

Concentric or eccentric training effect on eccentric exercise-induced muscle damage

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ABSTRACT

NOSAKA, K., and M. NEWTON. Concentric or eccentric training effect on eccentric exercise-induced muscle damage. *Med. Sci. Sports Exerc.*, Vol. 34, No. 1, 2002, pp. 63–69. **Purpose:** The purpose of this study was to compare changes in muscle damage indicators following 24 maximal eccentric actions of the elbow flexors (Max-ECC) between the arms that had been previously trained either eccentrically or concentrically for 8 wk. **Methods:** Fifteen subjects performed three sets of 10 repetitions of eccentric training (ECC-T) with one arm and concentric training (CON-T) with the other arm once a week for 8 wk using a dumbbell representing 50% of maximal isometric force of the elbow flexors (MIF) determined at the elbow joint of 90° (1.57 rad). The dumbbell was lowered from a flexed (50°, 0.87 rad) to an extended elbow position (180°, 3.14 rad) in 3 s for ECC-T, and lifted from the extended to the flexed position in 3 s for CON-T. Max-ECC was performed 4 wk after CON-T and 6 wk after ECC-T. Changes in MIF, range of motion (ROM), upper arm circumference (CIR), muscle soreness (SOR), and plasma creatine kinase (CK) activity were compared between the ECC-T and CON-T arms. **Results:** The first ECC-T session produced larger decreases in MIF and ROM, and larger increases in CIR and SOR compared with CON-T. CK increased significantly ($P < 0.01$) and peaked 4 d after the first training session, but did not increase in the following sessions. All measures changed significantly ($P < 0.01$) following Max-ECC; however, the changes were not significantly different between ECC-T and CON-T arms. **Conclusion:** These results showed that ECC-T did not mitigate the magnitude of muscle damage more than CON-T, and CON-T did not exacerbate muscle damage. **Key Words:** MAXIMAL ISOMETRIC FORCE, MUSCLE SORENESS, PLASMA CK ACTIVITY, CIRCUMFERENCE

Unaccustomed eccentric muscle activity is more likely to cause muscle damage than other types of muscular activity (1,4). It is well documented that subsequent bouts of the same eccentric exercise performed within several weeks after an initial bout result in significantly less damage (4,14,15). This protective effect against eccentric exercise-induced muscle damage is also produced when a smaller number of eccentric actions are performed in the initial bout (2,3). Compared with the protective effect produced by a single bout of eccentric exercise, the effect of long-term training against eccentric exercise-induced muscle damage has not been well established.

Eston et al. (8) showed that muscle soreness, the amount of strength loss, and increases in plasma creatine kinase (CK) activity after a downhill run were reduced when 100 maximal isokinetic eccentric actions were performed 2 wk before. This would suggest that a different mode of eccentric actions for the same muscle groups could produce the protective effect. It was observed in our previous studies that the extent of muscle

damage induced by maximal eccentric exercise of the elbow flexors was less for subjects who had previously experienced a similar, but not identical, type of eccentric muscle action of the elbow flexors. The maximal eccentric exercise, however, was unaccustomed to them. Fridén et al. (9) reported that muscle soreness, strength reduction, and myofibrillar damage following eccentric bicycling were reduced in repeated eccentric bicycle training. It seems likely that “training” will prevent or reduce muscle damage, even if the intensity of the eccentric exercise performed to elicit muscle damage is higher than that used during “training.” However, this has not been systematically investigated.

Because of the specificity of muscle adaptation to training, it is reasonable to assume that eccentric training could produce a greater protective effect against eccentric exercise-induced muscle damage than concentric training. In fact, it has been reported that concentric training does not reduce or prevent muscle damage (22,23). Interestingly, recent research has shown that concentric training may produce a negative effect on eccentric exercise-induced muscle damage (20,26). Whitehead et al. (26) examined the effect of 5 d of concentric training of the triceps surae (15 plantar flexions per minute for 30 min, for 5 d) on eccentric exercise (1 h of backwards walking). They found that the angle-torque curves for the triceps surae shifted

in the direction of longer muscle lengths more so for the muscle trained concentrically, which they used as an indicator of muscle damage. Ploutz-Snyder et al. (20) also reported that the quadriceps muscle trained only concentrically for 9 wk showed a larger decrease and slower recovery of strength and a greater area of muscle damage compared with the untrained leg.

In the present study, it was hypothesized that 1) elbow flexor muscles exposed to eccentric training for 8 wk using submaximal loads would become less susceptible to muscle damage produced by maximal eccentric exercise, compared with the muscles exposed to 8 wk of concentric training; and 2) 8 wk of concentric training would increase the susceptibility of elbow flexor muscles to eccentric exercise-induced muscle damage following subsequent exposure to maximal eccentric exercise. If this was the case, significantly faster recovery of force and range of motion, smaller increases in plasma CK activity, and less development of muscle soreness would be seen in the eccentrically trained arm as compared with the concentrically trained arm following subsequent maximal eccentric exercise.

METHODS

Experimental design. To examine the differences between eccentric and concentric training in relation to the protective effect against maximal eccentric exercise-induced muscle damage, 15 subjects performed eccentric training with one arm and concentric training with the other arm for 8 wk. The concentrically trained arm performed maximal eccentric exercise of the elbow flexors 4 wk after the training period, and the eccentrically trained arm performed the maximal exercise 2 wk later. Because responses to maximal eccentric exercise were compared between arms, the 2-wk separation between the two bouts was necessary to allow sufficient recovery from the first eccentric bout, specifically with regard to the increased muscle protein levels in the blood. To investigate whether a long-lasting protective effect against muscle damage is conferred by training, the maximal eccentric exercise was performed 4 or 6 wk after the last training session. Previous studies (4,14) have shown that even a single bout of maximal eccentric exercise can produce the protective effect that lasted more than 6 wk. Several indirect markers of muscle damage used in previous studies (4,16,17) were used as criterion measures, and changes in the measures were compared between the arms.

Subjects. Fifteen male students participated in this study after signing a written informed consent document consistent with ethical standards at Yokohama City University, which were in accordance with the policy statement regarding the use of human subjects as published by the American College of Sports Medicine. Their mean (\pm SD) age, height, and weight at the beginning of the study were 19.8 ± 1.9 yr, 169.7 ± 2.8 cm, and 58.9 ± 4.9 kg, respectively. There was no significant difference in the maximal isometric force of the elbow flexors (MIF), determined at an elbow joint angle of 90° (1.57 rad), between the eccentric training arm (164.2 ± 5.2 N) and concentric training arm (162.3 ± 7.7 N) before commencement of the study. No significant changes in height and weight were observed

during the experimental period. All subjects were free from any musculoskeletal disorders, and did not take antiinflammatory medicine or supplements during the experimental periods. Subjects were instructed not to perform any unaccustomed exercise or vigorous physical activities, other than the resistance training and maximal eccentric exercise required in the study, during the experimental period.

Training. A dumbbell representing 50% of MIF was used for both eccentric and concentric modes of training. The 50% load was used for the training because it had been observed in pilot work that the load equated approximately 10 repetition maximum (10-RM) for untrained male subjects performing eccentric or concentric actions of the elbow flexors in a slow controlled manner. Since maximal eccentric actions of the elbow flexors can produce larger force than maximal concentric action (7), the relative workload during eccentric training appeared to be smaller than that during concentric training. However, the same load was used for both concentric and eccentric training to equalize the absolute workload in this study. One arm lowered the dumbbell slowly from an elbow flexed (50° , 0.87 rad) to an extended position (180° , 3.14 rad) in 3 s, and the other arm lifted the dumbbell from the extended position to the flexed position in 3 s. Each eccentric (ECC-T) and concentric training (CON-T) session consisted of three sets of 10 repetitions with a 3-min rest between the sets. This training was performed once per week for 8 wk. The frequency of training was chosen on the basis of a previous study (18), which indicated that when a load equivalent to that of the present study was used with untrained subjects, recovery from the submaximal eccentric exercise took longer than 1 wk. Although the training might not have been frequent enough to obtain remarkable strength gains in 8 wk, it was reasoned that it would still be sufficient to observe an effect of training against muscle damage, since only a single bout of eccentric exercise has been shown to produce a protective effect (4,14). The ECC-T and CON-T arms were counterbalanced for dominant and nondominant arms among the subjects. The weight of the dumbbell was adjusted to 50% of MIF when MIF increased over the 8-wk training session, but no adjustment was made when MIF was decreased.

Maximal eccentric exercise. Subjects performed 24 maximal eccentric actions of the elbow flexors (Max-ECC) with the CON-T arm (4 wk after the last training bout) and 2 wk later with the ECC-T arm (6 wk after the last training bout). Max-ECC has been shown to induce muscle damage to the elbow flexors in previous studies, and the time course of changes in several markers of muscle damage has been well documented (3,17,18). Although 4 or 6 wk were set between the training (CON-T, ECC-T) and Max-ECC, it was reasoned that the effect of training on Max-ECC, if any, would be maintained for at least this time.

In Max-ECC, subjects sat on the bench, and the arm was positioned in front of the body on a padded support adjusted to 45° (0.79 rad) of shoulder flexion, and the forearm was kept supinated with the wrist placed against the lever arm. After 1 s of maximal isometric contraction, the forearm was forcibly extended from a half-flexed (100° , 1.74 rad) to an extended

elbow (180°, 3.14 rad) position in 3 s. Subjects were verbally encouraged to generate maximal isometric force at the flexed position and to maximally resist against the action throughout the range of motion. This action was repeated 24 times with 15 s of recovery between actions. During eccentric actions, the force of the elbow flexors was measured by a load transducer (9E01-L43, NEC San-ei Instruments, Tokyo, Japan) installed in a specially designed wrist attachment and monitored and recorded by a digital indicator (F360A, UNIPULSE, Saitama, Japan) and a computer (Macintosh Performa 5410, Apple Computer, Inc., Cupertino, CA). The peak force of each eccentric action was recorded from the digital indicator, and the work in each eccentric action was calculated as the integrated force for 3 s using a software program (LabVIEW, National Instruments, Austin, TX).

Criterion measures. MIF, relaxed (RANG) and flexed elbow joint angle (FANG) and range of motion of the joint (ROM), and circumference of the upper arm (CIR) were assessed immediately before and after, and 4 d after each training session, and immediately before and after, and for 4 d after the Max-ECC.

MIF was measured twice for 3 s (1 min between the measurements) by a load cell (Model 1269, Takei Scientific Instruments Co. Ltd., Niigata, Japan) located between cables, and connected to a digital recorder at an elbow joint angle of 90° (1.57 rad). MIF was determined by the average peak force for 1 s during the 3-s contraction, and the mean value of the two measurements was used for the analyses.

RANG and FANG were measured twice for each measurement by a goniometer, and the angle subtracting FANG from RANG was used as ROM of the elbow joint. CIR was assessed at 3, 5, 7, 9, and 11 cm from the elbow joint by a tape measure while allowing the arm to relax by the side, and the mean value of the five measurements was used for the analysis.

Muscle soreness on palpation of the upper arm and during flexion and extension of the elbow joint was evaluated by a visual analog scale (VAS) that had a 50-mm line with “no pain” on one end (0 mm) and “extremely painful” on the other (50 mm). Subjects were asked to mark their subjective scale of soreness on the line under the supervision of the examiner. The length of the line from 0 to the marked point provided a numeric measure of soreness. The VAS method has been established as a suitable method of assessing pain (21), and the 50-mm line has been used in previous studies (16,17). Muscle soreness (SOR) was evaluated before and for 4 d after each training session and after the damaging exercise.

Blood samples were taken from the antecubital vein before and 4 d after each training session and before and daily for 4 d after Max-ECC. Plasma CK was determined spectrophotometrically by the VP-Super System (Dynabot Co. Ltd., Tokyo, Japan) using a test kit (Dynabot). Since plasma CK activity has been shown to peak 72–120 h after eccentric exercise of the elbow flexors (4,17,18), the blood sample 4 d after training was considered to represent a peak. The normal reference ranges of plasma CK activity for male adults by this method are 45–135 IU·L⁻¹.

During the training period, B-mode ultrasound pictures of the elbow flexors were taken from the midbelly of the biceps

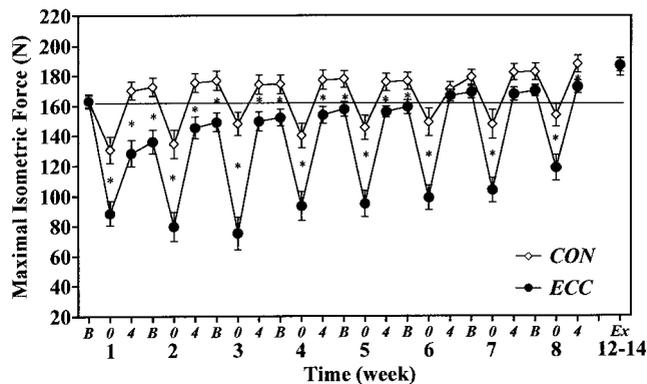


FIGURE 1—Changes in maximal isometric force over 8-wk training period. For each week (1–8), the data for immediately before (B), immediately after (0), and 4 d after exercise (4) are shown. The force at 4–6 wk after detraining period (weeks 12–14), when the maximal eccentric exercise was performed, is also plotted. Significant difference ($P < 0.05$) was found between concentric (CON) and eccentric (ECC) training arms. Difference between the CON and ECC for each data point is also shown. * $P < 0.05$.

brachii before, immediately after, and for 4 d after each training session by using the SSD-500 (Aloka, Co. Ltd., Tokyo, Japan) with a 7.5-MHz linear probe. To obtain the ultrasound images, the examiner placed the probe on the marked site on the upper arm while subjects were sitting on a chair with the forearm on an armrest, and found the transverse images by using the same references as in the preexercise image. The thickness of the elbow flexors was assessed on the ultrasound images by measuring the distance between the subcutaneous fat layer and the edge of the humerus. Maximal isokinetic torque was assessed before and 4 d after the fourth and eighth training sessions by an isokinetic dynamometer (Merac, Universal Gym Equipment, Inc., Cedar Rapids, IA) using angular velocities of 60°·s⁻¹, 120°·s⁻¹, and 180°·s⁻¹.

Statistical analyses. Changes in the criterion measures during the training and after the Max-ECC exercise were compared between the ECC-T and CON-T arms using a repeated measures ANOVA. The Tukey *post hoc* test was used to detect the differences between the arms for each time point. Significance level was set at $P < 0.05$ for all analyses.

RESULTS

Training effects. Figure 1 shows changes in MIF over the 8-wk training period. MIF changed significantly ($P < 0.01$) for both ECC-T and CON-T arms, with the changes being significantly different ($P < 0.01$) between them. The decrease in MIF from before to immediately after each training session was significantly ($P < 0.01$) larger for the ECC-T arm (30.5–49.3%; mean, 40.3 ± 5.6%) compared with the CON-T arm (15.6–21.2%; mean, 18.2 ± 2.4%). The recovery of MIF from immediately after to 4 d after the first training session was significantly smaller for the ECC-T arm (72.4% of before) compared with the CON-T arm (103.0% of before). In training sessions 2–8, however, MIF of both arms at 4 d after training was not significantly lower than each pretraining level. MIF of the ECC-T arm

did not recover to the pretraining level until week 6, and exceeded the pretraining level significantly ($P < 0.05$) at 4 d after the sixth training session. Compared with the ECC-T arm, the CON-T arm showed a significantly ($P < 0.01$) larger MIF until 4 d after the sixth training session. At the end of the training period (4 d after the eighth training session), increases in MIF were significantly ($P < 0.01$) larger for the CON-T arm (15% increase from the pretraining value (24.5 N)) compared with the ECC-T arm (6% increase from the pretraining value (9.8 N)). Detraining for 4–6 wk resulted in decreased MIF for the CON-T arm (-2.9 N) but increased MIF for the ECC-T arm ($+10.8$ N). This resulted in no significant difference in MIF between the arms before the damaging exercise bout.

Maximal isokinetic concentric torque (MIT) at the angular velocity of $60^\circ \cdot s^{-1}$ was the largest, followed by $120^\circ \cdot s^{-1}$, and $180^\circ \cdot s^{-1}$. Peak torque was recorded when the elbow joint angle was approximately 90° (1.57 rad). Before training, peak MIT at $120^\circ \cdot s^{-1}$ was 34.2 ± 1.5 Nm for the ECC-T arm, and 31.7 ± 1.3 for the CON-T arm. MIT increased significantly ($P < 0.05$) for the CON-T arm to 34.0 ± 1.3 (4 wk) and 36.9 ± 1.5 (8 wk), but decreased for the ECC-T arm at 4 wk (32.0 ± 1.2 Nm) before recovering to the pretraining level at 8 wk (34.4 ± 1.5 Nm). After 4 wk of detraining, MIT increased significantly ($P < 0.05$) for the ECC-T arm (38.7 ± 1.7 Nm), but not for the CON-T arm (37.4 ± 1.5 Nm).

CIR increased significantly ($P < 0.01$) with training in both ECC-T and CON-T arms; however, significantly ($P < 0.05$) larger increases were produced for the ECC-T arm compared with the CON-T arm. The first training bout produced significantly larger ($P < 0.01$) increases in CIR at 4 d after exercise for the ECC-T arm (8.9 ± 0.3 mm) compared with the CON-T arm (1.6 ± 0.1 mm). Increases in circumference after training sessions 2–8 were significantly ($P < 0.01$) smaller compared with the first session for the ECC-T arm. At the end of the training period, the amount of increase in circumference from the pretraining value was significantly ($P < 0.05$) larger in the ECC-T arm (9.0 ± 1.7 mm) than in the CON-T arm (5.5 ± 1.3 mm).

Ultrasonography demonstrated enlargement of muscle thickness that coincided with increases in CIR. Muscle thickness, assessed by the distance between the edge of the humerus and the subcutaneous fat layer, increased significantly ($P < 0.05$) at 4 d after the first training session for both ECC-T (5.7 ± 1.1 mm) and CON-T (1.3 ± 0.2 mm) arms. After 8-wk of training, muscle thickness was approximately 4 mm (ECC-T) or 2 mm (CON-T) larger compared with the pretraining levels, and the amount of increase was significantly ($P < 0.05$) larger in the ECC-T arm compared with the CON-T arm. ECC-T produced larger increases in echo signal intensity than CON-T after the first training session that was still elevated at 8 wk.

Muscle soreness developed after the first training session for both ECC-T and CON-T arms; however, the magnitude of soreness was smaller in the following training sessions (second through eighth sessions). Significantly ($P < 0.01$) greater development of muscle soreness was observed for

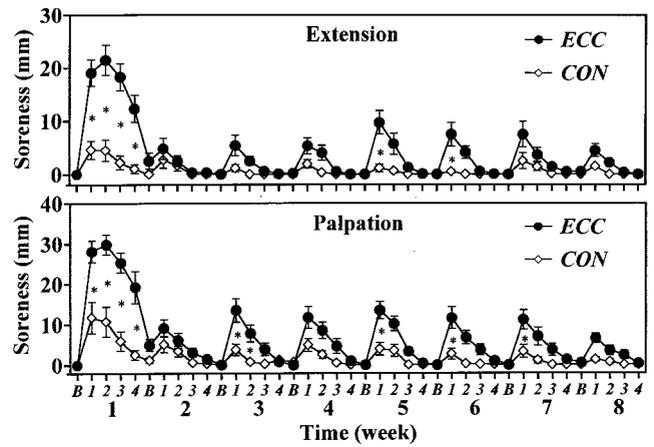


FIGURE 2—Changes in muscle soreness over 8-wk training period. For each week (1–8), the data for immediately before (B) and for 4 d after exercise (1, 2, 3, and 4) are shown. Significant difference ($P < 0.01$) was found between concentric (CON) and eccentric (ECC) training arms. Difference between the CON and ECC for each data point is also shown. * $P < 0.05$.

the ECC-T arm compared with the CON-T arm for both palpation and extension at all measurement days after the first training bout, and at various days after subsequent training sessions (Fig. 2).

As shown in Figure 3, the first training session produced significant increases ($P < 0.01$) in plasma CK activity, and the value at 4 d after exercise was 2910 ± 1015 IU·L⁻¹. Plasma CK activity decreased from before (1392 ± 318 IU·L⁻¹) to 4 d (280 ± 38 IU·L⁻¹) after the second training session. No significant changes were observed in the training sessions 3–8.

Changes after maximal eccentric exercise. Immediately before Max-ECC, there was no significant difference in MIF between CON-T (185.9 ± 6.1 N) and ECC-T (187.2 ± 4.4 N) arms, although both arms showed a significantly ($P < 0.05$) higher MIF compared with the pretraining level. The MIF before the Max-ECC was significantly ($P < 0.01$) higher than the posttraining level (172.8 ± 4.0 N) for the ECC-T arm, but significantly ($P < 0.05$)

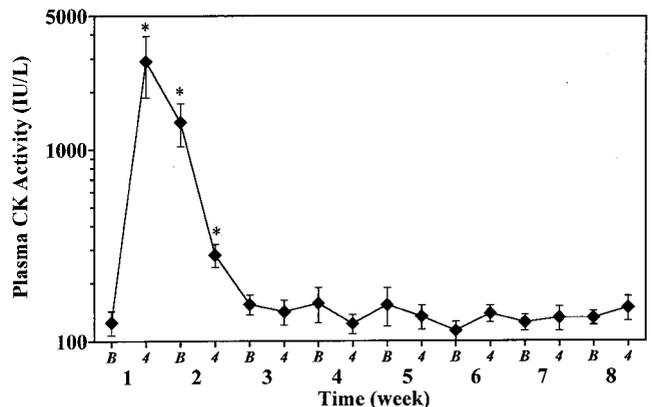


FIGURE 3—Changes in plasma CK activity over 8-wk training period. For each week (1–8), the data for immediately before (B) and 4 d after exercise (4) are shown. Significant difference from the pretraining value (pretraining value in the first week) is also shown. * $P < 0.05$.

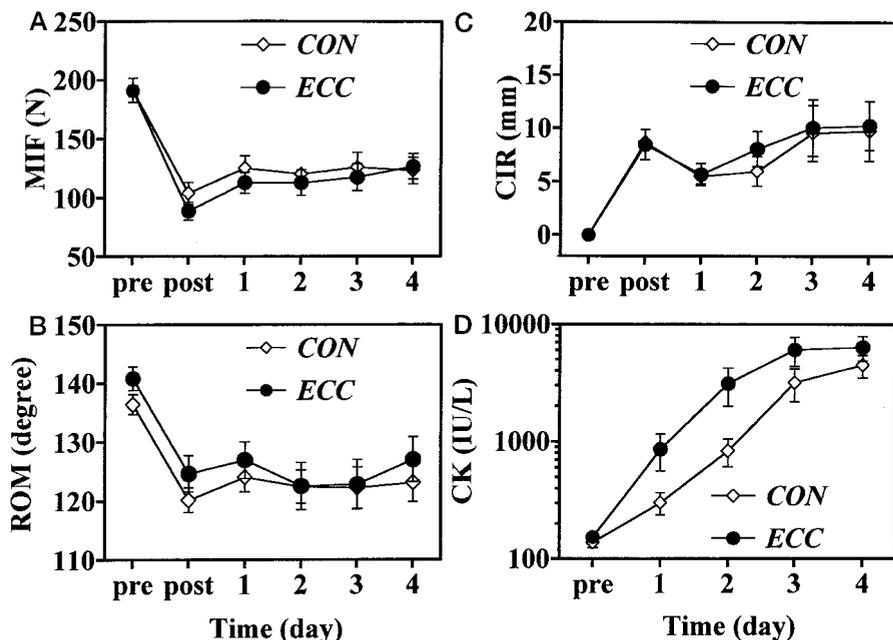


FIGURE 4—Comparison between the arms trained either concentrically (CON) or eccentrically (ECC) for the changes in maximal isometric force (MIF) (A), range of motion (ROM) (B), upper arm circumference (CIR) (C), and plasma CK activity (D) before (pre), immediately after (post), and for 4 d (1, 2, 3, and 4) after 24 maximal eccentric actions of the elbow flexors. No significant differences were observed between CON and ECC for all of the changes.

lower for the CON-T arm (187.8 ± 5.7 N). MIF decreased significantly ($P < 0.01$) to approximately 50% of the pre-exercise value immediately after exercise and recovered to approximately 70% at 4 d after exercise for both arms (Fig. 4A). No significant difference in the changes in MIF after exercise was evident between the arms.

The amount of increase in FANG immediately after exercise was approximately 14° for both arms, and no significant difference was observed between the arms after exercise. The largest decrease in RANG was seen at 2 d after exercise for both CON-T (13.1°) and ECC-T (14.7°) arms, and the changes were not significantly different between the arms. ROM decreased significantly ($P < 0.01$) immediately after exercise by approximately 20° , and did not recover for the next 4 d for both arms. No significant differences in ROM were evident between the arms (Fig. 4B).

Immediately before Max-ECC, CIR for the CON-T and ECC-T arms was 245.7 ± 0.3 mm and 248.0 ± 0.3 mm, respectively. This value was significantly ($P < 0.05$) higher than the pretraining level for both CON-T (238.4 ± 0.3 mm) and ECC-T (238.2 ± 0.3 mm) arms, but was not significantly different from the posttraining level for either CON-T (243.9 ± 0.3 mm) or ECC-T (247.2 ± 0.2 mm) arm. CIR immediately after Max-ECC was significantly ($P < 0.01$) greater than that before Max-ECC, and remained significantly ($P < 0.01$) elevated for the next 4 measurement days. The amount of increase in CIR (approximately 10 mm) was not significantly different between the arms at any time after Max-ECC (Fig. 4C).

Muscle soreness developed by 1 d and peaked at 2 d after exercise, although the magnitude of peak soreness on palpation was not significantly different between the CON-T (31.7 ± 3.0 mm) and ECC-T (31.2 ± 3.2 mm) arms. This was also the case for soreness during extension, where no significant difference was observed between the arms (ECC-T, CON-T) at any measurement time after Max-ECC.

There was no significant difference in plasma CK activity before Max-ECC between CON-T (138 ± 13 IU·L⁻¹) and ECC-T (154 ± 13 IU·L⁻¹). Plasma CK activity increased significantly ($P < 0.01$) and peaked 4 d after exercise for both arms (CON-T, 4449 ± 978 IU·L⁻¹; ECC-T, 6353 ± 1493 IU·L⁻¹). However, when comparison was made between the arms, changes in CK were not significantly different between the arms (Fig. 4D).

DISCUSSION

Changes with training. The present study found significant changes in all criterion measures in both CON-T and ECC-T arms; however, the magnitude of the changes was significantly larger for the ECC-T arm compared with the CON-T arm (Figs. 1 and 2). Significantly slower recovery of MIF (Fig. 1) and a larger development of muscle soreness (Fig. 2) were evident in the ECC-T arm after the first training session compared with the following sessions. Plasma CK activity showed a large increase after the first training session only (Fig. 3). Although there was no direct evidence that only the ECC-T was associated with the increases in CK, other indicators of muscle damage after CON-T were low in magnitude (Figs. 1 and 2), and it has been documented that concentric-only exercise does not result in severe muscle damage (1,4,14). Therefore, it seems reasonable to assume that involvement of CON-T with the increase in CK was small.

Our previous study (18) showed that eccentric exercise of the elbow flexors using the same load as the present study (50% MIF) induced muscle damage for untrained subjects, although the magnitude of the damage was significantly less, and the recovery from damage was significantly faster than eccentric exercise in which the elbow flexors were forcibly lengthened while producing maximal force. This was reinforced by the present study, which also found that the

magnitude of muscle damage encountered in the first ECC-T session was not as large as that induced by maximal eccentric exercise (4,17). When compared with 24 maximal eccentric actions of the elbow flexors (4,17), which is the same as the damaging eccentric exercise in this study, recovery of MIF was faster in the 50% MIF dumbbell exercise (78.6% at 4 d postexercise vs less than 60%), and peak plasma CK activity was lower (approximately $3000 \text{ IU}\cdot\text{L}^{-1}$ vs more than $10,000 \text{ IU}\cdot\text{L}^{-1}$).

The present study was the first to report changes in indicators of muscle damage over eight bouts of eccentric exercise repeated every 7 d. Muscle damage in subsequent ECC-T sessions appeared to be minor or negligible (Figs. 1–3). This phenomenon can be explained by a “repeated bout effect” that has been well documented in many studies (2–4,14–16,19). Although the subsequent ECC-T sessions were performed before the muscles had fully recovered from the first session, it seems unlikely that the training sessions exacerbated muscle damage or retarded the recovery process (16,19). By 4 d after the first training session, MIF of the CON-T arm was significantly higher (105.6%) than the pretraining level (100%), and remained so for the 8-wk training period (Fig. 1). This is in contrast to the ECC-T arm that appeared to be affected by eccentric exercise-induced stress until the beginning of week 6, by which time MIF was not significantly different from pretraining levels. It appears that the ECC-T arm was still in the recovery process from muscle damage induced by the initial training session for 5 wk. It has been reported that force deficits after maximal eccentric exercise often last more than 4 wk, and complete recovery from muscle damage is a slow process (4,14). Interestingly, the ECC-T arm showed a large increase in MIF after a 6-wk detraining period (Fig. 1), which could possibly be a supercompensation type effect.

Some studies (6,12) have shown greater preservation of strength (12 wk) after eccentric and concentric or eccentric-only training than concentric-only training. It appears that it takes a longer time for ECC-T to achieve a strength gain, but the effect is longer lasting than CON-T. It has been also reported that eccentric training produces larger increases in muscle strength and muscle size than concentric training (10,11). Larger increases in strength in the ECC-T arm were not shown in the present study (Fig. 1); however, increases in upper arm circumference and muscle thickness were significantly larger in the ECC-T arm than in the CON-T arm. It appears that swelling associated with muscle damage and inflammation (13,17) was related to the increases in circumference and muscle thickness for the first couple of weeks of training sessions. However, the increases in the later training sessions may reflect muscle hypertrophy, as documented in previous studies (10,11) that eccentric training has a potential to stimulate muscle growth more than concentric training. It has been also shown that eccentric training produces greater neural adaptations than concentric training (11). It is important to note that there was no significant difference in MIF between the ECC-T and CON-T arms when measured immediately before performing Max-ECC (Fig. 1). However, it could be that eccentric force was increased more for the ECC-T arm,

and concentric force for the CON-T arm, as shown in previous studies (5,11).

Effect of training on damaging eccentric exercise. It was hypothesized that ECC-T would produce a greater protective effect against muscle damage induced by the Max-ECC than CON-T, because the ECC-T arm had already experienced a similar mode of loading in which presumably the same muscle groups were activated. It is well documented that repeated bouts of the same eccentric exercise induces significantly less muscle damage than an initial bout (4,14,16,19,22), even when the number of eccentric actions in the subsequent bout is larger (2,3). Repeating the same eccentric exercise more than three times (9,15,24) appears to show more of a dramatic protective effect against muscle damage than a single initial bout. A different mode of eccentric exercise performed before a damaging eccentric exercise bout can also reduce the extent of muscle damage, if the same muscle groups are used in both the eccentric exercises (8). Recently, Ploutz-Snyder et al. (20) and Whitehead et al. (26) reported interesting results suggesting that concentric training increased the susceptibility to eccentric exercise-induced muscle damage. On the basis of these findings, it was expected that a significantly faster recovery of MIF; smaller decrease in ROM; and reduced increase in CIR, SOR, and plasma CK activity would be evident after Max-ECC in the ECC-T arm compared with the CON-T arm. However, no significant differences between the arms were found for all criterion measures (Fig. 4). Therefore, the results of the present study did not support the hypothesis that ECC-T was more effective than CON-T for mitigating the extent of muscle damage and enhancing the recovery process from subsequent damaging exercise.

Although the ECC-T did not appear to reduce the extent of muscle damage in the subsequent damaging eccentric exercise, the recovery of MIF (71.6% at 4 d after exercise), amount of decrease in ROM (17.9° at 3 d after exercise), amount of increase in CIR (10.3 mm at 4 d after exercise), and the peak plasma CK activity ($6353 \text{ IU}\cdot\text{L}^{-1}$) after Max-ECC seem to be smaller than after the same exercise performed as an initial bout. Our previous study (17), using subjects and eccentric exercise similar to the present study, showed a lower MIF recovery ($< 60\%$), larger decrease in ROM ($> 30^\circ$), larger increase in CIR ($> 20 \text{ mm}$), and higher peak CK ($> 10,000 \text{ IU}\cdot\text{L}^{-1}$) at the same time points. This would suggest that the magnitude of muscle damage was attenuated slightly by the ECC-T, but the effect was much smaller than when the same maximal eccentric exercise was performed in the first bout. Since the intensity of the eccentric loading between the training (50%) and the maximal eccentric exercise (100%) was different, muscle fibers damaged and adapted in training may not be the fibers recruited in the maximal eccentric exercise. It is also possible that the eccentric loading during the ECC-T was not stressful enough to the elbow flexors at strong elbow angles. Since the 50% load was determined at an elbow joint of 90° , the elbow flexors did not seem to have a problem in dealing with the eccentric loading except for when the elbow joint was at an extended position ($> 150^\circ$), where the least force can be produced (25).

The present study did not find an adverse effect of concentric-only training on eccentric exercise as shown by Ploutz-Snyder et al. (20) and Whitehead et al. (26). Ploutz-Snyder et al. (20) suggested that the increased strength allowed the trained muscle to be exposed to greater eccentric loading, and this was the reason for the adverse effect. The present study found that both ECC-T and CON-T increased maximal isokinetic concentric strength (ECC-T, 13%; CON-T, 18%) and MIF (ECC-T, 15%; CON-T, 14%) significantly from the pre-training level, and MIF was still elevated from the preexercise value when Max-ECC was performed (Fig. 1). However, despite the increases in "strength," no adverse effect of concentric training seemed to be evident in the present study (Fig. 4). Whitehead et al. (26) suggested that a reduction in the number of sarcomeres in concentrically trained muscle fibers would make the muscles more susceptible to the damage of eccentric exercise. If the CON-T in the present study also had decreased the number of sarcomeres, greater damage should have been seen in the CON-T arm than in the ECC-T arm; however, this was not the case (Fig. 4). The intensity and frequency of CON-T in the present study may not have been sufficient enough to reduce the sarcomere number. It is also possible that

the period between CON-T and Max-ECC (4 wk) may have been too long to maintain a reduced sarcomere number. Further studies are necessary to investigate to what extent sarcomere numbers change after concentric or eccentric training in human muscles, and how any changes are associated with the magnitude of eccentric exercise-induced muscle damage.

In conclusion, the hypotheses that 1) eccentric training would be more effective than concentric training in reducing the susceptibility of the exercised muscles to damage, and 2) concentric training would increase the vulnerability of the muscles to eccentric exercise-induced muscle damage were not supported by the results of this study. The common belief that "training" will prevent or reduce muscle damage and soreness may be too optimistic. In order to prevent or reduce eccentric exercise-induced muscle damage by training, the training should be specific to the damaging exercise such that the identical muscle groups are stimulated by the same muscle actions and intensity as the damaging exercise.

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