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Concentric Versus Enhanced Eccentric Hamstring Strength Training: Clinical Implications

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Objective: Hamstring injuries can be quite debilitating and often result in chronic problems. Eccentric muscle actions are often the last line of defense against muscle injury and ligament disruption. Traditionally, the focus of hamstring strength rehabilitation has been on concentric muscle actions. The purpose of our study was to compare hamstring muscle strength gains in concentric and eccentric hamstring strength training.

Design and Setting: A randomized-group design was used to examine differences in 1-repetition maximum (1RM) and isokinetic strength values among 3 groups of subjects. Subjects were tested in a biomechanics laboratory using an isokinetic dynamometer, while training was carried out in a physical therapy outpatient clinic.

Subjects: Twenty-seven healthy male subjects (age = 22.9 ± 3.1 years, wt = 81.8 ± 12.9 kg, ht = 178.6 ± 7.2 cm) participated in this study. Subjects were randomly assigned to 1 of 3 treatment groups: eccentric training, concentric training, or control.

Measurements: Subjects performed hamstring curls using an isotonic weight training device. Pretest 1RM weight values were determined for all subjects using a standardized 1RM protocol. In addition, maximum concentric and eccentric isokinetic strength values for knee-flexion strength were determined. Control group subjects refrained from weight training for 6 weeks. Subjects in the training groups trained 2 days per week for 6 weeks (12 sessions). After 6 weeks of training, all subjects returned for 1RM and isokinetic posttesting.

Results: The concentric group improved 19%, while the eccentric group improved 29%. The control group subjects did not show any significant change over the 6 weeks. In addition, there were improvements in eccentric isokinetic peak torque/body weight ratios at both 60°/s and 180°/s from pretesting to posttesting in the eccentric training group only.

Conclusions: Our results demonstrate the effectiveness of isotonic strength training on the development of hamstring muscle strength. More important is the dramatic effect of eccentric strength training on overall hamstring muscle strength, both isotonic and isokinetic. Clinicians should consider using eccentric hamstring strengthening as part of their rehabilitation protocols for hamstring and knee injuries.

Key Words: 1RM, peak torque/body weight ratios, enhanced eccentrics, isotonic, isokinetic

Hamstring injuries are a common and often debilitating occurrence among athletes performing demanding eccentric maneuvers. Many causative factors for these injuries have been suggested, including hamstring weakness, decreased flexibility, and improper flexor/extensor ratios.[1,2] Some studies have suggested that poor eccentric hamstring strength is a predisposing element to hamstring injuries in sprinting athletes.[3,4] Jonhagen et al[3] revealed a significantly higher hamstring eccentric peak torque in noninjured versus previously injured groups. Hamstring muscle strain injuries most frequently occur during the eccentric phase of an activity.[5–8]

Hamstring strength training has been widely used in the prevention and rehabilitation of hamstring strains. Because eccentric muscle actions are often the last line of defense against muscle injury and ligament disruption, an interest in determining the most efficient and effective method of training this muscle group has surfaced.[9–11] Previous works comparing strength gains after eccentric and concentric training are mixed. Numerous studies[12–15] have concluded that eccentric muscle actions are more efficient than concentric contractions. Eccentric muscle actions are capable of producing higher forces[13,15,16] at approximately 20% less oxygen consumption, carbon dioxide production, and energy expenditure than equal bouts of concentric work.[10,15,17] In a study examining elbow flexors, Komi and Buskirk[18] showed significant concentric strength gains for both isotonic concentric and eccentric training groups, but found that the eccentric group increased strength to a greater degree than the concentric group. Ellenbecker et al[19] compared isokinetic eccentric and concentric training of shoulder internal and external rotators and concluded that eccentric isokinetic training produced the greatest increases in concentric strength. Several studies[20–23] examining strength in various upper and lower extremity muscle groups, including knee extensors and flexors and elbow flexors, showed significant concentric strength gains for both eccentric and concentric training but found no significant differences between training groups. Other studies have suggested that strength gains are mode specific and therefore concluded that the greatest concentric strength gains are obtained with concentric training and the greatest eccentric gains with eccentric training.[24,25]

The potential benefits of eccentric training have been previously recognized by Garrett,[26] who demonstrated the capacity of muscles to act as energy absorbers in preventing injury to muscles and to associated bones and joints. He described a 2-component system of energy absorption composed of both passive and active elements. The passive components of stretched muscle have the ability to absorb energy, but the potential to absorb energy is greatly increased by active contraction of the muscle. His findings suggested 100% higher energy absorption before failure in activated muscles compared with nonactivated muscles. The ability of a muscle to withstand force and strain is a measure of the energy absorbed by the muscle before failure; therefore, increased eccentric strength can improve a muscle's ability to withstand force and strain without failing.[10,26] However, attempts to quantify and develop specific training protocols have often been limited by improper resistance methods, which have caused delayed-onset muscle soreness (DOMS).[27] Previous eccentric studies[20,28] have used isokinetic training rather than isotonic training or have been concentrically limited by design, using eccentric loads less than the concentric 1-repetition maximum (1RM) value. These studies have not permitted controlled, incremental increases in resistance for optimal eccentric training effects to take place. Few studies have been performed using eccentric training with eccentric loads equal to or greater than the concentric 1RM value.[21]

The purpose of our study was to examine the strength gains associated with a traditional, concentrically limited, hamstring strength-training protocol and an enhanced eccentric strengthening program using eccentric loads equal to the concentric 1RM value. We hypothesized that by removing the concentric limitations and permitting increased demands on the stronger eccentric muscle component, greater strength gains would result. By applying a known, incremental, and safe resistance (concentric 1RM value) during the eccentric phase of training, we theorized that a more intense stimulus for muscle strength gains would be achieved.

METHODS

Twenty-seven male students volunteered to participate in this study. All subjects filled out a preparticipation health status questionnaire to determine eligibility. Parameters for inclusion were no previous injuries to the hamstrings or knee or hip joints, no history of performance-enhancing drug use, no weight training of the lower extremity during the past 6 months, and no previous illness or condition limiting participation. Each eligible subject then completed an informed consent agreement approved by the University of Florida Institutional Review Board and a subject data questionnaire. Subjects were randomly assigned to 1 of 3 treatment groups. The control group (age = 22.4 ± 1.8 years; ht = 181.0 ± 7.6 cm; wt = 87.1 ± 15.4 kg), eccentric training group (age = 22.9 ± 3.8 years; ht = 178.2 ± 6.6 cm; wt = 78.7 ± 6.3 kg), and concentric training group (age = 23.3 ± 3.5 years; ht = 176.6 ± 7.5 cm; wt = 79.4 ± 14.6 kg) each consisted of 9 subjects. Lower extremity dominance was determined by asking participants which leg they would use to kick a ball.

Instrumentation

We determined 1RM data using a Cybex (Cybex Division, Lumex, Inc, Ronkonkoma, NY) isotonic prone hamstring-curl apparatus equipped with the Negator (Myonics Corporation, Metairie, LA) eccentric-loading counterbalance weight system (Figure 1). This system allows for muscle group isolation and independent selection of concentric and eccentric resistance, without changing the existing variable resistance machinery of the leg-curl apparatus. However, a materials engineer modified the shape of the existing cam from its original design to better replicate an average hamstring strength curve, thereby increasing the mechanical advantage during performance of the hamstring curl. By doing this, we were able to make the resistance curve closely match the average strength curve for knee flexion.

We determined isokinetic strength data using a KinCom 125 AP (Chattanooga Group, Hixson, TN) isokinetic dynamometer. We calibrated the dynamometer according to the manufacturer's recommendations before each testing session. The

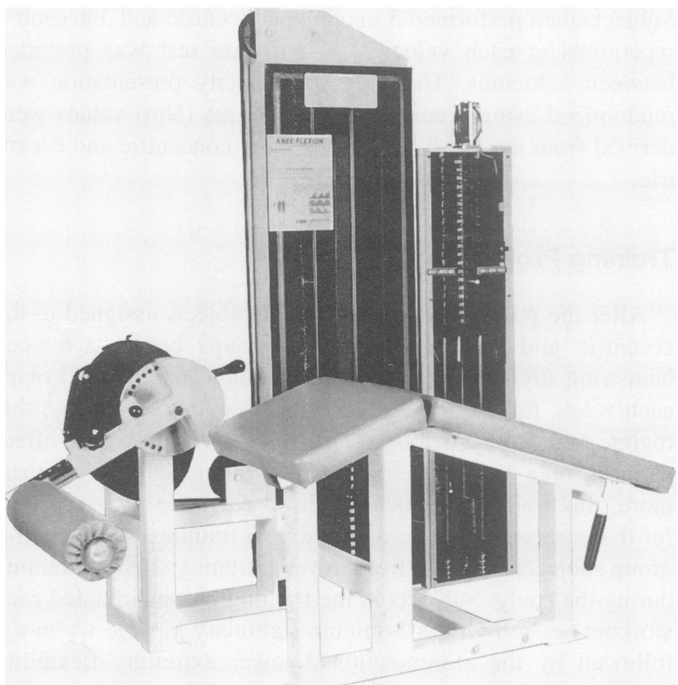

Figure 1. Negator enhanced eccentric isotonic device attached to a leg-curl machine.

isokinetic dynamometer is capable of measuring isokinetic force outputs for both eccentric and concentric muscle actions. We implemented gravity correction procedures according to the manufacturer's recommendations.

Test Procedures

Subjects reported for isotonic 1RM and isokinetic strength pretesting on 2 separate occasions. Each session began by having the subject perform a 3-minute warm-up on a stationary bicycle. Then each subject performed a series of lower extremity flexibility exercises, including hamstring, quadriceps, and calf stretches. Each stretch was performed 3 times and held for 15 s.

We tested isotonic 1RM on the Cybex isotonic prone hamstring-curl apparatus equipped with the Negator counterbalance device using a standardized 1RM protocol.[29] Each hamstring curl was performed with the dominant leg. Subjects were tested in the prone position with stabilization over both hips to minimize unwanted muscle substitution. 1RM values were obtained from concentric hamstring muscle actions only.

We tested isokinetic knee flexion strength on the KinCom 125 AP isokinetic dynamometer. We obtained concentric and eccentric peak torque values at test velocities of 60°/s and 180°/s. Subjects were seated in the dynamometer chair with the body securely fastened to the seat and the thigh held firmly by the thigh stabilizer. The knee flexion maneuver began with the knee at 5° from full extension and proceeded through a range of 85°. Subjects performed 3 submaximal and 3 maximal warm-up repetitions before testing at each velocity. A 1-minute rest was provided between warm-up and test repetitions. Subjects then performed 3 maximal concentric and 3 eccentric repetitions at each velocity. A 2-minute rest was provided between velocities. The order of velocity presentation was randomized using a coin flip. Peak torque (Nm) values were derived from the 3 test repetitions, both concentric and eccentric.

Training Procedures

After the pretesting sessions, those subjects assigned to the eccentric and concentric training groups began a 6-week hamstring strength-training program. Subjects exercised twice each week, for a total of 12 training sessions. We chose this regime based on previous studies that have shown the effectiveness of a twice-weekly training frequency.[30,31] Furthermore, this training frequency allows adequate recovery time for tissue repair after eccentric strength training.[32] The control group subjects refrained from lower extremity strength training during the study. Subjects in the training groups initiated each workout session with a 3-minute stationary bicycle warm-up, followed by the aforementioned lower extremity flexibility program. Each group started with 1 set of 8 repetitions using 50% of their predetermined 1RM value. The concentric and eccentric loads were equal during this warm-up set. Following the warm-up set, those subjects in the concentric training group performed 2 sets of 8 repetitions using a weight equal to 80% of their 1RM value. Those subjects in the eccentric training group also performed 2 workout sets of 8 repetitions; however, the concentric load was placed at 40% of the 1RM value and the eccentric load was placed at 100% of the 1RM value for both sets. A 1-minute rest period was given between sets. At the end of each workout session, the subjects were asked to assess their perceived level of exertion using the modified Borg scale.[33] Training sessions were separated by a 2-day rest period (Monday-Thursday or Tuesday-Friday).

If the subject was able to complete both training sets of 8 repetitions without failure and had a perceived level of exertion of less than 8, we increased the 1RM value by 5.44 kg (12 lb) (1 Cybex stack weight). The next hamstring-strengthening workout would then begin using this adjusted 1RM value. The concentric training group, therefore, maintained a workout load equal to 80% of their adjusted 1RM value at all times, while the eccentric group maintained a concentric:eccentric load ratio of 40% and 100% of the adjusted 1RM value, as previously mentioned. In addition, the 8-repetition warm-up set was sustained at 50% of the adjusted 1RM value. If the progression criteria were not met, the subject repeated the same workout during the next training session.

Upon returning for each subsequent training session, subjects were asked to report their level of muscle soreness (none, mild, moderate, severe) and whether or not that soreness limited their activities (none, mild, moderate, severe) between training sessions.

Subjects in each of the 3 groups returned at the end of the 6-week training period for posttesting. Posttesting procedures were performed in exactly the same manner as pretesting. Each subject then completed a poststudy questionnaire determining compliance, perceived level of progression, muscle soreness, and incidence of low back pain.

Statistical Analysis

We used the SPSS for Macintosh Release 6.1.1 (SPSS Inc, Chicago, IL) statistical package to analyze the data. 1RM/body weight (BW) ratios (kg/kg) and isokinetic peak torque (PT)/BW ratios (Nm/kg) served as the dependent measures. Separate mixed-model repeated-measures analyses of variance (ANOVAs) were used to determine if any differences existed between the pretest and posttest conditions among the groups for both dependent measures. For the 1RM/BW ratio measures, the between-subjects factor was group status (control, concentric training, or eccentric training) and the within-subjects factor was test (pretest and posttest). We analyzed the isokinetic PT/BW ratio measures using separate ANOVAs for the concentric and eccentric muscle actions at both 60°/s and 180°/s. In each ANOVA, the between-subjects factor was group status (control, concentric training, or eccentric training) and the within-subjects factor was test (pretest and posttest). We used level of muscle soreness as the dependent measure to determine if differences in muscle soreness existed among the 3 groups. We set an a priori alpha significance level at $P \leq .05$.

We assigned muscle soreness a number value to correspond with the participant's answer (0 = none, 1 = mild, 2 = moderate, and 3 = severe). We used a Wilcoxon rank sum procedure to analyze the nonparametric muscle soreness values. The significance level was set at $P \leq .05$.

RESULTS

1RM/BW ratios improved 28.8% in the eccentric training group and 19.0% in the concentric training group from the pretest starting values after 6 weeks of hamstring strength training. There was no notable change in the control group. The 1RM/BW ratio ANOVA revealed a significant group-by-test interaction ($F_{2,24} = 20.20$, $P < .001$; Figure 2). Tukey post hoc tests showed significant differences between the mean 1RM/BW ratios for pretest and posttest measures in both the eccentric and concentric training groups. There was no change in the pretest to posttest mean 1RM/BW ratio in the control group.

Eccentric isokinetic PT/BW ratios at both 60°/s and 180°/s improved 37.7% and 22.0%, respectively, from pretesting to posttesting in the eccentric training group only. The eccentric isokinetic PT/BW ratio ANOVA revealed a significant group-by-test interaction at both 60°/s ($F_{2,24} = 6.11$, $P = .007$; Figure 3) and 180°/s ($F_{2,24} = 5.88$, $P = .008$; Figure 4). The Tukey post hoc tests detected a significant increase in the PT/BW ratios from pretest to posttest mean values in the eccentric training group only, at the velocities of 60°/s and 180°/s. There were no significant changes in eccentric PT/BW ratios in either the concentric training group or the control group. Our results suggest that concentric strength training alone does not improve eccentric isokinetic PT/BW ratios.

Interestingly, when the concentric isokinetic PT/BW ratios were analyzed, no significant interactions occurred between group and test factors ($F_{2,24} = 1.55$, $P = .233$) at 60°/s and ($F_{2,24} = 1.35$, $P = .279$) at 180°/s. There were some trends that indicated improvements in concentric isokinetic PT/BW ratios in both the eccentric and concentric training groups (Table).

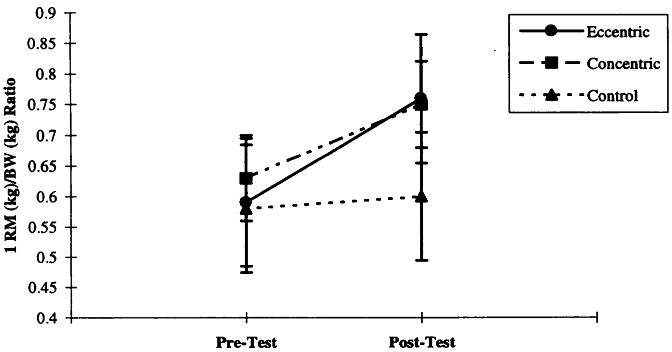

Figure 2. Graphic representation of the significant group (eccentric training, concentric training, and control)-by-test (pretest and posttest) interaction for 1RM/BW ratios.

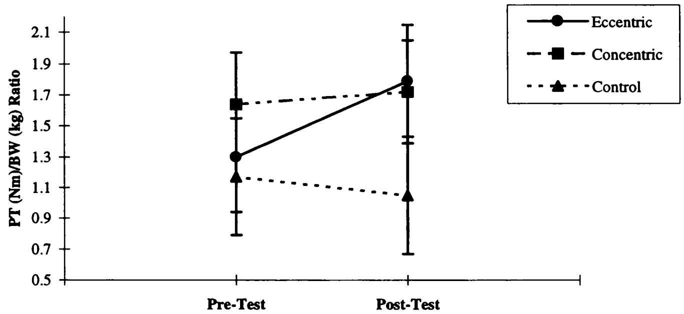

Figure 3. Graphic representation of the significant group (eccentric training, concentric training, and control)-by-test (pretest and posttest) interaction for eccentric PT/BW ratios at 60°/s.

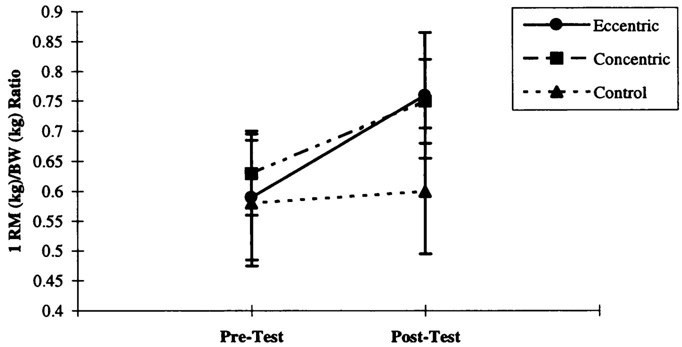

Figure 4. Graphic representation of the significant group (eccentric training, concentric training, and control)-by-test (pretest and posttest) interaction for eccentric PT/BW ratios at 180°/s.

Concentric Isokinetic PT (Nm)/BW (kg) Ratios in the Three Training Groups from Pretest to Posttest (means ± standard deviations)

Training Group	Pretest 60°/s	Posttest 60°/s	Pretest 180°/s	Posttest 180°/s
Eccentric	1.15 ± .09	1.35 ± .26	1.04 ± .21	1.30 ± .21
Concentric	1.15 ± .22	1.31 ± .20	1.21 ± .20	1.24 ± .21
Control	1.02 ± .25	1.05 ± .23	.90 ± .26	1.03 ± .26

These results suggest that isotonic concentric and eccentric strength training have little effect on concentric isokinetic PT/BW ratios.

Muscle soreness values for the eccentric training group averaged 0.25 ± 0.51, while those in the concentric training group averaged 0.07 ± 0.26. The control group had no soreness. The results of the Wilcoxon rank sum procedure indicated that a significant difference in DOMS was evident on day 1 between the groups ($P = .012$). However, no significant differences in DOMS existed between the groups for successive training days.

DISCUSSION

The results of our study support the premise that isotonic eccentric overload training may increase concentric strength to a greater degree than concentric training. Our findings contradict an earlier study by Johnson,[20] which suggested that no significant differences in strength gains were evident between concentric and eccentric training groups. In his study involving eccentric and concentric quadriceps strengthening, the training resistance was set at 80% of the 1RM value for both groups. This design failed to incorporate the concept of eccentric training equal to the concentric 1RM value. In a later study, Johnson et al[21] used eccentric loads of 120% of 1RM value vs concentric training loads of 80% of 1RM value. Once again, the results suggested no superiority of one training method over another. One possible explanation is the difference in eccentric training loads (120% versus 100% of 1RM value) used. Another possible explanation for the contradictory findings is that DOMS may have inhibited optimal strength gains. We monitored DOMS closely throughout our study and found it to be significantly different on day 1 only. However, the DOMS was not a limiting factor with progression or testing during the 6-week training period in any of the eccentric training group subjects. Our results suggest that an enhanced eccentric strengthening program using eccentric loads equal to the concentric 1RM value can be performed twice a week without the subject's being deterred by DOMS. Differences in training devices may also be responsible for the conflicting findings. Johnson et al[21] used a spring-loaded apparatus for knee flexion training as opposed to the Negator training device that we used. It would seem that using the spring-loaded device would make it difficult to control for the amount of resistance applied during the knee-flexion maneuver, whereas the enhanced eccentric device we used provides an incremental means of quantifying and separating concentric and eccentric loads.

Eccentric isotonic training produced significant improvements in eccentric isokinetic strength, while concentric isotonic training created no significant eccentric isokinetic strength gains. Neither training method resulted in significant concentric isokinetic gains. Our finding supports that of Housh et al,[11] who suggested that eccentric isotonic resistance training of the quadriceps musculature produced no significant concentric isokinetic strength gains at any velocity. Theirs appears to be the only research article that has examined isokinetic strength gains from eccentric isotonic training. However, on closer examination of the mean PT/BW ratio values in our study, a trend existed at both 60°/s and 180°/s toward improved concentric isokinetic strength for both training groups. Coincidentally, this trend was more pronounced in the eccentric training group.

Ellenbecker et al[19] looked at isokinetic rather than isotonic training and found that eccentric isokinetic training produced the greatest increases in concentric isokinetic strength. Comparisons of our study with this study are somewhat limited due in part to the fact that they used isokinetic training instead of isotonic training. However, the findings of both studies support the concept of eccentric training producing greater concentric strength improvements than concentric training. In general, it seems plausible to recommend assessing strength-training gains using the mode of the most frequent strength-training method.

Most muscle strain injuries occur during eccentric muscle actions; therefore, improving eccentric strength may help to diminish risk of injury. As clinicians, we are very interested in finding the most optimal method of increasing eccentric strength. Our isokinetic findings suggest that eccentric strength gains can be produced with eccentric isotonic training and not with concentric isotonic training. Duncan et al[24] supported this principle, concluding that eccentric isokinetic training gives specific eccentric gains, while concentric isokinetic training affects only concentric gains. Tomberlin et al[25] reported similar results, supporting the idea that strength gains are mode specific in isokinetic training. Our findings suggest that this may not be the case with isotonic eccentric training. We believe that safe, incremental eccentric training at 100% of the concentric 1RM value will produce the greatest concentric and eccentric isotonic strength gains. We recognize the limitations in reliability and safety with isotonic eccentric strength assessments and therefore are relying on isokinetic eccentric peak torque data to support this claim. Further studies with incremental eccentric training, including eccentric loads in excess of the concentric 1RM value are warranted. Long-term studies on injury prevention and rehabilitation with eccentric overload training are needed to truly confirm eccentric training as a vital component in injury prevention.

In summary, our findings suggest that isokinetic gains through isotonic training are limited, with the exception of eccentric isokinetic gains with eccentric isotonic training. Clinically, these findings are important to consider when one is trying to assess improvements in strength after isotonic training with isokinetic testing procedures.

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