm for men and 69.8 ± 10.9 Nm for women.

Fair as per cent normal

Estimated fair torque as a percentage of actual normal torque at 60 degrees per second, calculated for each subject, was 4.8 ± 1.2% among the men and 4.6 ± 1.0% among the women. The difference between men and women was not statistically significant (Fig. 2). Fair torque as a percentage of actual normal torque at 180 degrees per second was 7.7 ± 2.1% among the men and 7.1 ± 1.8% among the women, likewise not significantly different.

Discussion

We attempted here to characterize the fair grade of manual muscle testing of knee extensor strength as a percentage of normal strength to gain a more quantitative impression of the real meaning of fair in this situation. Although Daniels and Worthingham\(^1\) mention the idea of expressing the equivalent of fair force as a percentage of normal, they dismiss the idea on the basis of the variations among individuals being too large with respect to age, sex, body type, and athletic experience for such an expression to

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Table 2  Maximum values for isokinetic knee extensor torque and estimated fair torque

<table>
<thead>
<tr>
<th></th>
<th>Isokinetic knee torque</th>
<th>Isokinetic knee torque</th>
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<tr>
<td></td>
<td>at 60 degrees per second (Nm)</td>
<td>at 180 degrees per second (Nm)</td>
</tr>
<tr>
<td></td>
<td>men</td>
<td>women</td>
</tr>
<tr>
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<td>f</td>
<td>113.9</td>
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</tr>
<tr>
<td>mean</td>
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<td>86.4</td>
</tr>
<tr>
<td>S.D.</td>
<td>20.40</td>
<td>14.76</td>
</tr>
</tbody>
</table>
be able to have a wide degree of applicability.

We nevertheless consider the idea worth pursuing, particularly because identifiable sources of variation (age, sex, body type, athletic experience, etc.) can be taken into account. Considering just the variable of age, physical therapists treat persons from infancy through old age. Are therapists supposed to interpret *fair* as meaning the same thing for all age groups? Expressing *fair* as a certain percentage of *normal* for a given age group would provide more information about how much weakness *fair* really implies in that set of circumstances. The per cent of *normal* provides one type of information, and the function of moving the body part against gravity provides another type of information. Thus, we advocate specifying "*fair*", but also interpreting it as a specific percentage of maximum if such information can be validly determined.

We limited the scope of this study to healthy young subjects in their twenties to examine how consistently *fair* knee extension could be expressed as a percentage of *normal* when sex, height, and weight were taken into account.

The results we obtained suggest that knee extensors need only about 5 per cent of *normal* strength to successfully pass a *fair* test in young adults.

In the only other study that we know of concerning this issue, Beasley reported that *fair* for the knee extensors was 9 per cent of maximum strength, based on a static analysis5). This agrees roughly with our determination, which ultimately was based on a static analysis as well. As shown in equation (2), our results showed that including the effect of inertial force did not affect the percentage.

Maximum strength in men was larger than in women. Other research supports this finding67). In spite of this, the difference between men and women in terms of *fair*-to-*normal* ratio was not significant, implying that the actual strength required to extend the knee against gravity depends on the height and weight of the subject.

Maximum knee extension torque is also known to gradually decrease with age. Even in an elderly person, however, static torque required for the *fair* test is small compared to the available maximum knee extensor strength. If the maximum knee extensor torque in an elderly person is almost half of that in a young person, the *fair*-to-*normal* ratio would still be only about 10%. Thus *fair* strength of the knee extensors does not appear to greatly vary in relation to *normal* strength on the basis of age.

In manual muscle testing, the grade of *fair* for knee extensors is thus far below the midpoint of the scale from no activity to *normal*. This means that the good range between *fair* and *normal* grades is too wide to interpret quantitatively. We believe that other methods are needed, for example using a dynamometer, to evaluate intermediate muscle weakness in detail.

**Conclusion**

To clarify how weak *fair* is compared to *normal* in testing knee extensor strength, we attempted to evaluate *fair* as a percentage of *normal* strength using an isokinetic dynamometer and a rigid body model that included an estimate of dynamic inertial force. The results showed that *fair* was less than 10% of *normal* in young healthy subjects, and that differences in per cent strength were not statistically significant between men and women.

Because the good range between grade *fair* and *normal* is too wide to refer to one particular degree of strength, other methods are needed to evaluate intermediate muscle weakness in detail.

**References**

Appendix: Equation for knee extensor torque during knee extension

The equation of motion knee extension

\[ I_0 \frac{d^2 \theta(t)}{dt^2} = M(t) - m \times g \times a \times \sin \theta(t) \text{ ....equation 1} \]

\[ I_0 = mr^2 \quad r: \text{radius of gyration} \]

In the case of the leg and foot, the radius of gyration as a percentage of segment length is 73.5% from the proximal end.

The segment length is 21.2% of the subject’s height.

\[ m \] is the weight of the leg and foot. \( m \) is 5.8% of body weight (W).

\[ r = H (\text{height}) \times 0.212 \times 0.735 = 0.15582 \times H \]

Then, \( I_0 = 0.058 \times W \times (0.15582 \times H)^2 \)

\[ = 0.41 \times 10^{-3} \times W \times H^2 \]

\[ m = 0.058 \times W \text{ (kg)} \]

\[ g = 9.81 \text{ (m/s}^2\text{)} \]

\[ a \] indicates distance from the knee joint to the center of gravity of the segment (m).

Center of mass/segment length ratio to the proximal end is 47.5%.

Thus \( a = 0.212 \times H \times 0.475 = 0.1007 \times H \)

And, \( \frac{d^2 \theta(t)}{dt^2} = 0 \text{ radians/s}^2 \), when \( \theta(t) \) was 90 degrees.

Input \( m \), \( g \), \( a \), \( I_0 \), and \( \frac{d^2 \theta(t)}{dt^2} \) into equation 1

\[ M(t) = I_0 \frac{d^2 \theta(t)}{dt^2} + mga \sin \theta(t) \]

\[ = 0 \times W \times H^2 + 0.058 \times W \times 9.81 \times 0.1007 \times H \times \sin (90^\circ \times \frac{\pi}{180^\circ}) \]

\[ = 5.73 \times 10^{-2} \times W \times H \text{.....equation 2} \]

Equation 2 can thus estimate the antigravity extension torque by using only the subject’s weight and height.