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Test-retest and Intrarater Reliability of 2D Ultrasound Measurements of Distance Between Rectus Abdominis in Women

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Study design: Single-group test-retest reliability study.

Objectives: To evaluate test-retest intra-observer reliability of 2D ultrasound measurement of the distance between rectus abdominis**,** the **i**nter-rectus distance (IRD).

Background: Diastasis recti is defined as the separation of the two rectus abdominis muscles with a reported prevalence of between 30% and 70% in women during pregnancy and in the postpartum period. The condition is difficult to measure, and ultrasound imaging has been suggested as a useful method to quantify the diastasis. However, to date no studies have investigated intra or inter-tester reliability of ultrasound to measure distance between rectus abdominis during rest and contraction.

Methods: Ultrasound images from the rectus abdominis were recorded on 24 healthy female volunteers at rest and on two conditions of abdominal contraction: Abdominal Crunch and Drawing-In exercises. The probe was positioned **in** two locations: below and above the umbilicus. A blinded investigator measured the IRD offline from two different ultrasound images collected on two different days (test-retest). Additionally, re-analyses of the same ultrasound images were done on two separate occasions (intra-image).

Results: Test-retest measurements of IRD demonstrated good to very good reliability with ICC values between 0.74 and 0.90. The only exception was for IRD measured 2 cm below the umbilicus on the abdominal crunch exercise, with an ICC of 0.50. For intra-tester reliability of the same images, the ICC values were all above 0.90.

Conclusion: Ultrasound imaging is a reliable method for measuring the inter rectus distance at rest and during Abdominal crunch and Drawing- in exercises.

Keywords: Diastasis, Postpartum, Reliability, Ultrasonography.

Diastasis recti abdominis (DRA) has been defined as an impairment characterized by a midline separation of the two rectus abdominis (RA) muscles along the linea alba (LA).[27,22] This increased inter rectus distance (IRD) has its onset during pregnancy and/or immediately after birth and the first weeks following childbirth.[5,12]

As the fetus grows the two muscle bellies of the RA connected by the LA, elongate and curve as the abdominal wall expands, and separation of the two muscle bellies with protrusion of the umbilicus may occur.[5,14,13] Studies have found that diastasis recti may affect between 30% and 70% of pregnant women[5], and that it may remain separated in the immediate postpartum period in 34.9%[9] to 60% of women[7,5,6]. However the condition has also been found in 38.7% of older, parous women undergoing abdominal hysterectomy[25] and in 52% of urogynecological menopausal patients.[27]

Reported prevalence of diastasis recti or increased IRD may be inaccurate because of unreliable methods to measure the condition with the most common assessment method being palpation[5,7,22,19], and calipers[6,16]. Ultrasound imaging has recently been suggested as an useful method to assess muscular geometry and as an indirect measure of muscle activation via changes in muscle thickness.[24] Coldron et al[10] used ultrasound to characterize RA changes during the first year postpartum and Mendes[20] et al claimed ultrasonography to be an accurate method to measure diastasis recti above and at the umbilicus when compared with surgical compass during abdominoplasty. However, search of the literature did not reveal studies addressing the intra or inter-tester reliability of the ultrasound measurement of the IRD at rest or during abdominal muscle contraction. Across-days reliability may be of interest to physiotherapists who perform repeated assessments of abdominal muscle function over time[15] and factors such as relocation of the original imaging site, reproduction of the same transducer pressure and orientation, as well as maintenance of these factors during muscle contraction could adversely affect reliability.[15]

The aims of the present study were to evaluate test-retest and intrarater reliability of 2D ultrasound imaging of the IRD at rest and during Abdominal Crunch and Drawing-In exercises, and to verify the differences on IRD related to the postpartum condition.

METHODS

Design

This was a test–retest study evaluating the intrarater reliability of IRD measurements. For the test-retest analysis two test sessions were performed. In addition, the images collected during session 1 were analyzed a second time by the same investigator.

Participants

Twenty-four healthy female volunteers participated in this study. Twelve of the women were in the postpartum period and were recruited from a private physiotherapy clinic and the others among colleagues, friends and family. Demographic data with respect to age, body mass index (BMI) and parity are presented in Table 1. The participants were eligible for the study if they agreed to participate in two testing sessions and were able to perform two different abdominal exercises. To ensure external validity, 12 women in postpartum period (less then 6 months) and 12 women with different parity (range 0 to 2 births), were included in the study. Pregnant women were excluded from the present study.

The study was approved by the Review Board of the Technical University of Lisbon, Faculty of Human Kinetics. Signed informed consent was obtained before participation in this study and the rights of the participants were provided in verbal and written form.

Instrumentation and procedures

An ultrasound scanner (GE Logic-*e*) with a 4-12 MHz, 39 mm linear transducer was used to collect images in brightness mode (B-mode) by the same examiner. The investigator was a physiotherapist with specific training in image capturing and measuring IRD. Before starting the study, the ultrasound protocol and analysis were discussed and practiced with an experienced radiologist.

The transducer was placed transversely along the midline of the abdomen in two locations with the center of the umbilicus as a reference: 2 cm above the umbilicus and 2 cm below the umbilicus. Initially, each measurement location was marked on the skin in order to standardize the position of the transducer. Ink marks were drawn with the subject in supine resting position with the knees bent at 90º and feet resting on the plinth, arms alongside the body (Figure 1).

During image acquisition the bottom edge of the transducer was positioned to coincide with the correspondent skin marker and moved laterally until the medial borders of both RA muscles were visualized. The orientation of the transducer was then adjusted to optimize visualization of the image. Images were collected immediately at the end of exhalation, as determined by visual inspection of the abdomen following the recommendations of Teyhen et al.[29] Additionally particular attention was paid to the pressure imposed on the probe in order to avoid reflexive response from the participants.

Still images were obtained with subjects in the supine resting position (knees bent at 90º and feet resting on the plinth, arms alongside the body) and on two abdominal contraction conditions: Abdominal Crunch (Figure 2) and Drawing-In exercise (Figure 1). One image was taken at each location under each condition. The abdominal crunch exercise was started from the resting position and the subjects were instructed to raise the head and shoulders upwards until the shoulder blades cleared the table. Subjects held this position until told to return to the starting position. The Drawing-In exercise also started from the resting position, and the subjects were instructed to inhale and after exhaling draw in the abdominal musculature towards their spine. Before starting the procedure the subjects were verbally instructed about correct performance of the two exercises. The verbal instructions are provided in Table 2. During the Drawing-In maneuver activation of the transversus abdominis muscle was confirmed by placing the transducer laterally between the iliac crest and rib cage.[28] Every contraction was held for three seconds for data collection with a resting time of 6 to 10 seconds between each repetition. After the test a convenient day for retest was scheduled with the participants.

The set of 12 images per subject from each of the 3 conditions (Rest, Abdominal Crunch and Drawing-In) from both locations (2 cm above and below the umbilicus) in the 2 days were exported in JPG format for further offline processing. Reliability was analyzed on IRD measurements during session 1 (intra-image reliability) and between sessions (test-retest reliability). The investigator was blinded to the subjects ID and to the values of the IRD measurements.

Inter-rectus distance (IRD) measurement

Analyses of 2D ultrasound distances were conducted offline by the same investigator, using a customized code made on specific software (Matlab, Image Processing Toolbox, Mathworks Matlab, USA). Ultrasound images were assumed as a pixel based coordinate system, with the origin in the top left hand corner of the image. In this system an '*x*' and '*y*' coordinate could be used to locate a point in the image and distance between two or more point could be calculated. On ultrasound images the IRD is characterized by the transverse linear distance from the medial border of the rectus abdominis of one side to the corresponding position of its counterpart on the other side. Using this procedure, two points corresponding to the medial muscular insertions sites of both rectus abdominis on the linea alba, must be identified on the ultrasound images. From our observations these points are close to the inflection point of a parabola-like-curve that could be assumed for the ultrasound image of each rectus abdominis muscle contour Fig 3 (red dots and yellow line). In order to improve the accuracy of the identification of these two points, an algorithm was developed and implemented using a customized Matlab code. Thus, the first step in the algorithm was to interpolate a set of 8-10 points manually digitalized by the examiner on the visible contour of both muscle bellies, and fit them to a parabola-like-curve. Using the coordinates of those digitized points a fourth order polynomial equation was fitted in order to determine the coefficient of the polynomial and the inflexion point of the interpolated curve. The discrete derivative of the interpolated x-coordinate and the point at which the sign changed was considered as the parabola point of inflexion Fig 4 (white asterisks). The determined inflection point and the interpolated parabola-like-curve were overlapped on the original ultrasound image, to guide the examiner on the identification of the medial margins of the RA and improve the accuracy of IRD measurements. Besides the software suggestion, the examiner has the final decision about the location of the medial margins of the RA muscles used on IRD measurements.

Statistical Analyses

The intra-class correlation coefficient (ICC) for one way random effect model was used to assess the level of consistency across the 2 IRD measurements made on two different ultrasound images and collected on two different days (test-retest), and across the 2 IRD measurements made on the same ultrasound image (intra-image).

The scale from Altman[1] was used in the classification of the reliability values. ICC values less than or equal to 0.20 were considered poor, 0.21 to 0.40 fair, 0.41 to 0.60 moderate, 0.61 to 0.80 good and 0.81 to 1 very good.

Standard error of measurement (SEM) was used to examine the precision of measurement and it was calculated according to SEM = pooled Standard Deviation*$\sqrt{1 - ICC}$. To represent a difference in IRD beyond measurement error, the minimum detectable change (MDC) was calculated as 1.96 * SEM *$\sqrt{2}$ [23]. These analyses were performed for each of the outcome variables: IRD at rest condition, abdominal crunch and drawing in exercise, 2 cm above and 2 cm below the umbilicus.

The Bland-Altman plot of difference against the mean was also used to compare the limits of agreement and mean bias between plots.[4] The Standard Deviation (SD) of the differences between test and retest was calculated, and then multiplied by 1.96 to obtain the 95% random error component.[2]

In order to verify the differences on IRD related to the postpartum condition, the 12 postpartum women were compared to the women with different parity using an independent t-test.

All statistical analyses were made using specific software (IBM-SPSS, Version 19) and a critical level of $p < 0.05$ was considered statistically significant.

RESULTS

All participants returned for the second test after a mean of 3.9 days (SD = 3.9, range 1 to 16 days) and all reported that they complied with the request not to practice any of the exercises between tests. There were no dropouts. The IRD values for each measurement are shown in Table 3. No significant differences were found in the IRD between women in postpartum and the other women with different parity (Table 4). In general, the smallest IRD values were from Abdominal Crunch exercise, and the biggest were from the Drawing-In exercise.

Intra-tester reliability of the ultrasound analyses (intra-image)

The ICC values for the IRD measured on the same image at two different occasions revealed very good reliability for every condition tested (Table 5). The Rest condition demonstrated less variability than the measurements conducted during Abdominal Crunch and Drawing-In, but the ICC values were all above 0.90. The precision of repeated measurements of the same images was higher (revealed by lower SEMs) compared with recaptured images. The MDC values ranged from 1.80 to 5.52 mm. The Bland-Altman plot (Figure 5) showed that the mean of differences of IRD on test-retest was closer to zero (0.052) mm, and the limits of agreement were narrower compared with the values found on different images (-1.95 mm and 2.05 mm).

Test-retest across days (inter-image)

The ICC values for the IRD during the Rest condition demonstrated good reliability for 2 cm below the umbilicus with an ICC (95% CI) of 0.78 (0.56-0.90), and very good reliability for 2 cm above the umbilicus with an ICC (95% CI) of 0.87 (0.73-0.94), (Table 6). The inter rectus distance for the Rest condition demonstrated higher ICC values than the measurements from the Abdominal Crunch, which showed very good reliability above the umbilicus with an ICC (95% CI) of 0.83 (0.65-0.92), but moderate reliability below the umbilicus with an ICC (95% CI) of 0.50 (0.14-0.75). For the Drawing-In, ICC was very good 2 cm above umbilicus with an ICC (95% CI) of 0.90 (0.79-0.96), and good 2 cm below the umbilicus with an ICC (95% CI) of 0.74 (0.48-0.88) (Table 6). SEM values were very similar across all conditions, but 2 cm below the umbilicus during Drawing-In and Abdominal Crunch they showed higher variability with values of 3.15 mm and 4.36 mm respectively. The MDC values ranged from 6.32 to 12.08 mm. The Bland-Altman plot showed that the mean of differences of IRD on test-retest was - 0.33 mm and the limits of agreement were between -8.67 mm and 8.34 mm (Figure 6).

DISCUSSION

The present study demonstrated very good reliability for the intra-tester measurements in the same image for all the conditions tested, with ICC values above 0.90, low values of SEM (range 0.65 to 1.99) and MDC (range 1.80 to 4.29). These results are in line with the values found by Liaw et al.[18] The test-retest measurements across days showed good reliability during rest and drawing-in exercises below the umbilicus with ICC values of 0.78 and 0.74 respectively and very good reliability during rest, abdominal crunch and drawing-in exercises above the umbilicus with ICC values of 0.87, 0.83 and 0.90 respectively. The lowest ICC value of 0.50 was found below the umbilicus and during contraction, with moderate reliability for abdominal crunch. The higher values found on the SEM (range 2.28 to 4.36 mm) and on the MDC (range 6.32 to 12.08 mm) revealed lower precision of the IRD measurements.

The lower values found below the umbilicus may be explained by the influence of the amount of subcutaneous fat[18] in this location. This could have interfered with the determination of where to mark the skin, positioning of the probe and the ability to maintain a constant pressure during image acquisition. During the abdominal crunch exercise the participants had to move the upper body and this may have induced movements under the transducer. Nevertheless the ICC was moderate to good.

In general, there are several potential sources of measurement errors: the subjects, the testing, the scoring, the instrumentation and factors such as the instructions from the examiner, participant motivation, and the participants skill and motor control may affect performance in different days.[17] To mitigate against some of these potential sources of errors the position of the subject, examiner's instructions, the transducer location and its inclination, the pressure applied to the transducer on the abdominal wall, and the room temperature were standardized.

Criteria for the diagnosis of DRA vary in the literature.[5, 7, 14, 26, 27, 25, 8, 3] Beer et al[3] suggest that in nulliparous women, the LA could be considered "normal" when the width is less than 1.5 cm at the xiphoid level, 2.2 cm at 3 cm above the umbilicus, and 0.6 cm at 2 cm below the umbilicus. In our study we found higher mean values for IRD at 2 cm below the umbilicus in 12 subjects. An explanation for this difference is that we also included parous women who are expected to have wider or greater IRD.[14, 10,5 ,19] However, no significant differences were found in the IRD between women in postpartum and the other women with different parity.

In studies of postpartum women, DRA has been defined as the LA having a width greater than 2-finger breadth (1.5 cm) when measured with palpation,[5 , 14, 27] or 2 cm when measured with a dial caliper at or above the umbilicus during a partial sit-up.[18] However the inaccuracy and possible low reliability of the measurement tools used are possible limitations of previous studies.

Computed tomography (CT) and magnetic resonance imaging (MRI) are currently considered the methods of choice to examine the abdominal wall, but they are expensive and CT exposes the patient to radiation[20], making it impossible to use in pregnant women. Hence, ultrasonography has been proposed as a non-invasive technique that can be repeated several times[20] during pregnancy.

The current investigation examined many aspects of reliability of the ultrasound measurements. The two RA muscles were identified in both relaxed and contracted conditions. Furthermore, repeated measurements were conducted from the same stored images as well as across images collected and measured on two different days. It would be expected that measuring the IRD repeatedly, even on different days from stored images, would be associated with higher values of ICC. This is because measuring the distance between two well defined muscles in the ultrasound images is a relatively straight forward task. Our results from the IRD and the results of Hides et al[15], about the thickness of the internal oblique and transversus abdominis muscles, support this premise, with both studies reporting very high values of ICC from repeated measures of the same image. However, accurately re-imaging the subject to obtain comparable images may require a higher level of skill. On the current study the measurements from recaptured images showed from good to very good reliability, with the only exception of moderate reliability in the abdominal crunch exercise. The lower precision shown by higher SEM and MDC values an d the wide 95% limits of agreement confirm the inferior reliability of recaptured images compared to repeated measurements of the same stored image.

Interestingly, during the Drawing-In exercise the IRD values demonstrated a greater separation than during Rest or Abdominal Crunch (Table 3). This requires further study as this exercise is considered to be gentler than Abdominal Crunch and commonly recommended for low back pain both during pregnancy and after childbirth. However, to date there are no randomized controlled trials on the effect of different abdominal exercise to treat DRA in the peripartum period. A follow-up study on the IRD in pregnancy and postpartum in different muscle contraction conditions is being conducted.

The current study is unique in the reliability tests on the IRD measurements and the use of different locations and contraction conditions to better objectively quantify the separation between the two rectus abdominis muscles. A strength of this study is the blinding of the observer to all the results of IRD measurements until the end of the process. To ensure external validity, 12 subjects in postpartum period and 12 women with different parity, were included in the study. In general the IRD was greater in postpartum women, but no significant differences were found in the IRD between the two groups. Consistent with our findings, Liaw et al[18] also noted that the medial margins of the RA appear to be indistinct where the fascial borders become less clear in postpartum women. We used a customized Matlab code to implement a method of ultrasound images segmentation based on explicit shape representation defined by a known point distribution model. [11] In fact, a semi-automated ultrasound image segmentation method was used in order to help the examiner to identify the medial margins of both RA muscles and improve the accuracy of IRD measurement. However the examiner has always the final decision. We believe that in the near future this Matlab code could be implemented in the software embedded in the ultrasound scanners, helping clinicians to accurately measure the IRD or other muscular morphometric parameters (e.g. muscle cross sectional area).

The limitations of this study include the use of only one rater with limited experience in ultrasound imaging and inclusion of only healthy subjects with no musculoskeletal or neurological symptoms. It may be more difficult to reliably measure subjects with symptoms that can interfere in the performance of the exercises across the days or in the last gestational weeks where wider IRD may require a broader view of the abdominal wall to be able to see both RA muscles on the same image. Because the main goal of this study was to evaluate test-retest and intrarater reliability of the IRD in different contraction conditions, we excluded pregnant women from this study, because the IRD is constantly changing with the progress of pregnancy and movement/position of the baby. [21] This may influence the reliability of the test-retest. Only intra-rater test-retest reliability of IRD measurements with ultrasound imaging was studied. Data on inter-rater reliability is needed especially for longitudinal studies including more than one investigator.

CONCLUSION

The 2D ultrasound imaging proved to be a reliable method to measure IRD in women. We suggest the use of ultrasound imaging in future studies to reliably measure the changes in the IRD during Rest, Abdominal Crunch and Drawing-In exercises.

TABLE 1. Background Variables*

Variables	All subjects N=24	Post partum N=12	Women different parity N=12
Age (years)	30.54 (range 16-55)	31.17 (range 26-36)	29.92 (range 16-55)
Body Mass Index (kg/m^2)	22.71 (range 18.90-28.51)	23.96 (range 20.76-28.51	21.46 (range 18.90-24.61)
Parity	0.75 (range 0-2)	1	0.5 (range0-2)
Length of time since last pregnancy		10.91 weeks (range 9-13)	11.5 years (range 1-24)
College/University education	20/24	12/12	8/12

TABLE 2. Verbal instructions

Rest/Start Position	Flex your knees; keep your feet on the plinth. With your hands push your knees up to your chest and then let them go down **until** your feet reach the plinth again. Arms along your body and breath normally.
Abdominal Crunch	Inhale and exhale. Lift your head and slide your hands along the front of your thighs to touch your knees with the fingertips, until you feel your shoulder blades off the table. Hold there for three seconds.
Drawing-In	Inhale and exhale. Pull your belly button in and back towards the spine. Do not move your pelvis. Hold there for three seconds.

TABLE 3. Inter Rectus Distance measures during Rest, Abdominal Crunch and Drawing-In exercises* N=24

Condition	Probe location	IRD Test 1A	IRD Test 1B	IRD Test 2
Rest	2 cm Above	17.44 (7.34)	17.51 (7.51)	18.93 (7.88)
	2 cm Below	8.01 (4.82)	7.54 (4.98)	8.35 (4.80)
Abdominal Crunch	2 cm Above	16.99 (6.75)	17.01 (6.03)	18.45 (6.07)
	2 cm Below	9.22 (6.66)	9.37 (6.81)	7.93 (5.49)
Drawing-In	2 cm Above	19.38 (7.57)	19.11 (7.62)	19.51 (7.58)
	2 cm Below	9.91 (6.54)	9.90 (6.61)	9.44 (5.87)

*Values represent mean in mm (standard deviation) for each dependent measure based on state (Rest, Abdominal Crunch and Drawing-In) and site (2 cm above or below the umbilicus). Test 1 and 1B represent the measurements made on different days on the same stored image. Test 2 represent the measurements made on a different image collected across days.

TABLE 4. Inter Rectus Distance measures during Rest, Abdominal Crunch and Drawing-In exercises* for the women in post partum and women with different parity, and Independent t-test values

Condition	Probe location	PP N=12	DP N=12	Mean diff (95%CI)	t-test#
Rest	2 cm Above	18.26 (7.59)	16.62 (7.31)	-1.64 (-7.95-4.67)	0.595
	2 cm Below	8.87 (4.92)	7.15 (4.77)	-1.72 (-5.82-2.38)	0.394
Abdominal Crunch	2 cm Above	19.55 (7.00)	14.44 (5.64)	-5.12 (-10.50-0.27)	0.061
	2 cm Below	7.49 (5.33)	10.93 (7.60)	3.45 (-2.12-9.01)	0.212
Drawing In	2 cm Above	22.32 (8.05)	16.43 (6.01)	-5.89 (-11.90-0.12)	0.055
	2 cm Below	11.16 (7.50)	8.87 (5.46)	-2.49 (-8.05-3.06)	0.363

Abbreviations: PP, post partum women; DP, different parity women; Mean diff, mean difference between groups and confidence intervals.
*Values represent mean in mm (standard deviation) for each dependent measure based on state (Rest, Abdominal Crunch and Drawing-In) and site (2cm above or below the umbilicus) during test 1.
Significant difference in IRD between groups ($P<0.05$)

TABLE 5. Intra-rater reliability across repeated measurement of the same image

Condition	Probe location	$ICC_{1,1}$ (95%CI) Intra-image	SEM (mm)	MDC_{95} (mm)
Rest	2 cm Above	0.98 (0.95-1.00)	1.04	2.88
	2 cm Below	0.96 (0.90-0.98)	0.97	2.69
Abdominal Crunch	2 cm Above	0.94 (0.88-0.98)	1.55	4.29
	2 cm Below	0.97 (0.93-1.00)	1.15	3.20
Drawing-In	2 cm Above	0.93 (0.85-0.97)	1.99	5.52
	2 cm Below	0.99 (0.97-1.00)	0.65	1.80

Abbreviations: $ICC_{1,1}$, Intra class correlation one way random effect model (95% confidence interval); SEM, standard error of measurement; MDC_{95} minimum detectable change at the 95% confidence level.

TABLE 6. Intra-rater reliability across 2 days

Condition	Probe location	$ICC_{1,1}$ (95%CI) Inter-image	SEM (mm)	MDC_{95} (mm)
Rest	2 cm Above	0.87 (0.73-0.94)	2.75	7.63

	2 cm Below	0.78 (0.56-0.90)	2.28	6.32
Abdominal Crunch	2 cm Above	0.83 (0.65-0.92)	2.48	6.89
	2 cm Below	0.50 (0.14-0.75)	4.36	12.08
Drawing-In	2 cm Above	0.90 (0.79-0.96)	2.38	6.59
	2 cm Below	0.74 (0.48-0.88)	3.15	8.74

Abbreviations: $ICC_{1,1}$, Intra class correlation one way random effect model (95% confidence interval); SEM, standard error of measurement; MDC_{95} minimum detectable change at the 95% confidence level.

FIGURE 1. Rest position, start and end position of drawing-in exercise.

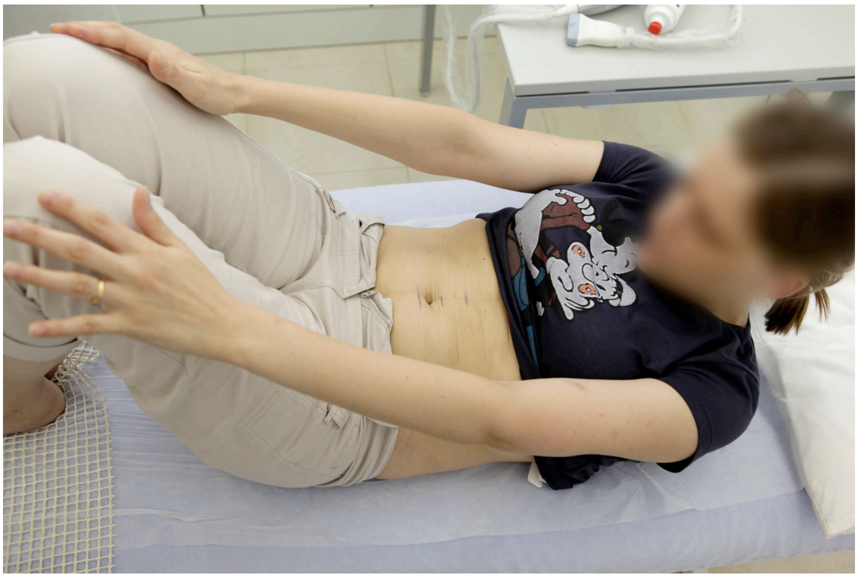


FIGURE 2. Abdominal Crunch exercise.

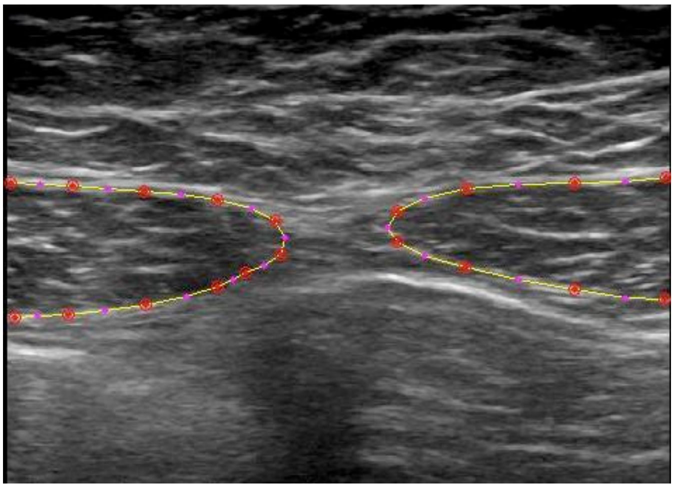
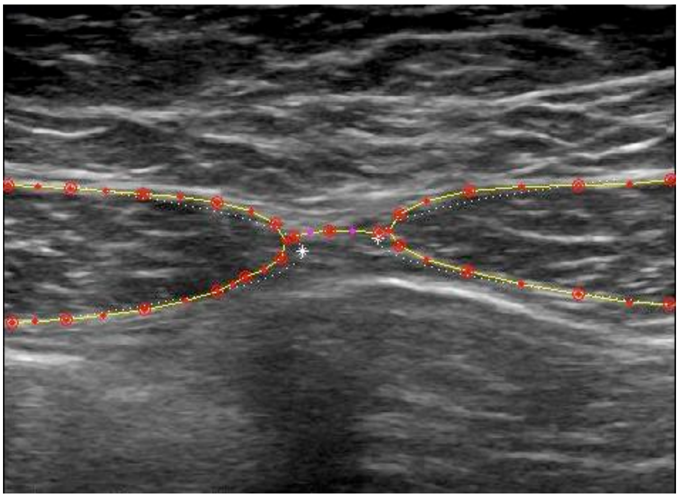


FIGURE 3. RA ultrasound image. Points digitalized by the examiner on the muscles contour (red dots).



B

FIGURE 4. RA ultrasound image. Interpolated points using an algorithm according to a parabola-shape like curve (white points); parabola inflection point (white asterisk) suggesting the end-points for IRD measurement on the medial margin of both RA.

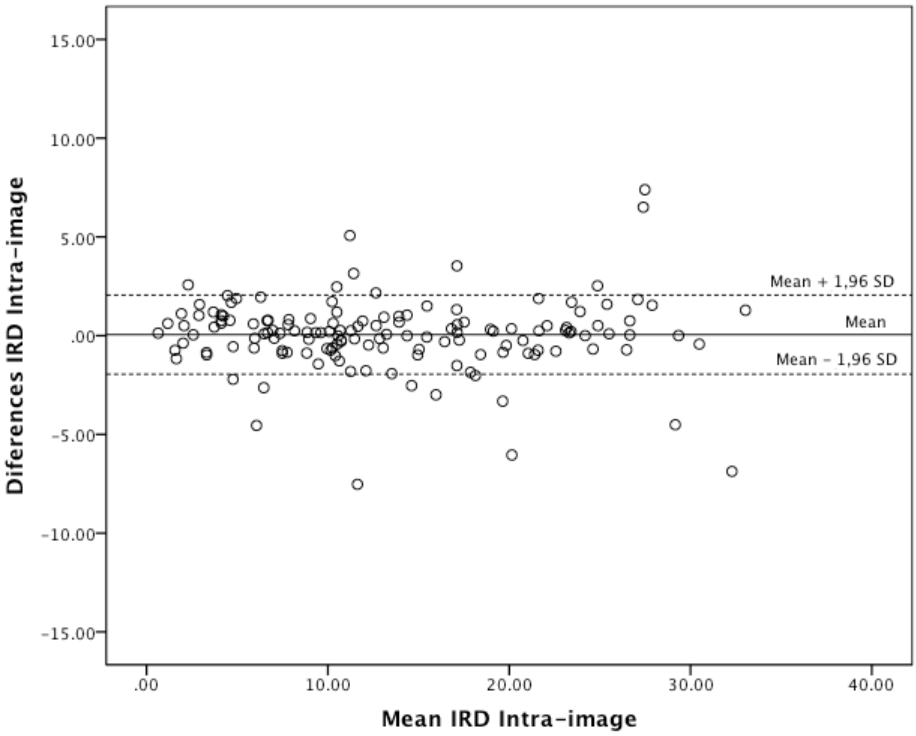


FIGURE 5. Plot of difference against mean (in mm) for measurements of the same stored images, with mean difference and 95% limits of agreement indicated.

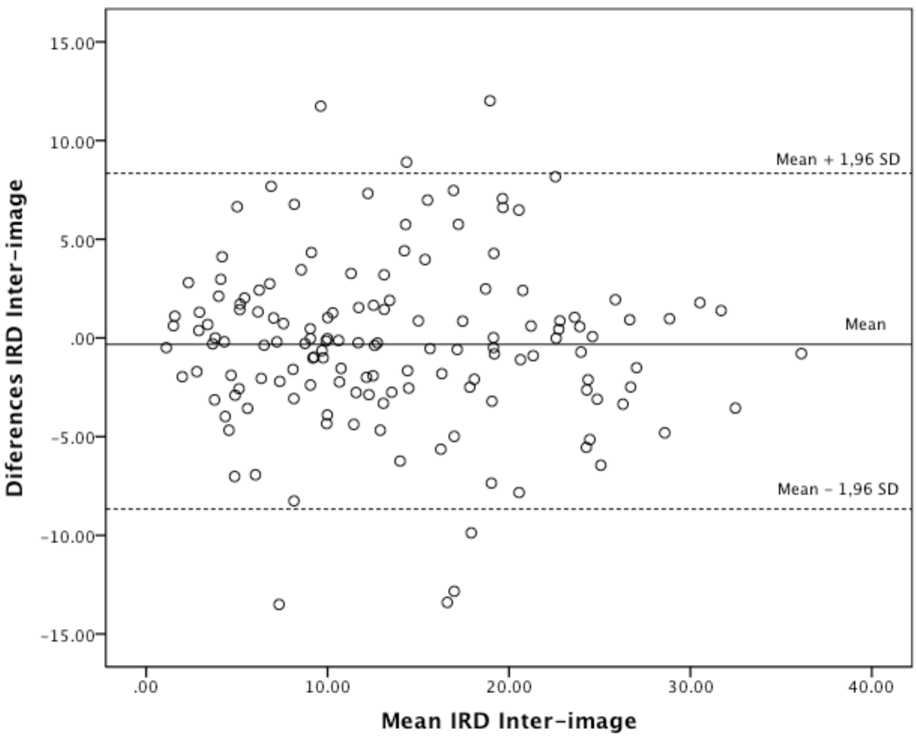


FIGURE 6. Plot of difference against mean (in mm) for the recaptured images, with mean difference and 95% limits of agreement indicated.

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References

1. Altman DG. *Practical statistics for medical research*. Chapman and Hall; 1991.

2. Atkinson G, Nevill AM. Statistical Methods For Assessing Measurement Error (Reliability) in Variables Relevant to Sports Medicine. *Sports Medicine*. 1998:217–238.

3. Beer GM, Schuster A, Seifert B, Manestar M, Mihic-Probst D, Weber SA. The normal width of the linea alba in nulliparous women. *Clinical Anatomy*. 2009:706–711.

4. Bland JM, Altman DG. Applying the right statistics: analyses of measurement studies. *Ultrasound in Obstetrics and Gynecology*. 2003:85–93.

5. Boissonnault JS, Blaschak MJ. Incidence of diastasis recti abdominis during the childbearing year. *Physical Therapy*. 1988:1082–1086.

6. Boxer S, Jones S. Intra-rater reliability of rectus abdominis diastasis measurement using dial calipers. *Aust J Physiother*. 1997:109–114.

7. Bursch SG. Interrater reliability of diastasis recti abdominis measurement. *Physical Therapy*. 1987:1077–1079.

8. Candido G, Lo T, Janssen PA. Risk factors for diastasis of the recti abdominis. *Journal of the Association of Chartered Physiotherapists in Womens Health*. 2005:49–54.

9. Chiarello CM, Falzone LA, McCaslin KE, Patel MN, Ulery KR. The Effects of an Exercise Program on Diastasis Recti Abdominis in Pregnant Women. *Journal of Women's Health Physical Therapy*. 2005:11.

10. Coldron Y, Stokes MJ, Di J Newham, Cook K. Postpartum characteristics of rectus abdominis on ultrasound imaging. *Manual therapy*. 2008:112–121.

11. Cootes TF, Taylor CJ, Cooper DH, Graham J. Active shape models-their training and application. *Comput. Vis. Image Underst.* 1995:38–59.

12. Dumas GA, Reid JG, Wolfe LA, Griffin MP, McGrath MJ. Exercise, posture, and back pain during pregnancy. *Clinical Biomechanics*. 1995:98–103.

13. Fast A, Weiss L, Ducommun EJ, Medina E, Butler JG. Low-back pain in pregnancy. Abdominal muscles, sit-up performance, and back pain. *Spine*. 1990:28–30.

14. Gilleard WL, Brown JMM. Structure and Function of the Abdominal Muscles in Primigravid Subjects During Pregnancy and the Immediate Postbirth Period. *Physical Therapy*. 1996:750–762.

15. Hides JA, Miokovic T, Belavy DL, Stanton WR, Richardson CA. Ultrasound imaging assessment of abdominal muscle function during drawing-in of the abdominal wall : An intrarater reliability study. *Journal of Orthopaedic and Sports Physical Therapy*. 2007:480–486.

16. Hsia M, Jones S. Natural resolution of rectus abdominis diastasis. Two single case studies. *Australian Journal of Physiotherapy*. 2000:301–307.

17. Koppenhaver SL, Hebert JJ, Parent EC, Fritz JM. Rehabilitative ultrasound imaging is a valid measure of trunk muscle size and activation during most isometric sub-maximal contractions: a systematic review. *Australian Journal of Physiotherapy*. 2009:153–169.

18. Liaw L-J. The Relationships Between Inter-recti Distance Measured by Ultrasound Imaging and Abdominal Muscle Function in Postpartum Women: A 6-month Follow-up Study. *The Journal of Orthopaedic and Sports Physical Therapy*. 2011:435–443.

19. Mantle J, Haslam J, Barton S. *Physiotherapy in obstetrics and gynaecology*. 2nd ed. Butterworth-Heinemann; 2004:489.

20. Mendes D de A, Nahas FX, Veiga DF, Mendes FV, Figueiras RG, Gomes HC, Ely PB, Novo NF, Ferreira LM. Ultrasonography for measuring rectus abdominis muscles diastasis. *Acta Cirúrgica Brasileira*. 2007:182–186.

21. Mota P, Pascoal AG, Vieira F. Changes in superficial abdominal muscles morphology during pregnancy: A case study. *XXII Congress of the International Society of Biomechanics*. 2011:30.

22. Noble E. *Essential exercises for the childbearing year: a guide to health and comfort before and after your baby is born*. New Life Images; 1995:177.

23. Portney LG, Watkins MP. *Foundations of clinical research: applications to practice*. Pearson/Prentice Hall; 2009.

24. Rankin G, Stokes M, Newham DJ. Abdominal muscle size and symmetry in normal subjects. *Muscle Nerve*. 2006:320–326.

25. Ranney B. Diastasis recti and umbilical hernia causes, recognition and repair. *South Dakota Journal of Medicine*. 1990:5–8.

26. Rath AM, Attali P, Dumas JL, Goldlust D, Zhang J, Chevrel JP. The abdominal linea alba: an anatomo-radiologic and biomechanical study. *Surgican and Radiologic Anatomy*.

1996:281–288.

27. Spitznagle TM, Leong FC, Van Dillen LR. Prevalence of diastasis recti abdominis in a urogynecological patient population. *International Urogynecology Journal*. 2007:321–328.

28. Teyhen DS, Miltenberger CE, Deiters HM, Del Toro YM, Pulliam JN, Childs JD, Boyles RE, Flynn TW. The use of ultrasound imaging of the abdominal drawing-in maneuver in subjects with low back pain. *Journal of Orthopaedic and Sports Physical Therapy*. 2005:346–355.

29. Teyhen DS, Rieger JL, Westrick RB, Miller AC, Molloy JM, Childs JD. Changes in deep abdominal muscle thickness during common trunk-strengthening exercises using ultrasound imaging. *The Journal of Orthopaedic and Sports Physical Therapy*. 2008:596–605.