Physiological quadriceps lag: Its nature and clinical significance

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A study of the limit of active and passive knee extension in 64 healthy adults revealed a physiological quadriceps lag; that is, in most subjects the active limit of knee extension fell short of the passive limit. With the subjects seated, for the passive test the examiner lifted the heel until the relaxed knee sagged into full extension under its own weight. The active test component comprised maximum active extension held for at least 5 sec. Videotaped reference markers on the lateral aspect of the limb were computer-analysed to derive the active and passive test positions. The active limit of knee extension was less than the passive limit by an average 2.5 degrees at the instant of maximum active knee extension, and by 2.9, 3.5, 4.0, 4.5 and 5.0 degrees 1, 2, 3, 4 and 5 sec later. At 0 and 5 sec, 16% and 41% of the subjects manifested a quadriceps lag of at least 5 degrees. There was no correlation between the magnitudes of passive knee extension and quadriceps lag. Since clinicians typically take several seconds to estimate visually or otherwise measure knee extension, account should be taken of the duration of maximum active contraction, as well as other details of test methodology, if quadriceps lag tests are to produce valid and reliable results. [Stillman BC (2004): Physiological quadriceps lag: Its nature and clinical significance. Australian Journal of Physiotherapy 50: 237–241]

Key Words: Skeletal Muscle; Muscle Contraction; Muscle Weakness; Knee Pathology; Physical Therapy

Introduction

The term ‘muscle lag’ and the more specific terms ‘extensor lag’ and ‘quadriceps lag’ have been in use for at least 40 years. Given that lag is a clinical sign with often profound functional relevance for patients, the reader may be surprised to find that few books on musculoskeletal assessment, orthopaedics, or knee rehabilitation even mention lag; and then only cursorily (Corrigan and Maitland 1983 and 1994, Greenfield 1993, Hertling and Kessler 1996, Magee 1992).

Muscle lag is an inability to actively move a joint to its passive limit. In more detail, the passive limit should be the passive limit that can be achieved without producing significant discomfort, and without exerting more than mild force against resistance from joint stiffness or other soft tissue tightness. The active limit should be determined with the patient positioned so that the moving segment is resisted by gravity but no other external load. It appears there is a widespread belief that lag is always abnormal. Whilst this is certainly the inference in the abovementioned texts, evidence is presented in this paper that quadriceps lag is common in healthy adult knees when tested carefully using a sensitive measuring instrument.

When a concentrically-contracting muscle shortens, its maximum contractile tension diminishes. Likewise, an isometrically contracting muscle is weaker than mild force against resistance from joint stiffness or other soft tissue tightness. The active limit should be determined with the patient positioned so that the moving segment is resisted by gravity but no other external load. It appears there is a widespread belief that lag is always abnormal. Whilst this is certainly the inference in the abovementioned texts, evidence is presented in this paper that quadriceps lag is common in healthy adult knees when tested carefully using a sensitive measuring instrument.

lag: 1) an abnormal increase in muscle length (as may occur following suture of ruptured muscle, or after fracture with loss of bone length), 2) disuse atrophy, 3) myopathy, 4) neurological deficit, and 5) pain-induced or other arthrogenic muscle inhibition.

A search of the CINAHL, Medline (PubMed), National Library of Medicine, and Web of Science databases produced 135 journal articles within the last decade that referred to muscle-, quadriceps-, extensor- or flexor-lag. The reason that 68 (50%) of these references were related to the knee, and 61 (45%) to the hand, is the relatively unique quadriceps and finger muscle biomechanics that predispose these regions to muscle lag. For example, the force developed by a contracting quadriceps must be increased 60% to achieve the final 15 degrees of active knee extension (Lieb and Perry 1968). Consequently, quadriceps weakness will be most evident in this final extension range, and is often accompanied by lag.

In addition to alerting the reader to quadriceps lag in normal knees, the aim of this paper is to examine how the method of testing, and in particular the duration of any sustained active muscle contraction, can affect the magnitude of quadriceps muscle lag.

Method

Approval for this study was provided by the Human Ethics Research Committee of The University of Melbourne. All participants gave informed written consent.

Subjects The participants were 64 physiotherapy students of mean age 20.4 (SD 1.7) years. Fifty were female and, based on the preferred lower limb for kicking a ball, 61 were right
lower limb dominant. No subject had any disorder, or any history of a disorder, that might influence the normal capacity to activity and passively extend the knee.

**Assessment** Each subject sat on the side of a treatment couch with the trunk supported in approximately 45 degree flexion to minimise any resistance from hamstring muscle tightness during the tests. For consistency, all tests were of the non-dominant knee. Reflective reference markers were fixed to the lateral aspect of this limb: one over the iliotibial tract at a convenient point distal to the greater trochanter, one over the iliotibial tract at a convenient level proximal to the femoral condyle, one over the neck of fibula, and one over the distal fibula proximal to the lateral malleolus (Figure 1).

The passive limit of knee extension was determined by the examiner straightening the relaxed knee with a hand behind the heel until the subject’s thigh just cleared the couch (Figure 1A). In this position the unsupported knee was allowed to sag into extension determined by the weight of the limb. A videotape record was obtained of this position from a camera directed at the lateral aspect of the limb. This procedure was selected as a suitable non-invasive means for measuring knee flexion/extension angles at a high sampling rate over time (see below). The elements of the reference marker positioning, video-taping, and subsequent analysis with the PEAK computer system (see below) have been described previously, along with details of their reliability and validity (e.g. Baker et al 2002, Bennell et al 2004, Stillman 2000, Stillman and McMeeken 2001). Stillman (2000) has shown that individual video-based knee measurements are accurate and reliable to within four degrees.

The active limit of knee extension was determined by the examiner asking each subject to straighten the knee ‘as far as possible’ and to hold the fully extended position ‘as hard as possible’ until told to lower the leg (after approximately 7 sec) (Figure 1B). The examiner provided constant instructions and tone/reinforcement across all subjects in an attempt to standardise each subject’s (maximum) effort during the active test. A videotape record was obtained of the subject straightening and holding the knee.

**Data analysis** The 2-dimensional module of the PEAK video-image analysis system was used to digitise the location of the four reference markers automatically at a sampling rate of 50 Hz. The angle of maximum passive knee extension was calculated as the average over 1 sec of digitised videotape with the knee in the fully extended position. Maximum active knee extension was digitised over approximately 7 sec, after which the maximum angle of active knee extension was noted — henceforth described as the angle at 0 sec — and the angle at 1, 2, 3, 4, and 5 sec thereafter. Figure 2 is a typical example of an active test result taken from one of the subjects.

To facilitate data processing the straight knee position was represented as 0 degrees flexion-extension, the flexed knee (as in Figure 1B) represented by angles with a positive sign, and knees in extension positions beyond the straight, by angles with a negative sign. For each subject, the magnitude of quadriceps lag, that is the angular limit of active extension minus the angular passive limit, was calculated at 0, 1, 2, 3, 4, and 5 sec. The behaviour of quadriceps lag over time was then investigated graphically, and by repeated measures analysis of variance.

Measurement error across the 0 to 5 sec data sets was zero for the 0 sec data and decreased to 1.0 degrees at 5 sec.

### Table 1. Mean and SD maximum active knee extension and quadriceps lag at 0 to 5 sec for all subjects (n = 64).

<table>
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<tr>
<th>Time (sec)</th>
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<th>Active limit SD</th>
<th>Quads lag Mean</th>
<th>Quads lag SD</th>
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</table>

**Figure 1.** Lateral view of subject and reference marker positions. A shows the method used to determine the limit of passive extension; B shows the method for determining the limit of active extension (see text for details).

**Figure 2.** Typical example of decay in maximum active extension over time (with zero set at point of maximum active extension) in one subject. The open circle symbols and related values show the magnitude of active extension at 0, 1, 2, 3, 4 and 5 sec.
determined using method error and its coefficient of variation (CV_{ME}) (Portney and Watkins 2000).

**Results**

The mean angle for the passive limit of knee extension was -3.5 (SD 3.5) degrees; and for the active limit at 0 sec, -1.1 (SD 3.8) degrees. Both of these data sets were normally distributed. The mean active extension limit and quadriceps lag at 0 through 5 sec are shown in Table 1. Repeated measures ANOVA with Scheffé post-hoc calculations revealed that the average lag at 4 and 5 sec (4.5 and 5.0 degrees respectively) was significantly greater than the average at 0 sec (2.5 degrees). Table 2 shows the percentage of subjects with 2 to 12 degrees lag at 0 to 5 sec after maximum active extension. No subjects manifested 14 degree lags at any time. and no subject had a negative lag by 3 sec. At 5 sec, 41% of all subjects had quadriceps lag > 5 degrees (maximum 13.5 degrees).

The question of whether individuals with greater passive knee extension have greater quadriceps lags was examined by scatterplot and regression analysis. There was no systematic trend, although it was noted that those knees which did not passively extend beyond 0 degrees did not manifest more than a 6 degree quadriceps lag at any time between 0 and 5 sec.

The method error for the quadriceps lag between 0 and 1 sec was 0.7 degrees, 0.5 degrees between 1 and 2 sec, 0.4 degrees between 2 and 3 sec, 0.3 degrees between 3 and 4 sec, 0.4 degrees between 4 and 5 sec, 1.0 degree between 0 and 3 sec and 1.2 degrees between 0 and 5 sec. The coefficient of variation (%) of the method error between 0 and 3 sec and between 0 and 5 sec was 33% and 32% respectively. Thus, for example, a lag of 3 degrees at 0 sec must increase by more than 1 degree to be deemed clinically significant.

**Discussion**

**Quadriceps lag at instant of maximum active extension**

This study has shown that most healthy young adults, when assessed in the manner described, manifest a quadriceps lag. At the instant of maximum voluntary active extension, 48% of the 64 subjects had a quadriceps lag of between 2.0 and 10.5 degrees. Since these subjects had no pain, and further passive extension was possible without substantial passive resistance, this lag at 0 sec can only be readily explained as a manifestation of normal quadriceps femoris active insufficiency, perhaps augmented in some subjects by a less than maximum voluntary effort. The apparent absence of any reference in the literature to quadriceps lag in normal knees is most likely because quadriceps lag does not appear to have been examined systematically in healthy subjects.
The sample comprised active young adults, most of whom were female. It is probable that the magnitudes and proportions of quadriceps lag might be different in asymptomatic knees with less mobility and strength, for example in the knees of middle-aged or older males. It is therefore recommended that the present study be extended to cover all age groups as well as both genders.

**Increase in quadriceps lag over time** The results of the present study show a rapid decay in maximum active knee extension over 5 sec. Thus, whereas 16% of subjects had at least a 5 degree lag at 0 sec, by 5 sec this proportion was 42%. Although previous research concerning the development of fatigue has involved much longer durations than 5 sec, it is clear there are many factors that may contribute to the decay of sustained muscle strength over a short time period. It is not possible or necessary to delve into this complex area in this paper — the reader is referred to Enoka and Stuart (1992) and Liu et al (2002) for detailed accounts. Nevertheless, it is noteworthy that the faster a muscle is brought to its maximum contraction, the faster is the rate of decay in strength thereafter (Liu et al 2002) — as suggested by the results of the present study. Whatever caused the decay in maximum active knee extension in the present study, this behaviour may influence the reliability of clinical tests for quadriceps lag significantly.

A delay of several seconds is not unusual as clinicians attempt to estimate knee joint angles visually, or to measure these angles with some form of goniometer. In the author’s experience, several seconds can easily be used to align the instrument correctly, and another several seconds to read the scale correctly. The present study has revealed that delays of 4 sec or more produce significantly larger values of quadriceps lag. In patients with knee pathology, where the rate of quadriceps fatigue may be greater than in normal individuals, this problem is likely to be more profound. Accordingly, it is recommended that clinicians note the time taken to derive measures of maximum active knee extension during quadriceps lag tests, and attempt to standardise this time during all subsequent tests of the same subject (or other subjects in comparative studies). It could also be helpful in minimising time delays during measurement to employ such strategies as: 1) pre-marking surface landmarks on the skin to facilitate positioning of a goniometer, 2) attaching the instrument (e.g. electrogoniometer or gravity goniometer) to the limb before commencing the tests, and 3) asking a second person to assist.

**Clinical test method for determining quadriceps lag** Over the years clinicians have used two fundamentally different methods to test for quadriceps lag, referred to here for convenience as the ‘heel block’ (Figure 3) and ‘thigh block’ (Figure 4) methods. In the heel block method (Figure 3A) the heel is placed on a small raised block and the relaxed limb allowed to fall into extension under its own weight. This is comparable to the passive test in the present study. The active test in the heel block method (Figure 3B) involves having the subject attempt to hold the knee straight whilst raising the heel off the block. The magnitude of quadriceps lag is determined by subtracting the angle of active knee flexion at the instant the heel leaves the block from the angle at the limit of passive extension.

In the thigh block method, the thigh is initially positioned over a substantive block so that the knee is in approximately 45 degrees flexion. The test for quadriceps lag starts with the active component (Figure 4A). The subject is asked to actively straighten the knee as far as possible. After determining the limit of active extension, the examiner places a hand behind the heel and straightens the knee (Figure 4B). In this method it is best if the subject does not relax when the examiner lifts the leg with a hand behind the heel (this minimises any jerking of the limb between the end of the active and start of the passive phase). Also, the examiner should raise the leg with a hand behind the heel until the thigh just lifts off the block. The latter standardises the force (lower limb weight) tending to extend the relaxed knee, as in the passive extension test in the heel block method.

When a patient has one established healthy knee, a comparison of the quadriceps lag test results from both knees is the simplest means of demonstrating an abnormal quadriceps lag — although the precise magnitude of asymmetry that characterises abnormality remains to be elucidated. Moreover, there is no simple way of determining whether a given magnitude of lag is likely to be responsible for any future functional disability. In the present study, the subject with the largest lag (10.5 degrees at 0 sec and 13.5 degrees at 5 sec) had no evidence of knee dysfunction at or prior to the time of assessment. While some clinicians might say that this lag might cause troubles in the subject’s future, it would be unwise for anyone to say that it will. Referring to the previously mentioned survey of 68 articles published in the past decade dealing with quadriceps lag, a 30 degree lag (variably measured) appears to be a common basis for surgical intervention. A general lack of accuracy in measuring quadriceps lag, combined with a lack of prospective studies, has most likely disguised functional knee disabilities resulting from less than 30 degree quadriceps lags.

Having found no useful information in the literature, the author questioned his physiotherapy colleagues at The University of Melbourne School of Physiotherapy about the size of quadriceps lag in terms of functional disability. While acknowledging its lack of scientific rigour, it may be of interest that my ‘expert’ colleagues considered that a lag greater than 10 degrees was definitely likely to cause problems, and that lags less than 10 degrees could cause problems in the case of elite sportspersons. In light of the current research findings, which included two subjects with at least 10 degrees of lag after 2 sec of maximum active extension, there seems an obvious need to investigate this question systematically. If, for example, 10 degrees lag is eventually found to be of functional significance, then ‘standard’ protractor goniometry should be a satisfactory measuring instrument. On the other hand, if less than 5 degrees is relevant, as perhaps in elite athletes, then clinicians will need to use a more sophisticated measuring instrument such as video-image analysis or electrogoniometry.

It would not be easy to clarify the functional significance of various magnitudes of quadriceps lag. Optimally it would be best to undertake a longitudinal epidemiological study, with observation of knees (and their quadriceps lags) over a period of several years. Then it would be possible to see how important the quadriceps lag was amongst a range of other factors likely to be implicated in symptomatic/functionally deficient knees.

**Conclusion**

Forty-seven percent of 64 healthy young adults had a quadriceps lag of at least 2 degrees at the instant of maximum
active extension in sitting, which increased to 89% after 5 sec. Thus some degree of quadriceps lag must be considered normal. Between 0 and 5 sec of active extension, the quadriceps lag increased by on average 4.1 degrees. It is therefore recommended that care be taken to ensure a constant method of repeat testing where particular attention is given to: 1) the time involved in deriving a measure of the maximum active knee extension, 2) the effects of gravity during the active test phase, and 3) the force used to generate the passive extension limit.

Footnotes (a)PEAK Performance Technologies Inc, 7388 S. Revere Parkway, Suite 901, Centennial, Colorado, CO 80112, USA

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