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original research

Assessment of Muscle Pain Induced by Elbow-Flexor Eccentric Exercise

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Context: Delayed-onset muscle soreness (DOMS) is a common muscle pain that many people experience and is often used as a model of acute muscle pain. Researchers have reported the effects of various interventions on DOMS, but different DOMS assessment protocols used in these studies make it difficult to compare the effects.

Objective: To investigate DOMS characteristics after elbow-flexor eccentric exercise to establish a standardized DOMS assessment protocol.

Design: Descriptive laboratory study.

Setting: Research laboratory.

Patients or Other Participants: Ten healthy, untrained men (21–39 years).

Intervention(s): Participants performed 10 sets of 6 maximal isokinetic eccentric contractions of the elbow flexors.

Main Outcome Measure(s): Indirect muscle-damage markers were maximal voluntary isometric contraction torque, range of motion, and serum creatine kinase activity. Muscle pain was assessed before exercise, immediately postexercise, and 1 to 5 days postexercise using (1) a visual analog scale (VAS), (2) a category ratio-10 scale (CR-10) when applying static pressure and palpation at different sites (3, 9, and 15 cm above the elbow crease), and (3) pressure-pain thresholds (PPTs) at 50 sites (pain mapping).

Results: Maximal voluntary isometric contraction and range of motion decreased and creatine kinase activity increased postexercise, indicating muscle damage. Palpation induced greater pain than static pressure, and longitudinal and transverse palpations induced greater pain than circular palpation ($P < .05$). The PPT was lower in the medial region before exercise, but the pain-sensitive regions shifted to the central and distal regions of the biceps brachii at 1 to 3 days postexercise ($P < .05$). The VAS was correlated with the CR-10 scale ($r = 0.91$, $P < .05$) but not with the PPT ($r = -0.28$, $P = .45$).

Conclusions: The way in which muscles are assessed affects the pain level score. This finding suggests that pain level and pain threshold cannot be used interchangeably and that the central and distal regions of the biceps brachii should be included in DOMS assessment using the VAS, CR-10 scale, and PPT after elbow-flexor eccentric exercise.

Key Words: muscle damage, delayed-onset muscle soreness, pressure-pain threshold, palpation, visual analog scale

Key Points

- Delayed-onset muscle soreness (DOMS) is induced by exercise consisting of eccentric muscle contractions and is regarded as mechanical hyperalgesia.
- Because DOMS is often used as a model of acute pain to investigate the effects of interventions on muscle pain in clinical trial studies, it is important to standardize the assessment protocol. However, no standardized protocol for DOMS assessment has been proposed.
- We propose a standardized protocol to assess DOMS of the biceps brachii after elbow-flexor eccentric exercise, a frequently used model.

Delayed-onset muscle soreness (DOMS) is a common form of musculoskeletal pain that occurs several hours to several days after performing unaccustomed exercise, especially when eccentric (lengthening) contractions are involved.[1,2] Characterized by a dull, aching pain, DOMS is usually felt when exercised muscles are moved, stretched, or palpated and is often accompanied by increased tenderness and stiffness.[1,3] Delayed-onset muscle soreness is regarded as mechanical hyperalgesia or allodynia, because a pain due to mechanical stimuli (eg, stretching, pressure, palpation) increases or a pain is caused by stimuli that do not normally provoke pain.[4,5] Damage to contractile proteins, intermediate filaments, and the connective tissue surrounding muscle fibers and the subsequent inflammatory processes are associated with DOMS.[2,6] Malm et al[7] and others[8–10] reported that DOMS could be associated more with increased inflammation in the epimysium or perimysium than with the muscle fibers. However, the mechanisms underpinning DOMS have not yet been fully elucidated.

One factor influencing our understanding of muscle pain is the difficulty assessing pain and especially quantifying the pain level, because it is subjective by nature. Visual analog scales (VASs) are widely used to quantify musculoskeletal pain,[11,12] and many authors have used VASs for DOMS assessment. Because DOMS is not felt without mechanical stimulus, quantifying muscle pain requires a standardized palpation, stretching, or muscle-

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contraction protocol. However, how stimuli should be imposed to quantify the pain level using a VAS is unclear, and no standardized protocols for stimulus application (such as palpation) have been documented. Hence, using palpation to assess DOMS is often criticized because of the ambiguity associated with the process.[13] In fact, in terms of the pressure and movement used in palpation, no standardized protocol has been established in previous studies, which raises the question of whether this assessment is reproducible. Moreover, the protocols for assessing muscle pain using VAS vary among investigations, which makes it difficult to compare their results.

Instead of VASs, some researchers used numerical rating instruments such as Likert[14] or category ratio-10 (CR-10) scales[15,16] to quantify the muscle-pain level, and the CR-10 scale is often used to quantify the pain level during exercise exertion.[15,16] Concerns similar to those regarding stimulus standardization exist for these scales when the level of muscle pain is assessed on palpation or with other mechanical stimuli. To the best of our knowledge, no previous authors have compared a VAS and CR-10 scale for the same mechanical stimuli, and no consensus has emerged as to which is better. It is important to know whether any fundamental difference exists between the VAS and CR-10 scale for the value representing the level of muscle pain after eccentric exercise.

An alternative method of quantifying muscle pain is to assess the pain threshold from pressure exerted using a pressure algometer. This quantification method is referred to as the pressure-pain threshold (PPT).[17,18] The PPT has been demonstrated as reliable for measuring the pain threshold[19,20] and has often been used to assess DOMS.[21,22] Some investigators studying the muscular distribution of PPT in response to DOMS in the lower limb muscles have found that the pain sensation is unevenly distributed.[23,24] For example, Edwards et al[23] reported that, after 15 minutes of eccentric stepping exercise, muscle pain in the quadriceps femoris was located close to the distal insertion of the myotendinous junction of the vastus medialis and lateralis. Hedayatpour et al[25] observed a greater reduction in PPT in the distal quadriceps region than in the proximal region after 100 eccentric knee extensions. In contrast, Andersen et al[26] found that tibialis anterior muscle belly sites became more sensitive to pressure stimulation than muscle-tendon junction sites after eccentric exercise. These results suggest that the choice of PPT assessment sites may influence the results obtained and, thus, the conclusions drawn. However, no previous researchers have examined the PPT distribution in the elbow-flexor muscles after eccentric exercise, which is one of the models used most frequently to investigate DOMS.[27,28]

Numerous authors[2,3,6] have investigated interventions such as massage, cryotherapy, electrotherapy, and supplements on DOMS using different eccentric exercise models. Yet the use of different DOMS assessment protocols makes it difficult for us to compare the effects of the interventions among the studies. Additionally, no previous researchers have systematically looked at region-specific pain changes in the upper arm after elbow-flexor eccentric exercise for several days until the return to baseline. Furthermore, DOMS is often used as a model of acute muscle pain in clinical trial studies in which the effects of drugs (eg, nonsteroidal anti-inflammatory agents, analgesics) on muscle pain are studied.

Therefore, we compared the changes in pain levels using a VAS for static pressure and palpation (circular, longitudinal, or transverse movements); assessed the relationships among VAS, CR-10 scale, and PPT; and examined the distribution of the PPT in the biceps brachii and brachialis using a grid method to clarify region-specific changes in sensitivity after eccentric elbow-flexor exercise. From these approaches, we sought to establish a standardized pain-assessment protocol for DOMS induced by elbow-flexor eccentric exercise.

METHODS

Participants

This study was approved by the Institutional Human Research Ethics Committee and complied with the Declaration of Helsinki. Ten healthy young men with no current or previous upper arm injuries who were not suffering from any present or ongoing upper arm pain and had not been involved in any resistance-training program for at least the previous 6 months were recruited for this study. Their mean (± standard deviation) age, body mass, height, and elbow-flexor maximal voluntary isometric contraction (MVIC) torque were 24.9 ± 5.4 years, 69.2 ± 8.3 kg, 169.8 ± 6.2 cm, and 60.2 ± 12.2 Nm, respectively. All participants provided informed written consent and completed a medical questionnaire before the study began. They were requested not to change their lifestyle and dietary habits, not to take any anti-inflammatory drugs or nutritional supplements, and not to perform unaccustomed exercise during the experimental period.

Eccentric Exercise

All participants performed 10 sets of 6 maximal isokinetic eccentric contractions of the elbow flexors with a randomly chosen arm (dominant arm: $n = 6$, nondominant arm: $n = 4$) on an isokinetic dynamometer (model 6000; Cybex International Inc, Medway, MA). They were individually positioned on a seated preacher arm-curl bench that secured the shoulder joint at 45° of flexion in front of the body; the elbow joint was aligned with the axis of rotation of the dynamometer and the lever arm of the dynamometer was attached to the wrist in a supinated forearm position. For each eccentric contraction, the elbow joint was forcibly extended from a flexed (60°) to a fully extended position (0°) in 1 second at an angular velocity of $60°\cdot s^{-1}$, while the participant was orally encouraged to generate maximal force in the flexed position and to maximally resist the elbow-extending action throughout the full range of motion (ROM). After each eccentric contraction, the isokinetic dynamometer was programmed to return the arm to the flexed position at a velocity of $6°\cdot s^{-1}$, which provided a 10-second rest between contractions. The rest period between sets was 3 minutes. Torque signals were recorded via a data-acquisition system (Powerlab Chart 7 software; ADInstruments, Bella Vista, Australia) at a sampling rate of 200 Hz, and real-time visual feedback of torque was displayed on a computer monitor.

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Muscle-Damage Markers

Indirect markers of muscle damage were MVIC torque and ROM, and they were measured before exercise and immediately and 1 to 5 days postexercise. Serum creatine kinase (CK) activity was measured before exercise and 4 and 5 days postexercise because CK activity in the blood has been reported[28,29] to peak 4 to 5 days after eccentric elbow-flexor exercise.

Maximal Voluntary Isometric Contraction Torque. The MVIC torque of the elbow flexors was measured using the isokinetic dynamometer with the same participant positioning described for the eccentric exercise. Each participant performed two 3-second MVICs at an elbow-joint angle of 90° with a 30-second rest between contractions. Measurements were taken twice and the peak torque of the 2 contractions was used as the MVIC torque.[22,28]

Range of Motion. A plastic goniometer was used to measure extended (EANG) and flexed (FANG) elbow-joint angles. The EANG was determined when participants attempted to fully extend the elbow joint while standing and hanging the arm by their side, and the FANG was determined when participants attempted to fully flex the elbow joint to touch the shoulder of the same side with the palm.[28] A semipermanent ink pen was used to mark the lateral epicondyle of the humerus, the acromion process, and the midpoint of the styloid process of the ulna and radius. Measurements were taken twice for each joint angle, and the mean value of the 2 measurements was used to calculate the ROM by subtracting FANG from EANG.[28]

Serum CK Activity. Approximately 8 mL of blood was taken from the antecubital vein by standard venipuncture technique. The samples were allowed to clot at room temperature and then centrifuged for 10 minutes at 4°C to obtain serum. Serum CK activity was determined using a Modular PT automated clinical chemistry analyzer (Hitachi Ltd, Tokyo, Japan) with a commercially available reagent (Roche Diagnostics, Indianapolis, IN). The normal resting reference value using this method is <200 IU·L^{-1}.

Muscle-Pain Assessments

Pain in the exercised arm was assessed in several ways, as we will describe. The level of pain was assessed using the VAS and CR-10 scale when the exercised upper arm received pressure and palpation by fingers followed by application of a cuff, and the PPT was measured from 50 sites (see following sections), before exercise and immediately and 1 to 5 days postexercise.

Visual Analogue Scale and CR-10 Scale. The level of muscle pain evoked by the standardized stimulus was assessed using a 100-mm VAS on which 0 indicated *no pain* and 100 represented *extreme pain*[28] and a CR-10 scale on which 0 indicated *no pain* and 10 represented *maximal pain*.[15,16] Each participant was asked to mark the level of perceived pain on the VAS, followed by the CR-10 scale (the 2 assessments were performed consecutively), when the investigator applied pressure to the biceps brachii at 3, 9, and 15 cm above the elbow crease. During the pressure assessment, the investigator placed his index and middle fingers over the site and applied pressure (approximately 35–40 kPa or 250 mm Hg) with the tips of the fingers toward the deeper tissues for 3 seconds. This pressure was hard enough to induce an uncomfortable feeling in the muscle but did not necessarily induce pain sensation. The palpation pressure was measured by a handheld dynamometer; the investigator practiced to reproduce the pressure repeatedly within 5% variation between trials, and we confirmed that the investigator could apply this pressure consistently. The protocol was kept as consistent as possible between days and among participants, and all measurements were taken by the same investigator throughout the study. In the palpation assessment, the investigator placed his index and middle fingers over the site and applied the same pressure as for the pressure assessment (35–40 kPa), moving his index and middle fingers clockwise 3 times to palpate the tissues while keeping the pressure as consistent as possible. In addition to these assessments, the investigator moved his fingers upward and downward longitudinally and then transversely (left and right) to palpate the site in order to compare different palpation protocols, and the participants were asked to report the pain from each assessment using only the VAS.

A cuff (5-cm width) with an inflator (model TD 312; DE Hokanson Inc, Bellevue, WA) was placed over the exercised arm at 3, 9, and 15 cm above the elbow crease; a solid wooden ball (3 cm in diameter) was placed between the cuff and the skin; and pressure (250 mm Hg) was applied to assess the pain level. This pressure was determined during pilot testing to be similar to the pressure induced by the finger method detailed above. The investigator gradually increased the cuff pressure to 250 mm Hg, and the participants were asked to report the pain using the VAS and CR-10 scales separately.

After this measure, the investigator reset the pressure to 0 mm Hg, reinflated the cuff to 250 mm Hg, and palpated the muscle with the ball under the cuff in circular, transverse, and longitudinal movements, as detailed above for the finger-palpation procedure. The investigator palpated the site by moving the ball without applying any extra pressure. The pain level was again assessed using the VAS and CR-10 scale (pressure and circular palpation only).

All measurements were collected while the participant was lying on a massage table with his relaxed arms by his side on the table in a supinated forearm position. One measurement was taken for each assessment for each time point. However, to examine the test-retest reliability of the VAS measures, the same assessments were repeated 1 hour later on day 1, 2, 3, or 4 postexercise in 5 of the 10 study participants.

Pressure-Pain Thresholds. A polythene sheet marked with a grid consisting of 50 squares (2 cm $\times$ 2 cm) was placed over the upper arm to assess the localization of pain (Figure 1) using an electronic algometer (Somedic AB, Hörby, Sweden). Among the 50 sites, 3 sites were the same as those for the pressure and palpation assessments using the VAS and CR-10 scale (3, 9, and 15 cm above the elbow crease; Figure 1). The probe head of the algometer (area = 1.0 cm^2) was placed perpendicular to each site, and the investigator gradually applied force at an application rate of 50 kPa·s^{-1} until the participant reported the first feeling of noticeable pain in the muscle. The value (in kPa) corresponding to the force applied to elicit pain was recorded, and this is referred to as the *PPT*. All measurements were taken while the participant was lying

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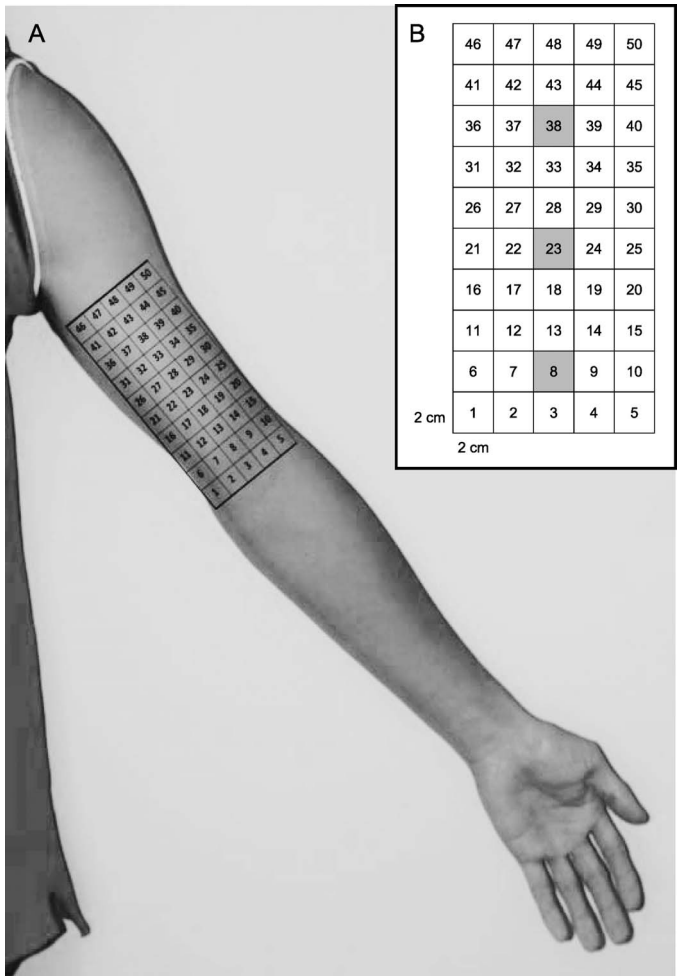

Figure 1. Pressure-pain threshold measured at 50 sites in the upper arm. A, A polythene sheet marked with a grid consisting of 5 × 10 (50) squares (each square was 2 × 2 cm = 4 cm^2) was placed on the upper arm. B, Sites 8, 23, and 38 represent the locations at 3, 9, and 15 cm above the elbow crease, respectively, used for the visual analog scale assessments.

on a massage table with his arms relaxed in a supinated forearm position. The order of measurements was standardized from 1 to 50 sites with a 10-second interval between measurements. After completing the first round of the PPT assessment, the subsequent round was performed in the same order with a 5-minute interval between rounds. The total duration of the 2 rounds was approximately 20 minutes, and the average of the 2 measures for each site was used for subsequent analysis.

Statistical Analysis

The coefficient of variation (CV) and standard error of measurement (SEM) were used to determine the test-retest reliability of the VAS palpation measurements. The CV and SEM were also used to determine the test-retest reliability of PPT measurements taken 1 to 3 days postexercise using the first and second PPT measures (sites 8, 23, and 38 in Figure 1).

One-way repeated-measures analysis of variance (ANOVA) was used to analyze the changes in muscle-damage markers (MVIC, ROM, and serum CK activity), VAS, CR-10 scale, and PPT over time (preexercise, immediately postexercise, and 1–5 days postexercise). Changes in the VAS and CR-10 scale over time were compared between pressure and palpation between finger and cuff protocols by 2-way repeated-measures ANOVA, and changes in the VAS over time were also compared among 3 palpation protocols (circular, longitudinal, and transverse movements) by a 2-way repeated-measures ANOVA. The PPT values for each day were compared among 50 sites by 1-way repeated-measures ANOVA. When the ANOVA showed a significant main effect, a Tukey post hoc test was used for multiple comparisons. Pearson product moment correlation coefficients were computed to determine the relationships between the VAS and CR-10 scale and between the VAS and PPT measures. Statistical significance was set at $P < .05$, and all data were presented as mean ± standard deviation.

RESULTS

Reliability of the Measurements

The CV was 3.6% and SEM was 2.6 mm for the 2 time points separated by 1 hour for VAS measurements. For PPT, the CV was 9.6% and SEM was 23.3 kPa for the 2 assessments separated by 10 minutes.

The MVIC Torque, ROM, and Serum CK Activity

The MVIC torque decreased from baseline (60.2 ± 12.2 Nm) by approximately 50% (31.2 ± 11.2 Nm) at 1 day postexercise and remained approximately 20% below baseline (47.0 ± 10.7 Nm) at 5 days postexercise ($P < .05$). The ROM decreased ($P < .05$) immediately postexercise from baseline (140° ± 6.7°) to 96.1° ± 16.4° and then slowly recovered to 134° ± 5.7° at 5 days postexercise. Serum CK activity increased from baseline (181.0 ± 78.2 IU/L) to 5 days postexercise (926.1 ± 434.9 IU/L; $P < .05$).

The VAS, CR-10, and PPT

Figure 2A shows changes in the VAS with biceps brachii palpation at the 3-, 9-, and 15-cm sites after eccentric exercise. The VAS increased postexercise, peaked between 1 and 2 days, and slowly recovered to baseline at 5 days postexercise ($P < .05$). This was also the case for the CR-10 scale (Figure 2B). No difference in the changes was evident among the 3 sites for either the VAS or CR-10 scale ($P = .59$–$.84$). Changes in the PPT at the same sites as those used with the VAS and CR-10 (ie, 3-, 9-, and 15-cm sites) are shown in Figure 2C. The pressure to elicit pain decreased from baseline to 1 day postexercise ($P < .05$) and remained below baseline at 3 days postexercise. No difference ($P = .29$) in the change in PPT was evident among the 3 sites postexercise.

The VAS and CR-10—Pressure Versus Palpation and Finger Versus Cuff Measures

Figure 3A compares the VAS score between pressure and palpation using fingers. The VAS score upon finger palpation was greater than with finger pressure on 1 day postexercise ($P < .05$); however, no difference was evident at 2 and 3 days postexercise ($P = .11$–$.74$). Figure 3B

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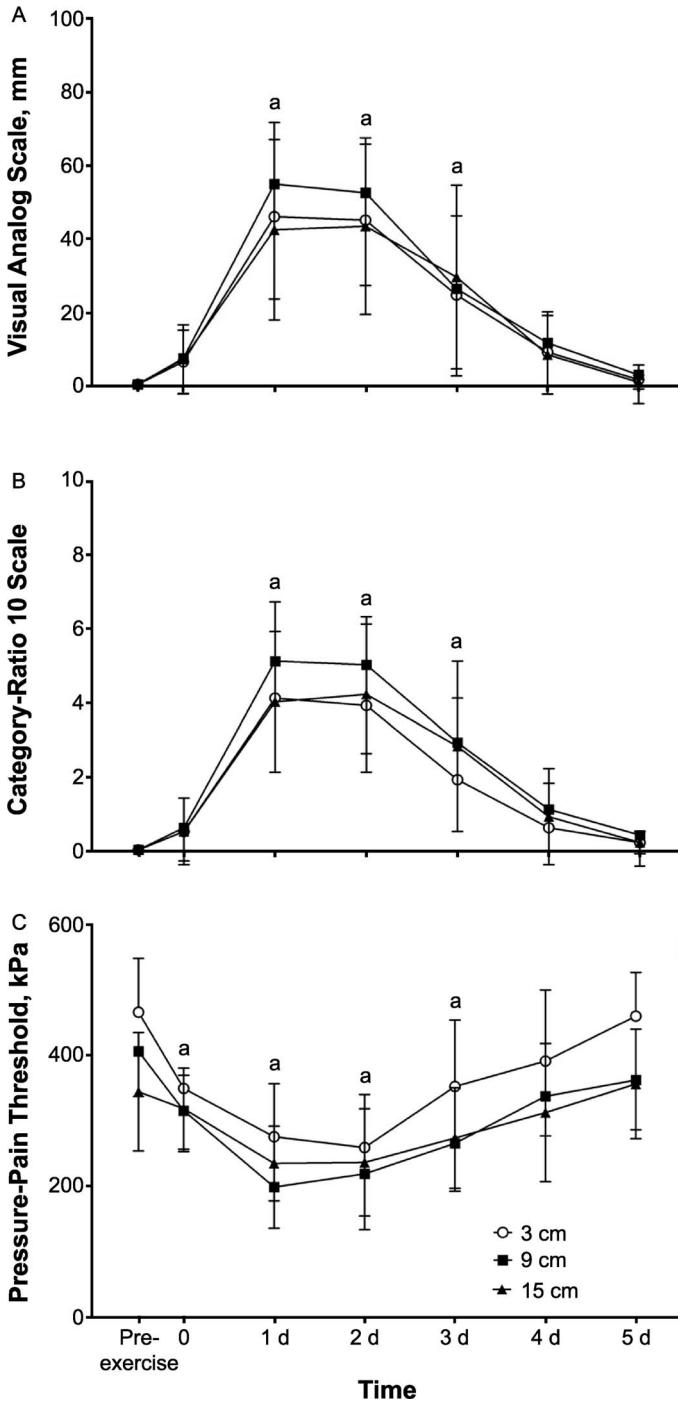

Figure 2. A, Changes in visual analog scale scores upon palpation, B, category ratio-10 scale upon palpation, and C, pressure-pain threshold of biceps brachii at 3, 9, and 15 cm above the elbow crease before (pre), immediately after (0), and 1–5 days after eccentric elbow-flexor exercise. [a] Indicates difference for the time course changes compared with baseline.

compares the VAS score upon cuff pressure and cuff pressure plus palpation. The VAS score upon cuff palpation was greater than that upon pressure at 1 to 3 days postexercise ($P < .05$). This was also the case for the CR-10 scale score (Figure 3C), with finger palpation inducing greater pain than finger pressure ($P < .05$), and cuff palpation inducing greater pain than pressure ($P < .05$; Figure 3D). No differences were evident, however, between the finger and cuff pressure measurements and the finger and cuff palpation measurements postexercise.

Comparison of 3 Palpation Methods

The VAS scores after circular, longitudinal, and transverse palpation at 1 to 3 days postexercise are shown in Figure 4. The VAS score upon longitudinal (82.4 ± 22.3 mm) and transverse palpation (79.4 ± 22.6 mm) was greater ($P < .05$) than that upon circular palpation (54.8 ± 31.4 mm) at 1 day postexercise, but no difference was found between longitudinal and transverse palpations. This was also the case at 2 and 3 days postexercise.

The PPT at 50 Sites

A difference occurred among the 50 sites before exercise ($P < .05$) such that the sites located medially showed a lower threshold ($P < .05$) than the other sites (Figure 5). After eccentric exercise, the pain-sensitive sites were located centrally in the midbelly at 1 day postexercise ($P < .05$); the distal sites became sensitive at 2 days postexercise and then returned to baseline at 4 days postexercise. It is of interest that the sites used for palpation measures (3, 9, and 15 cm above the elbow crease) were among those showing lower PPT values than other sites at 1 to 3 days postexercise when DOMS was evident.

Correlation Between the VAS and CR-10 Scale and Between the VAS and PPT

A significant correlation was noted between the VAS and CR-10 scale scores ($r = 0.91$), as shown in Figure 6A ($P < .05$). No correlation was found between the changes in the VAS score and PPT from the baseline ($P = .45$, $r = –0.28$), as illustrated in Figure 6B.

DISCUSSION

We aimed to establish a standardized protocol to assess muscle pain (DOMS) of the biceps brachii induced by eccentric elbow-flexor exercise. The main findings were that (1) the test-retest reliability of the VAS score and PPT assessments was high, (2) no difference was seen at 3, 9, and 15 cm above the elbow crease for the VAS and CR-10 scale scores, (3) the VAS and CR-10 scale values were greater upon muscle palpation than pressure, (4) no difference was evident between pressure and palpation by fingers and by a cuff when the pressure was standardized, (5) the VAS values upon palpation were greater with longitudinal or transverse movements than with circular movements, (6) distal and central sites showed increased PPT sensitivity during palpation compared with other sites at 1 to 3 days postexercise, and (7) scores on the 2 pain-rating scales (VAS and CR-10 scale) were significantly correlated, but no significant correlation was found between the VAS and PPT assessments. Based on these results, we make recommendations for a standardized protocol to assess muscle pain of the biceps brachii after eccentric exercise of the elbow flexors.

The VAS and PPT methods have been widely used in previous studies[22,30,31] to quantify DOMS, which is a prominent symptom after exercise-induced muscle damage, whereas the CR-10 scale is used to quantify pain

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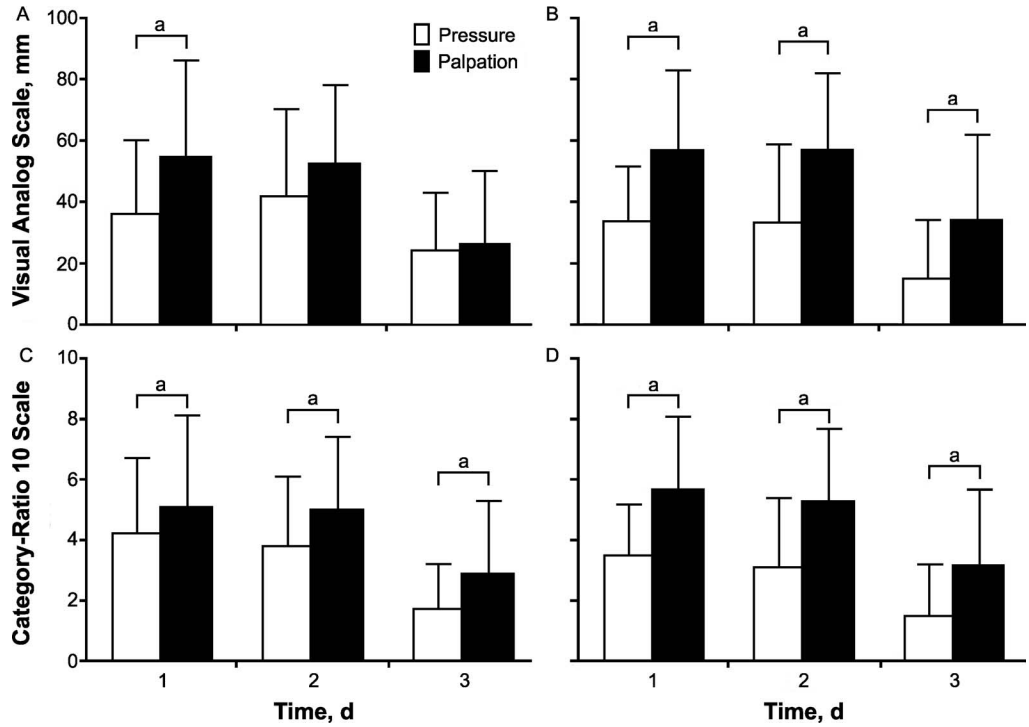

Figure 3. Comparison of the pain level using A and B, visual analog scale (VAS), and C and D, category ratio-10 (CR-10) scale at 1 to 3 days after eccentric exercise between pressure and palpation using the fingers (A, VAS; C, CR-10) and a ball located between the pressure cuff and the skin (B, VAS; D, CR-10). [a] Indicates difference between pressure and palpation ($P < .05$).

subjectively during exercise exertion.[16,32] The changes in MVIC, ROM, and serum CK activity after eccentric exercise in our study were similar to those reported in previous studies[22,33] and indicate that muscle damage was induced by the exercise. The time course of the changes in VAS score and PPT was also similar to those reported after eccentric elbow-flexor exercise in previous research.[22,28] As shown in Figure 2, no differences among the 3 sites (3, 9, and 15 cm above the elbow crease) were evident for the changes in the VAS and CR-10 scale values upon palpation or the PPT. A previous study[22] also showed no difference in VAS changes after elbow-flexor eccentric exercise among the 3 sites (ie, 5, 9, and 13 cm above the elbow crease). It should be noted that the sites were more dispersed in the present study than in the previous study[15]; however, the results were the same and showed that pain rated on the VAS upon palpation was similar along the central region of the biceps brachii, at least between 3 and 15 cm above the elbow crease. Thus, it is likely that when the VAS is used during palpation from any one of these 3 sites, it reflects a similar pain level of the biceps brachii. However, the relative location of the sites is affected by the length of the arm, such that the 9-cm site could be close to the proximal tendon for some participants but close to the midbelly for others. It is possible to normalize the site placements to arm length; however, it may be that if the measurements were taken close to the elbow joint (eg, less than 10 cm), a nonsignificant difference would be observed for the maximal biceps brachii pain level along the arm because distal regions become more sensitive to pressure after eccentric exercise, as we will discuss. It is also important to note that the changes in the VAS and CR-10 scale scores were similar (Figure 2). Thus, either the VAS or CR-10 scale can be used to assess pain level after eccentric elbow-flexor exercise.

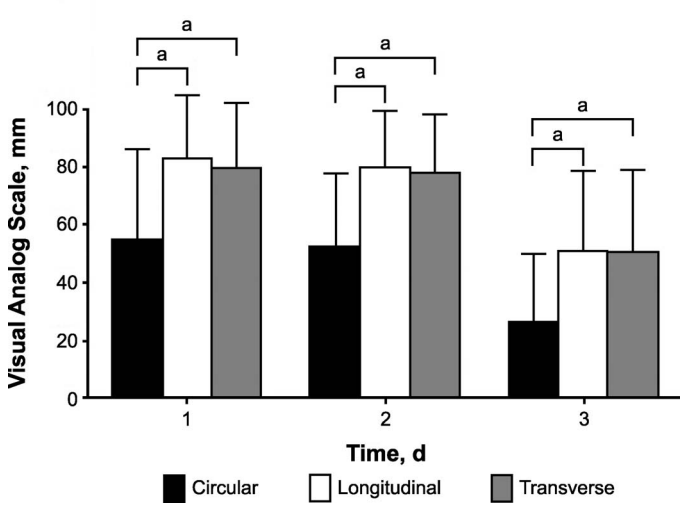

Figure 4. Comparison of the pain level recorded by a visual analog scale at 1–3 days after eccentric exercise among circular-, longitudinal-, and transverse-palpation assessments using the fingers. [a] Indicates difference between measures ($P < .05$).

It may be of practical importance that the use of fingers and cuff for the VAS and CR-10 scale measures for pressure only and palpation produced similar results (Figure 3) when the same pressure was applied. The finger-palpation technique is often criticized for its potentially poor reliability because of possible differences in pressure application among time points and among participants. We standardized the pressure and palpation measurement by using a cuff with an inflator that adjusted the pressure to approximately 250 mm Hg during

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Figure 5. Absolute changes in pressure-pain threshold at 50 sites (average of 10 participants) from baseline to 1–5 days after eccentric elbow-flexor exercise. The sites that were different ($P < .05$) from 5–9 or more than 10 other sites are shown in open and shaded circles, respectively.

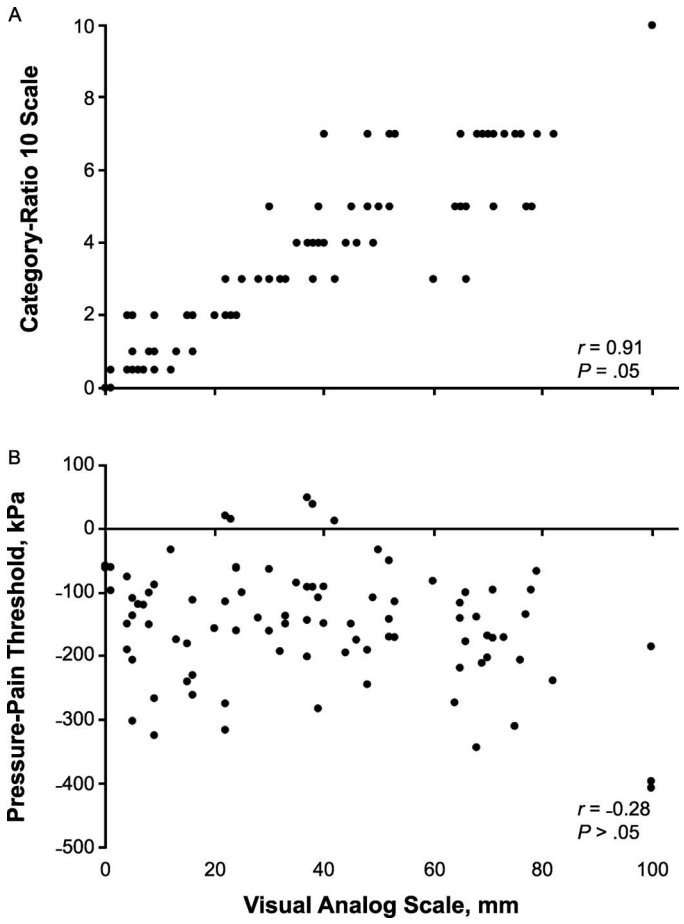

Figure 6. A, Correlations between visual analog scale (VAS) and category ratio-10 scale measurements of the pain level assessed using palpation at 3 sites (3, 9, and 15 cm above the elbow joint) between 1 and 3 days postexercise. B, Correlations between the VAS score assessed during palpation and the pressure-pain threshold assessed at 3 sites over 3 days (1–3 days postexercise) for the absolute change from preexercise values.

assessments. It is important to standardize the pressure for palpation assessment, ensuring that the same pressure can be reproduced over measurements. Our results showed that palpating the muscle in a circular motion induced greater pain than applying static pressure with the tips of the fingers. It seems possible that the movement activates more pain nociceptors in the skin, fascia, and connective tissues surrounding muscle fibers. Furthermore, when comparing 3 palpation movements (ie, circular, longitudinal, and transverse), we found that longitudinal and transverse muscle palpation induced greater pain than did circular palpation (Figure 4). Longitudinal and transverse palpation may impose greater mechanical pressure to a smaller area than circular palpation, where the application area can be larger. Therefore, we suggest that a standard palpation method be used, where pressure to the muscle is applied using either longitudinal or transverse palpation rather than circular palpation, and the distance of the movement should be small (eg, within 2 cm). It is also important that the stimulus (ie, palpation) intensity is sufficiently large, that is, close to a pressure that induces pain before exercise, as this intensity will clearly induce pain after eccentric exercise.

Regarding the PPT, we took 2 measurements at each of 50 sites, which required approximately 20 minutes. Although this may not be time efficient for some clinical or research uses, it appears to indicate pain sensitivity more precisely than other measures. We cannot rule out that measuring 50 sites of PPT measurements might have facilitated temporal summation of pressure pain. However, the order of measurements was standardized from 1 to 50 sites for 2 rounds of measurement. Even if temporal summation did occur, it seems unlikely that the regions that showed greater pain than others were different. It is important to note that the size of the grid sheet was the same for all participants, irrespective of their arm length; thus, the location of the measurement sites relative to the arm length varied among participants. Yet this did not appear to substantially influence the PPT assessment because the exercise typically affected the PPT in the distal regions (Figure 5). This indicates that distal regions are more vulnerable to eccentric exercise–induced muscle

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damage and are important for treating and preventing injuries in individuals who perform eccentric exercise of the elbow flexors.

The medial region was more sensitive to pressure before exercise than other regions, but the central and distal regions were more sensitive postexercise. This finding may be related to the medial region being closer to the biceps brachii–brachialis muscle junction, the brachial artery and veins, or the medial antebrachial cutaneous nerve. Fischer[34] reported that PPT values were influenced by muscle and subcutaneous tissue thickness and also by the inherent pain sensitivity difference among individuals. To our knowledge, we are the first to report the pain distribution over the biceps brachii after eccentric elbow-flexor exercise, although some authors[23,24,35] have observed that pain-sensitive regions were typically located in the distal regions of other muscles after eccentric exercise. The distal region may receive more mechanical stimulus during eccentric contractions; thus, damage and inflammation would be more substantial than in other muscle regions. Mense et al[36] noted that the innervation density of nociceptors in the connective tissue surrounding the calcaneal tendon in cats was approximately 5 times higher than in the gastrocnemius-soleus muscle but found no difference in innervation density throughout the muscle tissue. Further studies are necessary to investigate whether any regional differences in histologic changes within muscle fibers and surrounding connective tissue exist after biceps brachii eccentric exercise.

A strong and statistically significant correlation was observed between the VAS and CR-10 scale measurements (Figure 6A). This is not surprising given that the 2 measurements were obtained using the same stimulus. It should be noted that we defined maximal pain slightly differently between the VAS (*extreme pain*) and CR-10 scale (*maximal pain*). It is also important to recall that the 2 assessments were taken consecutively. These factors could have contributed to the significant correlation between the VAS and CR-10 scale scores. However, when looking at individual data for the same CR-10 scale value, we saw some spread of VAS values, possibly because the VAS is based on a continuous number scale. If only a single scale can be used, then the VAS may be a better option than the CR-10 scale because the former provides better resolution of the pain level. In contrast, there was no significant correlation between the changes in the VAS and PPT assessments, which confirmed the results of our previous study[22]: no significant correlations were observed between the VAS and PPT pain assessments taken at 5, 9, and 13 cm above the elbow crease 1 to 4 days after 60 eccentric elbow-flexor contractions. The PPT is a "semiobjective" pain-threshold assessment used to quantify the minimum pressure intensity to evoke pain, whereas the VAS is a subjective pain-scale assessment that uses a stimulus (either pressure or palpation in our study) generally exceeding the pain threshold. Thus, the 2 assessments are not the same and provide different information regarding subjective pain. However, if a choice has to be made between the VAS and PPT, it may be better to obtain information regarding the level of pain rather than the threshold of pain; thus, the VAS can be recommended.

In conclusion, when DOMS in the biceps brachii is assessed after eccentric elbow-flexor exercise, the following protocols should be considered: (1) The VAS assessments are included to rate pain level; yet it is also advisable to include PPT assessments to obtain information regarding pain thresholds. (2) The CR-10 scale can be used instead of the VAS to rate pain level; however, the VAS is preferable. (3) It is better to include multiple sites (eg, 3, 9, and 15 cm above the elbow crease) covering the distal and central muscle regions for the VAS and PPT assessments to account for region-specific differences in pain. (4) The muscle should be palpated in either a longitudinal or transverse direction, rather than in a circular direction, and this should be standardized before testing begins. Our results also indicate that DOMS might be associated with damage and inflammation to the connective tissue surrounding the muscle fibers (ie, the endomysium) or muscle bundles (ie, the perimysium or fascia) or both, especially close to the distal myotendinous junction. Further studies are required to investigate connective tissue damage in relation to DOMS.

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