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DIAGNOSTIC METHODS: CORRELATIONAL RELIABILITY

Reliability of modified adheremeter and digital pressure algometer in measuring normal abdominal tissue and C-section scars

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A R T I C L E I N F O

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A B S T R A C T

Objective: This study tested inter- and intrarater reliability of the digital pressure algometer and modified adheremeter and concurrent validity in the algometer in both normal abdominal tissue and in chronically painful C-section scars.
Study design: Correlational Reliability/Validity.
Background: The algometer is used to measure pressure-pain threshold (PPT). The adheremeter is a tool to measure tissue extensibility. Painful abdominal scars are being treated successfully with soft-tissue techniques yet reliable measurement tools for this tissue have not been reported.
Methods and measures: 59 subjects with normal abdominal tissue were marked at a point 2 inches inferolateral to the umbilicus. Two separate testers measured PPT twice with an algometer and tissue extensibility in superior/left/inferior/right directions with a modified adheremeter. 29 subjects with painful C-section scars were marked at 2.5 cm intervals along the scar. A total of 115 points were measured in the same manner as above. C-section subjects also were asked to rate their pain using the numeric pain rating scale (NPRS). Each tester was blinded to all other measurements.
Results: For PPT, intraclass correlations (ICC's) ranged from 0.814 to 0.933 with a standard error of measurement (SEM) ranging from 1.65N to 5.9 N. For tissue mobility, ICC's ranged from 0.430 to 0.914; SEM ranging from 1.67 mm to 3.7 mm. All but 2 measures had ICCs that were good-excellent. Inferior glide in C-section tissues showed the least and multi-directional measurement the strongest reliability. The PPT had a moderate negative correlation ($r = -0.551$) with the NPRS.
Conclusions: The algometer showed excellent inter- and intra-rater reliability on normal abdominal tissue and C-section scars. It showed moderate criterion validity when compared against the NPRS. The modified adheremeter showed good-excellent inter- and intra-rater reliability on both normal abdominal tissue and C-section scars. Both measures have clinical and research applications for women's health practitioners.

1. Introduction

Assessing pain is a fundamental component of physical examination. In current practice, pain information is typically collected via subjective tools such as the Numeric Pain Rating Scale (NPRS) or Visual Analogue Scale (VAS). Although these scales are validated (Childs et al., 2005; Majani et al., 2003), it would also be helpful to have tools that can collect this information more objectively. The digital pressure algometer is a tool currently available for pain assessment. It is used to measure the “pressure-pain threshold”. In some studies, it has been described as when pressure turns to discomfort, and in others, when discomfort turns to pain. These have been used in both research and clinical practice (Wasserman et al., 2016). For the purpose of this study, we chose to separate these two definitions and assess both. Pressure pain threshold (PPTh) was described and used as when pressure turns to discomfort. Pressure pain tolerance (PPT) was described and used as when discomfort turns to pain. The digital pressure algometer has been used in measurement of pain in the pelvic floor muscles (Tu et al., 2008), vaginal wall (Baguley et al., 2003), Caesarean section scars (Wasserman et al., 2016), oral mucosa (Gibbs et al., 1999; Ogimoto et al., 2002), TMJ (Nordahl and Kopp, 2003), neck

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musculature (Park et al., 2011; Ylinen et al., 2007), greater trochanter (Sayed-Noor et al., 2008), supraorbital nerves (Fernandez-de-las-Penas et al., 2009), painful epigastric area of the abdomen (Ko et al., 2016), and in the painful abdomen of children (Duarte et al., 2000). Pressure algometry has been shown reliable for trigger points in the posterior trunk and upper extremities (Cronbach's Alpha: 0.94–0.98) (Park et al., 2011). Reliability of the digital pressure algometer has also been reported in normal abdominal tissue (Montenegro et al., 2012), however, it has not been reported for measurement of abdominal pain. Painful abdominal scars are being treated successfully with soft-tissue techniques yet there has been no consistent way to measure that discomfort (Wasserman et al., 2016; Bove and Chapelle, 2012; Chapelle and Bove, 2013; Comesana et al., 2016; Kobesova et al., 2007; Le Blanc-Louvry et al., 2002; Lewit and Olsanska, 2004; Valouchová and Lewit, 2008).

Unfortunately, painful scarring is a common sequelae of soft tissue trauma and surgical procedures in general (Awonuga et al., 2011). It would be helpful to have a validated measure of tissue extensibility in assessment of symptoms associated with abdominal scarring or adhesions. The adheremeter was described by Ferriero et al. as a measurement tool to calculate the extensibility of peripheral surgical scars (Ferriero et al., 2010). They reported moderate correlation with the Vancouver Scar Scale, intra-rater reliability ICC = 0.96 and interrater reliability ranging from ICC = 0.87–0.99. It is unknown if similar reliability would be found in other tissues within the body. In particular, abdominal tissue is more extensible than peripheral tissue. Reliability needs to be established for the adheremeter in both healthy abdominal tissue and abdominal scars.

The purpose of this study was to test the inter-rater reliability (Inter RR) and intra-rater reliability (Intra RR) of 1) the digital pressure algometer for both pressure pain threshold and pressure pain tolerance and 2) the adheremeter for tissue mobility, on both lower abdominal tissue of healthy subjects and on chronically painful caesarean section (C-section) scars. The study also aimed to establish criterion validity for the algometer in subjects with painful C-section scars. It was hypothesized that the reliability for these instruments on healthy and scarred abdominal tissue would be consistent with the highly reported ratings of other studies and that the results of algometry on painful C-section scars would show a moderate to strong relationship with the results of the NPRS.

2. Methods and measures

2.1. Subjects

Study 1: A group of 59 healthy Doctor of Physical Therapy (DPT) students participated in the first study. (Males 47.5%; females 52.5%) Mean age was 25 (range 22–34); mean BMI 25.4. Exclusion criteria included presence of any type of abdominal scar.

Study 2: Subjects with a chronically painful C-section scar were solicited via: Facebook, fliers, and mailings to health professionals. Inclusion criteria: C-section scar >6 months ago, pain at least 3/10 in past month on NPRS due to chronic pain from the C-section. Exclusion criteria: currently pregnant or trying to get pregnant, currently undergoing additional treatment related to pain from C-section scar, history of cancer or radiation in the abdominal area.

One hundred and fifteen points were measured on 28 women: mean age 37 (range 28–58); mean BMI 28.5 (range 20.4–48.7); median time since C-section 36 months (range 6–420); median number of C-sections 1 (range 1–3).

2.2. Setting

Study 1: Testing was done in the orthopedic lab at Franklin Pierce University Doctor of Physical Therapy Program.

Study 2: Testing was done in a private treatment room in one of three locations as part of a larger study: 1) Franklin Pierce University Doctor of Physical Therapy Program, Manchester, NH, 2) ITR Physical Therapy, McClean, Virginia or 3) Experience Momentum, Lynwood, Washington.

2.3. Testers

Study 1: Testers were three Doctor of Physical Therapy Students trained in use of the measures and one experienced Physical Therapist. 59 subjects were separated randomly into two groups. Within each group, two testers measured each subject twice.

Study 2:

Location 1: Testers were Doctor of Physical Therapy Students trained in use of the measures and one experienced Physical Therapist. Testers were the same as used in study number one.

Locations 2 and 3: Testers were two experienced Physical Therapists. Testers were different in each of the three locations.

2.4. Training

A written training protocol was developed by the principle investigator. Training involved several hours of practice by all testers before beginning the study.

2.5. Data collection

Adheremeter: The adheremeter as described by Ferriero et al. has a radius of approximately 1.75 cm with concentric circles 2 mm apart (Ferriero et al., 2010) (Fig. 1). Initial attempts to use this in abdominal tissue failed, as the extensibility far exceeded the available radius. Final modifications resulted in a modified adheremeter with a radius of 4.6 cm (Fig. 2). The procedure for using the adheremeter as described by Ferriero et al. is as follows: A mark was made on the tightest part of the scar and on the same

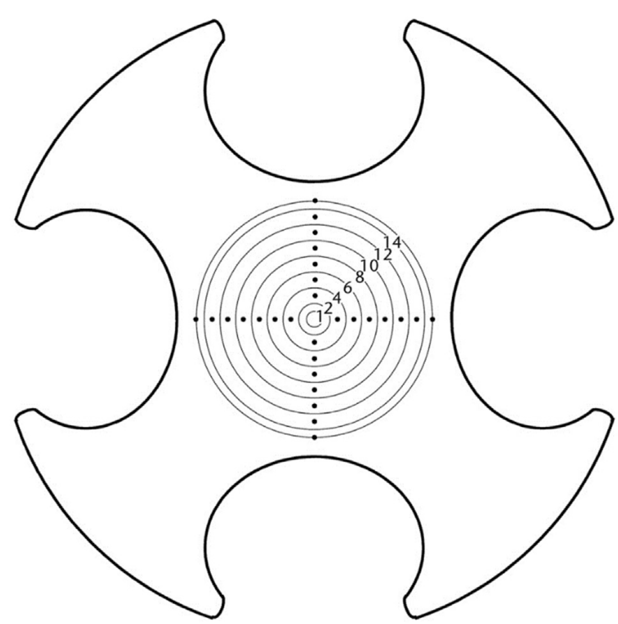

Fig. 1. Original adheremeter (Ferriero et al., 2010).

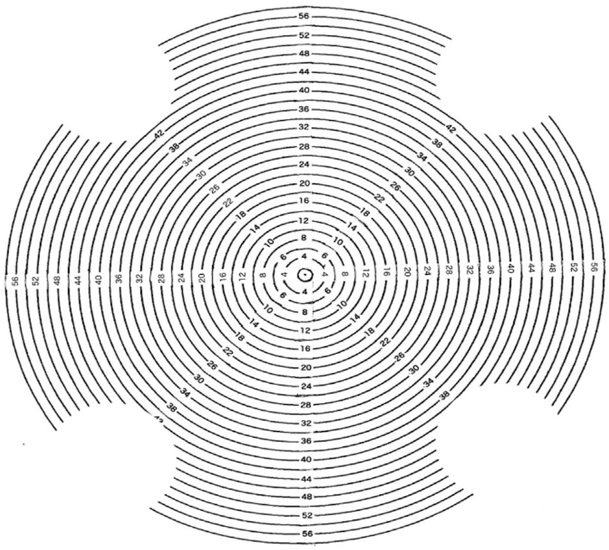

Fig. 2. Modified adheremeter.

spot on the contralateral side of the body. Mobility was measured in each of four directions (superior, inferior, right and left) and a calculation of the quadrilateral formed was done (superior + inferior) x (right + left) (Fig. 3). (Ferriero et al., 2010) This calculation they called the scar mobility index adherence (SM_A). They did the same procedure on the contralateral (normal) tissues that they labeled scar mobility index normal (SM_N) and developed a ratio of the adhered side to normal side (SM_A/SM_N)(Ferriero et al., 2010). As our study was looking at the effectiveness of the adheremeter in abdominal tissue where there is not a contralateral side, we modified the procedure and looked at reliability of each separate measure and of the SM_A, which we have called multi-directional mobility (MDM).

Numeric Pain Rating Scale: C-Section subjects filled out the Numeric Pain Rating Scale (0–10) scale for worst pain in past 48 h. This tool has been shown to be reliable and valid (Childs et al., 2005).

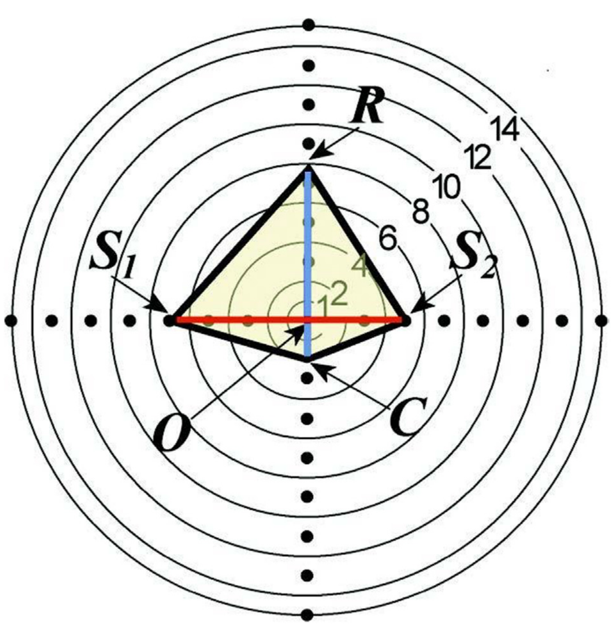

Fig. 3. Multi-directional scar mobility (Ferriero et al., 2010).

2.6. Procedures

Subjects lay supine on a plinth with arms at their sides and legs straight.

Study 1: A tape measure was used to make a small mark on the abdomen, 2 inches from the umbilicus. The mark was made at a 45-degree angle to the right/caudal side of the umbilicus.

Study 2: Marks were made on the C-section scar at 2.5 cm intervals. This resulted in from 5 to 8 measurement points along the scar (Fig. 4).

Modified Adheremeter: Two separate testers then used the marks to measure tissue extensibility in millimeters (mm) in each of four directions: superior/left/inferior/right (Fig. 5).

Digital Pressure Algometer: The Wagner model FDIX digital pressure algometer was used (Fig. 6). The same subjects, positioning and points were used when assessing the algometer as were used in assessing the adheremeter. The tool was gently and slowly pressed into the selected point of the abdominal tissue. The subject was instructed to report when the pressure from the tool began to feel like discomfort and that value in newtons (N) was recorded. The tester continued to apply slow consistent pressure and the subject was instructed to report when their discomfort became pain. Testing of both instruments in both subject populations was performed with the tester positioned to the right of the subject.

2.7. Timing

Study 1: Both testers collected one round of measurements with one to 3 min time elapsed in between testers. One to 3 min following the first round, the procedure was repeated, so that each tester had collected measurements twice for each subject.

Study 2: For study 2, tester one did all measurements and repeated them immediately after. Tester two performed there two sets of measurements fifteen to 20 min after tester one.

For both studies, testers were blinded to their own prior measurements and the other tester's measurements.

2.8. Data analyses

Data was analyzed using the intraclass correlation coefficient (ICC) two-way mixed method, absolute agreement using IBM's SPSS version 24. All data sets were tested for normality using a skew of −1 to +1 as the cut off. Skewed data sets were logarithmically transformed to achieve normality. The data sets for the pressure algometer in both studies as well as the data for the tissue extensibility in study 1 (normal abdominal tissue) were all skewed and then transformed. Please refer to Tables 1–7 for data sets. The standard error of measurement (SEM) was calculated as standard deviation (SD)(1-r). The minimal detectable change (MDC) was calculated using the formula 1.96 x SEM x 2 for both interrater and

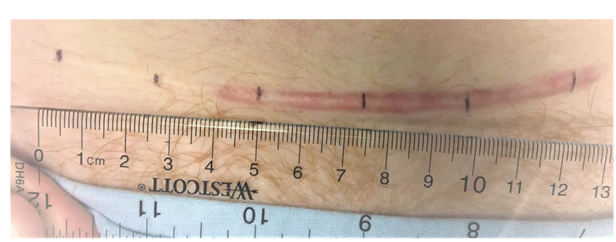

Fig. 4. Markings for Measurement points- C-section group.

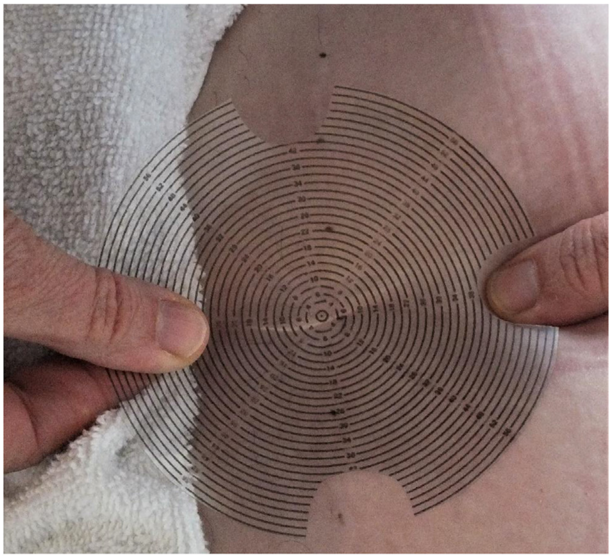

Fig. 5. Modified Adheremeter in use.

Fig. 6. Wagner digital pressure algometer in use.

intra-rater reliability. To test for criterion validity, the PPT measures for the C-section subjects and the NPRS results were analyzed for correlation using the Pearson's R statistic.

3. Results

The sample size, reliability coefficients, corresponding 95% confidence intervals (CIs), p-level, and standard error of measurement (SEM) and minimal detectable change (MDC) for intra and inter rater reliability for pressure pain threshold in both normal abdominal tissue as well as C-section scar tissue can be found in Table 1. The same data is documented for pressure pain tolerance in Table 2, superior tissue mobility in Table 3, inferior tissue mobility in Table 4, right tissue mobility in Table 5, left tissue mobility in Table 6, and multi-directional tissue mobility in Table 7.

3.1. Digital pressure algometer

Pressure pain threshold: Intrarater reliability was 0.895 (95% CI = 0.846–0.928) in normal tissue and 0.879 (95% CI = 0.843–0.907) in C-section scars. MDC was 6.6 N in normal tissue and 3.7 N in scar tissue. Inter-rater reliability in normal tissue was 0.853 (95%CI = 0.788–0.898) and 0.743 (95%CI = 0.667–0.802) in C-section scars. MDC was 7.8 N in normal tissue and 5.4 N in scar tissue.

Table 1
Pressure to discomfort threshold (PPTh).

	N-subj	N-pnts	ICC	95% CIs	P level	SEM (N)	MDC (N)
Intra-nrmls*	59	59	0.895	0.846–0.928	<0.000	2.36	6.55
Inter-nrmls*	59	59	0.853	0.788–0.898	<0.000	2.8	7.77
Intra-c-sec *	29	113	0.879	0.843–0.907	<0.000	1.35	3.74
Inter c-sec*	29	115	0.743	0.667–0.802	<0.000	1.94	5.37

ICC: Two way mixed; Absolute agreement; Average measures; Normality criteria: skew < =/- 1.
* Log transformation to achieve normality.

Pressure pain tolerance: Intrarater reliability was 0.933 (95% CI = 0.903–0.953) in normal tissue and 0.926 (95% CI = 0.903–0.943) in C-section scars. MDC was 11.7 N in normal tissue and 4.6 N in scar tissue. Inter-rater reliability in normal tissue was 0.899 (95%CI = 0.854–0.930) and 0.814 (95%CI = 0.759–0.857) in C-section scars. MDC was 14.4 N in normal tissue and 7.2 N in scar tissue.

Criterion Validity: Pressure pain tolerance and NPRS correlation $r = -0.551$ ($p = 0.002$).

3.2. Modified adheremeter

Superior tissue mobility: Intrarater reliability was 0.891 (95% CI = 0.836–0.926) in normal tissue and 0.914 (95% CI = 0.888–0.934) in C-section scars. MDC was 4.9 mm in normal tissue and 4.6 mm in scar tissue. Inter-rater reliability in normal tissue was 0.681 (95%CI = 0.506–0.790) and 0.755 (95% CI = 0.676–0.814) in C-section scars. MDC was 8 mm in normal tissue and 7.8 mm in scar tissue.

Inferior tissue mobility: Intrarater reliability was 0.871 (95% CI = 0.814–0.911) in normal tissue and 0.859 (95% CI = 0.817–0.892) in C-section scars. MDC was 5.2 mm in both normal and scar tissue. Inter-rater reliability in normal tissue was 0.759 (95%CI = 0.643–0.835) and 0.430 (95%CI = 0.262–0.560) in C-section scars. MDC was 7.1 mm in normal tissue and 10.3 mm in scar tissue.

Right tissue mobility: Intrarater reliability was 0.870 (95% CI = 0.809–0.911) in normal tissue and 0.840 (95% CI = 0.793–0.877) in C-section scars. MDC was 6.6 mm in normal tissue and 5.2 mm in scar tissue. Inter-rater reliability in normal tissue was 0.721 (95%CI = 0.405–0.848) and 0.447 (95% CI = 0.283–0.574) in C-section scars. MDC was 9.2 mm in normal tissue and 9.5 mm in scar tissue.

Left tissue mobility: Intrarater reliability was 0.902 (95% CI = 0.859–0.932) in normal tissue and 0.825 (95% CI = 0.773–0.865) in C-section scars. MDC was 6.2 mm in normal tissue and 4.7 mm in scar tissue. Inter-rater reliability in normal tissue was 0.717 (95%CI = 0.443–0.839) and 0.408 (95% CI = 0.233–0.544) in C-section scars. MDC was 10.1 mm in normal tissue and 8.6 mm in scar tissue.

Multi-directional tissue mobility: Intrarater reliability was 0.953 (95%CI = 0.931–0.967) in normal tissue and 0.917 (95% CI = 0.892–0.936) in C-section scars. MDC was 540 mm^2 in normal tissue and 322 mm^2 in scar tissue. Inter-rater reliability in normal tissue was 0.812 (95%CI = 0.488–0.909) and 0.667 (95% CI = 0.563–0.746) in C-section scars. MDC was 1012 mm^2 in normal tissue and 690 mm^2 in scar tissue.

Table 2
Pressure pain threshold (PPT).

	N-subj	N-pnts	ICC	95% CIs	P level	SEM (N)	MDC (N)
Intra-nrmls*	58	58	0.933	0.903–0.953	<0.000	4.23	11.74
Inter-nrmls*	58	58	0.899	0.854–0.930	<0.000	5.19	14.38
Intra-c-sec *	29	114	0.926	0.903–0.943	<0.000	1.65	4.58
Inter c-sec*	29	114	0.814	0.6670.857	<0.000	2.58	7.16

ICC: Two way mixed; Absolute agreement; Average measures; Normality criteria: skew < =/- 1.
* Log transformation to achieve normality.

Table 3
Tissue mobility- superior.

	N-subj	N-pts	ICC	95% CIs	P level	SEM (mm)	MDC (mm)
Intra-nrmls*	59	59	0.891	0.836–0.926	<0.000	1.77	4.91
Inter-nrmls*	59	59	.681	0.506–0.790	<0.000	2.9	8.03
Intra-c-sec	29	114	0.914	0.888–0.934	<0.000	1.67	4.64
Inter c-sec	29	114	0.755	0.676–0.814	<0.000	2.81	7.79

ICC: Two way mixed; Absolute agreement; Average measures; Normality criteria: skew < =/- 1.
* Log transformation to achieve normality.

Table 4
Tissue mobility- inferior.

	N-subj	N-pts	ICC	95% CIs	P level	SEM (mm)	MDC (mm)
Intra-nrmls*	59	59	0.871	0.814–0.911	<0.000	1.88	5.22
Inter-nrmls*	59	59	0.759	0.643–0.835	<0.000	2.55	7.08
Intra-c-sec	29	114	0.859	0.817–0.892	<0.000	1.86	5.15
Inter c-sec	29	114	0.430	0.262–0.560	<0.000	3.70	10.25

ICC: Two way mixed; Absolute agreement; Average measures; Normality criteria: skew < =/- 1.
* Log transformation to achieve normality.

Table 5
Tissue mobility- right.

	N-subj	N-pts	ICC	95% CIs	P level	SEM (mm)	MDC (mm)
Intra-nrmls*	59	59	0.870	0.809–0.911	<0.000	2.39	6.63
Inter-nrmls*	59	59	0.721	0.405–0.848	<0.000	3.32	9.22
Intra-c-sec	29	114	0.840	0.793–0.877	<0.000	1.86	5.16
Inter c-sec	29	114	0.447	0.283–0.574	<0.000	3.42	9.49

ICC: Two way mixed; Absolute agreement; Average measures; Normality criteria: skew < =/- 1.
*Log transformation to achieve normality.

Table 6
Tissue mobility- left.

	N-subj	N-pts	ICC	95% CIs	P level	SEM (mm)	MDC (mm)
Intra-nrmls*	59	59	0.902	0.859–0.932	<0.000	2.22	6.15
Inter-nrmls*	59	59	0.717	0.443–0.839	<0.000	3.63	10.06
Intra-c-sec	29	114	0.825	0.773–0.865	<0.000	1.70	4.72
Inter c-sec	29	114	0.408	0.233–0.544	<0.000	3.11	8.61

ICC: Two way mixed; Absolute agreement; Average measures; Normality criteria: skew < =/- 1.
* Log transformation to achieve normality.

Table 7
Tissue mobility- multidirectional = (inf + sup)*(left + right).

	N-subj	N-pts	ICC	95% CIs	P level	SEM (mm^2)	MDC (mm^2)
Intra-nrmls*	59	59	0.953	0.931–0.967	<0.000	195	540
Inter-nrmls*	59	59	0.812	0.488–0.909	<0.000	365	1012
Intra-c-sec	29	114	0.917	0.892–0.936	<0.000	116	322
Inter c-sec	29	114	0.667	0.563–0.746	<0.000	249	690

ICC: Two way mixed; Absolute agreement; Average measures; Normality criteria: skew < =/- 1.
* Log transformation to achieve normality.

4. Discussion

4.1. Reliability

We have reported the inter- and intra-rater reliability data of two tools: the modified adheremeter and digital pressure algometer, measuring the abdominal tissue extensibility in superior, inferior, right and left directions as well as the pressure threshold and pain tolerance, respectively.

According to Portney and Watkins, ICC values of >0.75 represent good reliability, ICC values of 0.50–0.74 represent moderate reliability, and ICC values of <0.50 represent poor reliability (Portney and Watkins, 2009). The algometer ICCs almost all fell well within the good reliability range including their 95% CIs. The only exception was the pressure threshold interrater reliability which fell just shy at 0.742. However, the 95% CI was 0.677–0.802 meaning that this measure likely still falls in the moderate to good reliability range. This is an easy device to use and relatively inexpensive to obtain. These results provide strong support for the use of the digital pressure algometer in measuring abdominal pain.

For the modified adheremeter, the intra-rater and inter-rater reliability ICC values of both normal and C-section tissue extensibility were good with ten out of sixteen directional ICCs greater than 0.75. Intra rater reliability for both normal tissue and C-section scars extensibility all fell in the good range including all 95% CIs with values from 0.825 (95% CI = 0.773–0.865) up to 0.914 (95% CI = 0.888–0.934). The multi-directional calculation, which takes into account all four directions of flexibility at a given point had the highest reliability at 0.953 (95% CI = 0.931–0.967) for normal tissue and 0.917 (95% CI = 0.892–0.936) for C-sections. Point values for inter rater reliability for normal tissue all fell in the moderate to good range (0.681–0.759) though the 95% CIs for left, right and multi-directional measures included values in the poor range (0.443, 0.405, and 0.488). Interrater reliability for C-section scar tissue was in the good range only for superior mobility with the 95% CI range including moderate values too (0.755 95% CI = 0.676–0.814). Other directions all showed poor reliability, though the 95% CIs did include values in the moderate range. Of note however, was that combining the point measures into the multi-directional calculation improved the interrater reliability in C-section tissue into the moderate range including the 95% CI range. The calculations for multi-directional mobility are in line with Ferriero et al.'s original reporting (Ferriero et al., 2010), proving it to be a reliable measurement for tissue mobility. The one difference is as where Ferriero compared this measurement to the contralateral extremity (specifically the shoulder), we did not have this comparison, given our measurements were taken on the anterior abdomen. Additionally, though this calculation proves to be reliable, the additional time that is needed to perform these calculations make it less realistic to use in the clinic. In summary, the modified adheremeter is easy to learn and use, costs essentially nothing and shows good intra rater reliability, which lends itself well to clinical use. For interrater use, the multi-directional calculation boosts the reliability and may be the appropriate choice when reporting research outcomes.

4.2. Standard error of measurement/minimal detectable change

The standard error of measurement (SEM) is a measure of the accuracy of an instrument. It is the standard deviation (SD) of measurement error. It was calculated as SD(1-r). MDC (MDC) was calculated using the formula 1.96 x SEM x 2. The MDC is the minimum amount of change in a patient's score that ensures the change isn't the result of measurement error (Portney and Watkins, 2009). On normal abdominal tissue, the algometer was determined to be accurate to ± 6.5–8 N for pressure threshold, and ± 12–14 N for pain tolerance. For scar extensibility in normal subjects, intra-rater reliability was accurate to ± 5–7 mm, and inter-rater reliability was accurate to ± 7–10 mm.

For individuals with C-section scars, the algometer was determined to be accurate to ± 4–5 N for both intra-rater and inter-rater reliability. The modified adheremeter was determined to be accurate to ± 4.5–7 mm for intra rater reliability, and ± 7–10 mm for interrater reliability. When the multi-directional mobility of both normal abdominal tissue and C-section scars were calculated, the MDC ranged from 322 mm^2 for intra-rater reliability on C-section scars to 1012 mm^2 for inter-rater reliability on normal abdominal tissue.

Overall, the use of both tools on C-section scars demonstrated greater accuracy than on normal tissues for both inter-rater and intra-rater reliability. The reasonable accuracy and good reliability makes both the digital pressure algometer and the modified adheremeter worthwhile instruments for clinicians to use to capture changes in pain and scar tissue mobility pre and post treatment.

4.3. Validity

The NPRS is a widely used, reliable and valid tool to measure pain. The algometer PPT showed a negative correlation of 0.551. We would expect this to be a negative relationship as the PPT values raise as pain lessens and the NPRS values lower as pain lessens. According to Portney and Watkins −0.5 is considered a moderate correlation (Portney and Watkins, 2009). These results provide a level of validity for use of the digital pressure algometer as a pain measurement tool.

4.4. Literature review

Ferriero et al. first described the adheremeter in 2010 as a new device to measure peripheral scar adhesion post-surgery. Their study assessed the reliability, validity, and sensitivity to change of the adheremeter to measure scar adhesions pre and post physical therapy. They used two testers to measure the scar mobility as compared to the contralateral skin in 25 patients with adherent post-surgical scars. Unlike our method of using each direction as a stand-alone measurement of scar mobility, Ferriero et al. used the 4 measurements taken from both scar and normal skin to obtain the area of a quadrilateral, which were then used to calculate two indexes, which were then compared as a ratio. It was interesting to note that in this study, both raters were only "briefly taught how to use the device", whereas our raters spent several hours practicing. Ferriero et al. reports that the adheremeter showed excellent intra-rater reliability for both examiners (ICC = 0.96), and good to excellent inter-rater reliability (ICC = 0.87–0.97) for both normal skin and post-surgical scars (Ferriero et al., 2010).

One of the early reports of the use of the pressure algometer in pain measurement was by Buchanan and Midgley in 1987. They reported high intra-rater reliability for pain threshold (Buchanan and Midgley, 1987). In the years since, many clinical studies have used pressure algometry as an outcome measure and a number of studies have discussed reliability in different body parts. Kinser et al. proposed that in order to provide the greatest reliability of the pressure-pain threshold, the rate at which manual force is applied should be consistent. They examined the manual application of pressure on a force place to determine the reliability of the application of the rate of force. The investigator who performed the measurement had previously become familiar with the tool. The maximum force reading was compared and force-time curves were analyzed for average slope, which represented the rate of application. The average pearson (r) correlations between the maximum force reading of the algometer and that of the force plate were excellent in both trials. Kinser et al. concluded that with previous familiarization of the instrument, an individual may have high reliability in the rate of force application of the digital pressure algometer (Kinser et al., 2009).

Park et al. examined the usefulness of the digital pressure algometer to measure the PPT in the upper extremities and trunk musculature in order aid in the diagnosis of myofascial pain syndrome (MFPS). Although the authors did not find that the tool is suitable to diagnose MFPS, it may be useful in determining treatment effect for musculoskeletal pain. Additionally, Park et al. reported that the tool showed high intra-rater reliability (Cronbach's Alpha: 0.94–0.98) for all muscles tested in their study (Park et al., 2011).

Montenegro et al. examined the inter- and intra-rater reliability of the pain pressure threshold of the abdominal wall in 21 healthy women. For this study, 14 points that were determined to be "clinically significant structures" in the abdomen were chosen on each. A digital pressure algometer was used to determine the PPT, which is defined in their study as "the minimal pressure (force) that induces pain" (Montenegro et al., 2012). Subjects were instructed to indicate when the pressure became painful. Furthermore, the subjects were specifically told that the objective was to capture the pain threshold, not pain tolerance. This was both a wise and important distinction to make, as it allowed the subject to make a more accurate decision as to when to indicate to the tester to stop pressure. The authors found that there was no statistically significant difference in mean pain threshold values obtained by the two examiners, and reported that the inter- and intra-rater reliability was good for the instrument in general (Montenegro et al., 2012). Similarly to our analysis of the digital pressure algometer, Montenegro also concludes that it is an inexpensive and reliable way to measure pain objectively, and to monitor the progress of treatment in an objective manner.

4.5. Limitations

Despite attempts to standardize the testing process, our results may have been affected by some of the following study limitations. Testers were located in three regions of the United States and did not have the opportunity to train together in person. This created potential for discrepancy amongst testing procedures, specifically the wording used by different testers when measuring pressure pain threshold and pressure pain tolerance. Testers were instructed to measure pressure pain threshold and tell patients, "tell me when pressure first turns to discomfort". To measure pressure pain tolerance, patients were told "Tell me when discomfort turns to pain and you need me to stop". This led to some patients being unclear about what they felt and how to differentiate between discomfort and pain, a distinction that is inherently subjective. In many cases, this led to patients asking follow-up questions and testers instructing patients to choose an appropriate level of pain that they could report on consistently throughout the study. Despite these potential discrepancies, the digital pressure algometer continued to show excellent reliability in both populations. Another limitation directly related to multiple testers was that tension used by each tester for the modified adheremeter was likely variable when measuring tissue extensibility. The mean age and mean BMI were slightly higher for those subjects who had a C-section scar compared to the healthy DPT students. This perhaps may account for the slight decrease in reliability in the C-section population.

5. Conclusion

We have reported the inter- and intra-rater reliability for two instruments, the digital pressure algometer and modified adheremeter. We determined that the digital pressure algometer and modified adheremeter are both reliable and accurate tools to objectively measure pressure-pain threshold and soft tissue extensibility in both normal abdominal tissue and C-section scars. When used properly, both tools show good to excellent intra and inter-rater reliability based on both the point estimates and 95% confidence intervals. These tests are appropriate for both clinical and research applications. Further studies should investigate the usefulness of both instrument tools in assessing pain and mobility in other abdominal surgical scars.

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