Effect of Submaximal Eccentric versus Maximal Isometric Contraction on Delayed Onset Muscle Soreness

Mohamed M. Ragab, Neveen A. Abdel Raoof, Reham H. Diab

Abstract**—***Background:* Delayed onset muscle soreness (DOMS) is the most common symptom when ordinary individuals and athletes are exposed to unaccustomed physical activity, especially eccentric contraction which impairs athletic performance, ordinary people work ability and physical functioning. Multitudes of methods have been investigated to reduce DOMS. One of the valuable methods to control DOMS is repeated bout effect (RBE) as a prophylactic method. *Purpose:* To compare the repeated bout effect of submaximal eccentric with maximal isometric contraction on induced DOMS. *Methods:* Sixty normal male volunteers were assigned randomly into three equal groups: Group A (first study group): 20 subjects received submaximal eccentric contraction on non-dominant elbow flexors as a prophylactic exercise. Group B (second study group): 20 subjects received maximal isometric contraction on non-dominant elbow flexors as a prophylactic exercise. Group C (control group): 20 subjects did not receive any prophylactic exercises. Maximal isometric peak torque of elbow flexors and patient related elbow evaluation (PREE) scale were measured for each subject 3 times before, immediately after, and 48 hours after induction of DOMS. *Results:* Post-hoc test for maximal isometric peak torque and PREE scale immediately and 48 hours after induction of DOMS revealed that group (A) and group (B) resulted in significant decrease in maximal isometric strength loss and elbow pain and disability rather than control group (C), but submaximal eccentric group (A) was more effective than maximal isometric group (B) as it showed more rapid recovery of functional strength and less degrees of elbow pain and disability. *Conclusion:* Both submaximal eccentric contraction and maximal isometric contraction were effective in prevention of DOMS but submaximal eccentric contraction produced a greater protective effect against muscle damage induced by maximal eccentric exercise performed 2 days later.

Keywords**—**Delayed onset muscle soreness, maximal isometric peak torque, patient related elbow evaluation scale, repeated bout effect.

I. Introduction

DELAYED onset muscle soreness (DOMS) is an exercise-induced phenomenon that is among the most common and recurrent forms of sports injuries [1]. DOMS is the perception of discomfort and pain in the muscles in the days following unaccustomed physical activity, especially when eccentric contractions are involved [2].

An unaccustomed exercise consisting of eccentric contractions induces muscle damage characterized by histological changes observed under light and electron microscopy [3], and symptoms such as muscle weakness, DOMS, increased muscle stiffness and muscle swelling, as well as increase in muscle proteins such as creatine kinase (CK) and myoglobin (Mb) in the blood [4].

Delayed onset muscle soreness is usually not present until 8-24 hours after exercise and peaks between 24 and 48 hours [5]. The symptoms then gradually disappear 5-7 days post exercise, in addition to muscle soreness and pain, functional strength is reduced [6].

One of the symptoms of DOMS presents immediately after eccentric exercise is decrease in maximal force post exercise and in the days following unaccustomed eccentric exercise [7]. It has been suggested that both immediate mechanical disruption of muscle fibers and the accompanying inflammatory response is contributing to the force decline in the days following eccentric exercise [8].

As DOMS is typically triggered by new and unaccustomed exercise, it can be minimized by previous introduction of that exercise known as the repeated bout effect (RBE) [9]. Skeletal muscles quickly adapt with repeated exercise; so, when a subsequent bout of the same or similar eccentric exercise is performed, the changes in the muscle damage markers are attenuated and recovered to the baseline

The repeated bout effect is accompanied by a shift of the length– tension curve in the direction of longer muscle length because of incorporation of extra sarcomeres in muscle fibers [10]. So it is proposed that there are two shifts in the active length–tension relation of muscle following unaccustomed eccentric exercise, the first shift is due to the presence of damage and the second shift is due to an adaptation response.

Recent studies showed that maximal isometric contractions at a long muscle length would attenuate muscle damage induced by the maximal eccentric exercise [2], and how low-intensity eccentric contractions or maximal isometric contractions performed at different muscle lengths would influence the repeated bout effect [11].

The length of this protective effect may be relatively short lived. Performance of a single eccentric exercise bout has been shown to reduce muscle soreness after a similar exercise bout from 24 hours [12] up to 6 weeks but not beyond 9 weeks [13].

There are many variables that guide the RBE study, such as different types of people, different exercises since its intensity, volume, and induction for being eccentric or isometric, sub maximal or maximum, interval between sessions. Accordingly, the purpose of the current study was to compare

Mohamed M. Ragab, Neveen A. Abdel Raoof, Reham H. Diab are with the Basic Science Department, Faculty of Physical Therapy, Cairo University (e-mail: Mohamed.ragab@cu.edu.eg; dr_neveen_69@cu.edu.eg; Reham.diab@cu.edu.eg).

the repeated bout effect of submaximal eccentric with maximal isometric contraction on the magnitude of eccentric exercise – induce delayed onset muscle soreness.

II. Subjects and Methods

A. Subjects

This study was conducted in the isokinetic laboratory at Faculty of Physical Therapy, Cairo University, in the period from June 2014 to November 2014 to compare the repeated bout effect of submaximal eccentric contraction with maximal isometric contraction on induced delayed onset muscle soreness. Participants were selected by using randomized sampling from the postgraduate students of Faculty of Physical Therapy, Cairo University.

Sixty normal male subjects participated in this study and were randomly assigned by closed envelops method into three groups of equal number: Group (A) "first experimental group": 20 subjects received submaximal eccentric contraction on non-dominant elbow flexors as a prophylactic exercise. Group (B) "second experimental group": 20 subjects received maximal isometric contraction on non-dominant elbow flexors as a prophylactic exercise. Group (C) "control group":20 subjects did not receive any prophylactic exercise.

B. Design of the Study

Repeated measure study design was conducted.

C. Selection of Subjects

Sixty normal male volunteers from the postgraduate students of faculty of physical therapy, Cairo University were included and participated in this study after signing an institutionally approved informed consent form prior to data collection. Their age ranged from 20 to 30 years old, they did not suffer from any current arm pain or discomfort, and had the ability to demonstrate full, pain-free range of motion about the elbow joint prior to participation in the study. The exclusion criteria for participants were recent shoulder or elbow operation, using of anti-inflammatory drugs and previous history of muscles, joint or bone injuries of the upper limb.

D. Instrumentations and Tools

1. Isokinetic machine for measuring maximal isometric peak torque of non-dominant elbow flexors.
2. Patient Related Elbow Evaluation (PREE) scale for measuring elbow pain and disability in activities of daily living.
3. Dumbbells for applying prophylactic exercise on non-dominant elbow flexors.
4. Weight and height scale for measuring subjects' weight and height.

E. Procedures

The following data were recorded at the beginning of the study (information sheet): Personal data name, height, age, weight, telephone number, Explanation of the whole study for each subject and any possible complication or risk, then the subjects signed a consent form. This study consists of 3 phases: prophylactic exercises, induction of DOMS, measurements before and after induced DOMS.

1. Prophylactic Exercise

The subjects in *the first experimental group (A)* (n=20) performed submaximal eccentric contraction on the elbow flexors of the non-dominant arm two days prior to maximal eccentric exercise (induction of DOMS) [14].

Each Subject in the study group started to warm up for 5 minutes, After warming up the one repetition maximum through 3 to 5 subject maximum concentric contraction of elbow flexors of the non-dominant arm was estimated [15].

The subjects in the group were sit on a chair and 50 eccentric contractions of 80% 1RM for 5 sets of 10 repetition was done using dumbbell. Each set includes 10 contractions that lower a person's weight from (90◦) elbow flexion as starting position to full elbow extension as end position in 3 seconds and At least 2 seconds to reach the next contraction without weights placed in full flexion**.** One-minute rest was given between each set [16].

The subjects in *the second experimental group (B)* (n=20) performed maximal isometric contractions on elbow flexors of non-dominant arm two days prior to maximal eccentric exercise (induction of DOMS).

Each subject in the second study group started to warm up for 5 minutes, After warming up the one repetition maximum through 3 to 5 subject maximum concentric contraction was estimated. After that, the subjects in the group were sit on chair and 5 sets of 10 maximal isometric contractions of the elbow flexors was done respectively, at an elbow angle of 20° elbow flexion (full elbow extension = 0°) [17].

The subjects in *the third control group (C)* (n=20) did not perform any prophylactic exercises.

2. Induction of DOMS

All Subjects were engaged in maximal eccentric contractions protocol on isokinetic dynamometer to induce delayed onset muscle soreness.

The Biodex system was started and then calibration was done prior to each testing session. Each subject was seated upright on a chair with the backrest angle at 90° and his chest and waist were immobilized by straps, placing the upper arm on a padded support that secured the shoulder joint angle at 45° flexion and 0° abduction. The elbow joint was set at 90° with the forearm in a fully supinated position; the axis of rotation of the right elbow (lateral epicondyle of the humerus) was aligned with the axis of rotation of the dynamometer. The load cell assembly was attached to the distal forearm via a wrist cuff and the upper arm was secured in place through the use of Velcro straps.

The eccentric exercise consisted of five sets of six maximal eccentric contractions of the elbow flexors at an angular velocity of 90°·s–1 from a half-flexed position (90°) to a fully extended position on the isokinetic dynamometer [18].

Each contraction lasted for three seconds and was repeated every 10 s during which the isokinetic dynamometer passively returned the elbow joint to the flexed position at the velocity of 9°·s–1, with a 2-min rest between sets. Subjects were verbally encouraged to maximally resist the movements of the isokinetic dynamometer to extend the elbow joint.

3. Measurements Before and After Induced DOMS

Maximal isometric contraction peak torque of elbow flexors as marker of muscle damage and Elbow pain and disability in daily activities (PREE scale) were measured for each subject before, immediately after and 48 hours after induction of DOMS as comparable measurements.

The method involves maximal voluntary contraction (MVC) of elbow flexors at a fixed joint angle (90°), Subjects were verbally encouraged to perform three maximal contractions, holding each contraction for 5 s and were allowed 5 s of passive rest between each effort. The peak torque of the three contractions was averaged [19].

Elbow pain and disability in daily activities (PREE scale) were measured for each subject through a 20–item questionnaire and subjects rated their level of elbow pain and disability from zero to 10.

F. Statistical Analysis

Descriptive statistics: mean and standard deviation were calculated for (1) Maximal isometric peak torque of elbow flexors and (2) Patient related elbow evaluation scale among the three groups.

A repeated measure analysis of variance (ANOVA) was used to measure statistical differences among the three groups. Comparisons among groups at points in time are made to determine the statistical differences among the three groups in the mean value of the maximal isometric peak torque of elbow flexors and patient related elbow evaluation scale using Tukey's post-hoc test (Least square difference (LSD) test) was performed ($P<0.05$).

III. Results

There were no significant differences among the three groups concerning age, weight and height.

A. Results of Maximal Isometric Peak Torque of Elbow Flexors

Repeated measure ANOVA revealed that there was no significant difference among the three groups in maximal isometric peak torque for the pre induction of DOMS value as ($F = 0.747$, $P = 0.478$). While there was significant difference for the immediately after induction of DOMS value as ($F=10.276$, $P = 0.0001$), and finally there was a significant difference for 48 hours after induction of DOMS value as ($F = 31.967$, $P = 0.0001$).

Post-hoc test was performed to determine the difference among the groups in the mean value of the peak torque. For immediately after induction of DOMS there was a significant difference between groups A and B (mean difference=3.49, P=0.021), between groups A and C (mean difference=6.65, P=0.0001), and finally between groups B and C (mean difference=3.16, P=0.036), as shown in Table I and Fig. 1.

For 48 hours after induction of DOMS there was a significant difference between groups A and B (mean difference=3.215, P=0.036), between groups A and C (mean difference=11.57, P=0.0001), and finally between groups B and C (mean difference= 8.355, P=0.0001), as shown in Table I and Fig. 2.

TABLE I
POST HOC TEST AMONG THE THREE GROUPS FOR PEAK TORQUE (NEWTON × METER)

Peak torque		Mean difference	P- value	S
Immediately after induction of soreness	Group A vs. group B	3.49	0.021	*S
	Group A vs. group C	6.65	0.0001	*S
	Group B vs. group C	3.16	0.036	*S
48 hrs. after induction of soreness	Group A vs. group B	3.21	0.036	*S
	Group A vs. group C	11.57	0.0001	*S
	Group B vs. group C	8.35	0.0001	*S

*P- Value: Probability Value *S: Significant*

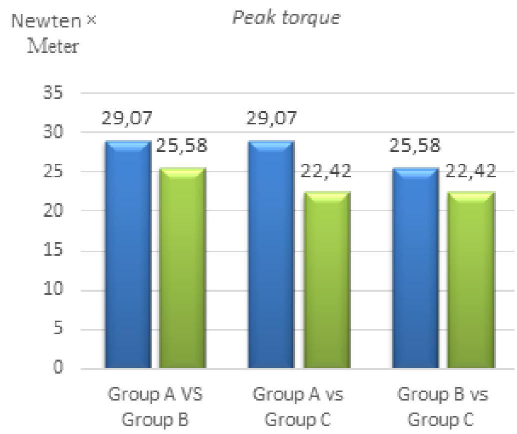

Fig. 1 Post-Hoc Test for Peak Torque: Immediately After Induction of DOMS for Groups A, B, and C

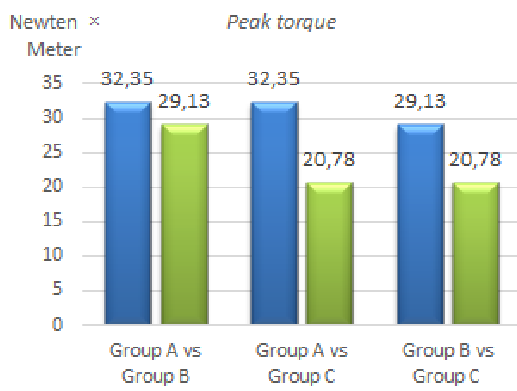

Fig. 2 Post-Hoc Test for Peak Torque: 48 Hours after Induction of DOMS for Groups A, B, and C

B. Results of Patient Related Elbow Evaluation Scale

Repeated measure ANOVA revealed that there was no significant difference among the three groups in the PREE Scale for the pre induction of DOMS value (F=.290, P=.750). While there was a significant difference for the immediately after induction of DOMS value (F=11.117, P=0.0001), and finally, there was a significant difference for 48 hours after induction of DOMS value (F=94.305, P=0.0001).

Post-hoc test was performed to determine the difference among the three groups in the mean value of the PREE scale. For immediately after induction of DOMS there was a significant difference between groups A and B (mean difference= -6.30, P=0.019), between groups A and C (mean difference= -12.35, P=0.0001), and finally, between groups B and C (mean difference= -6.05, P=0.025), as shown in Table II and Fig. 3.

For 48 hours after induction of DOMS there was a significant difference between groups A and B (mean difference= -6.5, P=0.016), between groups A and C (mean difference= -33.75, P=0.0001), and finally between groups B and C (mean difference= -27.25, P=0.036), as shown in Table II and Fig. 4.

TABLE II
POST HOC TEST AMONG THE THREE GROUPS FOR PREE SCALE

PREE SCALE		Mean difference	P- value	S
Immediately after induction of DOMS	Group A vs. group B	-6.30	.019	*S
	Group A vs. group C	-12.35	0.0001	*S
	Group B vs. group C	-6.05	0.025	*S
48 hours after induction of DOMS	Group A vs. group B	-6.5	0.016	*S
	Group A vs. group C	-33.75	0.0001	*S
	Group B vs. group C	-27.25	0.0001	*S

*P- Value: Probability Value *S: Significant*

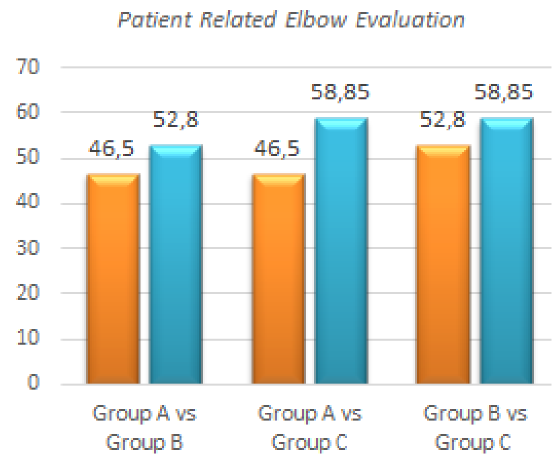

Fig. 3 Post-hoc Test for PREE scale: immediately after induction of DOMS for groups A, B. and C

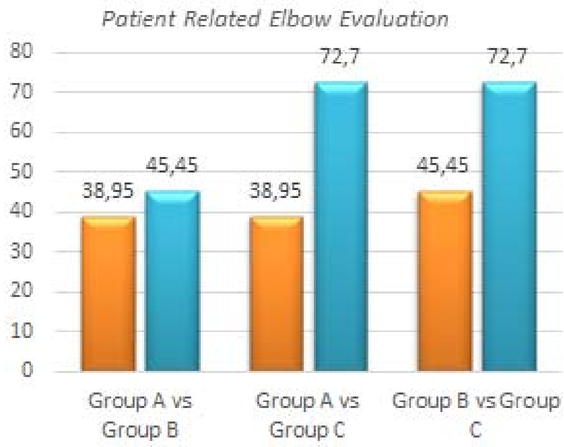

Fig. 4 Post-hoc Test for PREE scale: 48 hours after induction of DOMS for groups A, B, and C

IV. DISCUSSION

The findings of the current study revealed that submaximal eccentric group (A) was more effective than control group (C) which was agreed by [20] which reported that muscle function was improved and muscle pain was lower after second attack of maximal eccentric exercises ($p < 0.05$) when a bout of eccentric exercises performed prior to maximal eccentric exercises.

These results also supported by [21] which investigated whether a repeated series of various settings would result in difference in magnitude of muscle damage after the first and second exercise sessions. Ten untrained men underwent two sessions of eccentric exercise of the elbow flexors in each arm (4 sets in total) with sessions separated by 4 weeks. The results showed that range of motion (ROM), cross-sectional area of the biceps and DOMS changed significantly ($p < 0.05$) after exercise.

In addition, [22] showed that changes in indirect markers of muscle damage such as muscle soreness and pain were attenuated after the second bout, which was performed 2 weeks after an initial bout. It has also been reported that submaximal non-damaging eccentric contractions conferred protective effect against higher intensity eccentric contractions.

Additionally, our results agreed with [23] which hypothesized that an eccentric exercise session with a high or low volume protects against muscle damage after a high volume in the series and subsequent adaptation. Sixteen men performed either maximum 45 eccentric contractions (ECC45) or 10 maximum eccentric contractions (ECC10) using the elbow flexors. This was followed by a session of ECC45 two weeks later, session of maximum ECC45 induced more damage than an initial attack of maximum ECC10, however, both conferred protection from subsequent ECC45 maximum eccentric contractions and reduced muscle pain and soreness.

Also, our results agreed with [24] which compared the changes in indirect markers of muscle damage after eccentric exercise of the elbow flexors with different eccentric actions, the results showed that maximal isometric force (MIF) decreased significantly ($p<0.01$) to approximately 60% of pre-exercise levels immediately after initial eccentric session and recovery of about 70% three days later for all groups after second eccentric session, this suggested that repeated bout of eccentric exercise enhanced the recovery of muscle damage after second session of maximal eccentric exercise performed 3 days later regardless number of exercise repetitions in the initial session.

These finding agreed with those obtained by [25] which reported that eccentric contractions at long muscle lengths induce greater muscle damage than eccentric contractions at short muscle lengths, they found that the eccentric exercise at the long muscle length (100-180°, full extension: ~180°) produced a greater protective effect against muscle damage induced by maximal eccentric exercise performed 2 weeks later.

In addition, the findings revealed that maximal isometric group (B) was more effective than control group (C) which was agreed by [26] which have recently showed that the extracellular matrix is strengthened following 180 isometric contractions evoked by electrical stimulation, and that muscle soreness in the subsequent bout that was performed 28 days later was attenuated.

This concept was supported by [27] which stated that maximal isometric contractions at a long muscle length (160°) but not at a short muscle length (90°) conferred protective effect against maximal eccentric exercise performed 2 weeks later. This suggests that not only eccentric contractions but also isometric contractions at a long muscle length produce protective effect against muscle damage induced by eccentric contractions.

These results were also supported by [28] which reported that two sets of 25 maximal isometric contractions of the elbow flexors at a long muscle length (40° elbow flexion) resulted in decreases in maximal voluntary isometric strength loss and relaxed elbow joint angle. Furthermore, [29] reported that 50 maximal voluntary isometric contractions of the elbow flexors at the elbow joint angle of 140° resulted in a significant reduction of maximal voluntary contraction (MVC) strength loss (16% at 140° elbow angle at 24 h).

Finally, the findings revealed that submaximal eccentric group (A) was more effective than maximal isometric group (B) which was agreed by [17] which investigated how submaximal intensity eccentric contractions or maximal isometric contractions performed at different muscle lengths would influence the repeated bout effect. Subjects were placed into one of five groups and during the first exercise bout performed 30 contractions of either maximal eccentric actions, 10% of maximal voluntary isometric contractions (MVIC) eccentric exercise, 20% MVIC eccentric exercise, 90 degrees maximal isometric contractions, or 20 degrees maximal isometric contractions. Three weeks later all groups performed maximal eccentric actions. The greatest protection occurred when the maximal eccentric actions (64-98%) were performed at the first bout. After that, the largest protection was produced by the 20-degree maximal isometric contractions (27-63%) then 20% MVC eccentric actions (17-55%), 10% MVC eccentric contractions (0%-36%) and lastly the 90-degree maximal isometric contractions (0%-11%).

The current results are in consistent with those reported by [11] which documented that one of the potential cellular adaptations for the protective effect is a longitudinal addition of sarcomeres and this theory was indirectly supported by a shift in optimum angle to a longer muscle length. However, the maximal isometric contractions in previous studies did not shift the peak torque (optimum) angle, If a shift of peak torque angle is a sensitive marker of changes in sarcomere number in series, the longitudinal addition of sarcomeres does not appear to be occurred with isometric contractions, so the submaximal eccentric exercises was more effective the maximal isometric contractions in prevention of induced DOMS. This is also supported by [30] which found that both maximal voluntary and electrical stimulation-evoked isometric contractions of the elbow flexors at a long muscle length resulted in moderate but significant protection of muscle damage but less than high intensity eccentric contractions, they demonstrated that repeated maximal voluntary isometric contractions at a long muscle length (160°) resulted in small but significant decreases in MVC strength and ROM and increases in muscle soreness and tenderness.

In addition, [14] reported that repeated bout of non-damaging low intensity eccentric or maximal isometric exercises can provide a protective effect against muscle damage but less than maximal high intensity eccentric exercise. It seems that the combination of the first 40% ECC bout that resulted in minor damage and the second to fourth 40% ECC bouts that resulted in little or no damage provided the same magnitude of protective effect as one bout of 100% ECC. This is supported by [31] which reported that eccentric or lengthening contractions and muscle fiber degeneration are not required to induce protection against eccentric-induced muscle injury. This demonstrates that an acute non-eccentrically biased exercise of a low stimulus can induce adequate adaptation against subsequent injurious eccentric exercises but with less protection effect than submaximal eccentric exercises. Thus, acute exercises of non-eccentrically biased or having the same amounts of eccentric as maximal isometric contraction can be performed to induce protection in the skeletal muscles. This finding makes the stimulus of these non-eccentrically biased exercises appropriate given that less muscle soreness was reported in the repeated exercise. Thus, the repeated bout effect can be produced with non-injurious and low stimulus acute exercises. This approach will reduce muscle soreness and perhaps, as well motivate a sedentary person starting any exercise program to improve physical fitness.

Unlike our study, [11] reported that the effect of maximal isometric contractions on maximal eccentric contraction-induced muscle damage is stronger than that of submaximal eccentric contractions, because the smaller number of isometric contractions (n =10) conferred a protective effect similar to that of a larger number of eccentric contractions (n = 30).

Contrasting these studies, [32] demonstrated that both

Creatin Kinase and DOMS had no significant differences in RBE, with an interval of two days between the first session and the second.

In contrast to the previous results, [33] reported that first session of eccentric exercise of the elbow flexors performed three days prior to second session of maximal eccentric exercise did not affect changes in indicators of muscle damage. ECC1and ECC2 resulted in significant reductions in maximal isometric force and ROM, and development of DOMS for all groups.

These differences might be related to the large sample size in the current study while small sample size in the previous study, also It might be that intensity of eccentric contractions in previous study was not enough to produce protection effect, also eccentric exercise may not be performed at long muscle length in previous studies, while in the current study the submaximal eccentric exercise at 80% of maximal power was used and subjects performed eccentric contractions at long muscle length from 90° elbow flexion to full elbow extension which produced more protection against muscle damage.

V. Conclusion

This study was repeated measures study design, the results of this study can conclude the repeated bout effect of submaximal eccentric contractions with 80% of maximal power and maximal isometric contractions at long muscle length performed two days prior to maximal eccentric exercise session were effective in prevention of DOMS, but submaximal eccentric contractions produced a greater protective effect against muscle damage induced by maximal eccentric exercise.

Acknowledgment

The authors thank Shimaa Taha for her assistance with data collection and analysis. The authors declare that they have no potential conflict of interest.

References

[1] K. Cheung, P. Hume and L. Maxwell: Delayed onset muscle soreness: treatment strategies and performance factors. Journal of Sports Medicine; 33(2):145-64, 2003.
[2] H. Chen, K. Nosaka and T. Chen: Muscle damage protection by low intensity eccentric contractions remains for 2 weeks but not 3 weeks. Europe Journal of Applied Physiology; 112: 555-565, 2012.
[3] F. Lauritzen, G. Paulsen, T. Raastad, L. Bergersen and S. Owe: Gross ultra-structural changes and necrotic fiber segments in elbow flexor muscles after maximal voluntary eccentric action in humans. Journal of Applied Physiology; 107(6): 1923–1934, 2009.
[4] P. Clarkson and M. HubaL: Exercise-induced muscle damage in humans". American Journal of Physiologic Medical Rehabilitation; 81(11): 52-69, 2002.
[5] O. Prasartwuth, J. Taylor and S. Gandevial: Maximal force, voluntary activation and muscle soreness after eccentric damage to human elbow flexor muscles. J Physiology; 567: 337–348, 2005.
[6] DiPasquale, M. Dana, J. Robert and M. Richard: Determinants of the Repeated-Bout Effect after Lengthening Contractions. Original Research Articles: Musculoskeletal; 90 (10): 816-824, 2011.
[7] D. Chapman, M. Newton, M. McGuigan and K. Nosaka: Comparison between old and young men for responses to fast velocity maximal lengthening contractions of the elbow flexors. Europe Journal of Applied Physiology; 104(3): 531–539, 2008.
[8] S. Sayers and P. Clarkson: Force recovery after eccentric exercise in males and females Europe Journal of Applied Physiology; 84: 122-126, 2001.
[9] M. McHugh and D. Tetro: Changes in the relationship between joint angle and torque production associated with the repeated bout effect. Journal of Sports Science; 21:927-32, 2003.
[10] C. Brockett, D. Morgan and U. Proske: Human hamstring muscles adapt to eccentric exercise by changing optimum length. Medicine and Science in Sports and Exercise; 33: 783–790, 2001.
[11] T. Chen, H. Chen, AJ. Pearce, et al. Two maximal isometric contractions attenuate the magnitude of eccentric exercise-induced muscle damage. Journal of Medicine and Science in Sports and Exercise; 37: 680–689, 2012.
[12] L. Hirose, N. Nosaka, M. Newton, A. Lavender, M. Kano, J. Peake and K. Suzuki: Changes in inflammatory mediators following eccentric exercise of the elbow flexors. Exercise Immunology Review; 10: 75-90, 2004.
[13] A. Cleary, Michelle, et al: Temporal Pattern of the Repeated Bout Effect of Eccentric Exercise on Delayed- Onset Muscle Soreness. Journal of Athletic Training: 37(1):32-36, 2002.
[14] A. Lavender and K. Nosaka: A light load eccentric exercise confers protection against a subsequent bout of more demanding eccentric exercise. Journal of Medicine and Science in Sports and Exercise; 11(3): 291–298, 2008.
[15] N. Shahbazpour, et al: Early alternations in serum creatine kinase and total cholesterol following high intensity eccentric muscle actions. Perception and motor systems laboratory. The University of Queensland, 2004.
[16] M. Sahebazamani, H. Mohammadi and T. Ghahraman: The Effect of Repeated Bouts of Eccentric Exercise on Functional Markers of Delayed Onset Muscle Soreness. International Journal of Applied Exercise Physiology 1(2), 2012.
[17] T. Chen, H. Chen and A. Pearce: Attenuation of Eccentric Exercise induced Muscle Damage by Preconditioning Exercises. Journal of Medicine and Science in Sports and Exercise, 2012.
[18] T. Chen, H. Chen, M. Lin, C. Wu and K. Nosaka: Muscle damage responses of the elbow flexors to four maximal eccentric exercise bouts performed every 4 weeks. Europe Journal of Applied Physiology; 106(2): 267–275, 2009b.
[19] K. Nosaka and M. Aoki: Repeated bout effect: research update and future perspective. Brazilian Journal of Biomotricity; 5(1): 5-15, 2011.
[20] C. Starbuck and R. Eston: Exercise-induced muscle damage and the repeated bout effect: evidence for cross transfer. Europe Journal of Applied Physiology; 112 (3): 1005-13, 2012.
[21] R. Chan, R. Newton and K. Nosaka: Effects of set repetition configuration in eccentric exercise on muscle damage and the repeated bout effect. Europe Journal of Applied Physiology; 112:2653–2661, 2012.
[22] A. Aldayel, M. Jubeau, M. McGuigan and K. Nosaka: Less indication of muscle damage in the second than initial electrical muscle stimulation bout consisting of isometric contractions of the knee extensors. Europe Journal of Applied Physiology; 108:709 –717, 2010.
[23] G. Howatson, K. Someren and T. Hortobagyi: Repeated bout effect after maximal eccentric exercise. International Journal of Sports Medicine; 28(7), 557-563, 2007.
[24] T. Chen and K. Nosaka: Responses of elbow flexors to two strenuous eccentric exercise bouts separated by three days. Journal of Strength Conditioning Res; 20(1): 108–116, 2006a.
[25] K. Nosaka, M. Newton, P. Sacco, D. Chapman and A. Lavender: Partial protection against muscle damage by eccentric actions at short muscle lengths. Journal of Medicine and Science in Sports and Exercise; 37: 746-753, 2005b.
[26] A. Mackey, J. Bojsen, K. Qvortrup, M. Pedersen, S. Brandstetter and P. Schjerling: Sequenced response of extracellular matrix de adhesion and fibrotic regulators after muscle damage is involved in protection against future injury in human skeletal muscle. FASEB journal official publication of the Federation of American Societies for Experimental Biology; 25: 1943-1959, 2011.
[27] K. Nosaka: Muscle damage and adaptation induced by lengthening contractions. In: Shinohara, M (editor): Advances in Neuromuscular Physiology of Motor Skills and Muscle Fatigue. Kerela, India: Research Signpost; 415-435, 2009.
[28] A. Philippou, G. Bogdanis and A. Nevill: Changes in the angle-force curve of human elbow flexors following eccentric and isometric exercise. Europe Journal of Applied Physiology; 93: 237-244, 2004.

[29] A. Philippou, M. Maridaki and G. Bogdanis: Angle-specific impairment of elbow flexors strength after isometric exercise at long muscle length. Journal of Sports Science; 21: 859-65, 2003.
[30] J. Marc, M. Muthalib, Y. Guillaume, A. Nicola and K. Nosaka: Comparison in muscle damage between maximal voluntary and electrically evoked isometric contractions of the elbow flexors Europe Journal of Applied Physiology; 2011.
[31] T. Koh and S. Brooks: Lengthening contractions are not required to induce protection from contraction-induced muscle injury. American Journal of physiologic Regulatory Integrative Comp; 281(1):155-161, 2001.
[32] M. Uchida, K. Nosaka, C. Ugrinowitsch, A. Yamashita, E. Martins, A. Moriscot and M. Aoki: Effect of bench press exercise intensity on muscle soreness and inflammatory mediators. Journal of Sports Science; 27: 499-507, 2009.
[33] G. Howatson and K. Someren: Evidence of a contralateral repeated bout effect after maximal eccentric contractions. European Journal of Applied Physiology; 101: 207-214, 2007.