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**Research article**

# The Acute Effect of Local Vibration As a Recovery Modality from Exercise-Induced Increased Muscle Stiffness

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## Abstract

Exercise involving eccentric muscle contractions is known to decrease range of motion and increase passive muscle stiffness. This study aimed at using ultrasound shear wave elastography to investigate acute changes in biceps brachii passive stiffness following intense barbell curl exercise involving both concentric and eccentric contractions. The effect of local vibration (LV) as a recovery modality from exercise-induced increased stiffness was further investigated. Eleven subjects performed 4 bouts of 10 bilateral barbell curl movements at 70% of the one-rep maximal flexion force. An arm-to-arm comparison model was then used with one arm randomly assigned to the passive recovery condition and the other arm assigned to the LV recovery condition (10 min of 55-Hz vibration frequency and 0.9-mm amplitude). Biceps brachii shear elastic modulus measurements were performed prior to exercise (PRE), immediately after exercise (POST-EX) and 5 min after the recovery period (POST-REC). Biceps brachii shear elastic modulus was significantly increased at POST-EX (+53 ± 48%; $p < 0.001$) and POST-REC (+31 ± 46%; $p = 0.025$) when compared to PRE. No differences were found between passive and LV recovery ($p = 0.210$). LV as a recovery strategy from exercise-induced increased muscle stiffness was not beneficial, probably due to an insufficient mechanical action of vibrations.

**Key words:** Supersonic shear imaging, vibratory massage, biceps brachii, barbell curl exercise, muscle passive stiffness.

## Introduction

Exercise involving eccentric muscle contractions is well known to impair force production capacities (Janecki et al., 2011; Torres et al., 2007) and to induce reduced range of motion (ROM) immediately after exercise (Lau and Nosaka, 2011; Torres et al., 2007; Whitehead et al., 2001). Besides parameters such as stretch tolerance and neural factors (Guissard and Duchateau, 2006), ROM is mainly determined by passive muscle stiffness (Proske and Morgan, 2001; Murayama et al., 2000). An increased number of residual cross-bridges between myosin heads and actin is thought to largely contribute to this exercise-induced increased stiffness (Proske and Morgan, 2001). Accordingly, increased passive muscle stiffness has been extensively reported immediately and up to 3 weeks after purely eccentric contractions (Lacourpaille et al., 2014; Whitehead et al., 2001; Chleboun et al., 1998; Green et al., 2012; Howell et al., 1993; Murayama et al., 2000; Janecki et al., 2011; Torres et al., 2007), and is associated with delayed-onset muscle soreness (DOMS) (Cheung et al. 2003).

Increased muscle stiffness may alter muscle performance (Jones et al., 1987) and is further associated with greater risk of muscle damage and strain injury (McHugh et al., 1999; Watsford et al., 2010). Hence, it may be of interest to use recovery strategies to minimize the observed symptoms (Cheung et al., 2003). In some activities such as during a judo tournament, acute recovery is of importance since athletes often participate in several matches that are generally separated by 15 to 60 min (Franchini et al., 2009; Franchini et al., 2003). Several post-exercise recovery interventions are often employed to improve the acute recovery process (e.g. low intensity exercise (Mika et al., 2007), electrostimulation (Bieuzen et al., 2012), cryotherapy (Pournot et al., 2011)). Massage is currently one of the most popular recovery techniques (Torres et al., 2012). Massage is thought to increase ROM through decreased muscle passive stiffness (Weerapong et al., 2005). However, there is little scientific evidence to corroborate an effect of massage on muscle recovery (Moraska, 2005; Weerapong et al., 2005). This may be explained by the variety of techniques and durations used, difficulty in applying constant pressure during the massage, or the therapist's level experience (Moraska, 2007).

Alternatively, another way to mechanically stimulate muscles may be the use of vibratory massages (Green and Stannard, 2010). Using vibrations may provide the advantage to precisely control the frequency, duration, and amplitude of the stimulation (Edge et al., 2009), and can be easily use as a recovery tool in the sports field, especially when using local vibration (LV) directly applied onto muscles. LV has been demonstrated to prevent DOMS symptoms when applied before eccentric exercise (Bakhtiary et al., 2007; Imtiyaz et al., 2014). LV is also a useful post-exercise recovery modality in treating inflammation and DOMS when applied during 5 days after eccentric exercise (Broadbent et al., 2010). Regarding ROM, Lau and Nosaka (2011) demonstrated that LV has an immediate positive effect on elbow ROM when applied on days 1, 2 and 3 after an eccentric arm exercise inducing muscle damage. Although the authors' main hypothesis was based on the analgesic effects of vibration (Lau and Nosaka, 2011), it may also be hypothesized that such vibration-induced increased ROM was due to reduced passive muscle stiffness through a decreased number of residual cross-bridges, some of them being broken by the mechanical vibratory stimulation. Although massages have been demonstrated to reduce passive stiffness

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of relaxed muscles (Eriksson Crommert et al., 2014), the effects of LV remain to be determined, especially in the context of recovery from exercise.

Elastographic methods have recently been implemented to quantify local muscle mechanical properties (Drakonaki et al., 2012). One of these methods is Supersonic shear wave imaging (SSI) (Bercoff et al., 2004). It consists of measuring the velocity of shear waves remotely induced by focused ultrasound. The squared velocity is directly related to tissue stiffness, i.e. the shear elastic modulus (in kPa). SSI technique has been recently shown to provide reliable measurements of shear elastic modulus in a variety of resting muscles (Lacourpaille et al., 2012), and with linear increase of shear elastic modulus during passive stretching (Maisetti et al., 2012).While SSI has been used to demonstrate increased passive muscle stiffness after eccentric exercise (Lacourpaille et al., 2014), this technique may allow the quantification of increased passive muscle stiffness after more natural exercise involving both concentric and eccentric actions, and may determine the potential effects of LV as a recovery method.

The first aim of the present study was to investigate the acute changes in biceps brachii muscle passive stiffness following intense barbell curl exercise involving both concentric and eccentric actions. We hypothesized that biceps brachii passive stiffness would increase (as characterized by increased shear elastic modulus), following eccentric contractions. The second aim of this study was to investigate the acute effect of LV applied immediately after exercise as a recovery technique on muscle stiffness. We hypothesized that LV massage would reduce the acute exercise-induced increased stiffness.

## Methods

### Subjects

Eleven physically active adults (5 females and 6 males ; age 38 ± 9 years, height 1.74 ± 0.09 m, body mass 73 ± 8 kg) without prior experience of resistance training specific to biceps curl, participated in this study. Subjects with neuromuscular pathology and arm injury were excluded. Written informed consent was obtained from all subjects prior to their participation and this study conformed to the standards from latest revision of the *Declaration of Helsinki* and was approved by the local ethics committee.

### Study design

In the present study, exercise-induced increased muscle passive stiffness was induced by 4 bouts of 10 movements of bilateral barbell curl exercise (i.e. bilateral elbow flexion/extension with a barbell ) at 70% of the one-rep maximal flexion force (1RM, mean 1RM of 21.7 ± 7.2 kg), with a 1-min resting period between each bout. This was designed according to the training load and repetitions per set recommended for novice and intermediate individuals (Kraemer et al. 2002). Participants supported their back against a wall and maintained a 120° knee angle (controlled through a goniometer before each bout and visual inspection during movements). During flexion, subjects had to lift the load from full extension to full flexion over a period of 1 to 2 s. During extension, subjects were asked to lower the load slowly over a 5-s period and keeping the velocity as constant as possible. Subjects had to perform their flexion/extension movements according to the instruction of the experimenter. 1RM was determined during a familiarization session performed at least 2 days before experimental procedures. To control if both arms performed a similar amount of work, elbow joint flexion maximal voluntary contraction (MVC) of both arms was recorded on a custom-made ergometer equipped with a S-type load cell force transducer (F2712 Celians, France) before (PRE) and immediately after exercise (POST-EX). The largest value from two isometric maximal contractions was considered as the MVC at each time interval and for each arm.

Subjects laid prone on a massage table with arms extended (180°) where biceps brachii shear elastic modulus measurements were performed on both arms (always LV arm first) prior to exercise (PRE), 5 min after exercise (POST-EX), and 5 min after the recovery period (POST-REC) The 5-min delays post-exercise and post-recovery are explained by the time needed to perform other shear elastic measurements that were not included here.

To assess the effect of LV as a recovery tool, an arm-to-arm comparison model was used: one arm was randomly assigned to the passive recovery condition (PAS arm), while the other arm was assigned to the local vibration recovery condition (LV arm). Lying prone on a massage table with arms extended (180°) LV arm was exposed to a 10-min recovery period of vibration, while PAS arm remained passive. A 10-min period was selected according to the common duration of massages performed in the context of recovery (Weerapong et al., 2005). LV was applied by a handheld mechanical vibration generator (Vibralgic 5, YSY Medical; Gallargues-le-Montueux, FRANCE). Without any pressure applied on the head of the vibrator (1 cm in diameter), the experimenter performed random sweeps over the biceps brachii muscle belly. The head of the vibrator was applied on the skin in multiple and random directions with the aim for the experimenter to homogeneously treat the whole muscle belly. Subjects were asked to remain fully relaxed during the recovery period. According to information provided by the manufacturer and since previous studies demonstrating beneficial effects of vibration in the prevention (Bakhtiary et al., 2007) or treatment of DOMS (Broadbent et al., 2010; Lau and Nosaka, 2011) used vibration frequencies ranging from 40 to 65 Hz, vibration was set in the current study at a 55-Hz frequency and 0.9-mm amplitude. The vibratory load of the vibration intervention was calculated from the frequency (*f*, in Hz), amplitude (*A*, in m) and duration (t, in s) of the vibration exposure (Cochrane, 2011):

$$\text{Vibratory load} = (2 \,.\, \pi \,.\, f)^2 \,.\, A \,.\, t$$

This intervention resulted in a 64,488 $m \cdot s^{-1}$ vibratory load, comparable to Lau and Nosaka (2011) of 60,047 $m \cdot s^{-1}$.

### Elastography

Muscle shear elastic modulus was measured at PRE, POST-EX, POST-REC using an AixPlorer ultrasonic scanner (version 6.1.1, Supersonic Imagine, Aix en Provence, France), coupled with a linear transducer array (4–15 MHz, SuperLinear 15–4, Vermon, Tours, France). The scanner was used in the musculo-skeletal preset of the SSI mode. The principle is to generate a remote radiation force through focused ultrasonic beams that induce the propagation of transient shear waves. An ultrafast ultrasound imaging sequence was then performed to determine shear wave velocity (Vs) along the principal axis of the probe using a time-of-flight estimation. The shear elastic modulus (μ) was calculated using Vs as follows (Gennisson et al. 2003; Gennisson et al. 2005):

$\mu = \rho \cdot Vs^2$

with ρ the muscle mass density (1000 $kg/m^3$). Maps of the shear elastic modulus were obtained at 1Hz with a spatial resolution of 1 × 1 mm.

Measurements were performed with the subject lying prone with arms extended at 180°. The ultrasound probe was centered on the biceps brachii belly, carefully aligned with the shortening direction of the muscle, and perpendicular to the skin. The location of the probe was marked on the skin to allow the same placement across time for all measurements. Since the biceps brachii is fusiform, the shear wave propagation was measured in the fiber direction (Nordez and Hug 2010). Biceps brachii shear elastic modulus was measured for 10 s (i.e. 10 maps recorded). On each map, shear modulus was averaged in the selected circular area placed on the biceps brachii (1 cm in diameter) using the Aixplorer scanner software (Q-Box$^{TM}$). Mean of the 10 maps values was then calculated for each arm and each time interval.

### Statistical analyses

Statistical analyses were performed using SigmaStat software (SigmaStat 3.5, Systat Software, San Jose, CA). The distribution was examined with the Kolmogorov-Smirnov normality test and homogeneity of variance was verified by Levene's test. A two-way repeated measures ANOVA was performed on MVC with the factors condition (PAS *vs* LV) and time (PRE, POST-EX and POST-REC). A two-way repeated measures ANOVA was performed on averaged biceps brachii shear elastic modulus with the factors condition (PAS *vs* LV) and time (PRE, POST-EX and POST-REC). When the ANOVA identified significant effects, post-hoc Student-Newman-Keuls testing was performed. Data are presented as means ± SD. Statistical significance was set at $p < 0.05$.

## Results

ANOVA demonstrated a significant main effect of time for MVC ($p < 0.001$). When compared to PRE, MVC values were significantly decreased at POST-EX ($p < 0.001$; 256.7 ± 84.1 *vs* 302.5 ± 99.8 N and 262.1 ± 86.6 *vs* 296.5 ± 101.7 N for PAS and LV, respectively). There was no main condition effect (p = 0.985) or interaction effect (p = 0.170).

Figure 1 illustrates mean biceps brachii passive stiffness (i.e. shear elastic modulus) for each arm and each time point. There was a significant main effect of time (p = 0.001), with post-hoc tests demonstrating increased muscle stiffness at POST-EX (+53 ± 48%; p = 0.001) and POST-REC (+31 ± 46%; p = 0.025) when compared to baseline values (PRE). There was no main effect of condition (p = 0.186) or interaction effect (p = 0.210) between PAS and LV.

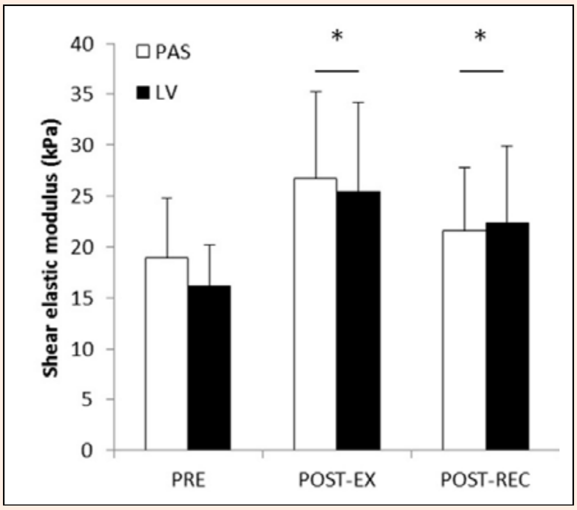

**Figure 1. Biceps brachii passive stiffness (shear elastic modulus) (mean ± SD) at baseline (PRE), immediately after exercise (POST-EX), and after the recovery period (POST-REC) for passive rest (PAS) and local vibration (LV) conditions.** Significantly different from PRE: * p<0.05.

## Discussion

The aim of the present study was to investigate the changes in biceps brachii passive stiffness following barbell curl exercise and to determine whether local vibration could prevent the exercise-induced increased stiffness. Our results demonstrated increased passive stiffness immediately after exercise, with no positive effect of the tested recovery method.

### Methodological considerations

To assess the effect of LV as a recovery tool, an arm-to-arm comparison model was used in the present study. Both arms were exercised and one arm was randomly assigned to PAS while the other arm was assigned to LV. As indicated by similar force production and force decline immediately after exercise for both arms, it can be considered than LV and PAS arms performed the same work during the barbell curl exercise and their level of exercise-induced increased stiffness is thus comparable.

### Exercise-induced increased stiffness

In the present study, biceps brachii shear elastic modulus measured at rest (17.5 ± 5.1 kPa) were in accordance with the 16.8 ± 2.8 kPa reported by Lacourpaille et al. (2014) using the same technique on the same muscle (at a 160° elbow angle). In agreement with results from Howell et al. (1993) where muscle stiffness was inferred from the passive torque–angle curve, muscle stiffness characterized by biceps brachii shear elastic modulus was significantly increased (+53 ± 48%) immediately after exercise. This is slightly less than the mean 78 ± 55% biceps brachii shear modulus increase reported 1 h after purely eccentric exercise (Lacourpaille et al., 2014). Differences in the exercise-induced magnitude of increased stiffness may be explained by differences in the type of exercise performed (i.e. maximal eccentric contractions *vs* barbell curl exercise at 70% of the 1RM). For instance, eccentric contractions are known to induce greater muscle damage than isometric or concentric actions (Howatson and van Someren, 2008). Nevertheless, the present results confirms that exercise-induced increased muscle stiffness may not only be observed following intense eccentric contractions (Chleboun et al., 1998; Green et al., 2012; Howell et al., 1993; Lacourpaille et al., 2014; Murayama et al., 2000; Whitehead et al., 2001) but also following more natural exercise involving successions of concentric and eccentric actions, as recently observed following a plantar flexion exercise involving both eccentric and concentric contractions (Yanagisawa et al., 2015).

Such increase in shear modulus after exercise may be due to an increase in resting level of myoplasmic calcium due to muscle fibers damage (Balnave et al., 1997; Chen et al., 2007). As a consequence, the residual number of cross-bridges between myosin heads and actin (Hill, 1968) may increase, leading to greater passive stiffness (Lacourpaille et al., 2014; Whitehead et al., 2001).

### Local vibration as a recovery modality

In the present study, it was hypothesized that LV could represent a recovery method against exercise-induced increased stiffness. Conversely, our results demonstrated similar shear elastic modulus changes between PAS and LV arms at POST-REC. This suggests that LV had no acute recovery effect on passive muscle stiffness immediately after exercise. Vibration was previously reported to decrease the stiffness perception of subjects with acute or subacute ankle sprain and hamstring strain injuries (Peer et al., 2009) or with hamstring or low back stiffness (Siegmund et al., 2014). It may be that this perceptual measure does not provide a pertinent measurement of mechanical properties of individual muscles, at least in the context of exercise-induced increased stiffness as in the present study. As a recovery technique, vibration previously demonstrated an acute positive effect on ROM when applied on days 1, 2 and 3 after a purely eccentric arm exercise, but no beneficial effect when applied immediately after exercise (Lau and Nosaka, 2011). While muscle passive stiffness is acknowledged as a main determinant of ROM (Proske and Morgan, 2001), passive stiffness was not investigated in the study of Lau and Nosaka (2011). Several ways of applying pressure and stretching on muscle tissue (i.e. 10-15 s of hand flapping, vibration, massage) were previously reported to induce decreased passive torque during passive movement (Axelson and Hagbarth, 2001), suggesting that mechanical agitation of a muscle may decrease the number of residual cross-bridges spontaneously formed at rest (Hill, 1968), some of them being broken. Accordingly, Eriksson Crommert et al. (2014) demonstrated decreased medial gastrocnemius shear elastic modulus immediately after 7 min of massage performed on relaxed muscles (i.e. without prior exercise). It was recently demonstrated similar results after 5 bouts of 1-min stretching (Taniguchi et al., 2015). Interestingly, decreased passive stiffness was transient and did not persist 4 min after cessation of the massage (Eriksson-Crommert et al., 2014) and 20 min after stretching (Taniguchi et al., 2015). In the present study, the lack of observed effects of LV on biceps brachii shear elastic modulus after exercise-induced increased stiffness may be explained by a too long period between the LV intervention and post-recovery measurements (5 min) or by an inability of the employed vibration parameters to break residual cross-bridges.

### Limitations

While the present results did not demonstrate any beneficial effect of LV on muscle passive stiffness, this may be explained by the 5-min delay between the end of the recovery period and the beginning of post-recovery measurements. Hence, it would have been interesting to have performed the post-recovery measurements immediately after LV. Nonetheless, the fact that no beneficial effect was reported as soon as 5 minutes after LV is not in favor of the recommendation of this technique as an acute recovery modality.

Nevertheless, it cannot be ruled out that despite the absence of acute effects, LV may be a useful method to reduce DOMS symptoms when applied the days after exercise (Broadbent et al., 2010; Lau and Nosaka, 2011).

## Conclusion

Using supersonic shear imaging, the present study demonstrated that the increased muscle passive stiffness observed following intense eccentric contractions can also be observed following more natural exercise involving successions of concentric and eccentric actions, as in many sport actions. The administration of local vibration as an acute recovery strategy did not reduce this exercise-induced increased stiffness, probably due to an insufficient mechanical action of vibrations.

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## Key points

- Bouts of barbell curl exercise induce an immediate increased passive stiffness of the biceps brachii muscle, as evidenced by greater shear elastic modulus measured by supersonic shear imaging.
- The administration of a vibratory massage did not reduce this acute exercise-induced increased stiffness.

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