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TENDER OR NOT TENDER: TEST-RETEST REPEATABILITY OF PRESSURE PAIN THRESHOLDS IN THE TRAPEZIUS AND DELTOID MUSCLES OF HEALTHY WOMEN

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Objective: **To examine the test-retest repeatability of pressure pain thresholds in the shoulder muscles of healthy women.**

Design: **Four experimental sessions (days 1, 3, 28, 30), each including 4 consecutive pressure pain threshold measurements at 10-minute intervals.**

Subjects: **Twenty-four healthy female volunteers, mean age 42 years.**

Methods: **Two examiners measured pressure pain thresholds bilaterally over the trapezius and deltoid muscles with an electronic algometer. Student's paired *t*-test, intraclass correlation coefficient, ANOVA repeated measures, 95% confidence interval and mean maximal absolute measurement error, were used for statistics.**

Results: **Reliability for each point in all sessions was high; ICC range 0.70–0.94, mean maximal differences; 53–102 kPa (all 4 muscles), and between points in each muscle: ICC right trapezius 0.59–0.77, left 0.67–0.84, right deltoid 0.66–0.83, left 0.70–0.90. Mean maximal differences were 69–101 kPa and 65–111 kPa for the trapezius and deltoid muscles, respectively. The inter-individual variation was 5-fold (trapezius 88–574 kPa; deltoid 91–529 kPa). At the group level, the variation was limited when the first measurement was excluded. Inter-rater and intra-rater repeatability was high without significant differences. Only small side-to-side differences were seen.**

Conclusion: **Repeated measurements show stable intra-individual values. The method can be recommended when used by trained and experienced examiners.**

Key words: reproducibility, pain threshold, pain measurement, shoulder pain, muscle.

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INTRODUCTION

Shoulder pain is a common complaint in patients with long-standing musculoskeletal pain, with local tenderness as a clinical finding (1, 2). The definition of tenderness is given as "abnormal sensitiveness to touch or pressure" in Dorland's *Illustrated Medical Dictionary*, or as the report by the individual of distinct pain of mild or greater degree upon digital palpation of the tender point by the examiner. A semi-objective method for measuring deep tenderness in muscles, and for quantifying localized pain, is measuring pressure pain thresholds (PPTs) using an algometer that consists of a strain gauge or a force transducer that applies a gradually increasing force to the measured region with the subject (patient) signalling when the sensation of pressure becomes painful (3–5). This method has been developed over the years, and many investigators have studied the reliability in healthy subjects (3, 5–9).

The PPT response can be confounded by skin hyperestesia. If the skin is not anesthetized, the measured PPTs include thresholds from all underlying structures (10, 11).

The electronic algometer was developed by Jensen et al. (12) to improve the technique and minimize any confounding factors. They found that the size of the contact area and the rate of the pressure force increase influenced reliability (see also (13)). Another influencing factor that was addressed was the time lost in verbal communication between the subject and the examiner. This was overcome by allowing the subject to use a push button to stop the PPT measurement (14, 15). The subject's pain threshold is largely dependent on the instructions given (5, 16), and is related to the internal threshold criterion set by the subject, i.e. a psychophysical method (15) using the ascending Method of Limits (see (17)) that demands the full attention and co-operation of the subject during the test situation.

The reliability of measuring PPTs using an electronic algometer supplemented with a push button, has been studied in the whole body (18, 19), or in a specific region (9, 12, 20, 21). In 2 previous studies (22, 23) we have measured PPTs in the trapezius and deltoid muscles, using an electronic algometer (Somedic®, Sweden), before and after a static abduction endurance test in healthy subjects and in patients with shoulder pain. The trapezius muscle, with respect to reliability in healthy subjects, has only been studied with a mechanical algometer (6). No study has to our knowledge, specifically covered the repeatability of PPT measurements in the trapezius and deltoid muscles as a whole. Some researchers have studied PPTs (4, 24) and examination (25, 26) of trigger points, and found varying inter-rater reliability. We therefore set out to study the PPT

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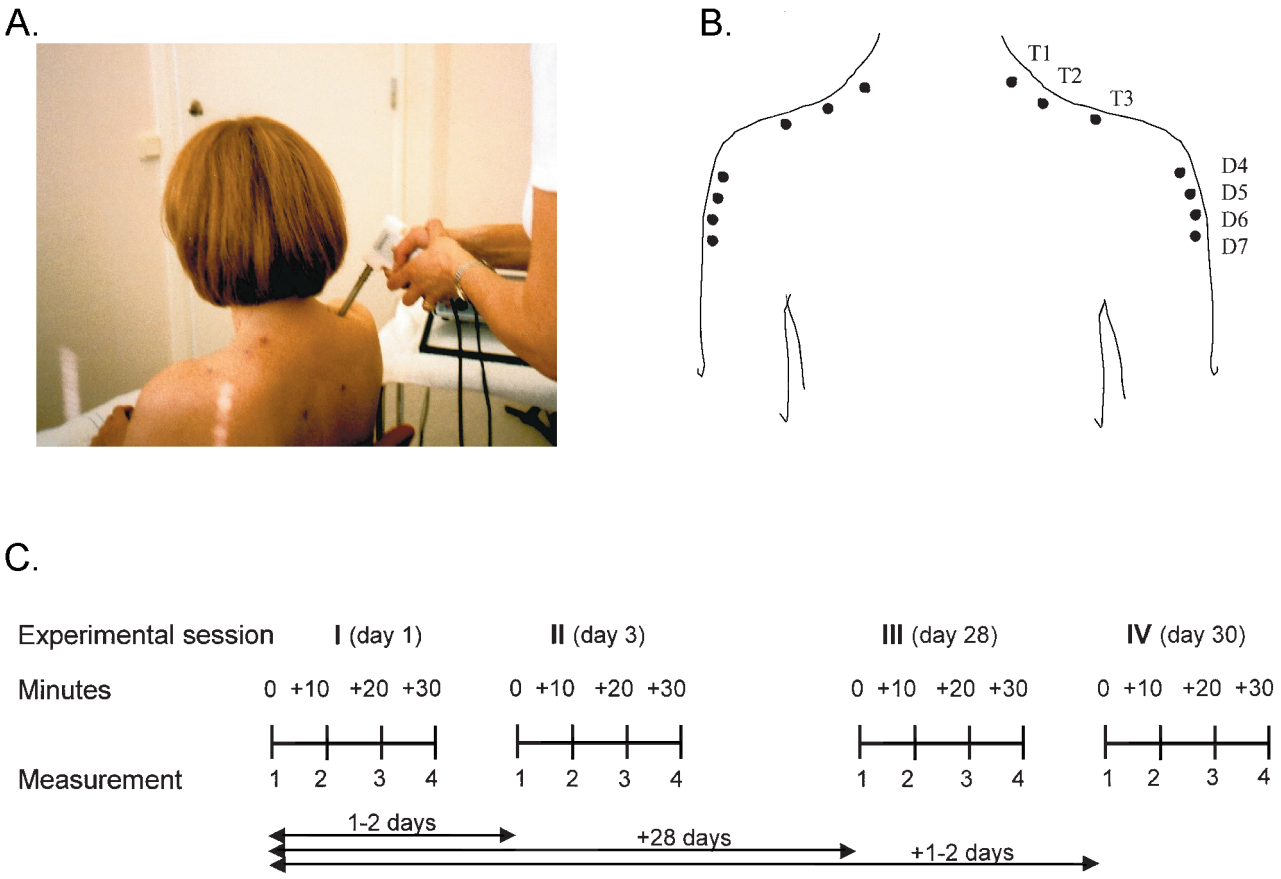

Fig. 1. Experimental set-up showing, (A) the electronic pressure algometer, (B) the pressure pain threshold markings on the trapezius and deltoid muscles and (C) the flow chart of the study design.

measurement method over time, but without any interventions, using the same standardized procedure and the same PPT point localization as in our previous studies (22, 23). Furthermore, we have adhered to the recommendations of Eliasziw et al. (27), about using statistical methods based on repeated-measures design, when both inter-rater and intra-rater reliability are being assessed. They also recommend that appropriate statistical tests, confidence intervals, and error of measurements, should always be used in conjunction with estimated reliability coefficients. We have included all this in our analysis.

The purposes of this study were to examine whether the PPTs of 2 shoulder muscles (the trapezius and the deltoid muscles) vary in a test-retest situation: (a) over time; in the short term (minutes), and the long term (days, months), (b) within subjects; (i) at the same point, (ii) between points in the same muscle, (c) between subjects, (d) between the right and the left side, (e) within examiners (intra-rater), and (f) between examiners (inter-rater).

METHODS

Subjects

Twenty-seven healthy female volunteers participated in the study. The inclusion criteria were: no pain from the musculoskeletal system, no previous injury in the neck-shoulder region, no analgesic or antidepressive medication, and regular menstrual cycles in the last 3 months prior to the experimental sessions. Three subjects dropped out, 2 because they found the procedure unpleasant, and 1 because she developed bruising at the measurement sites after the first PPT session. The remaining 24 subjects were all working as hospital staff in a university rehabilitation setting. The average age was 42 (range, 24–59) years, the average height was 167 (range, 151–174) cm and the average weight was 65 (range, 52–90) kg.

Questionnaire

Before the PPT measurements were taken all the subjects answered a standardized questionnaire about their menstrual cycle, the number of children they had borne, their smoking habits, whether they were on medication and whether they had sustained any previous injury in the neck-shoulder region.

All subjects were right-handed. Eight subjects had never given birth, 3 had given birth to 1 child, 10 to 2 children and 3 to 3 children. Twenty of the subjects were non-smokers, 3 smoked 1–10 cigarettes a day, and 1 smoked >10 cigarettes a day. None had any previous injuries in the shoulder region or were on analgesic or antidepressive medication.

Equipment

An electronic pressure algometer (Somedic®, Sweden) (Fig. 1A) was used to measure PPTs (12, 22). It consists of a gun-shaped handle with a pressure-sensitive strain gauge at the tip and is connected to a power supply, an amplifier and a display unit. The contact area was 11 mm in diameter, and the flat end of the probe was covered with a 2-mm thick rubber pad to minimize irritation of the skin. The pressure increase was standardized to a speed of 40 kPa/s (kiloPascal per second). A scale on the display unit helped the examiner to keep the rate of the pressure increase constant. The registered pressure in kPa remained on the screen

when the subject indicated the pressure pain threshold by pressing the signal button. The instrument was calibrated at the start of the series and the zero level was balanced before each measuring session.

Test protocol

Two examiners (AP, CB) performed all the PPT measurements and both were present at the sessions, thus both equally familiar to the subjects. The subjects were scheduled for the 4 experimental sessions (days 1, 3, 28 and 30; Fig. 1C), and registered in a time-book in an order according to their menstrual cycle, and at the time of day that was convenient and possible for them, taking into account their work schedule. The 2nd week of the menstrual cycle (days 5–15) was chosen to standardize the test situation, as a variation in PPTs during the menstrual cycle has been reported (28).

For practical reasons, it was not possible to randomize the order the subjects were measured by the 2 examiners (AP, CB), between days 1 and 3, and days 28 and 30, respectively. Each subject was measured in a total of 4 sessions, 4 times in each session with 10-minute intervals, and on 2 occasions by each examiner (Fig. 1C). Twelve out of the 24 subjects were measured first on day 1 and day 3 by AP and 12 by CB, respectively. Fifteen out of the 23 subjects were measured first on day 28 by AP, and 8 out of 23 subjects first on day 30 by CB.

Pressure pain threshold measurements

The subject was comfortably seated in a chair with a low support for the back and with a pillow on their lap for arm support. The PPT recording points, 14 points in total (22) (Fig. 1B), were located and marked bilaterally with an ink pen, 3 points over the descending part of the trapezius (points T1, T2, T3) muscle, along a straight line from the spinous process of the 7th cervical vertebra to the lateral edge of the acromion, and 4 points over the mid-portion of the deltoid (points D4, D5, D6, D7) muscle. An effort was made to standardize the anatomic locations at each session. This procedure took 5–10 minutes, during which the subject had time to relax before the test.

The same examiner (AP) was responsible for palpating and marking all the PPT points on each subject before PPT measurements both on day 1 and day 28. They remained visible on the skin on the consecutive days. Each session was conducted in the same room, using the same equipment and the same standardized measurement procedure. The temperature in the room was comfortably warm, so the subjects did not feel cold. The same instructions were given verbally each time, and written instructions were also placed on the wall in front of the subject, to serve as a reminder.

The PPTs were measured over the relaxed shoulder muscles. Two test trials, on a single point over each rhomboid muscle, were performed to familiarize the subject with the procedure. The pressure was applied perpendicularly (Fig. 1A) against the skin over the marked points in a fixed order, starting medially on the right hand side over the trapezius muscle and continuing laterally over the deltoid muscle. Thereafter, the same sequence was repeated on the left-hand side. The subjects were instructed to press the signal button, held in the dominant hand, when the sensation of "pressure" changed to one of "pain or discomfort" (5) and the measurement ceased at that time. The time spent assessing the 14 PPT points was 2–4 minutes, depending on the PPT levels (see (22)).

In an earlier pilot study with 5 subjects, 3 had shown bruising indicating tissue damage when they returned for the second session, on day 3. The bruises were located where the PPTs had been measured 2 days previously, mostly in the deltoid muscle.

To avoid tissue damage we decided to set a cut-off point when the PPT value exceeded 600 kPa. This cut off was activated in 3 of the 24 subjects and in only 52 out of 21,056 measurements (*vide infra*). For 18 out of the 24 subjects the experimental set-up for measuring PPTs was a new experience. Six subjects had prior PPT measurement experience. One subject had PPT recordings for days 1 and 3 only.

Statistical analysis

The data were analysed using the Statistical Package for the Social Sciences (SPSS) version 10.0 Software for Windows (SPSS, Chicago, IL, USA).

The mean of the 3 trapezius points and of the 4 deltoid points was calculated to obtain the mean PPT values for each muscle. Systematic differences in the intra-rater and inter-rater repeatability and side-to-side differences were analysed using Student's two-tailed paired *t*-test. A *p*-value <0.05 was considered to show statistical significance and a 95% confidence interval (CI) was used. For analysing changes over time, one-way analysis of variance, ANOVA, with repeated measures and Tukey's *post hoc* test were used. The intraclass correlation coefficient, $ICC_{2.1}$ (29) was calculated for the PPT values, examining agreement within subjects and between subjects, using two-way analysis of variance for each measured PPT point, and for the 4 measurements at each session. The measurement error was analysed and presented as the mean maximal absolute difference with standard deviation (±SD) in kPa, between 4 consecutive PPT measurements at 10-minute intervals, and between the 3 points in the trapezius muscle and the 4 points in the deltoid muscle, respectively. The mean absolute difference ± SD in kPa was calculated for differences between and within examiners. All PPT values exceeding 600 kPa were cut off, registered and analysed as missing values.

Ethics

Verbal and written information about the procedure was given before and at the time of the test. The Ethics Committee of Lund University approved the study.

RESULTS

The results include PPT measurements in 24 subjects from days 1 and 3, and in 23 subjects from days 28 and 30. Sixteen PPT measurements at each of the 14 points on each subject and on 4 different days were made, making a total of 21,056 measurements, 896 for each subject. For 18 of the subjects one day elapsed between the PPT measurements on days 1 and 3, and on days 28 and 30, respectively. For 4 of the subjects 2 days elapsed between the PPT measurements, and for 1 of the subjects the measurements were made on 2 consecutive days. Since no systematic statistical differences were found between the 2 examiners (AP and CB), we chose to disregard the order in which the subjects were first measured by each examiner when analysing the rest of the results, and therefore the data were pooled from days 1 and 3 and days 28 and 30 regarding measurements between examiners.

All measurements of menstruating subjects occurred in the 2nd week of their menstrual cycle, within the period of days 5–15, with the exception of 3 of the subjects (on days 17 and 19 for 2 of them, and on days 39 and 2 for 1 of them). Six subjects had reached menopause, 2 of whom used hormone replacement therapy. Six of the remaining 18 subjects used hormonal contraceptives and 1 used complementary medicine. Fifteen subjects did not use any medication at all.

Intra-individual pressure pain threshold differences

The short-term test-retest repeatability, or the intra-individual precision of the 4 PPT measurements at 10-minute intervals for each point in each of the 4 sessions, was analysed with respect to ICC (95% CI). As can be seen in Tables IA and B, the ICCs of the 4 consecutive PPT measurements at the 14 points in the 4 examined muscles in the 4 experimental sessions, were generally high, ranging from 0.70 to 0.94. The range of the mean maximal difference was 53–102 ± 25–72 kPa. An identical analysis of ICCs of the short-term test-retest repeatability of the mean PPTs in each muscle, i.e. points T1, T2, T3 and points D4, D5, D6, D7 respectively, show even higher values (0.84–

Table IA and B. *Intraclass correlation coefficient (ICC), confidence interval (CI), mean pressure pain threshold (PPT) maximal difference ± SD (kPa) between 4 consecutive PPT measurements in 10-minute intervals, (0, +10, +20, +30 minutes) in 7 PPT points on the right shoulder (A) and the left shoulder (B) in 24 women days 1 and 3, and in 23 women days 28 and 30. Four experimental sessions on days 1, 3, 28 and 30*

A. Right side	Day 1	Day 3	Day 28	Day 30
	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)
Trapezius point T1	0.85 (0.73–0.92) 85 ± 38	0.70 (0.51–0.85) 90 ± 48	0.80 (0.62–0.90) 93 ± 51	0.73 (0.53–0.86) 94 ± 38
Trapezius point T2	0.77 (0.61–0.88) 82 ± 39	0.79 (0.66–0.89) 82 ± 40	0.79 (0.62–0.90) 80 ± 52	0.76 (0.58–0.89) 82 ± 39
Trapezius point T3	0.75 (0.60–0.87) 101 ± 56	0.83 (0.69–0.92) 81 ± 43	0.80 (0.65–0.91) 92 ± 41	0.85 (0.73–0.93) 96 ± 63
Trapezius mean of points T1 + T2 + T3	0.86 (0.72–0.93) 68 ± 34	0.84 (0.68–0.93) 63 ± 40	0.89 (0.75–0.95) 70 ± 36	0.90 (0.78–0.96) 70 ± 32
Deltoid point D4	0.74 (0.58–0.87) 102 ± 72	0.83 (0.71–0.91) 90 ± 65	0.85 (0.73–0.93) 90 ± 45	0.85 (0.73–0.93) 78 ± 49
Deltoid point D5	0.77 (0.63–0.88) 93 ± 60	0.88 (0.77–0.94) 67 ± 35	0.87 (0.77–0.94) 68 ± 41	0.80 (0.64–0.91) 91 ± 52
Deltoid point D6	0.81 (0.68–0.90) 84 ± 57	0.89 (0.81–0.95) 61 ± 26	0.87 (0.77–0.94) 80 ± 47	0.85 (0.74–0.93) 62 ± 42
Deltoid point D7	0.73 (0.57–0.86) 90 ± 58	0.81 (0.69–0.90) 72 ± 29	0.85 (0.74–0.92) 80 ± 46	0.77 (0.63–0.88) 80 ± 57
Deltoid mean of points D4 + D5 + D6 + D7	0.85 (0.75–0.93) 67 ± 45	0.90 (0.82–0.95) 53 ± 34	0.91 (0.84–0.96) 60 ± 33	0.86 (0.75–0.93) 60 ± 50

B. Left side	Day 1	Day 3	Day 28	Day 30
	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)
Trapezius point T1	0.87 (0.78–0.94) 73 ± 37	0.80 (0.67–0.90) 86 ± 43	0.83 (0.71–0.91) 93 ± 59	0.91 (0.84–0.96) 64 ± 26
Trapezius point T2	0.78 (0.60–0.90) 73 ± 39	0.82 (0.67–0.91) 77 ± 32	0.90 (0.80–0.95) 76 ± 43	0.81 (0.65–0.91) 87 ± 45
Trapezius point T3	0.79 (0.65–0.89) 96 ± 59	0.86 (0.72–0.93) 82 ± 39	0.84 (0.71–0.93) 88 ± 45	0.86 (0.73–0.93) 82 ± 33
Trapezius mean of points T1 + T2 + T3	0.86 (0.74–0.93) 64 ± 38	0.88 (0.76–0.95) 64 ± 25	0.90 (0.80–0.96) 71 ± 41	0.92 (0.83–0.97) 53 ± 29
Deltoid point D4	0.82 (0.70–0.91) 93 ± 35	0.87 (0.77–0.93) 85 ± 45	0.85 (0.72–0.93) 68 ± 42	0.85 (0.73–0.93) 73 ± 41
Deltoid point D5	0.80 (0.65–0.90) 82 ± 43	0.83 (0.71–0.91) 79 ± 48	0.85 (0.72–0.93) 73 ± 48	0.81 (0.67–0.91) 78 ± 47
Deltoid point D6	0.71 (0.54–0.84) 81 ± 52	0.82 (0.69–0.91) 79 ± 43	0.90 (0.82–0.95) 62 ± 37	0.87 (0.77–0.94) 74 ± 45
Deltoid point D7	0.72 (0.54–0.86) 76 ± 48	0.78 (0.63–0.89) 80 ± 40	0.87 (0.76–0.94) 76 ± 46	0.87 (0.78–0.94) 71 ± 41
Deltoid mean of points D4 + D5 + D6 + D7	0.85 (0.71–0.93) 65 ± 33	0.90 (0.80–0.95) 57 ± 28	0.94 (0.89–0.98) 48 ± 30	0.92 (0.84–0.96) 56 ± 35

Table II. *Intraclass correlation coefficient (ICC) and confidence interval (CI), mean pressure pain threshold (PPT) maximal difference ± SD (kPa) for PPTs between 3 points (T1, T2, T3) in the right and left trapezius muscle, respectively, and in 4 points (D4, D5, D6, D7) in the right and left deltoid muscle, respectively, in 24 women days 1 and 3, and in 23 women days 28 and 30. Four experimental sessions at days 1, 3, 28 and 30, each with 4 separate measurements in 10-minute intervals, (0, +10, +20, +30 minutes)*

	Day 1		Day 3		Day 28		Day 30	
	Right	Left	Right	Left	Right	Left	Right	Left
Trapezius muscle								
Minutes	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)
0	0.73 (0.55–0.86) 69 ± 61	0.69 (0.48–0.84) 81 ± 57	0.61 (0.38–0.79) 83 ± 67	0.69 (0.49–0.84) 72 ± 51	0.71 (0.46–0.86) 90 ± 71	0.79 (0.63–0.89) 82 ± 67	0.59 (0.34–0.79) 90 ± 52	0.72 0.53–0.86) 67 ± 39
+10	0.72 (0.51–86) 82 ± 68	0.79 (0.63–0.89) 93 ± 60	0.67 (0.44–0.83) 84 ± 58	0.71 (0.51–0.85) 77 ± 54	0.60 (0.34–0.79) 86 ± 62	0.84 (0.71–0.92) 72 ± 47	0.65 (0.42–0.82) 102 ± 72	0.83 (0.63–0.93) 79 ± 53
+20	0.69 (0.48–0.84) 93 ± 65	0.68 (0.48–0.83) 64 ± 63	0.65 (0.42–0.82) 95 ± 71	0.77 (0.58–0.88) 66 ± 40	0.77 (0.59–0.89) 80 ± 54	0.75 (0.57–0.88) 89 ± 69	0.67 (0.45–0.83) 88 ± 55	0.82 (0.67–0.91) 77 ± 47
+30	0.63 (0.41–0.80) 101 ± 70	0.79 (0.63–0.90) 77 ± 60	0.61 (0.40–0.79) 97 ± 74	0.77 (0.55–0.90) 79 ± 42	0.73 (0.50–0.87) 92 ± 69	0.76 (0.58–0.89) 82 ± 44	0.66 (0.41–0.83) 82 ± 81	0.67 (0.45–0.83) 88 ± 61
Deltoid muscle								
Minutes	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)	ICC (CI) Mean max. diff. ± SD (kPa)
0	0.73 (0.57–0.86) 87 ± 70	0.77 (0.62–0.88) 76 ± 51	0.70 (0.53–0.84) 89 ± 59	0.74 (0.58–0.86) 85 ± 58	0.79 (0.65–0.89) 92 ± 74	0.84 (0.72–0.92) 85 ± 43	0.69 (0.52–0.83) 94 ± 69	0.85 (0.73–0.93) 89 ± 65
+10	0.80 (0.66–0.90) 89 ± 55	0.75 (0.59–0.87) 91 ± 52	0.67 (0.49–0.82) 98 ± 72	0.71 (0.55–0.85) 98 ± 62	0.75 (0.60–0.87) 114 ± 79	0.90 (0.82–0.95) 102 ± 64	0.72 (0.55–0.85) 111 ± 82	0.84 (0.72–0.92) 91 ± 51
+20	0.79 (0.66–0.90) 95 ± 64	0.76 (0.62–0.87) 77 ± 57	0.66 (0.47–0.82) 104 ± 81	0.70 (0.53–0.84) 65 ± 36	0.83 (0.70–0.92) 90 ± 50	0.84 (0.72–0.92) 86 ± 45	0.75 (0.60–0.88) 88 ± 55	0.86 (0.75–0.93) 67 ± 35
+30	0.78 (0.64–0.88) 78 ± 76	0.70 (0.53–0.84) 75 ± 45	0.72 (0.54–0.85) 99 ± 98	0.80 (0.67–0.90) 75 ± 36	0.77 (0.62–0.89) 94 ± 72	0.86 (0.74–0.93) 80 ± 46	0.78 (0.63–0.89) 109 ± 96	0.84 (0.70–0.93) 78 ± 47

0.94) with a narrower range of mean maximal difference (53–71 ± 25–41 kPa; Tables IA and B).

Pressure pain threshold differences within the muscle

The correlation between the PPT measurements for the trapezius muscles at points T1, T2, T3 and for the deltoid muscles at points D4, D5, D6, D7, on both the right and the left side for each point in time (at 0, +10, +20, and +30 minutes) are given in Tables IIA and B. They were analysed with respect to ICC (95% CI), and the range for the trapezius muscle was 0.59–0.77 on the right side, and 0.67–0.84 on the left side. The ICC range for the deltoid muscle was 0.66–0.83 on the right side, and 0.70–0.90 on the left side. The mean maximal difference for the trapezius muscle was 69–101 ± 39–81 kPa and 65–111 ± 36–98 kPa for the deltoid muscle.

Inter-individual pressure pain threshold differences

The absolute mean PPT (kPa) in the trapezius muscle (points T1 + T2 + T3) and deltoid muscle (points D4 + D5 + D6 + D7) of each individual on the right-hand side at times 0, +10, +20, and +30 minutes in each of the 4 sessions are shown in Fig. 2. Each diagram represents one session (days 1, 3, 28 and 30) for the trapezius (A–D) and the deltoid (E–H) muscles. It can be seen that the absolute intra-individual PPT differences are small within and also, to a great extent, between the 2 muscles, whereas the inter-individual differences are considerable (right side trapezius muscle range 88–542 kPa, deltoid muscle range 91–474 kPa; left side (not shown) trapezius muscle range 92–574 kPa, deltoid muscle range 105–529 kPa).

In spite of the variation between individuals, the mean absolute value for each muscle in the 24 subjects at each point in time shows a limited variation (95% CI; Fig. 3A–D). However, one-way analysis of variance for repeated measures indicated significant differences between measurements within all sessions. Tukey's *post hoc* test usually sampled out the first mean PPT values (at 0 minutes) as significantly different from the rest. In fact there were no significant differences between the 16 measurements comparing +20 minutes with +30 minutes, and in 10 out of the 16 measurements comparing +10 minutes with +20 minutes and +30 minutes. There were, on the other hand, significant differences in all but 2 of the 16 measurements comparing 0 minutes with +20 minutes, and in all of the 16 measurements comparing 0 with +30 minutes.

Side-to-side pressure pain threshold differences

As regards side-to-side differences (Fig. 4), there were no significant differences between the mean PPTs of all measurements on the right side compared with all measurements on the left side in the trapezius muscle in any of the 4 sessions (A), whereas in the deltoid muscle (B) there was a small but significant difference between the sides on day 28 ($p = 0.002$) and on day 30 ($p = 0.004$; paired *t*-test), but not on days 1 and 3.

Pressure pain threshold differences within and between examiners

Table III shows the mean absolute PPT differences ± SD in kPa between examiners (or inter-rater) and within examiners (or intra-rater), at the second PPT measurement (at +10 minutes) of each session, in the trapezius and the deltoid muscles respectively of the right and left side.

The intra-examiner repeatability, i.e. testing with the same examiner (AP/AP or CB/CB), and the same subjects 1 month after the first 2 sessions, i.e. long-term test-retest repeatability, showed no significant systematic differences except in the deltoid muscle on the left side ($p = 0.020$, AP and $p = 0.008$, CB; paired *t*-test). The intra-examiner mean absolute PPT differences were small, range 74–91 ± 44–76 kPa.

The test-retest repeatability between examiners, showed no significant systematic differences regarding measurements, for examiners AP and CB within sessions I–II, and within sessions III–IV, respectively. The mean absolute differences were 44–71 ± 38–67 kPa. Furthermore, it is evident from Tables IA and B, that the ICCs are high for any point when data from both examiners are pooled.

DISCUSSION

Our results indicate that the correlation between consecutive PPT measurements at a certain point over the trapezius or deltoid muscle is high (Table I). The same is true for the correlation between PPT measurements at different points in the same muscle (Table II). Other workers have usually limited their analysis to correlations and means (5, 12, 18, 19). Here, we have further analysed the mean maximal absolute differences that appear in and between points. This analysis shows that the mean maximal absolute difference between measurements for a single point can be 100 kPa, making single observations hard to interpret. The corresponding difference for either of the 2 muscles at any point in time is 50–70 kPa, which is more reasonable. At the group level (Fig. 3) the PPT variation is limited in our study. There is a small but significant increase over time within each session. Our subset analysis indicate a closer similarity between observations made at +10, +20 and +30 minutes than at 0, +10 and 20 minutes. We therefore recommend that the first measurement be excluded from scientific calculations in accordance with the suggestions of others (30), (see also (21)), although, in contrast to our findings, they found a *higher* first PPT measurement in each session. If this procedure is followed for the data in Fig. 3, a calculation of the mean PPT (95% CI) for each of the 4 muscles produces the following values: trapezius right side 263 (229–306) kPa; trapezius left side 272 (236–308) kPa; deltoid right side 259 (224–293) kPa; deltoid left side 272 (238–306) kPa. This in turn means that even the mean maximal absolute difference gives a measurement error of less than 13–14% in any of the muscles on the group level.

On the other hand the present study demonstrates that the

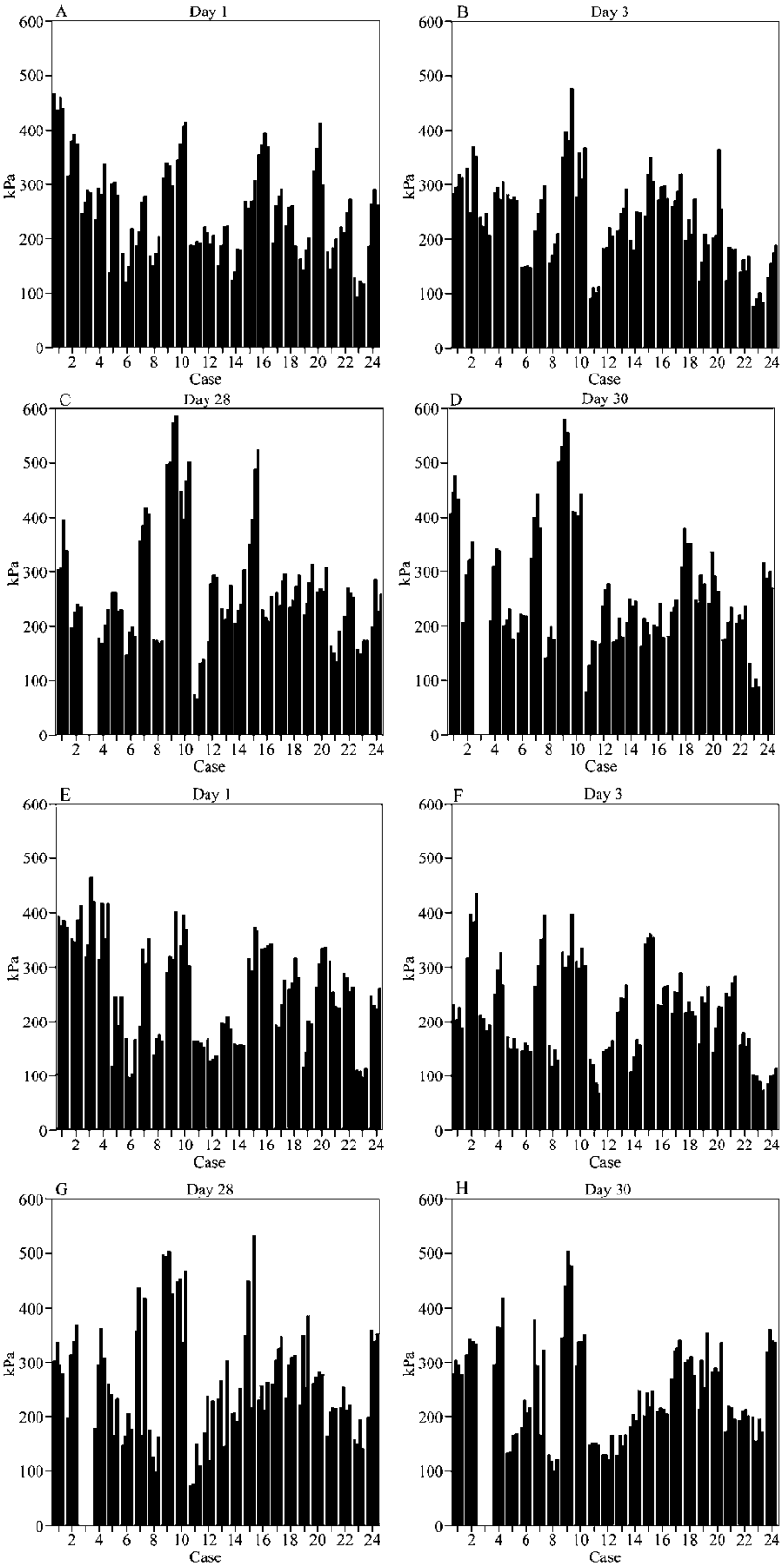

Fig. 2. Individual absolute mean pressure pain thresholds (kPa) in the trapezius (A–D: points T1 + T2 + T3) and deltoid (E–H: points D4 + D5 + D6 + D7) muscles, both on the right side, at 4 experimental sessions; (n = 24 days 1 and 3, n = 23 days 28 and 30). Each bar in a cluster represents measurements at 0, +10, +20 and +30 minutes in 1 subject. Each cluster represents the same subject as numbered on the x-axis at all sessions.

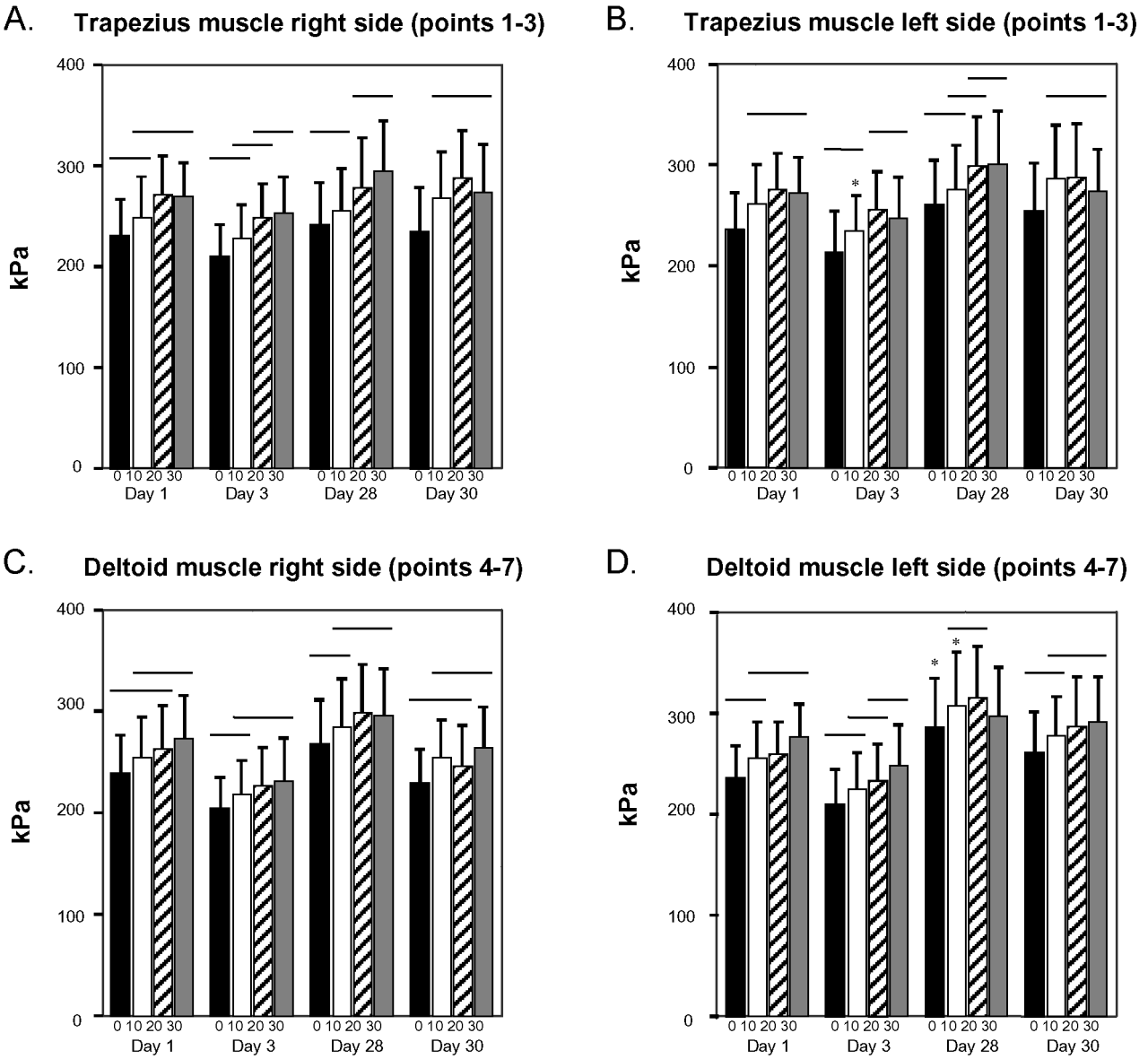

Fig. 3. Columns show absolute group mean pressure pain thresholds (kPa) in the trapezius (points T1 + T2 + T3) and deltoid (points D4 + D5 + D6 + D7) muscles, right and left side. Four consecutive measurements at 0, +10, + 20 and + 30 minutes, in each of the 4 experimental sessions, days 1, 3, 28 and 30. Error bars show 95% CI of mean. Univariate ANOVA with Tukey's *post hoc* test ($p < 0.05$). The horizontal lines above the error bars represent subsets where no statistically significant differences were seen between the mean PPT values, (*indicates subset with mean PPT at +30 minutes).

inter-individual variation of PPTs in the trapezius and the deltoid muscles is more than 5-fold, making the usefulness of comparisons of absolute PPT values between individuals (12, 18, 21) and also for different muscles (5) less meaningful. Obviously it is necessary to normalize PPT values when using this method for longitudinal/intervention studies of the current muscles, although the measurement situation may vary in other body regions where the tissue composition is different.

It could be argued that the threshold criterion for our subjects may have been unclear. However, our subjects were all white-collar workers with good communication skills, and were clearly instructed about the threshold criterion when the pressure gave rise to "pain or discomfort" which is similar to the criterion defined and employed by Fischer (5). Nørregaard et al. (31) used the instruction "the pressure at which the sensation changes from pressure alone to a combination of pressure and pain". The inter-individual variation, illustrated in Fig. 2, may reflect the situation that a certain subject decides her threshold criterion and holds on to it at later PPT measurements. This is also supported by the limited intra-individual variation (Table II, Fig. 2). Some of the subjects seemingly decided to choose one of 2 possible threshold criteria, either defining it as pain (higher PPTs), or defining it as discomfort (lower PPTs). In addition, the first measurement may have served as a learning process,

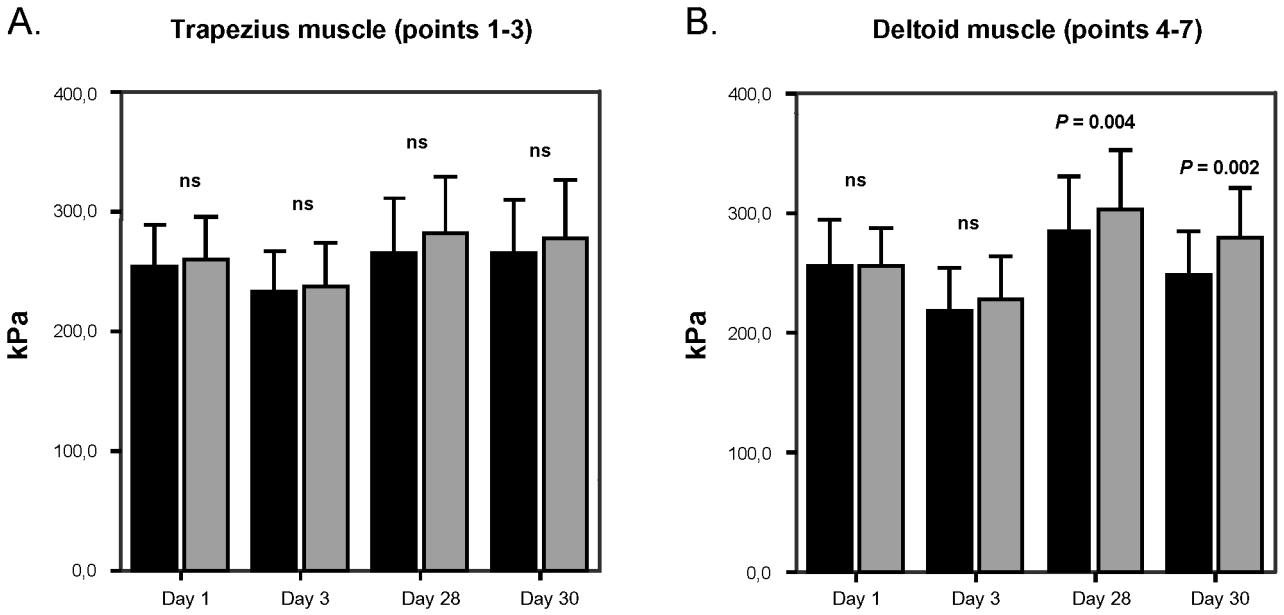

Fig. 4. Mean pressure pain thresholds for the trapezius and deltoid muscles of all measurements on the right side (solid) compared with all of the measurements on the left side (shaded) in 4 experimental sessions, days 1, 3, 28 and 30. Columns show means, error bars show 95% CI of mean (paired *t*-test).

assisting the subject to set their internal threshold criterion at a certain session. The present results of no, or only small side-to-side differences are in agreement with the findings of others (12, 32). When comparing the 2 muscles, the small but significant systematic differences seen in the deltoid muscle, days 28 and 30 (Fig. 4), and within examiners also in the left deltoid (Table III), could possibly be due to the mirrored body position of the subjects. Since the examiner used the dominant hand, the position may not have been exactly the same when measuring the right and left sides. There is also more subcutaneous fat over the deltoid than over the trapezius muscle, and the underlying structures might slide more easily during the measurement (22).

It has been reported that PPTs may vary during the menstrual cycle (28). To achieve stable conditions we tried to carry out all the PPT measurements in the 2nd week of the menstrual cycle, to ensure that the PPTs were not affected by any premenstrual pain symptoms or pain during menses. In addition, we intentionally did not include subjects with any ongoing pain, since this may give rise to sensory threshold changes (33).

Since 2 different examiners collected our data for intra-individual analysis it seems safe to conclude that the inter-rater reliability is also high (8, 9). Previous studies have often arrived at the same conclusion but with less adequate analysis (4, 7, 20). A specific analysis of inter-rater absolute mean PPT differences further supports this statement (Table III).

We selected the $ICC_{2,1}$ from several ICCs that are available (29), where the $_2$ relates to a specific statistical model. $ICC_{2,1}$ uses a two-way ANOVA model where we consider the raters to be randomly selected from a population of raters, i.e. a random factor (34). But as the ICC is a correlation it does not indicate the magnitude of agreement between measurements, and therefore in this study the mean maximal absolute differences have been calculated.

As regards the minimum suitable interval between consecutive measurements our study only includes data with 10-minute intervals, as in our previous studies (22, 23). Other researchers have recommended even longer intervals such as 15–30 minutes (20, 21, 32), whereas some groups have measured PPTs with only 15–30-second intervals. Several investigators have been

Table III. *Mean absolute pressure pain threshold (PPT) differences ± SD (kPa) between (AP/CB) and within (AP/AP and CB/CB) examiners at the second PPT measurement (+10 minutes) of each session, for the trapezius and deltoid muscles of the right and left side, respectively*

	Trapezius right side	Trapezius left side	Deltoid right side	Deltoid left side
	Mean absolute differences ± SD (kPa)	Mean absolute differences ± SD (kPa)	Mean absolute differences ± SD (kPa)	Mean absolute differences ± SD (kPa)
AP/CB (Session I–II)	44 ± 38	67 ± 47	71 ± 46	69 ± 65
AP/CB (Session III–IV)	55 ± 48	69 ± 55	57 ± 54	69 ± 67
AP/AP (Session I–II and III–IV)	74 ± 55	91 ± 52	77 ± 44	84 ± 62
CB/CB (Session I–II and III–IV	76 ± 45	69 ± 45	76 ± 66	76 ± 76

able to show that consecutive measurements of PPTs over the same point reveal little variation and that no measurement effects of repeated pressure application to the same point can be seen (9, 12, 35). In many PPT studies of populations only 1 measurement session or only 1 measurement is carried out, and therefore the risk of measurement effects or subjects complaining of soreness or bruising at measurement sites, i.e. exhibiting evidence of tissue damage, is less obvious. It is questionable whether the registered PPT value represents a true PPT threshold if bruising results. Only a few PPT values exceeded 600 kPa in our study, and there was no bruising at any time in any of the subjects included in the study. We found this problem commented on in only 1 recent study measuring PPTs on 3 consecutive days (9) but Jensen et al. (12) mention in their study of the temporal region that PPTs never exceeded 1600 kPa! Furthermore, Lavigne et al. (15) found that subject controlled responses as we used them gave lower absolute PPTs compared with examiner controlled conditions. Further investigations are necessary to clarify this problem.

Since the purpose of the present study was to examine PPTs of the trapezius and deltoid muscles as a whole, we deliberately did not include a specific search for tender/trigger points. The occurrence of tender/trigger points varies not only between subjects but also from day to day within subjects, some being "latent" and some "active", rendering systematic studies difficult (25, 26).

In conclusion, repeated measurements with short intervals show stable intra-individual PPT values when the first measurement is excluded. The method can therefore be recommended, with repeated measures (time or point), but the large inter-individual variation means that relative PPTs are to be preferred (see (22, 23)). Furthermore, when used by experienced and trained examiners, the inter-rater repeatability is high.

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