Single-joint eccentric knee extension training preferentially trains the rectus femoris within the quadriceps muscles

Sumiaki Maeo1 | Xiyao Shan2 | Shun Otsuka2 | Hiroaki Kanehisa3 | Yasuo Kawakami2

1Ritsumeikan Global Innovation Research Organization, Ritsumeikan University, Kusatsu, Shiga, Japan
2Faculty of Sport Sciences, Waseda University, Tokorozawa, Saitama, Japan
3Department of Sports and Life Science, National Institute of Fitness and Sports in Kanoya, Kanoya, Kagoshima, Japan

Correspondence
Sumiaki Maeo, Ritsumeikan Global Innovation Research Organization, Ritsumeikan University, Kusatsu, Shiga, Japan.
Email: smaeo1985@gmail.com

Funding information
Japan Society for the Promotion of Science, Grant/Award Number: 15F03228; Ministry of Education, Culture, Sports, Science and Technology of Japan

Eccentric contraction-induced quadriceps strains, particularly in the rectus femoris (RF), frequently occur in sports. By using MRI-based transverse relaxation time (T2) as an index of exercise-induced muscle edema, previous studies found pronounced damage in RF after an acute single-joint eccentric knee extension exercise. This study examined whether single-joint eccentric knee extension training would preferentially train RF, resulting in greater hypertrophy of RF than the other quadriceps muscles. Twelve males conducted work-matched single-joint isokinetic (180°/s) maximal eccentric contractions of the knee extensors in one leg (ECC-leg) and concentric in the other (CON-leg), six sets/session (3-5 sets in the initial 1-3 sessions), two sessions/wk for 10 weeks. Muscle volume of each quadriceps was measured pre- and post-training. T2 of each muscle was assessed weekly throughout the training period and pre- and post-training. Muscle volume significantly increased in all muscles in ECC-leg only, with a greater degree for RF (+7.3%) than the vasti (2.9%-3.7%). T2 did not change in all muscles throughout. These results suggest that RF can be preferentially trained by single-joint eccentric knee extension training. Cooperatively with the potential repeated bout effect (ie, protective effect) in eccentric exercise, this training modality would have positive implications for strain injury prevention of RF.

KEYWORDS
eccentric contraction, edema, preferential hypertrophy, quadriceps femoris, repeated bout effect

1 | INTRODUCTION

Muscle strain injuries of the quadriceps femoris (QF) commonly occur in sports that require repetitive kicking and sprinting (eg, soccer, rugby, American/Australian football).1-3 Such strain injuries often occur when QF is exposed to a sudden forceful eccentric (ECC) contraction during regulation of knee flexion and hip extension.2 Of the QF muscles, the rectus femoris (RF) is the most commonly injured muscle, likely due to its bi-articular nature and complex musculotendinous architecture.1-3 Given that prior bouts of ECC contractions largely protect against muscle damage and reduce the risk of strain injuries,4-7 known as the repeated bout effect,8 identifying a training modality that preferentially trains RF with ECC stimuli may be beneficial in strain injury prevention of this muscle.

By using MRI-based transverse relaxation time (T2) as an index of exercise-induced muscle edema, we recently reported that an acute bout of single-joint ECC (ie, lowering phase-only) knee extension exercise preferentially induced damage (pronounced increase in T2) in RF compared with the other QF muscles (ie, mono-articular vasti).9 By contrast, in the same study,9 multi-joint ECC squat exercise matched with the former for exercise variables (ie, % load of one
repetition maximum, repetitions, sets) did not increase T2 in RF. These findings are in line with previous studies showing pronounced T2 increase in RF after single-joint ECC knee extension exercise10,11 and no T2 increase after squat exercise,12 indicating that RF is preferentially recruited (or exposed to ECC stimuli) during single-joint ECC knee extension exercise. Wakahara et al13 reported that regional differences in a T2 increase within a muscle group after an acute bout of resistance exercise corresponded to those in the hypertrophy after training (ie, the magnitude of hypertrophy was greater at sites where the acute T2 increase was pronounced). Taken together, it is assumed that single-joint ECC knee extension training induces greater hypertrophy in RF than the vasti as a result of high recruitment/exposure to ECC stimuli during the exercise.

In another recent study of ours,14 we compared changes in QF muscle size following work-matched single-joint maximal ECC vs concentric (CON) knee extension training conducted for 10 weeks. After the intervention, only ECC training induced a significant increase in muscle size,14 suggesting that an ECC stimulus promotes muscle hypertrophy.14-16 In that study, we reported muscle size data as muscle volume of the “whole” QF (ie, the sum of all QF muscles) because comparing hypertrophic responses of “individual” QF muscles was not the purpose of that study.14 In addition, we measured T2 weekly throughout the training period and pre- and post-training,14 but again only the representative values for the QF (ie, an average of all QF muscles) were reported. It is worth examining how each individual muscle responded following the training to explore whether RF was preferentially trained by single-joint ECC knee extension training as we suggested above.

Therefore, by using unreported data from our previous study,14 we examined how muscle volume and T2 of each QF muscle changed following single-joint ECC or CON knee extension training. We hypothesized that single-joint ECC knee extension training would preferentially train RF, resulting in greater hypertrophy of RF than the vasti. We also hypothesized that CON training would not necessarily result in such preferential hypertrophy because of its insufficient overall hypertrophy (ie, no increase in whole QF muscle volume) after the intervention,14 which is likely due to low mechanical stress by choosing a fast velocity (180°/s) for the training velocity (discussed in more detail in our previous study).14 Additionally, we calculated changes in strength and concomitant muscle activity during maximal ECC, CON, and isometric (ISO) contractions following the ECC and CON training to provide comprehensive information on training-induced changes in strength and muscle activity, which were only partly reported in our previous study.14 It is worth noting that ECC strength is suggested to contribute to reducing the risk of strains.3,17 For this, we hypothesized that ECC strength could be improved by ECC training to a greater extent than by CON training, owing to the task specificity in resistance training.16

2 | MATERIALS AND METHODS

2.1 | Participants

This is a retrospective study using data from our recent study14 which compared single-joint ECC and CON training matched for total work. Briefly, 12 healthy young males with no history of systematic training (≥30 min/d, ≥2 days/wk) of any kind participated in the study (age: 25.6 ± 3.9 years, height: 1.69 ± 0.04 m, body mass: 63.5 ± 9.1 kg). All participants were right leg dominant, and one of their legs was assigned to ECC (ECC-leg) and the other CON (CON-leg) training, which was counterbalanced between the right and left legs among participants. Participants were instructed to avoid any intensive and unfamiliar physical activities within 2 days before the pretest and throughout the experimental period. This study was approved by Waseda University Ethics Committee and was consistent with institutional ethical requirements for human experimentation in accordance with the Declaration of Helsinki. Written informed consent was obtained prior to any measurements for each participant.

2.2 | Overview

Training was conducted 2 sessions a week, separated by at least 2 days, for 10 weeks. Pre- and post-tests were conducted 2-5 days before and after the first and last training sessions, respectively, and included assessments of MRI-based T2 and whole muscle volume of each QF muscle, as well as maximal torque and electromyogram (EMG) during ECC, CON, and ISO contractions. T2 measurement was also conducted between sessions in each week (ie, between sessions 1 and 2, 3 and 4…19 and 20), at least 2 days apart from the previous training session.

2.3 | Training

Participants sat in an adjustable chair of an isokinetic dynamometer (CON-TREX; CMV AG, Dübendorf, Switzerland) with the hip joint at 90° (anatomical position = 0°), and the range of motion of the knee joint was from 20° to 90°. The torso and hips were held tightly in the seat using adjustable lap belts to prevent extraneous movement during training. After a warm-up consisting of 4-6 submaximal to near maximal contractions (~50%-90% effort) with the assigned contraction mode, the preceding leg performed maximal ECC or CON contractions at 180°/s, 10 repetitions/set, for six sets. 8-seconds and 2-minutes rests were taken in between repetitions and sets, respectively. The number of the
sets in the initial training phase was gradually increased from three, four, and then five sets at the first, second, and third sessions to minimize exercise-induced muscle damage, which often occurs when unaccustomed ECC exercise is performed. Six sets were performed at the fourth session and thereafter. Work performed by each contraction as well as total work per set were monitored and recorded. After training one leg, the equivalent volume of work per set was performed by the contralateral leg with the assigned contraction mode (ie, the number of repetitions was manipulated each set). This made it necessary for CON-leg to perform more repetitions than ECC-leg to match the total work (results detailed in our previous study). The preceding leg was counterbalanced in the first training session among participants, and it was switched every session for each participant. Torque signal was recorded at a sampling rate of 2000 Hz using a 16-bit A/D converter (Power lab 16 s; ADInstruments, Sydney, Australia), and stored on a personal computer running data acquisition/analysis software (LabChart version 8; ADInstruments, Sydney, Australia). Visual feedback of the torque signal and verbal encouragement were provided for each contraction through all training sessions. After each session, participants ingested 30 g of whey protein, which is reported to augment muscle hypertrophy regardless of contraction modes used in training.

2.4 | Pre- and post-tests

2.4.1 | Torque and EMG

Using the same isokinetic dynamometer and posture as for the training, the maximal torque of the knee extensors was measured. Following the warm-up as described above for each contraction mode, maximal torque during ISO (at 90° knee flexion), CON (180°/s), and ECC (180°/s) contractions in this order were performed twice for each leg with ≥30 seconds of rest. If the difference in the peak torque between the two trials was ≥10%, additional trials were conducted until the closest two peak torques were <10%. The highest peak torque was adopted for further analysis.

EMG was recorded using a wireless EMG system (Trigno; Delsys, Boston, USA). Following skin preparation, surface EMG electrodes were placed over the belly of RF, vastus lateralis (VL), and vastus medialis (VM) at 50% (RF, VL) and 80% (VM) of the thigh length (distance between the greater trochanter and lateral femoral condyle) and parallel to the presumed orientation of the muscle fibers. EMG signals were amplified (×300) and band-pass-filtered (20- to 450-Hz) at source and sampled at 2000 Hz via the same A/D converter and computer software as for the torque signal. In offline analysis, EMG signals were corrected for the 48-ms delay inherent in the Trigno EMG system. From the trial in which the highest peak torque occurred for each contraction mode, root-mean-square was calculated for the 30°-80° range of knee joint excursion for ECC and CON contractions, and for a 500-ms window centered on the time at which peak torque occurred for ISO contraction. EMG was normalized to M-max for each of the three muscles and then averaged across the three muscles to provide a whole QF value [(EMG/M-max (%)]. Details for the M-max measurement are described elsewhere.

2.5 | MRI

At pre- and post-tests and weekly throughout the training period, T2-weighted MRIs (echo times: 25, 50, 75 and 100 ms, slice thickness: 1.5 cm, gap: 1 cm) for each thigh in the transverse plane were recorded using an 8-channel body array coil (GE Medical Systems; Chicago, USA). Before the scanning, oil capsules were put as markers at 50% and 80% of the thigh length on the skin surface at the lateral side for both legs (at pre- and post-tests only). Participants lay supine with their legs fully extended and muscles relaxed in a magnet bore (Signa EXCITE 1.5T; GE Medical Systems, Chicago, USA). The most proximal slice was always set at the proximal edge of the femoral head, and the nearest slice to the 50% marker in the pretraining scanning was used for analysis throughout for each participant. Images were analyzed using OsiriX software (version 8, Pixmeo, Geneva, Switzerland). Regions of interest (ROIs) were drawn by manually tracing the border of each of the QF muscles. Care was taken to exclude visible adipose and connective tissue incursions. T2 relaxation time was calculated by least-squares analysis fitting the signal intensity at each of the four echo times (n × 25 ms: 25, 50, 75, 100 ms) to a monoexponential decay.

T1-weighted MRIs (echo times: 5 ms, slice thickness: 4 mm, gap: 0 mm) of the whole thigh for both legs were obtained from 2 to 3 overlapping blocks at pre- and post-tests. The oil capsule markers allowed alignment of the blocks during the analysis. ROIs of each of the QF muscles were manually outlined in every third image (ie, every 12 mm) from the most proximal to the most distal image in which the muscle was visible, and areas for the skipped images were estimated on the basis of a linear relation between the images in which ROIs were outlined. The volume of each muscle was determined by summing all areas multiplied by the slice thickness (4 mm). During the MRI analysis, the investigators were blinded to the training modes and measurement timing.

2.6 | Statistical analysis

Descriptive data are presented as means ± SDs. All data were analyzed using SPSS software (version 24.0, IBM
Corp, Armonk, NY, USA). Statistical significance was set at \( P < 0.05 \). Paired \( t \)-tests were used to compare changes in muscle volume for each QF muscle, as well as torque and EMG for each contraction mode, in each leg. Percentage changes (\( %\Delta \)) from pre at post were calculated for these variables and were compared among muscles or contraction modes by a one-way ANOVA. Changes in \( T_2 \) throughout the intervention period were compared by a one-way ANOVA in each leg. When an ANOVA found a significant main effect, a Tukey post-hoc test was performed. Sphericity was checked by Mauchly’s test in ANOVA and \( P \) values were modified with Greenhouse-Geisser correction when necessary.

3 | RESULTS

3.1 | Muscle volume

Muscle volume pre- and post-training are shown in Table 1. Significant increases were found in all muscles in ECC-leg (\( P \leq 0.008 \)), but not in CON-leg (\( P \geq 0.291 \)). Figure 1 shows \( %\Delta \) in muscle volume. \( %\Delta \) in muscle volume for ECC-leg was significantly greater for RF (7.3 \( \pm \) 4.5%) than VL (2.9 \( \pm \) 3.0%, \( P = 0.011 \)) and VM (3.7 \( \pm \) 2.9%, \( P = 0.049 \)) (Figure 1A), with no differences among muscles in CON-leg (\( P = 0.665 \) by ANOVA) (Figure 1B).

3.2 | \( T_2 \)

Figure 2 shows changes in \( T_2 \) pre-, during, and post-training. While a significant main effect of time was found in several muscles (\( P \leq 0.026 \)), post-hoc tests showed no significant changes over time in all muscles for both legs (\( P \geq 0.110 \)).

3.3 | Torque and EMG

Torque and EMG pre- and post-training are shown in Table 2. Maximal torque significantly increased in all contraction modes for both legs (\( P \leq 0.004 \)). Significant increases were also found in EMG in all contraction modes for both legs (\( P \leq 0.035 \)), except for CON contraction of ECC-leg (\( P = 0.450 \)).

\( %\Delta \) in torque and EMG are shown in Figure 3. \( %\Delta \) in torque was significantly greater for ECC contraction for both legs than the other conditions (Figure 3A). Similarly, \( %\Delta \) in EMG was significantly greater for ECC contraction for both legs than most of the other conditions (Figure 3B).

4 | DISCUSSION

The primary finding of this study was that muscle volume significantly increased in all muscles in ECC-leg only, with a greater degree for RF than the vasti. This supported our main hypothesis that single-joint ECC, but not CON, knee extension training preferentially trains RF among QF muscles, while the hypothesis on the changes in ECC strength was partly refuted (discussed later). Coupled with the potential repeated bout effect in eccentric exercise, the current result suggests that this training modality may have positive implications for strain injury prevention of RF.

Muscle volume significantly increased in all muscles in ECC-leg only (Table 1), with significant differences in the degree of hypertrophy found between RF and VL, RF and VM, but not between RF and the vastus intermedius (VI) (Figure 1A). The reason for the lack of a significant difference between RF and VI is unclear, but may be partly due to a relatively small change in overall muscle volume (+4% as the whole QF), which would be attributable to relatively small total work achieved by this training intervention (discussed in detail in our previous study). Nevertheless, the current result suggests that RF is indeed preferentially trained by single-joint ECC knee extension training. Interestingly, the available literature suggests that resistance training comprising multi-joint leg extensions (ie, simultaneous knee extension and hip extension) such as the squats, rowing, and cycling induces less hypertrophy in RF than the vasti. Precise mechanisms for such exercise modality-dependent inter-muscle differences in QF hypertrophy are unknown, but are probably mainly attributable

| TABLE 1 | Changes in muscle volume (MV) measured pre- and post-training |
|-----------------|-----------------|-----------------|-----------------|
|                | ECC-leg         |                | CON-leg         |                |
|                 | Pre          | Post          | Pre            | Post          |
| MV (cm\(^3\))   |              |               |                |               |
| RF              | 219.9 ± 52.8  | 234.8 ± 49.9* | 220.7 ± 46.2   | 222.6 ± 46.1  |
| VL              | 513.1 ± 105.4 | 527.5 ± 105.3*| 515.1 ± 123.8  | 514.7 ± 120.3 |
| VM              | 396.9 ± 91.3  | 410.7 ± 90.6* | 417.9 ± 82.6   | 417.1 ± 76.2  |
| VI              | 474.1 ± 122.0 | 495.5 ± 122.2*| 489.0 ± 121.3  | 488.1 ± 121.6 |

CON-leg, concentrically trained leg; ECC-leg, eccentrically trained leg; RF, rectus femoris; VL, vastus lateralis; VM, vastus medialis; VI, vastus intermedius.

*Significantly different from pre (\( P < 0.05 \)).
to the difference between RF and the vasti being bi- and mono-articular muscles, respectively. More specifically, while all QF muscles act as knee extensors, only RF also works as a hip flexor. Thus, during exercises involving leg extensions represented by the squats, activation of RF should be low to efficiently produce the hip extension torque. This notion is supported by a recent study comparing EMG activities during single-joint knee extension vs multi-joint squat-like leg press exercise. These findings collaboratively suggest that although both of the single-joint knee extension and multi-joint squat exercises are often adopted as the major training modalities for targeting QF, their training stimuli to RF and the vasti largely vary between these exercises. In other words, it appears that single-joint knee extension, particularly with ECC stimuli (discussed in detail below), is a better training strategy for RF.

**FIGURE 1** Percentage changes (%Δ) from pre at post in muscle volume for the eccentrically trained leg (ECC-leg, A) and concentrically trained leg (CON-leg, B). RF, rectus femoris; VL, vastus lateralis; VM, vastus medialis; VI, vastus intermedius. Values are means ± SDs. Dashed lines indicate significant differences between muscles at *P* < 0.05. Asterisks indicate significant increases from pre based on absolute changes shown in Table 1.

**FIGURE 2** Absolute changes in transverse relaxation time (T2) for the eccentrically trained leg (ECC-leg, A) and concentrically trained leg (CON-leg, B). RF, rectus femoris; VL, vastus lateralis; VM, vastus medialis; VI, vastus intermedius. Values are means ± SDs.

**TABLE 2** Changes in maximal torque and electromyogram (EMG) measured pre- and post-training.

|            | ECC-leg | CON-leg |
|------------|---------|---------|
|            | Pre     | Post    | Pre     | Post    |
| Torque (Nm)|         |         |         |         |
| ECC        | 158.6 ± 46.7 | 271.7 ± 75.3* | 161.1 ± 33.9 | 246.8 ± 35.2* |
| ISO        | 160.6 ± 56.2 | 189.7 ± 58.1* | 154.2 ± 30.3 | 183.2 ± 44.2* |
| CON        | 135.7 ± 35.7 | 155.1 ± 45.9* | 129.9 ± 26.8 | 164.8 ± 35.1* |
| EMG (% M-max) |         |         |         |         |
| ECC        | 5.1 ± 1.7 | 8.2 ± 2.9* | 5.7 ± 2.1 | 8.5 ± 3.3* |
| ISO        | 6.5 ± 1.2 | 7.5 ± 2.3* | 6.7 ± 2.0 | 8.6 ± 3.6* |
| CON        | 6.7 ± 1.3 | 7.1 ± 2.3 | 6.5 ± 1.5 | 8.6 ± 3.7* |

CON, concentric; CON-leg, concentrically trained leg; ECC, eccentric; ECC-leg, eccentrically trained leg; ISO, isometric.

*Significantly different from pre (*P* < 0.05).
consider that single is crucial for muscle damage/strain injury prevention, we have reported after single – in terms of greater hypertrophy of RF than the vasti has training. However, it should be noted that a similar result responses of individual QF muscle after ECC vs CON RF.

This study is the first to show different hypertrophic responses of individual QF muscle after ECC vs CON training. However, it should be noted that a similar result in terms of greater hypertrophy of RF than the vasti has been reported after single-joint knee extension training using a conventional weight lifting/lowering model (ie, involving both CON and ECC contractions), or even after CON-only knee extension training, but not after ISO knee extension training (ie, equivalent hypertrophy among QF muscles). These findings and the current result together imply that (a) dynamic (ECC and/or CON) but not static (ISO) knee extension training results in pronounced hypertrophy in RF and (b) an ECC stimulus is not a requisite but promotes muscle hypertrophy. Importantly, while increasing/maintaining muscle size is a fundamental factor for achieving high athletic performance or quality of life, we acknowledge the possibility that muscle hypertrophy per se may not have any protective effect against muscle strain injuries. Rather, we interpret the finding(s) on the pronounced hypertrophy of RF to signify that RF was preferentially being trained among QF muscles. Given that prior exposure to ECC stimuli, but not CON stimuli, is crucial for muscle damage/strain injury prevention, we consider that single-joint ECC knee extension training, among others, is likely a strong preventive measure against strain injuries in RF.

As demonstrated by many studies, mechanical stress is one of the primary stimuli for muscle hypertrophy (eg, ECC-leg in this study). On the other hand, conducting exercise until/under a state of fatigue, thereby increasing metabolic stress, is also an important stimulus for hypertrophy. In our previous study, we calculated a fatigue index for both ECC-leg and CON-leg as the average peak torque of the final set divided by the average peak torque of the first set ×100, for all training sessions. Briefly, the results indicated no fatigue for both ECC-leg and CON-leg, with no difference between the training modes (discussed in detail in our previous study). This would be due to that (a) sufficient (2-minutes) rest periods were taken between sets, and (b) each contraction was brief (training velocity was fast). It is worth noting that several studies have shown evidence of hypertrophy after training composed of brief (explosive), unfatiguing contractions, given a certain level of mechanical stress (eg, ECC-leg in this study). Therefore, it seems that fatigue/metabolic stress is not a necessary stimulus for muscle hypertrophy. Nevertheless, future studies should be directed toward understanding the role of fatigue/metabolic stress together with mechanical stress in a training program to better understand each of their roles, as well as their potential interactions, in promoting hypertrophy.

T2 did not change throughout the intervention period in all muscles, even in RF, for both legs (Figure 2). Previous studies using the T2-MRI technique to localize muscle damage following an acute exercise bout had participants perform damaging eccentric exercises (ie, ~10 reps × 5-10 sets) in an unaccustomed (naive) state to “induce” certain degrees of damage. By contrast, we tried to “avoid” potential muscle damage, which often has negative influences on muscle performances and causes discomfort muscle soreness, by gradually increasing the set numbers at the initial sessions (ie, ~10 reps × 3-5 sets in the initial 1-3 sessions). Thus, caution is needed to interpret the results of previous studies and this study (ie, increases vs no change in T2). Our result suggests that edema (ie, swelling) derived from muscle damage did not noticeably occur (or was successfully avoided) through training, even in RF, likely owing to the repeated bout effect. At the same time, the result indicates that the observed hypertrophy in ECC-leg is indeed true hypertrophy with no influence of edema.

ECC strength, which is suggested to contribute to reducing the risk of strain injuries, was largely improved in ECC-leg after the training (Figure 3A), as often demonstrated in previous studies. Surprisingly, a similar degree of improvement in ECC strength was also observed in CON-leg (Figure 3A). This is most likely attributable to the cross-education whereby training of one limb
gives rise to enhancements in the performance of the contralateral homologous limb.\textsuperscript{40} The cross-education effect is reported to occur following various types of training including ECC\textsuperscript{40-42} and CON\textsuperscript{40,41} training, with a greater transferring effect for ECC strength following ECC training (of the other limb) than for CON strength following CON training (of the other limb).\textsuperscript{30,41} Such a greater cross-education effect following ECC training is likely due to a strong pre-training neural inhibition during ECC contractions and its subsequent disinhibition (ie, neural adaptation) after the training.\textsuperscript{14,19} Indeed, large increases in EMG during ECC contractions were found in both legs following training (Figure 3B), indicating that the training-induced improvements in ECC strength are accounted for by increases in neural drive for both legs. On the other hand, it is important to remark that several studies have reported no cross-education effect on CON strength following ECC training of the other limb\textsuperscript{40,42} and vice versa,\textsuperscript{40,41} suggesting that the cross-education is highly contraction type-specific used in training. Thus, we consider that there were little, if any, cross-education effect on strength of the untrained contraction modes in our previous\textsuperscript{14} and this study as well, although it is impossible to quantify its potential influence from the observed strength changes because both limbs were trained in this study unlike others cited above.\textsuperscript{40-42} Further research is needed to better understand the influence of cross-education with particular attention to, but not limited to, contraction modes used in training/testing and whether both limbs were trained or not.

In summary, after work-matched maximal ECC vs CON training, only ECC-leg showed a significant increase in muscle volume, with a greater degree for RF than the vasti. A growing body of evidence suggests that multi-joint leg extension exercise represented by the squat, another one of the major training modalities for targeting QF, does not provide sufficient training stimuli to RF.\textsuperscript{22-24} Furthermore, it is well documented that prior exposure to ECC stimuli,\textsuperscript{4,7} but not CON stimuli,\textsuperscript{34,35} is crucial for muscle damage/strain injury prevention. Considering the current result together with the potential repeated bout effect in ECC exercise, single-joint ECC knee extension training, among others, may have positive implications for strain injury prevention of RF from the viewpoint of exercise modality (eg, vs squat) and contraction mode (eg, vs CON).

5 | PERSPECTIVES

As discussed above, we consider that single-joint ECC knee extension training is likely a strong preventive measure against RF strain injuries. What can be manipulated in this exercise, in order to increase its potential preventive effect against strains, is hip and/or knee joint angle thus the active muscle lengthening of RF during exercise. It is reported that an ECC exercise at a long compared to short muscle length induces more damage and confers greater protection against further damage.\textsuperscript{43} Thus, to maximize the degree of active lengthening of RF, the hip and knee joints during exercise should be at extended and flexed positions, respectively, as much as possible (practically). For example, one could perform the exercise with the hip joint kept at ~0° (eg, lying flat on the back on a bench/customized machine) while QF is eccentrically contracted until the knee joint reaches the most flexed position (eg, ~120°). Reverse Nordic hamstring, requiring no device/machine, is an alternative whereby a practitioner kneels on the ground followed by slowly lowering the body backward to the ground.\textsuperscript{3} With careful familiarization/acclimatization, these exercises would be one of the most effective preventive measures against RF strain injuries, which warrants further research.

ACKNOWLEDGEMENTS

This study was supported by a Grant-in-Aid for Japan Society for the Promotion of Science Research Fellow (15J03228) and MEXT-Supported Program for the Strategic Research Foundation at Private Universities, 2015-2019 from the Ministry of Education, Culture, Sports, Science and Technology (S1511017). The authors thank all the participants for their time and effort.

CONFLICT OF INTEREST

None.

ORCID

Sumiaki Maeo \textsuperscript{\textcopyright} http://orcid.org/0000-0003-0919-4799

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*How to cite this article:* Maeo S, Shan X, Otsuka S, Kanehisa H, Kawakami Y. Single-joint eccentric knee extension training preferentially trains the rectus femoris within the quadriceps muscles. *Transl Sports Med*. 2018;1:212–220. [https://doi.org/10.1002/tsm2.38](https://doi.org/10.1002/tsm2.38)