Comparison between old and young men for changes in makers of muscle damage following voluntary eccentric exercise of the elbow flexors

Andrew P. Lavender and Kazunori Nosaka

Abstract: This study aimed to investigate if old men were more susceptible than young men to muscle damage induced by exercise consisting of repeated-lengthening muscle actions. The responses to a bout of eccentric exercise were compared between 10 young (mean age ± SEM = 19.4 ± 0.4 y) and 10 old (70.5 ± 1.5 y) men. All subjects performed 6 sets of 5 lengthening actions of the left elbow flexors at a range of 90° from an elbow flexed (90°) to an extended (180°) position in 5 s using a dumbbell massed at 40% maximal isometric strength (MVC) at an elbow joint angle of 90°. Changes in MVC, range of motion (ROM), upper arm circumference (CIR), muscle soreness (DOMS), plasma creatine kinase activity (CK), and myoglobin (Mb) concentration over 7–10 d following exercise were compared between groups by 2-way repeated measures analysis of variance (ANOVA). Significant differences between groups were evident at baseline for ROM (significantly smaller for the older group) and CIR (significantly larger for the older group), but not for MVC and other measures. Contrary to the hypothesis, the young group showed significantly larger decreases in MVC and ROM and larger increases in circumference, DOMS, CK activity, and Mb concentration than those of the old group. These results suggest that muscle damage is not necessarily greater in old versus young men following voluntary eccentric exercise. It may be that physiological changes that occur with ageing, including a decrease in ROM, reduce damaging stress to muscles during lengthening muscle actions.

Key words: ageing, maximal isometric strength, muscle soreness, creatine kinase, myoglobin.

Résumé : Cette étude vérifie l'hypothèse selon laquelle les hommes âgés sont comparativement aux hommes jeunes plus sujets aux lésions musculaires causées par la répétition d'action d'étirement musculaire. Les ajustements à une série d'actions pliométriques faites par 10 jeunes hommes (moyenne ± et = 19,4 ± 0,4 ans) sont comparés aux ajustements de 10 hommes âgés (70,5 ± 1,5 an). Tous les sujets exécutent 6 séries de cinq actions pliométriques des fléchisseurs du coude gauche depuis un angle de flexion de 90° jusqu'à une pleine extension (180°); chacune des actions d'une durée de 5 s est effectuée contre une charge équivalant à 40% de la tension maximale isométrique (MVC) mesurée à un angle du coude de 90°. On utilise une analyse de variance pour comparer chez les deux groupes les variations des valeurs des mesures de MVC, d'amplitude de mouvement (ROM), de la circonférence du bras (CIR), de la douleur musculaire d'apparition retardée (DOMS), de l'activité de la créatine kinase (CK) et de la concentration de myoglobine (Mb) sur une période de 7 à 10 jours suivant l'exercice. On observe des différences significatives entre les valeurs de base de ROM (plus réduite chez les plus âgés) et de CIR (plus importante chez les plus âgés). À l'encontre de l'hypothèse, le groupe de jeunes hommes affiche une plus grande diminution de MVC et de ROM et une plus grande augmentation de CIR, de DOMS, de CK et de Mb que le groupe d'hommes âgés. D'après ces observations, les lésions musculaires causées par les actions pliométriques ne sont pas automatiquement plus importantes chez les hommes âgés comparativement aux hommes plus jeunes. Parmi les changements physiologiques observés avec le vieillissement dont la réduction de ROM, il y a peut-être moins de lésions musculaires causées par les actions d'étirement musculaire.

Mots clés : vieillissement, tension isométrique maximale, douleur musculaire, créatine kinase, myoglobine.

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Introduction

Muscle mass and strength decrease with advanced age, a process often referred to as sarcopenia (Welle 2002). It is known that type II (fast-twitch) fibers are more susceptible to atrophy with ageing (Monemi et al. 1998), and resistance training is essential for elderly individuals to minimize sarcopenia (Welle 2002). Hortobágyi et al. (1995) showed that eccentric training results in greater increases in type II fiber area than concentric training when applied to atrophied muscles. This would suggest that eccentric exercise is important for the elderly; however, it should be noted that unaccustomed eccentric exercise induces prolonged loss of muscle function and delayed-onset muscle soreness (Nosaka et al. 2002). It is possible that muscle soreness and a further reduction in strength as a result of eccentric exercise may have adverse effects on the daily function of older individuals (Ploutz-Snyder et al. 2001). It is important to know if elderly individuals are more susceptible than the young to muscle damage induced by eccentric exercise.

A number of studies have compared responses to eccentric exercise between young and old. It has been shown that stretching of electrically activated extensor digitorum longus muscle of old mice results in greater force deficit (Brooks and Faulkner 1996) and slower recovery of muscle force (Brooks and Faulkner 1990) compared with young mice. However, it is less clear if this is also the case for humans, and the results of the animal studies do not necessarily apply for voluntary eccentric exercise of humans. In fact, contradiction exists concerning the effect of ageing on susceptibility of muscle to muscle damage induced by eccentric exercise.

Manfredi et al. (1991) reported greater myofibrillar damage to the contractile proteins following eccentric exercise of the knee extensors for old men than for young men. Muscle damage is directly assessed by ultrastructural changes in skeletal muscle, but it is important to consider symptoms of muscle damage such as loss of muscle function, swelling, and muscle soreness, because these may affect daily activities. Ploutz-Snyder et al. (2001) showed that decreases in muscle strength were greater in older women than young women after a bout of knee extension exercise. Two studies from the same laboratory (Clarkson and Dedrick 1988; Dedrick and Clarkson 1990) reported that recovery of muscle strength was slower and the decrease in relaxed elbow joint angle was larger for older women than young women after maximal eccentric exercise of the elbow flexors. Roth et al. compared ultrastructural abnormality in muscle fibres after 9 weeks of high-volume, heavy-resistance strength training between young and older subjects, and reported that young and older men exhibited similar levels of muscle damage (Roth et al. 1999), but that older women exhibited higher levels of muscle damage than young women (Roth et al. 2000). These results suggest that an age–gender interaction exists regarding susceptibility to muscle damage, although the authors stated that the basis for this interaction was unknown.

The data from Roth et al. (1999) suggested that ultrastructural changes in skeletal muscle after lengthening are similar between young and old men. However, it is currently unknown whether differences in muscle function, swelling, and soreness previously reported in young versus old females (Clarkson and Dedrick 1988; Dedrick and Clarkson 1990; Ploutz-Snyder et al. 2001) also exist in young versus old males. No study has yet compared young and old male subjects for changes in muscle strength, muscle soreness, and other indirect markers of muscle damage following eccentric exercise of the elbow flexors. Moreover, the responses of old men to submaximal eccentric exercise of the elbow flexors, in which self-controlled muscle-lengthening actions are performed, have not been examined in comparison with young men.

Therefore, the present study tested the hypothesis that following a bout of voluntary eccentric exercise of the elbow flexors old men would show larger changes in indirect markers of muscle damage than young men.

Materials and methods

Experimental design

Eccentric exercise of the elbow flexors was chosen for the present study, because of its previous use in studying exercise-induced muscle damage. Changes in several indirect markers of muscle damage, which have been used to examine muscle damage in eccentric exercise of the elbow flexors in previous studies (Nosaka et al. 2005; Nosaka and Clarkson 1996), were compared between 10 young and 10 old subjects after the exercise.

Subjects

All subjects received a medical examination before commencing the study to confirm that they were free from any musculoskeletal disorders and diseases and all signed a written informed consent document consistent with the ethical standards at Yokohama City University, which were in accordance with the Declaration of Helsinki. The mean (±SEM) age, height, mass, and percent body fat for both groups of subjects are shown in Table 1. Body fat was determined using a body composition analyzer (InBody 3.0, Biospace, Seoul, Korea). Comparing between the young and old groups, significant differences ($P < 0.05$) were evident for age, height, and percent body fat. None of the young subjects were athletes, but they performed recreational physical activities at least twice a week. The old subjects were also physically active and performed physical activities on a daily basis. However, none of the subjects had been involved in a resistance-training program. Subjects were asked to avoid any vigorous exercise apart from the exercise performed in the study, and to take no medication or dietary supplements during the experimental period.

Exercise

The exercise used the non-dominant arm and consisted of 6 sets of 5 lengthening muscle actions of the elbow flexors on a standard seated arm curl bench. A dumbbell was used for the exercise, and the mass was set at 40% of each individual's maximal isometric strength (MVC) at an elbow joint angle of 90° (1.57 rad). Pilot testing indicated that this mass (i.e., 40% MVC) was close to the maximal mass at which subjects could complete 6 sets of 5 lengthening muscle actions. It should be noted that the lengthening muscle actions performed in the exercise were not forced lengthening of maximally contracted muscles. The exercise workload of the present study was considered to be submaximal; however, this kind of eccentric exercise is often performed in resistance training, and older adults may also be exposed to this type of muscle action during training. This was the reason for the choice of exercise protocol for this study. A previous investigation (Nosaka and Newton 2002) showed that 3 sets of 10 repetitions at 50% MVC induced muscle damage in young untrained men, but that the magnitude of muscle damage was significantly smaller than that of eccentric exercise consisting of forced lengthening of maximally contracted

Table 1. Physical characteristics (mean ± SEM) of subjects in the young and old groups.

	Age (y)	Height (cm)	Mass (kg)	Body fat (%)	Maximal isometric strength (kg)	Range of motion (°)	Upper arm circumference (mm)
Young (*n* = 10)	19.4±0.4	173.5±2.0	65.8±3.5	16.2±0.5	23.4±0.8	141.3±1.5	247.0±9.2
Old (*n* = 10)	70.5±1.5*	164.5±0.9*	66.6±2.0	25.4±0.4*	23.9±1.1	133.2±1.0*	258.6±3.7*

Note: For maximal isometric strength, range of motion, and upper arm circumference, pre-exercise values are shown.

*Significant difference ($p < 0.05$) from the young group.

muscles. The exercise protocol of the present study was modified from the previous study (Nosaka and Newton 2002) so that more sets of fewer repetitions were performed to minimize muscle fatigue and other factors that might result in unexpected injury, especially for the older subjects.

Subjects were asked to lower the dumbbell from an elbow flexed (90°) to an extended position (180°) in 5 s in a controlled manner and keeping the velocity as constant as possible. Subjects were seated on a bench with the arm positioned in front of the body on a padded support that secured the shoulder angle at 45° flexion, and the forearm was kept supinated throughout the range of motion. After each lengthening muscle action, an investigator took the dumbbell from the subject, and brought the dumbbell to the flexed position. Therefore, subjects did not perform shortening muscle actions under load, and the rest between each lengthening muscle action was approximately 3 s; a 2 min rest was given between sets. Subjects were supervised during the exercise and continually encouraged to lower the dumbbell in the instructed manner. The investigator spotted the subject and assisted in keeping the velocity of movement constant when necessary, especially at wide elbow angles when subjects showed difficulty in controlling the dumbbell.

Criterion measures

Maximal isometric strength at 90° elbow flexion (MVC); flexed, relaxed, and stretched elbow joint angles and range of motion of the elbow joint (ROM); and upper arm circumference were assessed as markers of muscle damage before, immediately, and 1 h after exercise, and 1, 2, 3, 4, 5, 7, and 10 d after exercise. Muscle soreness, plasma creatine kinase (CK) activity, and myoglobin (Mb) concentration were also measured in blood samples collected before and 1, 2, 3, 4, 5, and 7 d after exercise. The test–retest reliability of these measures has been tested in our previous studies (Hirose et al. 2004; Nosaka et al. 2005), and the intraclass correlation coefficient of the measures is higher than 0.85.

MVC

MVC was measured at 90° elbow flexion using a transducer (model 100, Takei Scientific Instruments, Niigata, Japan) connected to an Apple computer (Macintosh Performer 5410, Apple Computer, Cupertino, Calif.) via a Power Lab system with the accompanying software program (PowerLab/8SP, ADInstruments, Castle Hill, Australia). Subjects were seated on a specially designed bench and the arm was positioned in front of the body with the shoulder joint at 90° flexion and elbow joint angle was also flexed to 90°. A wristband worn by the subject was attached to the transducer by a metal cable. Subjects were familiarized with the measurement of MVC by practicing several submaximal and maximal contractions before the MVC test. They were then asked to perform 2 maximal isometric contractions for 3 s each with 30 s between trials. The mean of 2 trials was used for further analyses.

Elbow joint angles and ROM

A plastic goniometer was used to measure elbow joint angles for the relaxed (RANG), stretched (SANG), and flexed (FANG) positions. Subjects stood with their arm hanging in a relaxed position at their side and the goniometer was applied twice to measure RANG. They were then asked to extend their elbow as much as they could, and the elbow joint angle was determined for SANG. For FANG, subjects were asked to flex their elbow as much as possible to touch their shoulder with their palm while keeping the elbow joint at their side. These measurements were taken twice and the average of the 2 was used for further analyses. Range of motion (ROM) was defined as the difference between SANG and FANG. To ensure measurements were taken from the same point each time, a semi-permanent ink pen was used to mark a point over the apex of the deltoid, the axis of rotation of the elbow, the styloid process, and the dorsal tubercle of the radius.

Upper arm circumference

Upper arm circumference (CIR) was measured using a constant tension tape measure at 3, 5, 7, 9, and 11 cm proximal to the elbow joint. The 5 measurement sites were marked with a semi-permanent ink pen at the first testing session, and remarked at each test. During the measurement, subjects stood with their arm hanging in a relaxed position by the side. Two measurements were taken from each site, and the average of the 2 was used for further analysis.

Muscle soreness

Magnitude of delayed onset muscle soreness (DOMS) was quantified by a visual analogue scale (VAS) consisting of a 50 mm line with "no pain" at one end and "extremely sore" at the other. With the subject in a seated position and the exercised arm resting on a table, the investigator palpated the elbow flexors (3 portions on the upper arm: mid-belly of the biceps brachii and 3 cm above and below the mid belly), then passively extended and flexed the joint to test each subjects' perception of soreness. Subjects were asked to mark the pain level for each assessment (palpation, extension, flexion) on the 50 mm line for each of these evaluations and the distance from the lefthand end of the line to the marked position was taken as the magnitude of DOMS in mm. For the palpation measure, the highest score of the 3 palpated sites was used for further analysis.

Plasma CK activity and Mb concentration

Approximately 5 mL of blood was drawn from an antecubital vein by a standard venipuncture technique using a disposable needle (Terumo, Tokyo, Japan) and vacutainer (Terumo). The blood was centrifuged for 10 min to obtain plasma, and the plasma samples were stored at –40 °C until they were analysed for creatine kinase (CK) activity and myoglobin (Mb) concentration. Plasma CK activity was determined spectrophotometrically using a VP-Super (Dinabott, Tokyo, Japan) with a commercially available kit (Dinabott). Plasma Mb concentration was measured using a biochemical analyser (Model TBA-30A, Toshiba, Tokyo, Japan) with a commercially available kit (Denka-Seiken, Tokyo, Japan). The normal reference ranges for male adults using this method are 45–135 $IU \cdot L^{-1}$ for CK and <85 $ng \cdot mL^{-1}$ for Mb.

Statistical analyses

Changes in criterion measures were compared between young and old groups by 2-way analysis of variance (ANOVA) with repeated measures. When ANOVA showed a significant interaction effect, Tukey's post hoc test was employed to locate the differences. The level of statistical significance was set at $p < 0.05$. Data are presented as mean ± SEM unless otherwise stated.

Results

Exercise

The average dumbbell mass used for exercise was 9.3 ± 1.0 kg for the young, 9.5 ± 1.3 kg for the old with no significant difference between the groups. All subjects were able to complete the exercise, but required some assistance from the investigator to keep the slow lengthening muscle actions at extended elbow joint positions, especially for the 5th and 6th sets, regardless of age.

MVC

No significant difference in MVC was evident before exercise between the groups (Table 1). Therefore, changes in MVC were normalized to the pre-exercise values and compared between the groups. As shown in Fig. 1, MVC decreased significantly immediately after exercise, and the young group showed a significantly larger decrease (60.3 ± 4.5%) compared with the old group (49.1 ± 3.4%). Significantly larger decreases in MVC were evident for the young group than were evident for the old group over time, and MVC 10 d post-exercise for the young group was 64.2% ± 10.0% of the baseline, which was significantly lower than that of the old group (87.4% ± 6.5%).

Elbow joint angles and ROM

RANG was similar between the young (164.4° ± 1.0°) and old (161.4° ± 1.8°) groups before exercise. RANG decreased significantly immediately after exercise for both groups (young, –14.1° ± 4.9°; old, –10.1° ± 3.3°) without significant differences between groups. The young group showed further decreases in RANG and the nadir was seen 4 days after exercise (–22.1° ± 2.2°); however, no further decreases in RANG were observed for the old group. SANG was significantly larger for the young (174.4° ± 0.9°) than for the old group (168.6° ± 2.24°) before exercise, and reached its nadir on day 4 for the young group (154.8° ± 4.8°) and on day 2 for the old group (161.7° ± 2.4°). The changes in SANG following exercise were significantly larger for the young than for the old. FANG was similar between the young (33.1° ± 1.4°) and the old (35.4° ± 1.7°) groups and increased significantly immediately after exercise for both groups (young, 19° ± 3.2°; old, 17° ± 2.5°) and no difference in the changes after exercise was evident between groups.

Before exercise, ROM was significantly ($p < 0.05$) smaller for the old compared with the young (Table 1), because of the smaller SANG for the old. Figure 2 shows changes in ROM from the pre-exercise value. The old group showed the largest decrease in ROM immediately after exercise and recovered gradually thereafter; however, the young group showed further decreases in ROM 3–4 d after exercise. This

Fig. 1. Normalized changes in maximal isometric strength from pre-exercise value (100%, absolute values are also shown) immediately (post), 1 h (0), and 1–10 d after exercise for the young and old groups. Asterisk indicates significant difference between groups ($p < 0.05$).

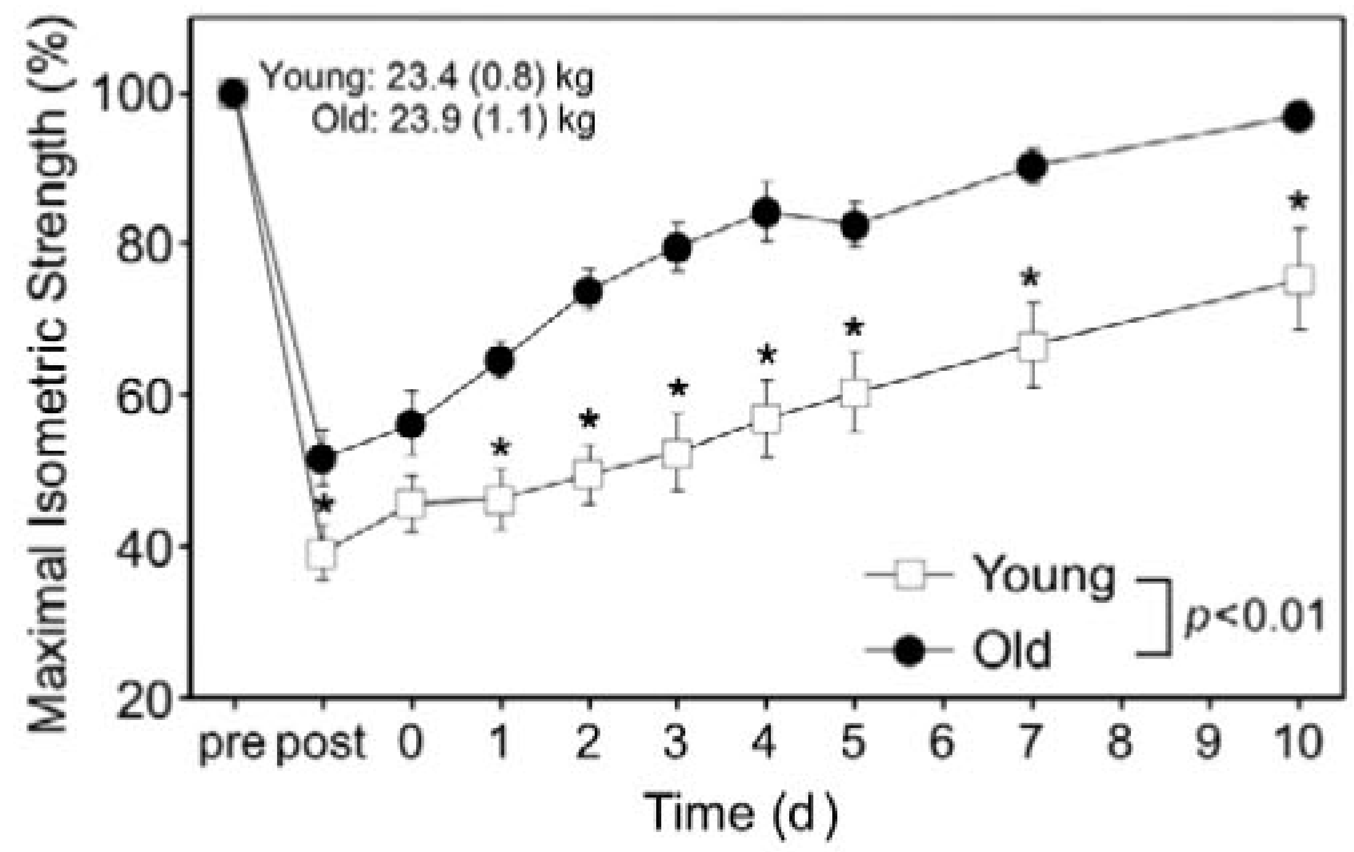
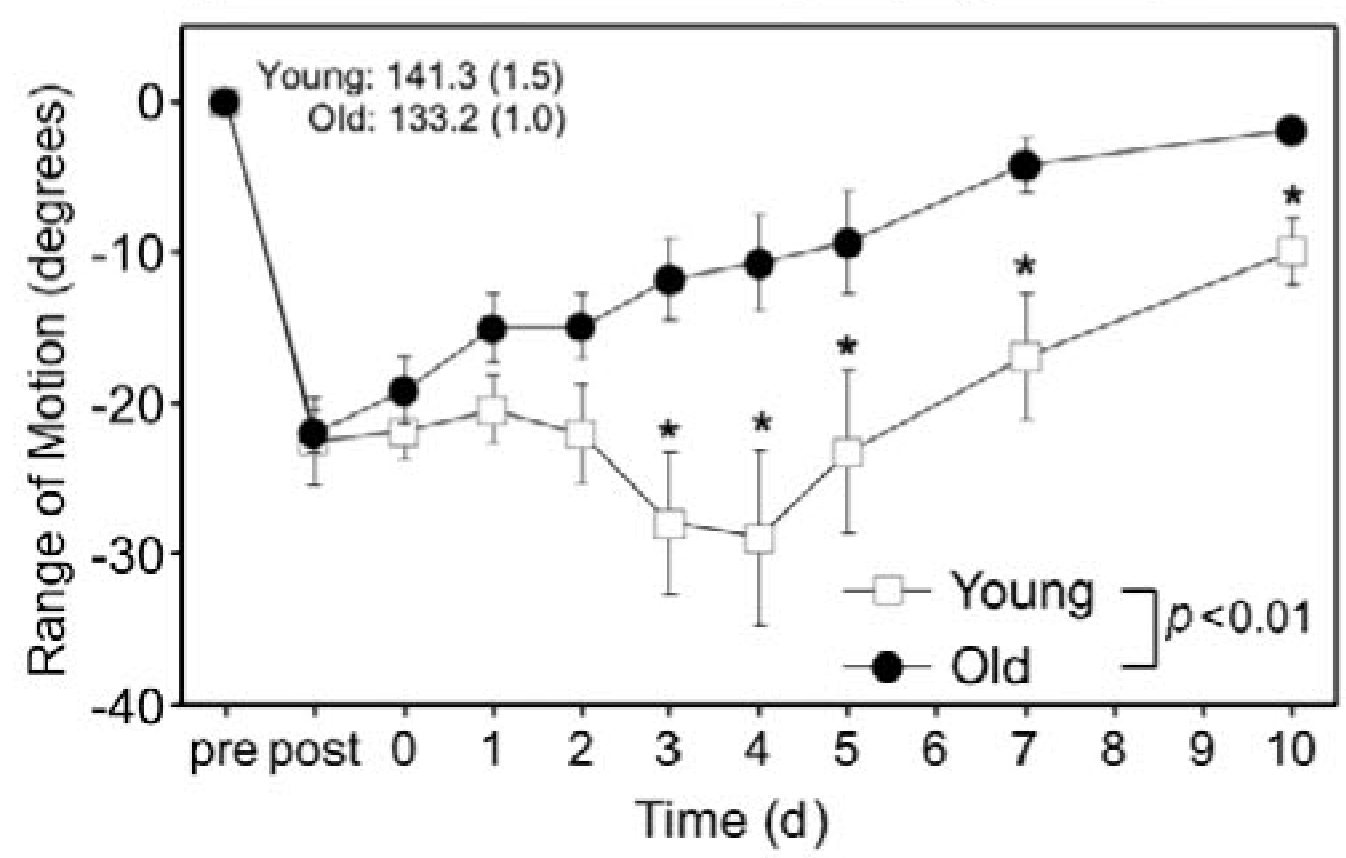


Fig. 2. Changes in range of motion from pre-exercise value (0, absolute values are also shown) immediately (post), 1 h (0), and 1–10 d after exercise for the young and old groups. Asterisk indicates significant difference between groups ($p < 0.05$).



resulted in a significantly slower recovery of ROM for the young compared with the old group.

Upper arm circumference

Before exercise, upper arm circumference at the mid-belly of the biceps brachii was significantly ($p < 0.05$) greater in the old group compared with the young group (Table 1). Changes in the circumference at this site (7 cm from the elbow joint) are shown in Fig. 3. Both groups showed similar increases in upper arm circumference immediately after exercise (10 mm). A slight recovery of circumference was seen 1 h after exercise, but circumference continued to increase for both groups peaking 5 d post-exercise (young, 19 ± 0.7 mm; old, 14 ± 2.1 mm). No significant difference in the changes over time between the groups was evident. Other sites showed a similar trend.

Muscle soreness

Muscle soreness developed 1 d after exercise in a similar manner for palpation and extension soreness, but soreness upon flexion showed significantly lower values compared with the others. Figure 4 shows changes in muscle soreness upon palpation. Muscle soreness peaked 1–2 d after exercise for both groups, but the young group consistently scored higher than the old. A significant difference between groups was evident for all time points between 1 and 5 d following exercise. The peak soreness values for the young and old groups were 33.4 ± 1.6 mm and 16.6 ± 3.8 mm, respectively.

Plasma CK and Mb

Plasma CK activity was within normal reference range for both young (124 ± 17.8 $IU \cdot L^{-1}$) and old (147 ± 28.4 $IU \cdot L^{-1}$) groups before exercise, and increased significantly after exercise for both groups. Peak plasma CK activity was observed 4–5 d after exercise for both groups; however, the peak value was significantly greater for the young compared with the old as shown in Fig. 5*a*. This was also the case for plasma Mb concentration (Fig. 5*b*).

Fig. 3. Changes in upper arm circumference from pre-exercise value (0, absolute values are also shown) immediately (post), 1 h (0), and 1–10 d after exercise for the young and old groups. n.s., not significant.

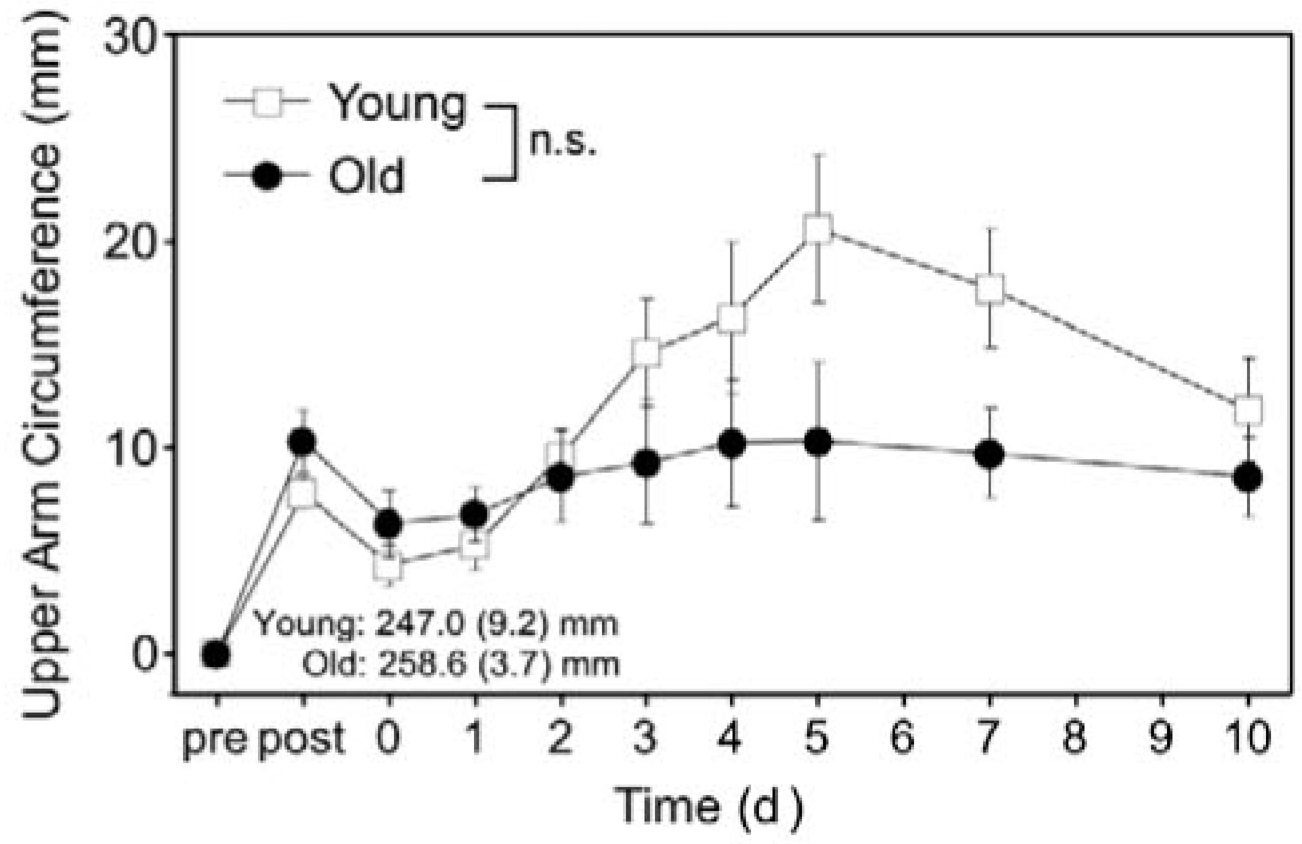
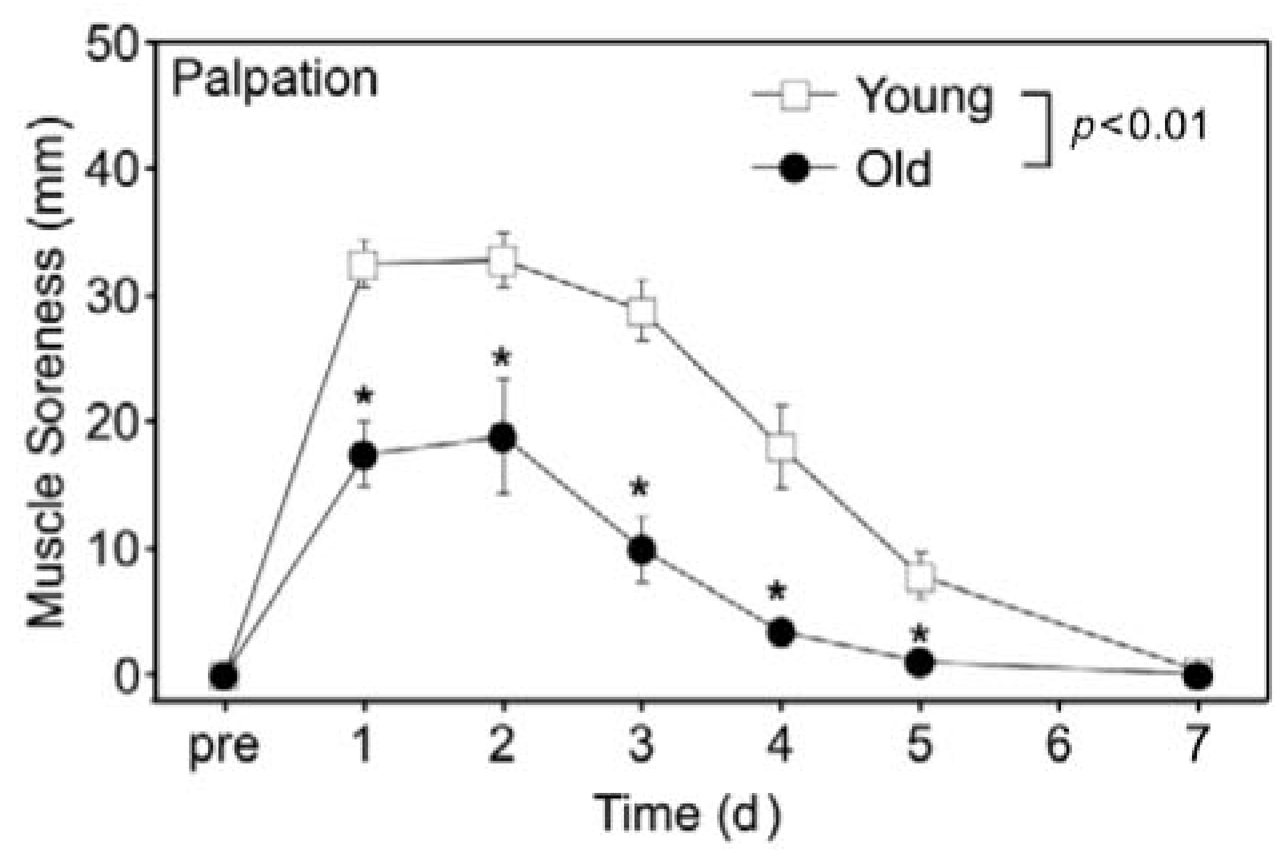


Fig. 4. Changes in muscle soreness upon palpation before (pre) and 1–7 d after exercise for the young and elderly groups. Asterisk indicates significant difference between groups ($p < 0.05$).



Discussion

The purpose of this study was to investigate whether old men are more susceptible than young men to muscle damage induced by voluntary eccentric exercise of the elbow flexors. Unexpectedly, there were no differences in strength between young and old men at baseline (Table 1). Furthermore, contrary to the hypothesis, changes in muscle function (Figs. 1 and 2), muscle soreness (Fig. 4), and blood markers of muscle damage (Fig. 5) after exercise were greater in the young men than in the old men. Therefore, the present data suggest that when young and old men are matched for strength, ageing does not increase muscle damage nor impair recovery from voluntary eccentric exercise.

A limitation of the present study was that no direct markers of muscle damage such as morphological changes in muscle were included. Some studies have also questioned the relevance of CK activity or Mb concentration in the blood to represent the magnitude of muscle damage (Sorichter et al. 1997; Komulainen et al. 1995). All of the criterion measures taken in the present study are indirect markers of muscle damage. However, it is important to note that muscle soreness, loss of muscle function, and swelling might have adverse effects on the daily activities, and are therefore of practical significance.

The similar MVC levels between the old and young groups (Table 1) were unexpected, since muscle mass and strength generally decrease with ageing (Lindle et al. 1997; Lynch et al. 1999; Welle 2002). Clarkson and Dedrick (1988) also reported no significant difference in isometric strength of the elbow flexors between young and old women. In the present study, the subjects in the old group were healthy and active, but not involved in any resistance-training program. Therefore, it may be that stimuli from daily activities prevented a decrease in MVC of the elbow flexors in this particular group. It was not possible for the present study to measure muscle cross-sectional area, which might have explained why young and old subjects had similar MVC. Although the pre-exercise upper arm circumference was larger for the old group compared with the young group, it is likely that the larger upper arm circumference was due to a greater fat mass, since the percent body fat was larger for the old subjects (Table 1). Therefore, we assume that muscle mass of the elbow flexors was similar between the 2 groups, and this likely accounts for the similar MVC.

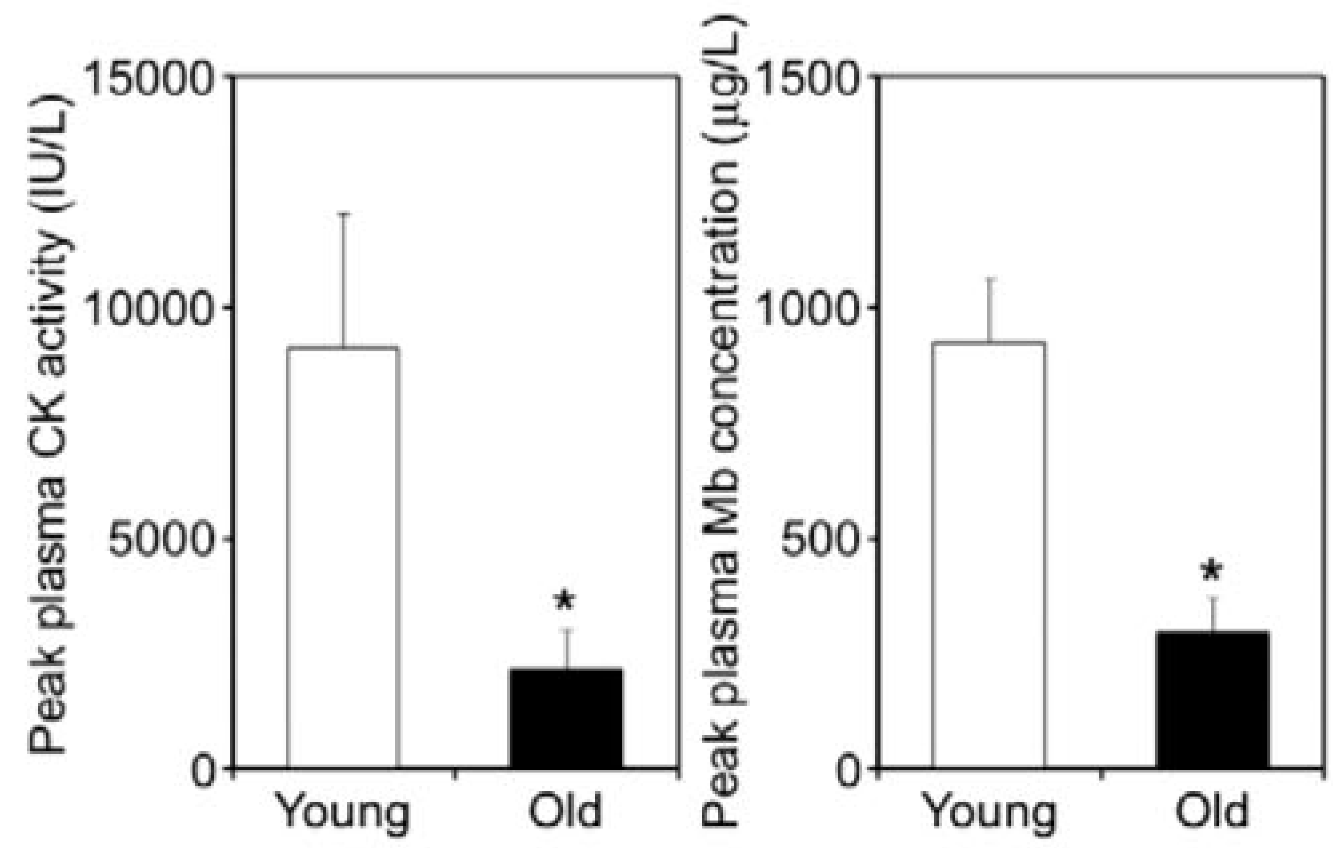
Some evidence suggests that arm muscles are less susceptible to sarcopenia than leg muscles (Aniansson et al. 1983). In some older individuals, arm muscles may follow a different pattern of strength changes than leg muscles as ageing occurs, such that arm muscle strength may decline at a slower rate than leg muscle strength. This issue would seem to be an important consideration when studying the effects of ageing on muscle responses to exercise.

We hypothesized that old men would be more susceptible to eccentric exercise-induced muscle damage than young men, based on the results of previous human (Ploutz-Snyder et al. 2001; Manfredi et al. 1991; Clarkson and Dedrick 1988; Dedrick and Clarkson 1990) and animal studies (Brooks and Faulkner 1990, 1996; Zerba et al. 1990). Ploutz-Snyder et al. (2001) compared young and older women for changes in muscle strength and magnetic resonance images (MRI) following 10 sets of 10 eccentric actions of the knee extensors, and reported that the decrease in muscle strength and changes in MRI were larger for the old than for the young subjects. Manfredi et al. (1991) reported greater ultrastructual muscle damage of the vastus lateralis following 15 min eccentric exercise on a cycle ergometer for older men compared with young men, but no significant difference in plasma CK activity was evident between the groups. Using the elbow flexors, 2 studies by the same authors (Clarkson and Dedrick 1988; Dedrick and Clarkson 1990) showed that the recovery of muscle strength was slower and decreases in relaxed elbow joint angle were larger for older women compared with young women, but there were no significant differences in serum CK and muscle soreness between the groups.

Some of the differences between the present data and the findings from some of the studies described above may be related to differences in markers of muscle damage and exercise used. Differences in ultrastructural changes between young and old after eccentric exercise may not necessarily reflect changes in muscle function and other indirect markers of muscle damage (Roth et al. 2000). As stated previously, leg muscles may be more susceptible to sarcopenia with ageing than arm muscles (Aniansson et al. 1983). This might explain why, in contrast to the present findings, greater muscle damage was noted in old versus young individuals after exercise involving the leg muscles (Ploutz-Snyder et al. 2001: Manfredi et al. 1991). Small differences in exercise protocol such as intensity and range of motion may influence the results dramatically. For example, lengthening muscle actions started from a 45° and ended at a 150° elbow joint angle in the previous elbow flexor studies (Clarkson and Dedrick 1988; Dedrick and Clarkson 1990). However, the present study used a greater range of motion that finished at a more extended angle (180 °). This might explain the contradicting results between the present study and previous studies (Clarkson and Dedrick 1988; Dedrick and Clarkson 1990).

In the present study, the ROM at baseline was smaller in the old group than the young group, and this was probably due to the inability of the older subjects to fully extend the elbow joint. It has been shown that increasing age results in an increase in joint stiffness in the region of the calf muscle–tendon (Gajdosik et al. 1999), a decrease in the elasticity of tendon–aponeurosis structures, and an increase in their viscosity (Kubo et al. 2003). If this is the case for the elbow flexors, it may be that the changes in joint stiffness and (or) tendon–aponeurosis structures with ageing reduce the strain on the muscles. One explanation for the smaller changes in the criterion markers of muscle damage in the old group is that the limited ROM restricted the mechanical strain placed on the muscle during the eccentric exercise. This might be expected to limit the amount of damage incurred by lengthening muscle fibres. It has been reported that the magnitude of muscle damage is greater when eccentric exercise of the elbow flexors is performed at a more-extended elbow position (Nosaka and Sakamoto 2001). Therefore, we speculate that lengthening muscle actions did not occur at vulnerable elbow joint angles for the old subjects, and this was one of the reasons why less muscle damage developed for the old men than developed for the young men. Future studies should consider ROM as a factor affecting responses of older individuals to exercise-induced muscle damage.

Fig. 5. Peak plasma CK activity (*a*) and myoglobin concentration (*b*) after exercise for the young and old groups. Asterisks indicate significant difference between groups ($p < 0.05$).



The inability of the old group to fully extend the elbow joint raises the question of whether both groups received the same stimulus from the exercise. If elderly subjects are generally unable to fully extend the elbow joint, this might have implications for the way in which they perform resistance training. The results of the present study appear to provide practical information about the eccentric exercise-induced muscle damage in older adults. It may be that older adults can avoid eccentric exercise-induced muscle damage "instinctively". It is also possible that inhibitory mechanisms, for example, a high level of antagonist co-ctivation that inhibits maximal effort (Macaluso and De Vito 2004), are involved to prevent severe muscle damage in elderly subjects.

It has been shown that type II (fast-twitch) muscle fibres are more affected by ageing than type I (slow-twitch) muscle fibres (Monemi et al. 1998), and a significant reduction in the number of type II fibres of the vastus lateralis has been reported (Jones et al. 1986). Monemi et al. (1998) reported a significant decrease in the type II fibre content in the biceps brachii of old subjects (mean age of 74 y). It has been documented that type II fibres are more susceptible to eccentric exercise-induced muscle damage than type I fibres (Jones et al. 1986). It is possible that the smaller responses to the eccentric exercise in the older group are attributed to a lower population of type II fibres. Alternatively, the older subjects might have recruited more type I fibres, which were less susceptible to damage by eccentric exercise. Further studies are necessary to investigate these speculations.

It has been documented that the perception of pain is influenced by many factors and that the level of pain does not necessarily indicate the severity of injury or inflammation (Gagliese and Melzack 2000). Therefore, it is important to consider muscle soreness level after exercise separately from other symptoms of muscle damage. DOMS could negatively affect exercise adherence in the elderly (Nosaka et al. 2002), and could have been worse and more protracted for the old than for the young subjects. However, the present study found that DOMS was significantly lower for the old group compared with the young (Fig. 4). Gibson and Helme (2001) have stated in their review paper that pain perception would decrease with ageing. This could explain the lower DOMS score of the old group compared with the young.

Hamada et al. (2005) compared transcript levels of cytokine responses between young and old men after a bout of downhill running, and showed that accumulation of cytokine transcripts was smaller for the older subjects than it was for the young men and that interleukin-6 transcript accumulation was not induced in the old men. Interestingly, they reported that a greater increase in serum CK activity was found for the young compared with the old. Toft et al. (2002) also reported that interleukin-6 did not increase as much for the elderly subjects as for the young subjects following a cycling eccentric exercise, and increases in plasma CK activity and Mb concentration were also less for the elderly compared with the young subjects. It could be speculated that the impaired cytokine responses to exercise-induced muscle damage are related to the attenuated muscle damage seen in the old group, and blunted inflammatory responses in the old men result in smaller changes in markers of muscle damage including CK and Mb responses. In the present study, the tendency of the smaller degree of muscle swelling in the old group (Fig. 3) provides further indirect evidence that ageing restricts inflammation after exercise-induced muscle damage.

In conclusion, the data presented in the present study did not confirm the commonly believed notion that elderly muscles are more susceptible to muscle damage and take longer to recover from eccentric exercise-induced muscle damage. The results of the present study showed that muscle damage induced by eccentric exercise of the elbow flexors was less for old men than for young men, at least when the eccentric exercise was performed voluntarily. Therefore, old adults may not be as susceptible to eccentric exercise-induced muscle damage as is generally considered.

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