Comparison of Three Methods of Assessing Muscle Strength and Imbalance Ratios of the Knee

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Abstract: *Three strength measurement methods for determining muscle strength and imbalance ratios of the knee were compared in 41 (23 female, 18 male) NCAA Division I track and field athletes. Peak quadriceps extensions and hamstring flexions were measured isotonically, isometrically, and isokinetically. Isokinetic measurements were performed on a Cybex II at 60°/s. Isometric extension and flexion measurements were performed using the Nicholas Manual Muscle Tester (Lafayette Instruments; Lafayette, Ind). Isotonic measurements were done on both Universal and Nautilus apparatuses. Testing order was randomized to avoid a treatment order effect. A repeated measures ANOVA and a post hoc Tukey test were used to compare the three methods of assessing strength and imbalance ratios of the knee. Absolute strength values were significantly different according to gender and mode of testing. Bilateral strength imbalance ratios for knee flexion were significantly lower for the Nautilus leg curl machine. Ipsilateral strength imbalance ratios were significantly greater for the Cybex II. Our results indicated that absolute strength values cannot be interchanged between testing modes. Except for Cybex II (ipsilateral) and Nautilus (bilateral knee flexion), strength imbalance ratios could be interchanged.*

The term "muscular strength" usually refers to a measure describing an individual's ability to exert maximal muscular force, either statically or dynamically. Traditionally, muscle strength is measured by three different methods: isometric, isotonic, and isokinetic.[6,8] All three methods determine the amount of external load that is overcome as the muscle attempts to contract against resistance. In isometric strength testing, the muscle acts against an immovable resistance at a specific joint angle. Isotonic exercise allows for a complete range of motion, although maximal muscle demand occurs during only a small portion of the movement. Isokinetic strength testing does allow for full muscle tension throughout the range of motion, while holding the speed of movement constant.[6,12] Because isometric, isotonic, and isokinetic strength testing requires a maximum muscle contraction, a strong relationship would be expected among these three modes of testing. However, while some studies have found moderate to high correlations,[2,4,7,8,15] other studies have not produced the same results.[3,8,13-15]

Although isometric and isotonic testing methods are being used, the isokinetic procedure is now the most widely accepted evaluation technique. Unfortunately, isokinetic equipment is expensive and not readily accessible to most athletes. Therefore, the purpose of this study was to compare the three methods of measuring strength to determine if absolute strength values and strength imbalance ratios could be interchanged between testing modes.

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Methods

Forty-one NCAA Division I varsity track and field athletes (23 female, 18 male) volunteered to participate in this study. None of the athletes had sustained a knee injury. We informed the subjects of risks associated with the testing, and they gave informed consent prior to participation. One procedure was performed on each testing day, and no less than 3 days' rest was given between testing sessions.

Isometric Testing Procedures

We used the Nicholas Manual Muscle Tester (Lafayette Instrument; Lafayette, Ind) to test maximal isometric knee extension and flexion. For knee extension, the subject sat in a Cybex chair. The angle between the back and the seat of the Cybex chair was 110°. The subject was secured with velcro straps across the chest, directly under each arm, across the pelvis, and over the thigh at a point 6 to 8 cm proximal to the superior aspect of the patella. Each strap was adjusted to ensure subject stability and to prevent extraneous movement. With the knee fully extended, the Manual Muscle tester was placed between the examiner's hand and the subject's leg, four to six cm proximal to the malleoli (Fig 1). We applied a downward force over 1 second to allow the subject to adjust and recruit the maximum amount of muscle fibers. Additional force was applied until the muscle contraction

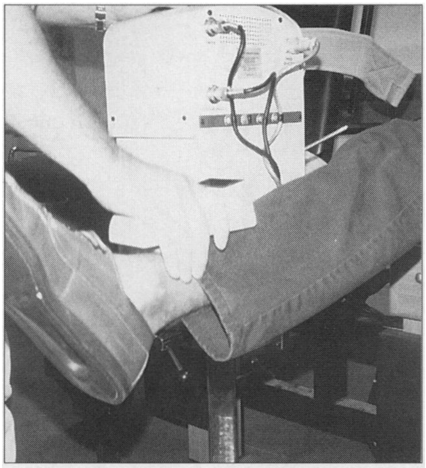

Fig 1.—Starting position for knee extension isometric testing using the Manual Muscle Tester.

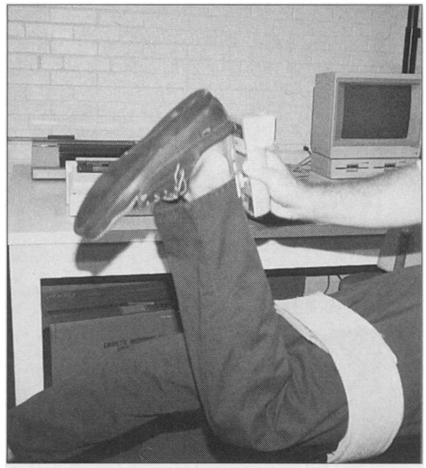

Fig 3.—Starting position for knee flexion isometric testing using the Manual Muscle Tester.

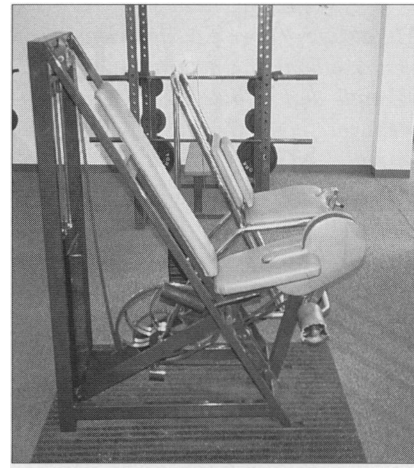

Fig 5.—Nautilus leg extension machine.

began to break and the limb began to lower. Further force completely lowered the limb, and the test ended before the limb touched the Cybex chair (Fig 2). We instructed the subject that the test was over when the limb had been lowered. Testing lasted no longer than 3 seconds. The peak force achieved was recorded as the maximum strength effort for that motion.[1,10]

To test maximal knee flexion, subjects lay prone on the Cybex II Upper Body Exercise and Testing Table. Velcro straps across the back, directly under each arm, across the pelvis, and over the thighs at a point 6 to 8 cm proximal to the superior aspect of the patella secured the subject. Each strap was adjusted to ensure subject stability and to prevent extraneous movement. With the knee fully flexed, we placed the Manual Muscle Tester between the examiner's hand and the subject's leg, 4 to 6 cm proximal to the malleoli (Fig 3). We applied a downward force using the same techniques described earlier and ending before the limb touched the testing table. The peak force achieved was recorded as the maximum strength effort for that motion.[1,10]

Isotonic Testing Procedures

One repetition maximum (1RM) isotonic strength was measured with both Universal (Universal Gym Equipment, Inc; Cedar Rapids, Iowa) and Nautilus (Nautilus Sports/Medical Industries; Deland, Fla). Leg Extension and Leg Curl machines (Figs 4-6). The subjects warmed up for 5 minutes prior to testing. Leg order and movement were randomized to avoid a treatment order effect.

To measure quadriceps strength, the subject sat on the Leg Extension machine with the knee flexed at a 90° angle (full extension = 0°), with the lever arm of the device resting on the tibia of the lifting leg just proximal to the malleoli. To measure hamstring strength, the subject lay prone on the Leg Curl machine, with the lever arm across the Achilles tendon of the lifting leg. The maximum amount of weight

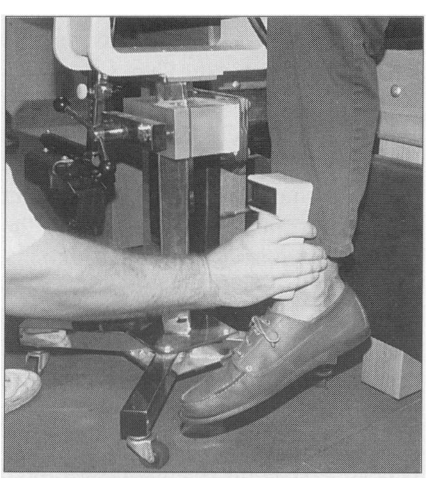

Fig 2.—Ending position for knee extension isometric testing using the Manual Muscle Tester.

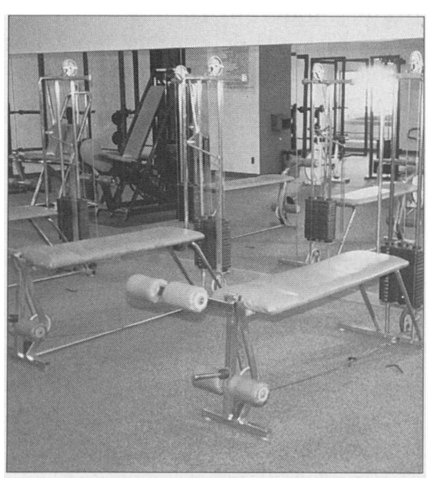

Fig 4.—Universal leg extension/curl machine.

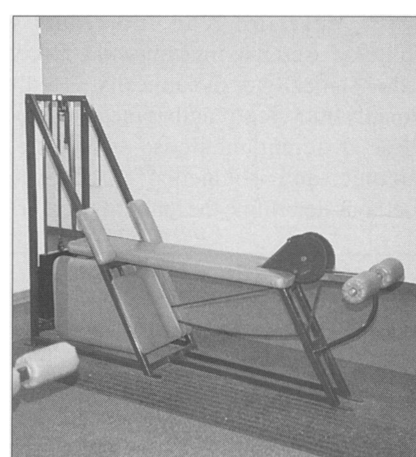

Fig 6.—Nautilus leg curl machine.

Table 1.—Knee Flexion and Extension Strength Measures (Mean ± SD)

Mode	Males* (lbs; n=18)		Females* (lbs; n=23)	
	dominant	nondominant	dominant	nondominant
Knee Extension (Quadriceps)				
Cybex II	190.0±34.1	188.3±36.9	123.1±18.4	124.5±19.7
Manual Muscle Tester	124.2±27.1	121.7±26.4	87.6±16.1	84.2±20.4
Nautilus	105.6±22.8	105.6±23.3	66.1±12.3	61.7±14.0
Universal	76.1±25.0	74.4±27.3	42.2±11.3	41.7±11.9
Knee Flexion (Hamstrings)				
Cybex II	117.3±22.0	115.4±21.8	76.4±13.2	76.1±11.7
Manual Muscle Tester	69.0±13.0	69.7±16.2	47.1± 8.4	47.2 ± 7.9
Nautilus	54.4±13.4	52.8±14.1	37.4± 9.6	33.9±10.3
Universal	40.6±11.6	38.3±12.0	22.6± 8.1	21.7± 8.3

*Males and females different (p<.05)

Table 2.—Strength Imbalance Ratios of the Knee

Mode	Knee Flexion Dominant vs nondominant (%)	Ham/quad (%)
Manual Muscle Tester	100.8	56.7
Cybex II	99.5	61.9*
Universal	96.1	54.0
Nautilus	93.2*	53.9

*Statistically different from other 3 (p<.05)

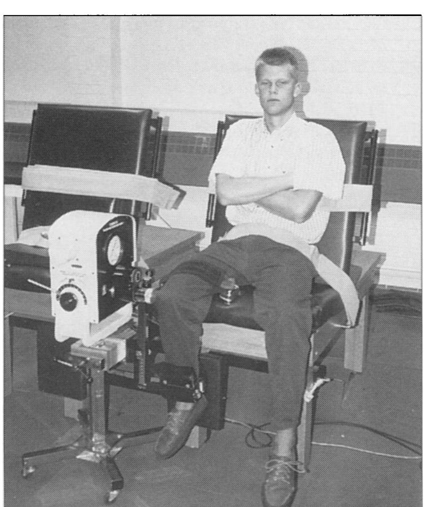

Fig 7.—Cybex II isokinetic testing device.

that could be moved through a 90° range of motion in 3 seconds and held for a duration of 2 seconds was recorded as the one repetition maximum (1RM).[12]

Isokinetic Testing Procedures

Isokinetic testing was conducted using a Cybex II. The angle between the back and the seat of the Cybex chair was 110°. The subject was secured by velcro straps across the chest, directly under each arm, across the pelvis, and over the thigh at a point 6 to 8 cm proximal to the superior aspect of the patella. We adjusted each strap to assure subject stability and to prevent extraneous movement. The shin pad of the dynamometer was adjusted for leg length so that the lower edge of the pad was 4 to 6 cm proximal to the malleoli and secured to the tibia by a strap around the lower leg. We aligned the rotational axis of the knee joint with the input shaft of the dynamometer. Subjects were asked to cross their arms over their chest (Fig 7).

Testing began after a 5-minute dynamic warm-up consisting of knee extension and flexion against minimal resistance. The speed selector was set at 60°/s. A damping setting of two and chart speed of 5 mm/s was used. Three maximal extension-flexion trials in succession were performed. The highest torque generated in each movement was recorded from the strip chart recording. We did not correct for the effect of gravity.[7,12]

A repeated measure ANOVA and a post hoc Tukey test were used to compare the three methods of assessing strength and imbalance ratios of the knee.

Results

Knee flexion strength of the dominant leg ($\bar{x}$=56.6 lb) was significantly greater than the nondominant leg ($\bar{x}$=55.4 lb; F[1,39]=5.39, p=.03). There was no difference in knee extension strength between dominant and nondominant legs (F[1,39]=.01, p=.91). There was no interaction, however, between leg strength and either gender or testing technique for either knee flexion (F[3,117]=0.90, p=.44) or knee extension (F[3,117]=1.04, p=.38). Therefore, dominant and nondominant strength measurements were combined.

There was a significant interaction between gender and testing technique (mode); each mode was significantly different from each other, and males were significantly stronger than females (Table 1; Knee flexion, F[3,117]=16.29, $p \leq .0001$; Tukey p<.05; Knee extension, F[3,117]=11.12, $p \leq .0001$; Tukey p<.05). Knee extension strength of dominant and nondominant legs was not significantly different (F[3,117]=1.04, p=.38) with either gender and testing technique.

The bilateral strength imbalance ratios for knee extension were not different between testing devices (modes) (F[3,117]=1.42, p=.42) or gender (F[1,39)]=0.35, p=.56). Knee flexion showed a significant difference between testing technique (mode); Nautilus recorded significantly lower than the other three modes (Table 2; $F[3,117]=3.40$, $p=.02$; Tukey $p<.05$).

The ipsilateral strength imbalance ratios for knee flexion/extension showed a significant difference between testing devices (mode); Cybex II produced significantly greater ratios than the other techniques ($F[3,117]=7.65$, $p\leq.0001$; Tukey $p<.05$) (Table 2). There was no significant difference ($F[1,39]=0.15$, $p=.70$) for gender.

Reliability for the Manual Muscle Tester and Cybex II were .96 and .97, respectively.

Discussion

Isometric, isotonic, and isokinetic strength testing methods have been studied extensively. A limited number of studies, however, have compared the three methods.[5,7,9,11,12] These studies indicate that the absolute strength values of the three measurement techniques are unique in what they measure and should not be generalized from one method of strength assessment to another. Our results confirm this (Table 1). The higher absolute measures of both the Cybex II and the Manual Muscle tester might be attributed to what and how they measure strength. The Cybex II measurements of foot- pounds were not converted to pounds, and the Manual Muscle Tester measured an eccentric contraction instead of a concentric, as described by Nicholas.[1] Eccentric contractions have been shown to record higher contractile strength than concentric. Further studies are indicated to compare these three absolute measurements.

Even though the absolute strength values between testing techniques were significantly different, the information gained from testing muscular strength can be used to assess an athlete's muscular strength imbalance. The ratio of strength of the antagonist to agonist is used for determining an ipsilateral muscle imbalance, while the contralateral strength of the corresponding muscles is used to determine bilateral imbalance.

Except for Nunn and Mayhew,[12] previous studies have not compared the three methods of strength evaluation for computing muscle imbalance ratios. Reliability for the Manual Muscle Tester and Cybex II was determined by the test/retest method. The retest was recorded 3 days prior to the initial test. We did not perform a retest for both the Nautilus and Universal leg machines. Therefore, reliability for these modes was not determined for this study. Even though the absolute strength values among the three methods might be different, if the proportion of strength between the hamstrings and quadriceps was constant, the bilateral and ipsilateral muscle strength ratios would be comparable.[5,12] The various methods then could be used interchangeably in evaluating muscle strength imbalance in athletes. In the study by Nunn and Mayhew,[12] none of the bilateral imbalance ratios were significantly different for the three methods tested, isometric (Cybex II), isotonic (Nautilus), and isokinetic (Cybex II).

Our study differs in that the Manual Muscle tester was used for isometric testing in place of the Cybex II, and that Universal isotonic measurements were also collected. Our results agree with Nunn and Mayhew[12] that isometric, isotonic (Universal and Nautilus), and isokinetic (Cybex II) could be used interchangeably to evaluate the bilateral muscle strength imbalance for knee extension. However, the Nautilus showed a significantly lower bilateral ratio for knee flexion than the other methods tested (Table 2) and should not be used interchangeably. For ipsilateral strength ratios, however, the isokinetic (Cybex II) method produced significantly greater values of measurement than the other methods (Table 2). Nunn and Mayhew[12] reported the same results for ipsilateral strength ratios. According to our results, the isokinetic (Cybex II) ipsilateral strength ratios should not be used interchangeably with other strength measurement techniques.

We conclude that:

1. bilateral strength imbalance ratios for knee extension can be determined using either isometric (Manual Muscle Tester), isotonic (Universal or Nautilus), or isokinetic (Cybex II) techniques interchangeably;
2. bilateral strength imbalance ratios for knee flexion can be determined using either isometric (Manual Muscle tester), isotonic (Universal), or isokinetic (Cybex II) techniques interchangeably; and
3. ipsilateral strength imbalance ratios of the knee can be determined using either isometric (Manual Muscle Tester) or isotonic (Universal or Nautilus) techniques interchangeably.

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