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Intra-rater within-session and inter-rater reliability of MyotonPRO® and IndentoPRO for assessing abdominal wall viscoelastic and biomechanical properties in late postpartum women

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Article

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Abstract

Background

Pregnancy and postpartum-related changes in abdominal wall morphology may lead to diastasis recti abdominis, a condition characterized by increased inter-rectus distance and altered mechanical behavior of the linea alba and surrounding myofascial tissues. Although ultrasound is commonly used to assess inter-rectus distance, the objective evaluation of abdominal wall viscoelastic and biomechanical properties remains limited in clinical practice. Portable devices such as MyotonPRO® and IndentoPRO may provide feasible alternatives for assessing these properties in postpartum rehabilitation. This study aimed to evaluate the intra-rater within-session and inter-rater reliability of MyotonPRO® and IndentoPRO for assessing abdominal wall viscoelastic and biomechanical properties in late postpartum women.

Methods

A repeated-measures reliability study was conducted with 62 women between 8 and 24 months postpartum. Diastasis recti abdominis was assessed by ultrasound imaging and functional abdominal bulging during trunk flexion. Two trained raters independently performed abdominal wall measurements using MyotonPRO® and IndentoPRO during a single session. Measurements were performed at the supra-umbilical, infra-umbilical, and transversus abdominis regions. MyotonPRO assessed tone, stiffness, elasticity, mechanical relaxation time, and creep, while IndentoPRO assessed stiffness. Intra-rater and inter-rater reliability were analyzed using intraclass correlation coefficients, standard error of measurement, and Bland–Altman analysis.

Results

MyotonPRO® demonstrated excellent intra-rater reliability for all parameters and anatomical regions, with intraclass correlation coefficient values above 0.90. Inter-rater reliability for MyotonPRO® was also excellent for most parameters, except for elasticity and creep in the transversus abdominis region, which showed good reliability. IndentoPRO demonstrated good-to-excellent intra-rater reliability for most measurements, although moderate reliability was observed for transversus abdominis distance in one rater. Inter-rater reliability for IndentoPRO ranged from moderate to good.

Conclusions

MyotonPRO® and IndentoPRO demonstrated acceptable reliability for assessing abdominal wall viscoelastic and biomechanical properties in late postpartum women. MyotonPRO showed superior consistency between raters and may be particularly useful for clinical and research applications in postpartum rehabilitation. Objective assessment of abdominal wall mechanical behavior may provide clinically relevant information beyond inter-rectus distance alone.

Introduction

Diastasis recti abdominis (DRA) is a common condition during pregnancy and the postpartum period and is usually defined by an increased inter-rectus distance (IRD) resulting from stretching and thinning of the linea alba [1–4]. The linea alba is a collagen-rich myofascial structure formed by the aponeurotic fibers of the abdominal wall muscles, and its structural organization is fundamental for transmitting forces between the right and left sides of the abdominal wall [5–7]. During pregnancy, hormonal changes, progressive abdominal expansion, and increased intra-abdominal pressure contribute to connective tissue remodeling, widening of the linea alba, and changes in abdominal wall mechanical behavior [8].

The prevalence of DRA is high in the early postpartum period and may persist for several months or years after delivery. Previous studies have reported that approximately 60% of women present DRA at six weeks postpartum and that nearly one-third may continue to present increased IRD at 12 months postpartum [9]. More recent studies have also shown that DRA may persist in the long-term postpartum period, reinforcing that this condition is not restricted to the immediate months following childbirth [10, 11]. Beyond the anatomical separation between the rectus abdominis muscles, women with DRA frequently report abdominal bulging, concerns about abdominal appearance, impaired body perception, reduced abdominal strength, and negative effects on quality of life [12–14].

Traditionally, postpartum rehabilitation and clinical assessment of DRA have focused mainly on measuring and reducing IRD [2, 15, 16]. However, growing evidence suggests that IRD alone may not fully explain abdominal wall function or the symptoms reported by postpartum women [17, 18]. The mechanical behavior of the linea alba, including its ability to generate tension, resist deformation, and transfer forces across the abdominal wall, may be more directly related to functional impairment than the distance between the rectus abdominis muscles alone [19, 20]. Therefore, objective assessment of viscoelastic and biomechanical properties may contribute to a broader understanding of postpartum abdominal wall dysfunction.

Previous studies have demonstrated that women with DRA may present reduced linea alba stiffness and greater distortion during abdominal tasks compared with women without DRA [17, 19]. Alterations in collagen composition have also been reported in women with DRA, suggesting that connective tissue remodeling may contribute to impaired mechanical behavior of the linea alba [21]. In this context, assessing tissue properties such as stiffness, tone, elasticity, creep, and mechanical relaxation time may provide clinically meaningful information for postpartum rehabilitation.

Ultrasound imaging is widely used to measure IRD and has demonstrated better validity and reliability than palpation or caliper-based approaches [22–25]. Shear wave elastography has also been used to assess abdominal muscle and linea alba stiffness, providing objective information about tissue mechanical properties [26–29]. However, elastography is expensive, requires specialized training, and is not widely available in routine rehabilitation settings [26]. Consequently, many clinicians still rely on subjective palpation-based assessments, despite their limitations.

Portable devices capable of objectively assessing soft tissue mechanical properties may represent a feasible alternative for clinical practice. MyotonPRO® is a handheld, non-invasive device that applies brief mechanical impulses to the skin and records tissue oscillation responses, allowing assessment of tone, stiffness, elasticity, creep, and mechanical relaxation time [30]. Previous studies have demonstrated good-to-excellent reliability of MyotonPRO® in different tissues, including muscles, fascia, subcutaneous tissue, scars, and skin [31–35].

IndentoPRO is another portable device designed to assess tissue stiffness through controlled indentation. Previous studies have demonstrated promising reliability of IndentoPRO for assessing myofascial tissue stiffness, including studies involving human calf tissues and multilayered phantom models [36, 37]. However, because indentation-based methods depend on tissue depth, applied force, and evaluator handling, reliability may vary according to tissue region and population.

Despite the increasing clinical interest in postpartum abdominal wall function, no previous study has investigated the reliability of MyotonPRO® and IndentoPRO for assessing abdominal wall viscoelastic and biomechanical properties in postpartum women. Establishing reliability is essential before these devices can be incorporated into clinical decision-making, longitudinal follow-up, or intervention studies [38, 39]. Therefore, the primary aim of this study was to evaluate the intra-rater within-session and inter-rater reliability of MyotonPRO® and IndentoPRO for assessing abdominal wall and linea alba viscoelastic and biomechanical properties in late postpartum women.

Methods

Study design and ethics

This was a repeated-measures reliability study designed to evaluate intra-rater within-session and inter-rater reliability. The study was reported according to the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) [39]. Ethical approval was obtained from the National Research Ethics Committee under Certificate of Presentation for Ethical Assessment number 76196523.9.0000.5345. All procedures were conducted according to the principles of the Declaration of Helsinki. All participants signed written informed consent before enrollment.

Participants

A convenience sample of 62 postpartum women was recruited through social media advertisements posted by the main researcher. Women were eligible if they were between 18 and 45 years old and had delivered their most recent baby between 8 and 24 months before the study. Women were excluded if they reported being pregnant at the time of enrollment, had a history of abdominal, gynecological, or urological surgery except cesarean section, presented any condition that could affect muscle contractility or lumbopelvic function, had respiratory dysfunction, had a history of pathology that could interfere with the abdominal wall, had received abdominal rehabilitation through exercises or aesthetic interventions after

delivery, or presented subcutaneous fat thickness greater than 20 mm measured by ultrasound. The 20 mm cut-off was adopted because the MyotonPRO® user manual indicates limitations when assessing tissues covered by subcutaneous fat above this thickness [30].

Data collection procedure

Participants initially provided information through a standardized questionnaire including age, height, weight, number of pregnancies, number of abortions, date of last delivery, type of delivery, habitual weekly physical activity, working habits, and smoking habits. All measurements were conducted in a standardized manner under constant environmental conditions, with room temperature maintained between 20°C and 24°C. Participants were examined in a private clinical room, and all assessments were performed on the same day at Medicina Diagnóstica Clinic in Porto Alegre, Brazil.

For ultrasound assessment, participants were positioned in supine lying with 15° trunk elevation, head supported by a pillow, hips and knees relaxed with a pillow under the knees, and arms resting beside the body. This positioning was selected based on previous technical recommendations for ultrasound measurement of IRD and abdominal wall assessment [23, 25]. A Canon Toshiba Aplio 300 ultrasound system was used to assess subcutaneous fat thickness and diagnose DRA. All ultrasound imaging was performed by a radiologist with more than 15 years of experience, who did not participate in any other part of the study and was blinded to device measurements.

Three abdominal wall locations were assessed for DRA diagnosis: inferior to the xiphoid process, 3 cm above the umbilicus, and 2 cm below the umbilicus. All ultrasound images were captured at the end of expiration, with breathing paused until image acquisition was completed, as recommended in previous studies and reviews addressing technical aspects of IRD measurement [25]. DRA was defined according to Beer et al. as IRD greater than 1.5 cm inferior to the xiphoid, greater than 2.2 cm above the umbilicus, or greater than 1.6 cm below the umbilicus [23].

The presence of abdominal bulging was also assessed as a functional sign of linea alba distortion. This assessment consisted of asking participants to slightly lift the head and shoulders from the supine position, similar to a trunk flexion task. The presence of visible bulging along the linea alba was considered indicative of altered abdominal wall function. Functional assessment of linea alba behavior during trunk tasks has been increasingly discussed as clinically relevant because static IRD may not fully represent connective tissue function [17, 20].

Raters and blinding

Two raters independently performed the measurements using MyotonPRO® and IndentoPRO. Both raters received the same standardized training during three months before data collection. One rater was a physiotherapist with ten years of clinical experience, and the other had one year of clinical experience. The

raters were blinded to each other's measurements, DRA diagnosis, and participant clinical history. The radiologist responsible for ultrasound assessment did not participate in the device-based measurements.

Measurement sites

Three anatomical sites were assessed using MyotonPRO® and IndentoPRO: supra-umbilical region, infra-umbilical region, and transversus abdominis region (Fig. 1). The supra-umbilical and infra-umbilical points corresponded to two of the sites used for DRA diagnosis. The transversus abdominis site was located 2 cm proximal to the midpoint of the line between the anterior superior iliac spine and the pubic symphysis, as previously described in studies assessing abdominal tissue mechanical properties [41]. To confirm localization, participants were asked to contract the transversus abdominis, and the point was marked at this time. All sites were marked with a water-soluble marker to ensure consistency between measurements and between raters.

Measurement sequence

Rater 1 first performed three repeated measurements at each of the three abdominal sites using MyotonPRO®. Measurements were performed in the following order: supra-umbilical region, infra-umbilical region, and transversus abdominis region. After completing one round at all sites, two additional rounds were performed, resulting in three repeated measurements per site. A one-minute interval was used before changing to IndentoPRO. This interval was adopted to minimize potential viscoelastic adaptation processes, such as creep or hysteresis, caused by repeated mechanical compression, as previously described in indentation-based tissue assessment studies [37].

After MyotonPRO assessment, Rater 1 performed three repeated measurements at the same sites using IndentoPRO. After Rater 1 completed all measurements, a short interval of approximately two minutes allowed the change of raters. Rater 2 then performed the same measurements over the same marked points, using the same standardized procedure.

MyotonPRO® outcomes

MyotonPRO is a portable handheld device designed to assess soft tissue mechanical properties by applying brief mechanical impulses to the skin and recording the tissue oscillation response. The device measures resting tone, stiffness, elasticity, creep, and mechanical relaxation time [30]. Resting tone is expressed in hertz and represents the natural oscillation frequency of the tissue. Stiffness is expressed in N/m and reflects tissue resistance to deformation. Elasticity is expressed as logarithmic decrement, with lower decrement values indicating higher elasticity. Mechanical relaxation time is expressed in milliseconds and represents the time required for the tissue to return toward its initial state after deformation. Creep reflects tissue deformation under constant stress.

The MyotonPRO probe was positioned perpendicular to the skin surface over each marked abdominal point. The device was held stable until the green indicator light confirmed appropriate positioning. The device was preset to deliver five gentle mechanical impulses. The coefficient of variation estimated from the five impulses was required to be below 3%. If the coefficient of variation was above 3%, the measurement was repeated, according to device recommendations [30].

IndentoPRO outcomes

IndentoPRO is a portable indentation device developed to assess tissue stiffness through controlled indentation. Previous studies have demonstrated its reliability in assessing myofascial tissue stiffness [37]. In the present study, an indentation depth of 15 mm was selected based on the possible thickness of skin, subcutaneous connective tissue, and abdominal wall tissues, considering previous anatomical and biomechanical studies of the linea alba and abdominal fascia [5, 6, 42].

IndentoPRO was positioned perpendicular to the skin surface over each previously marked abdominal point. A compressive force was applied to the top of the device until the indentation probe reached the target depth. The device emitted auditory signals indicating when the indentation depth was successfully achieved and when the device was ready for the next measurement. Each measurement set comprised three repetitions performed at five-second intervals. The device displayed mean stiffness, applied force, and resulting indentation depth. A maximal coefficient of variation of 15% between trials was adopted as the cut-off for valid measurements, according to manufacturer recommendations and previous reliability studies [37].

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics (version 25.0; SPSS). Sample size was calculated based on an expected intraclass correlation coefficient (ICC) of 0.84, as reported by Koch and Wilke [37]. A sample of 62 women was estimated to provide 95% confidence intervals (95% CI) with adequate precision.

Categorical variables were presented as absolute and relative frequencies, while quantitative variables were presented as means and standard deviations (SD). Normality was assessed using the Shapiro-Wilk test. Intra-rater reliability was determined by comparing the three repeated measurements performed by the same rater. Inter-rater reliability was examined by comparing measurements obtained by Rater 1 and Rater 2.

Reliability was assessed using ICC with corresponding 95% CI. ICC values were interpreted as poor (< 0.50), moderate (0.50–0.74), good (0.75–0.90), and excellent (> 0.90), according to the recommendations of Koo and Li [43]. An ICC value greater than 0.75 was considered indicative of acceptable reliability. Absolute reliability was evaluated using the standard error of measurement (SEM). Agreement between raters was further examined using Bland-Altman analysis, from which the mean bias and the 95% limits of agreement (LoA) were calculated and graphically displayed. Statistical significance was set at $\alpha = 0.05$.

Results

Sample characteristics

Sixty-two women were assessed and included in the study, with a mean age of 34.8 ± 4.8 years. Most participants had experienced one pregnancy, and cesarean delivery was more frequent than vaginal delivery. DRA prevalence was 69.4%, indicating that abdominal wall alterations remained highly prevalent between 8 and 24 months postpartum. Functional abdominal bulging was observed in 32.3% of participants. Participant characteristics are presented in Table 1.

Table 1
Demographic, obstetric, and abdominal wall characteristics of the participants (n = 62).

Variable	Value
Age (years)	34.8 ± 4.8
Weight (kg)	65.2 ± 12.7
Height (m)	1.60 ± 0.10
Body mass index (kg/m²)	24.9 ± 4.2
Number of pregnancies	
1	37 (59.7)
2	20 (32.3)
3	5 (8.1)
Delivery type	
Vaginal	14 (22.6)
Cesarean section	44 (71.0)
Vaginal and cesarean section	4 (6.5)
Diastasis recti abdominis	43 (69.4)
Abdominal bulging during trunk flexion	20 (32.3)
Time postpartum (months)	14.9 ± 5.6
Inter-rectus distance supra-umbilical (cm)	2.3 ± 0.9
Inter-rectus distance infra-umbilical (cm)	1.6 ± 0.8
Inter-rectus distance epigastric (cm)	0.8 ± 0.7
Para-umbilical fat thickness (cm)	1.1 ± 0.5

Data are expressed as mean ± standard deviation or number (percentage). Inter-rectus distance and para-umbilical fat thickness were assessed by ultrasound imaging. Abdominal bulging was evaluated during trunk flexion. DRA = diastasis recti abdominis.

Intra-rater reliability

The intra-rater reliability results for MyotonPRO® are presented in Table 2. MyotonPRO demonstrated excellent intra-rater reliability for all viscoelastic and biomechanical parameters across the supra-umbilical, infra-umbilical, and transversus abdominis sites. ICC values were consistently above 0.90 for both raters, indicating excellent consistency among repeated measurements performed within the same assessment session. Furthermore, the low SEM values observed across all parameters indicate high absolute reliability and measurement precision.

Table 2
Intra-rater within-session reliability of MyotonPRO® measurements in late postpartum women.

Localization	Property	Rater	M1	M2	M3	p-value	ICC	95% CI	SEM
Supra-umbilical	Tone	1	11.4 ± 2.8	11.1 ± 2.8	11.4 ± 3.0	0.347	0.925	0.886–0.952	0.35
		2	11.0 ± 2.6	10.9 ± 2.5	10.8 ± 2.5	0.257	0.956	0.933–0.972	0.18
	Elasticity	1	2.1 ± 0.5	2.2 ± 0.5	2.1 ± 0.5	0.307	0.953	0.929–0.970	0.04
		2	2.1 ± 0.4	2.0 ± 0.5	2.0 ± 0.4	0.405	0.917	0.873–0.947	0.06
	Stiffness	1	171.8 ± 66.3	170.8 ± 67.9	167.5 ± 65.6	0.158	0.987	0.981–0.992	1.46
		2	157.6 ± 61.0	159.3 ± 62.6	160.3 ± 64.8	0.422	0.988	0.982–0.993	1.26
	Creep	1	1.7 ± 0.3	1.7 ± 0.3	1.7 ± 0.3	0.441	0.970	0.954–0.981	0.02
		2	1.7 ± 0.3	1.7 ± 0.3	1.7 ± 0.3	0.801	0.967	0.950–0.979	0.02
	Relaxation	1	29.5 ± 5.6	29.7 ± 5.5	30.1 ± 5.3	0.105	0.974	0.961–0.984	0.24
		2	30.5 ± 5.3	30.5 ± 5.7	30.6 ± 5.6	0.852	0.978	0.966–0.986	0.21
Infra-umbilical	Tone	1	11.2 ± 3.4	11.0 ± 3.0	11.1 ± 3.0	0.648	0.928	0.890–0.954	0.37
		2	10.9 ± 3.1	10.9 ± 2.9	10.6 ± 2.7	0.100	0.970	0.954–0.981	0.15
	Elasticity	1	2.1 ± 0.5	2.0 ± 0.5	2.1 ± 0.5	0.193	0.960	0.939–0.975	0.03
		2	2.0 ± 0.5	1.9 ± 0.6	1.9 ± 0.5	0.009	0.972	0.956–0.982	0.03
	Stiffness	1	153.2 ± 56.7	154.5 ± 52.3	157.3 ± 58.3	0.333	0.972	0.957–0.982	2.63
		2	150.0 ± 56.0	148.6 ± 53.8	147.3 ± 56.9	0.139	0.993	0.990–0.996	0.65
	Creep	1	1.8 ± 0.3	1.8 ± 0.3	1.8 ± 0.3	0.543	0.971	0.956–0.982	0.01
		2	1.8 ± 0.3	1.8 ± 0.3	1.8 ± 0.4	0.537	0.958	0.936–0.973	0.02

Localization	Property	Rater	M1	M2	M3	p-value	ICC	95% CI	SEM
	Relaxation	1	31.7 ± 4.4	31.8 ± 4.4	31.6 ± 4.5	0.208	0.988	0.982–0.993	0.09
		2	32.1 ± 4.7	32.1 ± 4.4	32.4 ± 4.7	0.382	0.979	0.968–0.987	0.16
Transversus abdominis	Tone	1	11.3 ± 2.0	11.4 ± 2.5	11.0 ± 2.2	0.071	0.935	0.900–0.958	0.24
		2	11.2 ± 2.0	11.1 ± 2.0	11.2 ± 2.1	0.371	0.992	0.988–0.995	0.03
	Elasticity	1	1.4 ± 0.3	1.4 ± 0.3	1.4 ± 0.3	0.796	0.980	0.970–0.987	0.01
		2	1.4 ± 0.3	1.4 ± 0.3	1.4 ± 0.3	0.999	0.970	0.955–0.981	0.02
	Stiffness	1	150.0 ± 54.6	152.7 ± 73.3	148.9 ± 58.2	0.301	0.982	0.973–0.989	1.91
		2	145.0 ± 53.0	144.5 ± 58.1	147.6 ± 59.4	0.103	0.992	0.988–0.995	0.78
	Creep	1	1.5 ± 0.2	1.5 ± 0.2	1.5 ± 0.2	0.484	0.955	0.931–0.971	0.02
		2	1.5 ± 0.2	1.5 ± 0.2	1.4 ± 0.2	0.173	0.946	0.918–0.966	0.02
	Relaxation	1	27.6 ± 4.0	27.5 ± 4.3	27.7 ± 4.0	0.317	0.983	0.974–0.989	0.12
		2	27.9 ± 4.4	27.9 ± 4.1	27.5 ± 4.2	0.071	0.980	0.970–0.988	0.14

Data are expressed as mean ± standard deviation. M1–M3 represent three repeated measurements obtained by the same evaluator during a single assessment session. Intra-rater reliability was assessed using ICC, with corresponding 95% CI and SEM. Tone was expressed in Hz, stiffness in N/m, relaxation time in ms, and elasticity and creep in arbitrary units. p-values refer to comparisons among repeated measurements.

The intra-rater reliability results for IndentoPRO® are presented in Table 3. Overall, IndentoPRO demonstrated good-to-excellent reliability for stiffness, force, and distance measurements across all anatomical sites. However, the distance measurement at the transversus abdominis site showed only moderate reliability for one rater (ICC = 0.725). Despite this finding, most ICC values exceeded 0.80, supporting the consistency of repeated measurements obtained by the same evaluator. Together, these results indicate that both devices provide reliable measurements of abdominal wall biomechanical properties when used by trained evaluators within a single assessment session.

Table 3
Intra-rater within-session reliability of IndentoPRO® measurements in late postpartum women.

Localization	Property	Rater	M1	M2	M3	p-value	ICC	95% CI	SEM
Supra-umbilical	Stiffness	1	0.51 ± 0.25	0.50 ± 0.24	0.50 ± 0.22	0.567	0.936	0.902–0.959	0.02
		2	0.54 ± 0.28	0.50 ± 0.24	0.49 ± 0.21	0.072	0.892	0.836–0.932	0.04
	Force	1	3.6 ± 2.2	3.4 ± 2.1	3.3 ± 2.1	0.213	0.953	0.929–0.970	0.17
		2	3.4 ± 2.0	3.0 ± 1.8	2.9 ± 1.5	0.004	0.900	0.845–0.937	0.29
	Distance	1	6.2 ± 1.7	6.3 ± 1.6	6.0 ± 1.7	0.223	0.875	0.810–0.921	0.33
		2	6.0 ± 1.4	5.7 ± 1.5	5.7 ± 1.6	0.014	0.904	0.853–0.940	0.23
Infra-umbilical	Stiffness	1	0.50 ± 0.21	0.50 ± 0.20	0.49 ± 0.18	0.722	0.890	0.832–0.930	0.03
		2	0.46 ± 0.16	0.49 ± 0.18	0.47 ± 0.17	0.301	0.871	0.804–0.918	0.03
	Force	1	3.4 ± 1.9	3.2 ± 1.7	3.1 ± 1.6	0.050	0.946	0.918–0.966	0.15
		2	2.7 ± 1.3	2.8 ± 1.3	2.7 ± 1.2	0.523	0.885	0.825–0.927	0.23
	Distance	1	6.2 ± 1.7	6.1 ± 1.5	6.0 ± 1.4	0.413	0.875	0.810–0.921	0.30
		2	5.8 ± 1.4	5.6 ± 1.2	5.5 ± 1.3	0.098	0.867	0.797–0.915	0.27
Transversus abdominis	Stiffness	1	0.52 ± 0.19	0.51 ± 0.18	0.51 ± 0.17	0.566	0.946	0.885–0.952	0.02
		2	0.69 ± 0.29	0.61 ± 0.22	0.62 ± 0.24	0.004	0.828	0.736–0.892	0.07
	Force	1	4.2 ± 1.9	4.0 ± 2.0	4.0 ± 1.8	0.183	0.936	0.902–0.959	0.20
		2	5.7 ± 3.0	5.1 ± 2.3	4.9 ± 2.3	0.003	0.901	0.846–0.938	0.41
	Distance	1	7.7 ± 1.3	7.4 ± 1.4	7.6 ± 1.3	0.111	0.869	0.801–0.917	0.27
		2	7.9 ± 1.6	7.8 ± 1.3	7.5 ± 1.5	0.157	0.725	0.582–0.825	0.56

Data are expressed as mean ± standard deviation. M1–M3 represent three repeated measurements obtained by the same evaluator during a single assessment session. Intra-rater reliability was assessed using ICC, with corresponding 95% CI and SEM. Stiffness and force were expressed in N/m and kg, respectively; distance in cm. p-values refer to comparisons among repeated measurements.

Inter-rater reliability

Inter-rater reliability results are presented in Table 4. MyotonPRO demonstrated excellent inter-rater reliability for almost all parameters and anatomical sites. Only elasticity and creep measured at the transversus abdominis site were classified as good rather than excellent. These results suggest that MyotonPRO® measurements are highly reproducible between trained evaluators.

Table 4
Inter-rater reliability of MyotonPRO® measurements in late postpartum women.

Localization	Property	Rater 1	Rater 2	p-value	ICC	95% CI	SEM	Bias	LoA95%
Supra-umbilical	Tone	11.3 ± 2.7	10.9 ± 2.4	0.005	0.952	0.913–0.973	0.17	0.38	-1.64; 2.41
	Elasticity	2.1 ± 0.4	2.0 ± 0.4	0.000	0.930	0.845–0.964	0.04	0.10	-0.29; 0.50
	Stiffness	170.0 ± 65.8	159.1 ± 62.1	0.000	0.982	0.912–0.993	1.62	10.94	-15.01; 36.88
	Creep	1.7 ± 0.3	1.7 ± 0.3	0.720	0.960	0.933–0.976	0.02	-0.01	-0.25; 0.24
	Relaxation	29.8 ± 5.4	30.5 ± 5.4	0.000	0.977	0.944–0.988	0.18	-0.79	-3.63; 2.05
Infra-umbilical	Tone	11.1 ± 2.9	10.8 ± 2.8	0.026	0.956	0.924–0.974	0.18	0.33	-1.92; 2.58
	Elasticity	2.1 ± 0.5	1.9 ± 0.5	0.000	0.910	0.782–0.955	0.06	0.15	-0.36; 0.66
	Stiffness	155.0 ± 54.3	148.6 ± 55.2	0.000	0.983	0.963–0.991	1.29	6.34	-18.39; 31.06
	Creep	1.8 ± 0.3	1.8 ± 0.3	0.349	0.947	0.912–0.968	0.02	0.02	-0.24; 0.28
	Relaxation	31.7 ± 4.4	32.2 ± 4.5	0.009	0.969	0.945–0.982	0.19	-0.50	-3.40; 2.39
Transversus abdominis	Tone	11.3 ± 2.1	11.2 ± 2.0	0.361	0.961	0.935–0.976	0.11	0.09	-1.48; 1.66
	Elasticity	1.4 ± 0.3	1.4 ± 0.3	0.003	0.894	0.808–0.940	0.04	0.07	-0.28; 0.42
	Stiffness	150.5 ± 61.5	145.7 ± 56.5	0.012	0.983	0.970–0.990	1.42	4.84	-23.97; 33.65
	Creep	1.5 ± 0.2	1.5 ± 0.2	0.226	0.878	0.798–0.926	0.04	0.02	-0.27; 0.31
	Relaxation	27.6 ± 4.1	27.8 ± 4.2	0.504	0.948	0.913–0.968	0.30	-0.16	-3.78; 3.46

Data are expressed as mean ± standard deviation. Inter-rater reliability was assessed using ICC, with corresponding 95% CI and SEM. BlandAltman analysis is presented as mean bias and 95% LoA. Tone was expressed in Hz, stiffness in N/m, relaxation time in ms, and elasticity and creep in arbitrary units. p-values refer to comparisons among repeated measurements.

Inter-rater reliability results are presented in Table 5. IndentoPRO demonstrated moderate-to-good inter-rater reliability. The lowest ICC values were observed in the infra-umbilical region for stiffness and force measurements, with ICC values of 0.570 and 0.516, respectively. Although SEM values suggested acceptable precision, the lower ICC values indicate that IndentoPRO may be more sensitive to differences in evaluator handling, applied force, and tissue indentation technique.

Table 5
Inter-rater reliability of IndentoPRO® measurements in late postpartum women

Localization	Property	Rater 1	Rater 2	p-value	ICC	95% CI	SEM	Bias	LoA95%
Supra-umbilical	Stiffness	0.50 ± 0.22	0.51 ± 0.22	0.768	0.721	0.536–0.832	0.08	-0.008	-0.42; 0.40
	Force	3.4 ± 2.0	3.1 ± 1.6	0.183	0.673	0.460–0.802	0.75	0.31	-3.28; 3.90
	Distance	6.2 ± 1.5	5.8 ± 1.4	0.035	0.701	0.505–0.820	0.54	0.37	-2.30; 3.05
Infra-umbilical	Stiffness	0.50 ± 0.18	0.47 ± 0.15	0.268	0.570	0.289–0.741	0.09	0.026	-0.33; 0.39
	Force	3.2 ± 1.7	2.7 ± 1.1	0.018	0.516	0.209–0.705	0.82	0.49	-2.64; 3.63
	Distance	6.1 ± 1.4	5.6 ± 1.2	0.010	0.631	0.388–0.778	0.59	0.44	-2.12; 3.01
Transversus abdominis	Stiffness	0.51 ± 0.17	0.64 ± 0.22	0.000	0.612	0.217–0.793	0.10	-0.126	-0.50; 0.25
	Force	4.1 ± 1.8	5.2 ± 2.4	0.000	0.667	0.340–0.820	0.91	-1.15	-4.94; 2.64
	Distance	7.6 ± 1.2	7.7 ± 1.2	0.216	0.830	0.719–0.897	0.26	-0.14	-1.91; 1.62

Data are expressed as mean ± standard deviation. Inter-rater reliability was assessed using ICC, with corresponding 95% CI and SEM. Bland–Altman analysis is presented as mean bias and 95% LoA. Stiffness was expressed in N/mm, force in N, and distance in mm. p-values refer to comparisons among repeated measurements.

Bland-Altman plots illustrating agreement and bias between raters for MyotonPRO® measurements at the supra-umbilical, infra-umbilical, and transversus abdominis sites are presented in Figs. 2A, 2B, and 2C, respectively.

Bland-Altman plots for IndentoPRO measurements at the supra-umbilical, infra-umbilical, and transversus abdominis sites are presented in Figs. 3A, 3B, and 3C, respectively, providing visual information regarding

agreement and bias between raters for each anatomical region.

Discussion

This study evaluated the intra-rater within-session and inter-rater reliability of MyotonPRO® and IndentoPRO for assessing abdominal wall viscoelastic and biomechanical properties in late postpartum women. The main findings were that MyotonPRO demonstrated excellent reliability for almost all parameters and anatomical sites, while IndentoPRO demonstrated acceptable intra-rater reliability but lower inter-rater reliability. To our knowledge, this is the first study to evaluate the reliability of these portable devices for abdominal wall and linea alba assessment in postpartum women.

The excellent intra-rater reliability observed for MyotonPRO® indicates that repeated measurements performed by the same evaluator are highly consistent. These results are consistent with previous studies that demonstrated good-to-excellent reliability of MyotonPRO® in different tissues and populations, including cesarean section scars, unscarred skin, skeletal muscles, subcutaneous tissue, and neuromuscular conditions [31–35, 44]. The high ICC values and low SEM values observed in the present study support the use of MyotonPRO® as a reliable tool for measuring abdominal wall tissue properties in late postpartum women.

The inter-rater reliability of MyotonPRO® was also excellent for almost all parameters. This finding is particularly relevant for clinical practice, where different professionals may evaluate the same patient during follow-up or rehabilitation. The ability to obtain consistent measurements between raters may support the use of MyotonPRO® in women's health rehabilitation services and clinical research. Previous studies have also shown strong inter-rater reliability of MyotonPRO® in other anatomical regions, although some variability has been reported depending on probe type, tissue location, and tissue composition [31, 34, 35].

IndentoPRO showed good-to-excellent intra-rater reliability for most measurements, suggesting that the device can provide consistent results when used by the same trained evaluator. However, inter-rater reliability was lower, with most results classified as moderate and only some classified as good. These findings are consistent with previous studies showing that indentation-based assessments may be more dependent on evaluator technique and applied force [36, 37]. In the present study, force and distance variables were retained to help identify potential sources of discrepancy between raters. The lower reliability observed for infra-umbilical stiffness and force suggests that small differences in how the device was applied to the tissue may have influenced stiffness estimates.

The abdominal wall is a multilayered and mechanically complex region. In postpartum women, this complexity may be increased by pregnancy-related stretching, changes in collagen organization, widening of the linea alba, and possible reductions in connective tissue stiffness [8, 19, 21]. The linea alba is known to present anisotropic properties and site-specific mechanical behavior, which may influence how tissue responds to compression or mechanical impulse [5, 6]. Therefore, the lower inter-rater reliability observed

for IndentoPRO may reflect not only device handling but also the biomechanical complexity of postpartum abdominal tissues.

The present study also reinforces the clinical importance of evaluating abdominal wall function beyond IRD. Although IRD remains the most commonly used diagnostic criterion for DRA, recent evidence suggests that linea alba stiffness, distortion, and bulging during functional tasks may provide additional information about abdominal wall behavior [17, 19, 20, 45]. In our sample, the prevalence of DRA remained high between 8 and 24 months postpartum, and a relevant proportion of women presented abdominal bulging. These findings are consistent with studies showing that DRA and abdominal wall complaints may persist beyond the early postpartum period [9–11, 14].

Objective assessment of abdominal wall viscoelastic and biomechanical properties may contribute to improving clinical decision-making in postpartum rehabilitation. Current evidence regarding conservative treatment for DRA remains limited, and exercise-based interventions may have little effect on reducing IRD alone [2, 15]. Therefore, relying exclusively on IRD as an outcome may underestimate clinically meaningful changes in tissue function. Measures of stiffness, tone, elasticity, and creep may help clinicians evaluate whether rehabilitation strategies influence the mechanical behavior of the abdominal wall and linea alba.

Shear wave elastography has been used to assess abdominal muscle and linea alba stiffness, but its clinical implementation is limited by cost, technical complexity, and the need for specialized training [26–29]. Portable devices such as MyotonPRO® and IndentoPRO may offer a more accessible alternative for rehabilitation settings. However, reliability is only the first step before clinical implementation. Future studies should evaluate concurrent validity with elastography, responsiveness to intervention, minimal detectable change, normative reference values, and associations between tissue mechanical properties and symptoms or functional outcomes.

This study has limitations. First, intra-rater reliability was assessed within a single session, and therefore the results do not represent between-day reliability. Second, only two raters participated in data collection, which may limit generalizability to other clinicians with different levels of training. Third, the sample included only postpartum women and did not include a nulliparous control group. Finally, although both raters received standardized training, differences in clinical experience may have influenced IndentoPRO inter-rater reliability, particularly because indentation-based measurements depend on applied force and manual control.

Despite these limitations, this study provides novel evidence supporting the reliability of portable devices for objective assessment of abdominal wall mechanical properties in postpartum women. MyotonPRO demonstrated particularly robust reliability and may be suitable for use in clinical and research contexts. IndentoPRO also showed promising intra-rater reliability, although further standardization may be needed before its use in settings involving multiple evaluators.

Conclusion

The present study demonstrated that MyotonPRO® and IndentoPRO are reliable tools for assessing abdominal wall viscoelastic and biomechanical properties in late postpartum women, particularly for intra-rater measurements. MyotonPRO showed excellent intra- and inter-rater reliability across most parameters and anatomical sites, while IndentoPRO demonstrated good-to-excellent intra-rater and moderate-to-good inter-rater reliability, suggesting the need for greater standardization between evaluators. These findings support the use of portable objective tools to complement IRD assessment and improve postpartum rehabilitation planning. Future studies should investigate validity, responsiveness, normative values, and associations with postpartum symptoms and function.

Abbreviations

95% CI
95% confidence interval
BMI
Body mass index
DRA
Diastasis recti abdominis
ICC
Intraclass correlation coefficient
IRD
Inter-rectus distance
LoA
Limits of agreement
SEM
Standard error of measurement
SD
Standard deviation
SPSS
Statistical Package for the Social Sciences

Declarations

Ethics approval and consent to participate

Ethical approval for this study was obtained from the National Research Ethics Committee under Certificate of Presentation for Ethical Assessment number 76196523.9.0000.5345. All procedures were conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent prior to participation.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

L.Z.F, C.M.V. and F.C.S. contributed to Conceptualization, Methodology, Investigation, Data curation, Data analysis, Writing original draft, and Writing review and editing. R.H.C.J. contributed to Validation, Visualization, and Writing review and editing. Ro.S. and M.F.S. contributed to Writing original draft and Writing review and editing. Re.S contributed to data collection. All authors approved the final version of the manuscript.

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Figures

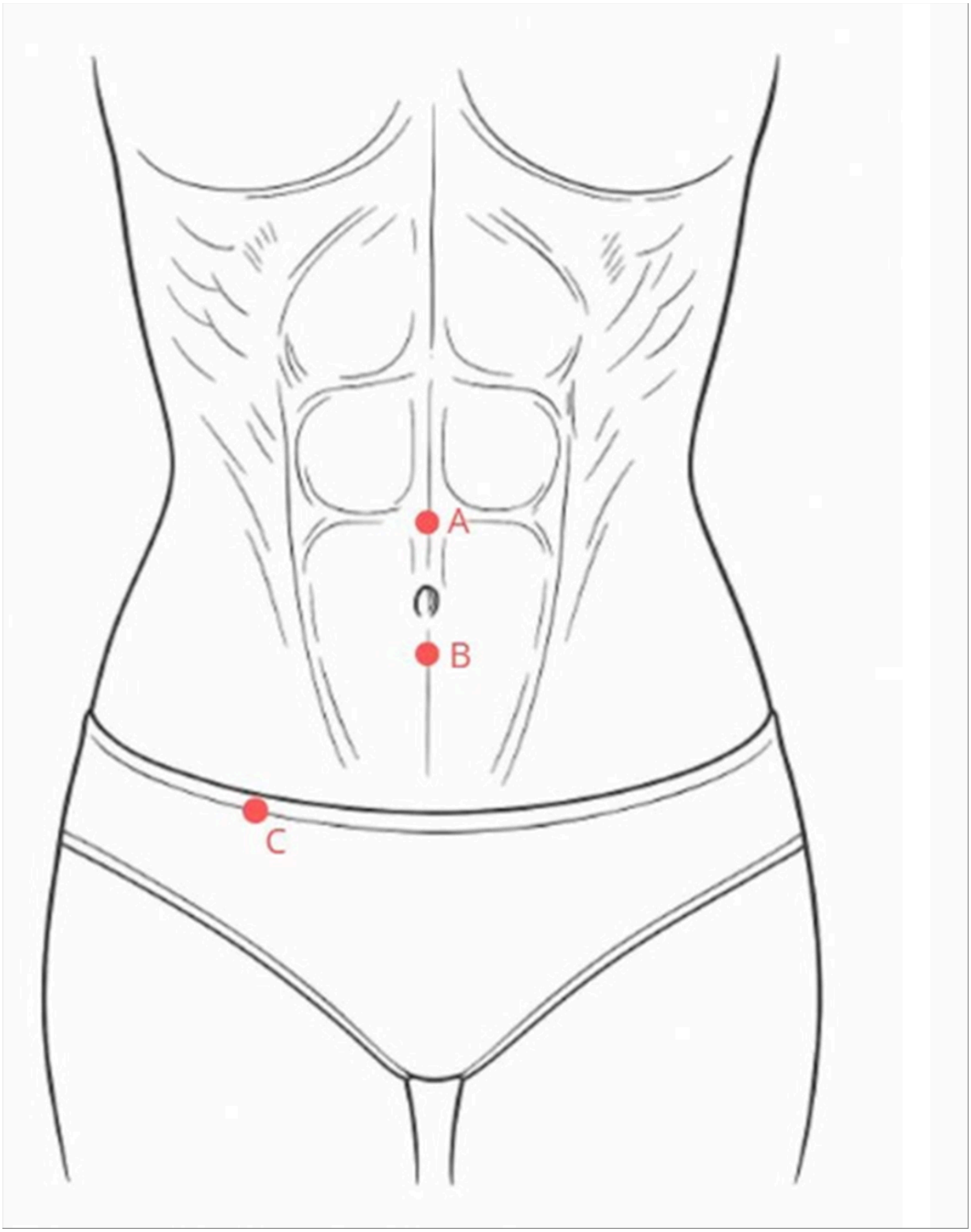


Figure 1

AI-generated illustration showing the three abdominal measurement points, edited by the authors (2025). Abbreviations: A, supra-umbilical point (3 cm above the umbilicus); B, infra-umbilical point (2 cm below the umbilicus); C, transversus abdominis point (2 cm proximal to the midpoint of the line connecting the anterior superior iliac crest and the pubic symphysis).

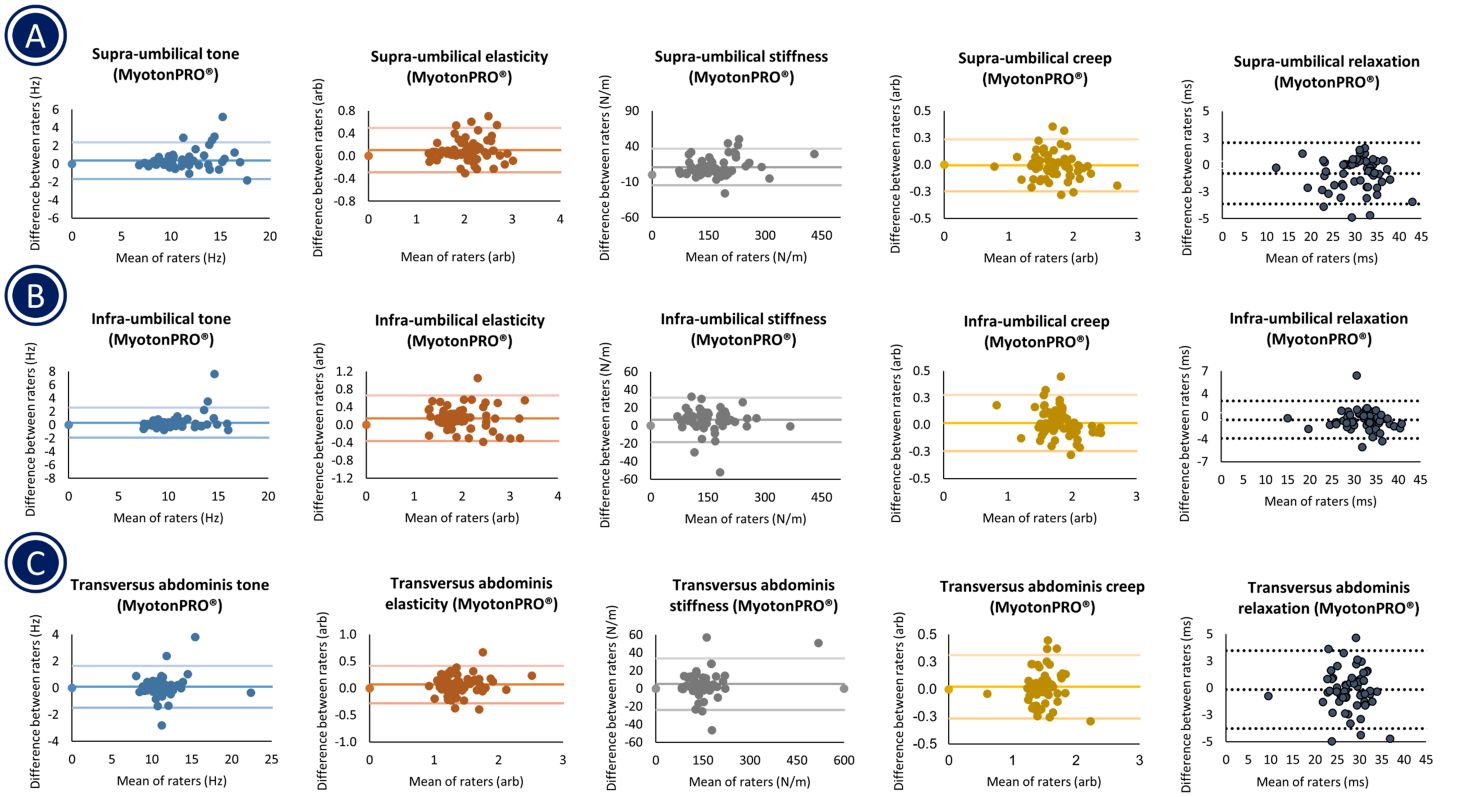


Figure 2

Bland-Altman plots showing agreement and bias between raters for MyotonPRO® measurements at supra-umbilical (A), infra-umbilical (B), and transversus abdominis (C) sites.

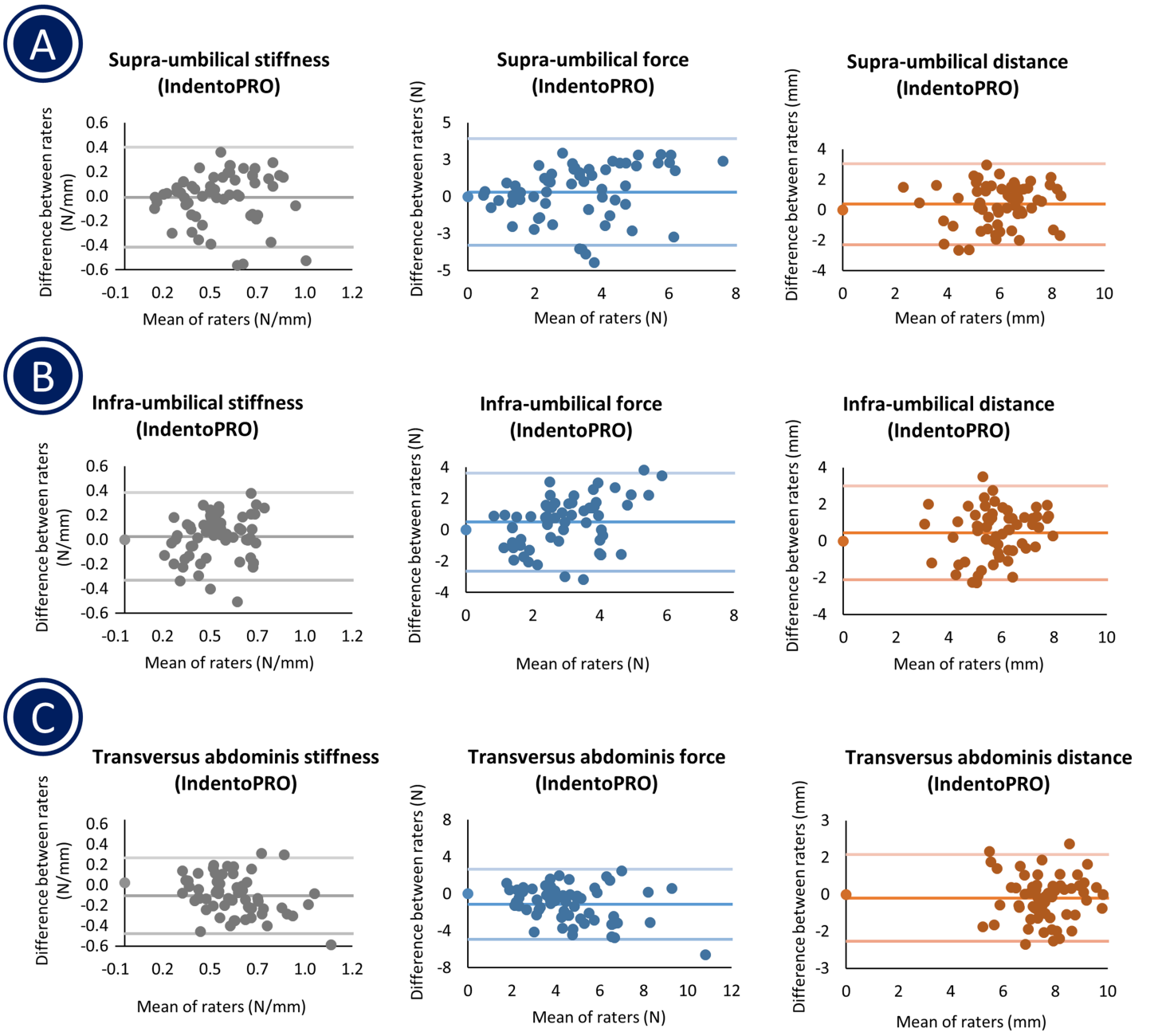


Figure 3

Bland-Altman plots showing agreement and bias between raters for IndentoPRO® measurements at supra-umbilical (A), infra-umbilical (B), and transversus abdominis (C) sites.