This study won the ML Roberts prize awarded for the best 4th year undergraduate research project at the School of Physiotherapy, AUT University in 2013. NZJP publishes the resulting paper without external peer review.

The reliability of measuring the inter-recti distance using high-resolution and low-resolution ultrasound imaging comparing a novice to an experienced sonographer

Tom Iwan *BHSc (Physiotherapy)*

Briar Garton *BHSc (Physiotherapy)*

Richard Ellis *(PhD, PostGradDip HSc, BPhty)*

Senior Lecturer, Health & Rehabilitation Research Institute, School of Rehabilitation and Occupation Studies, Faculty of Health and Environmental Sciences, AUT University

ABSTRACT

Diastasis recti abdominis is an increase in inter-recti distance. This commonly occurs in women postpartum and may lead to weakness and dysfunction of the abdominal muscles. Ultrasound imaging has been previously used to quantify the inter-recti distance. The aims of this study were: 1) to examine the reliability of an experienced versus a novice sonographer in the measurement of inter-recti distance, and 2) to examine the reliability of using high-resolution versus low-resolution ultrasound imaging in the measurement of inter-recti distance. Ultrasound measures of the inter-recti distance were recorded in thirty healthy participants at rest and during an abdominal contraction by both an experienced and novice sonographer. Intra-rater, within-session measurement of inter-recti distance demonstrated good to very good reliability. Intra-rater, between session reliability remained very good for the experienced sonographer but declined for the novice sonographer. Results demonstrated excellent agreement between both low and high-resolution ultrasound imaging with no significant differences recorded. There were no significant differences between the novice and experienced sonographers' measurements. The results of this study indicate the potential of low-resolution ultrasound imaging to be implemented clinically in the future.

Iwan T, Garton B, Ellis R (2014) The reliability of measuring the inter-recti distance using high-resolution and low-resolution ultrasound imaging comparing a novice to an experienced sonographer New Zealand Journal of Physiotherapy 42(2): 154-163.

Key Words: Ultrasound imaging, Inter-recti distance, Diastasis recti abdominis, Reliability

INTRODUCTION

Diastasis recti abdominis (DRA) has been defined as a condition characterised by an abnormal midline separation of the rectus abdominis (RA) from the linea alba (Barbosa et al 2013, Mota et al 2013). The cause of a DRA is most commonly related to pregnancy (Barbosa et al 2013). In males, as well as females, DRA has also been associated with increasing age (Chiarello and McAuley 2013, Lockwood et al 2006, Rath et al 1996), greater abdominal circumference (Chiarello et al 2012), hernia (Spitznagle et al 2012), and abdominal aortic aneurysm (McPhail 2009).

During pregnancy, the two rectus abdominis muscle bellies elongate and curve round the abdominal wall as it expands (Boissonnault and Blaschak 1988, Gilleard and Brown 1996) causing midline separation along the linea alba and protrusion of the umbilicus (Boissonnault and Blaschak 1988, Mota et al 2013). A measure of this mid-line separation is referred to as the inter-recti distance (IRD). From studies looking at the IRD using medical imaging, a separation of greater than 2.7cm at the level of the umbilicus has been suggested to indicate DRA (Coldron et al 2008, Rath et al 1996).

It is purported that DRA does not completely resolve and remains larger than in nulliparous women (Boissonnault and Blaschak 1988, Coldron et al 2008, Liaw et al 2011). The abdominal musculature performs an imperative role in stabilising the lumbar spine (Rankin et al 2006). Adverse clinical effects that have been reported with DRA are: lumbosacral instability (Chiarello and McAuley 2013, Coldron et al 2008); low back and pelvic girdle pain (Chiarello and McAuley 2013, Coldron et al 2008); decreased strength and endurance of the rectus abdominis (Chiarello and McAuley 2013); respiratory, pelvic floor and postural changes (Barbosa et al 2013, Chiarello and McAuley 2013).

It has been recently proposed that the current prevalence of DRA in the community may be either inaccurate or reported unreliably due to the present methods used to diagnose the condition (Mota et al 2012, Mota et al 2013). To date, the most commonly used assessment methods to evaluate IRD in physiotherapy clinical practice are calipers (Boxer and Jones 1997, Hsia and Jones 2000) and palpation (Boissonnault and Blaschak 1988, Boxer and Jones 1997, Bursch 1987). Recent studies have advocated the use of ultrasound imaging (USI) to assess IRD as advancement from traditional techniques. Chiarello and McAuley (2013) investigated the construct validity between ultrasound imaging (USI) and calipers when measuring IRD. Their results depicted a strong correlation at the supra-umbilical (SU) location, however, IRD at the infra-umbilical (IU) level tended to be overestimated using the calipers (Chiarello and McAuley 2013). de Almeida Mendes et al (2007) found no significant difference between the values at the SU and IU levels obtained by USI compared to the intra-operative measurements during surgery for abdominoplasty.

There is scope to utilise USI in clinical practice for assessment of IRD in people with DRA. USI has been proposed as the gold standard in the assessment of DRA, with a growing body of literature reporting it as an accurate method to measure DRA above and at the level of the umbilicus (Barbosa et al 2013, Chiarello and McAuley 2013, Mota et al 2013). Although USI is relatively inexpensive when compared to other imaging techniques, there remain several issues in regard to appropriate equipment and adequate training. Diagnostic USI requires high-resolution equipment to afford the clarity of ultrasound image necessary for clinical diagnosis. Widespread interest in the use of USI has led to improvements in technology and the development of more portable, less expensive machines with improved resolution (Ghamkhar et al 2010, Hing et al 2009). For rehabilitative USI, it is reasonable to use low-resolution machines for many practical purposes, for example examination of muscle morphology and activation (Hides et al 1998). With an adequate level of anatomical knowledge, it is reasonable to assume that physiotherapists trained in using USI could use this tool to quantitatively assess muscle morphological and functional issues such as DRA.

Therefore, the present study had two aims. The first aim was to establish and then compare the intra-session and inter-session reliability of an experienced versus a novice sonographer to measure IRD in healthy participants. The second aim was to also establish and then compare the intra-session reliability of using a high-resolution versus a low-resolution ultrasound machine to measure IRD in healthy participants.

METHODS

Design

A cross sectional, observational study.

Participants

Thirty healthy males and females (nulliparous, primiparous and multiparous) over the age of 18 years were recruited for this study. Participants were recruited, using advertisements, from the AUT University physiotherapy clinic and AUT University Campus.

Participants met the inclusion criteria if they were healthy individuals over the age of 18 years, could participate in at least one testing session, and were able to perform the required abdominal contractions in supine lying. Participants were excluded if they had neuromuscular or joint disease; significant spinal abnormality (eg, scoliosis); inflammatory, rheumatologic or connective tissue disease; or any medical condition which would prohibit active abdominal muscle contraction i.e. recent abdominal or gynaecological surgery. This study was approved by the Auckland University of Technology Ethics Committee (AUTEC) (Authorisation reference 13/132). Signed written informed consent was obtained before participation in this study.

Instrumentation and examination

Two independent examiners: a novice sonographer (an undergraduate fourth year physiotherapy student) and an experienced sonographer (eight years' sonography experience) performed sixteen measurements of the IRD on the same participant, using both low-resolution USI (Chison ultrasound machine) and high-resolution (Phillips iu22 machine) USI.

Prior to the first scanning session, the novice sonographer attended two, two hour training sessions held by the experienced sonographer. These sessions consisted of basic training in the use of USI and identification of abdominal anatomy, and measurement of IRD.

Procedures and IRD measurement

Using both the high-resolution and low-resolution machines, IRD measurements were taken at two locations (above and below the umbilicus) under two conditions (abdominal muscles at rest and contracted). The initial measurements occurred during a single session performed on the same day, as per the protocol described by Chiarello and McAuley (2013).

The desired measurement locations were marked with a marker pen at 2cm above the umbilicus (supra-umbilical, SU) and at 2cm below the umbilicus (infra-umbilical, IU) (Figure 1). The measurement points were marked on the participant's abdomen prior to the examination session to ensure standardised positioning of the ultrasound transducer placement between the two examiners (Mota et al 2012). These anatomical locations have previously been reported and have been established as having high intra-rater and inter-rater reliability in the quantification of IRD using USI (Boissonnault and Blaschak 1988, Chiarello et al 2005, Chiarello and McAuley 2013, Chiarello et al 2012).

Figure 1: Measurement location 2cm above and 2cm below the umbilicus

Previous investigation of DRA using USI have measured IRD with the abdominal muscles at rest (Gilleard and Brown 1996, Mota et al 2013) and contracted (Chiarello and McAuley 2013, Mota et al 2013). To measure the IRD with the abdominal muscles at rest; each participant was positioned lying supine, knees bent to 90 degrees, arms alongside the body, and feet resting on the plinth (Figure 2). A pillow was placed under the participant's head for comfort during the procedure (Mota et al 2012). To measure the IRD with the abdominal muscles contracted, each participant crossed their arms over their chest and raised their head until the scapulae were raised off the plinth surface (Figure 3). The participants maintained this partial curl-up while the examiner measured the IRD with the USI.

To avoid order effects, randomisation of the following conditions was achieved for all participants from rolling a dice: 1) novice versus experienced sonographer, 2) high-resolution versus low-resolution USI, 3) rested versus contracted abdominals, and 4) SU versus IU measurement location.

Figure 2: Abdominal resting position

Figure 3: Abdominal curl-up contraction

Ten participants returned for testing in order to assess between-session reliability. There was a five week period between the initial measurement and follow up session.

Ultrasound imaging

All IRD measurements were attained using a Chison 8300 Deluxe (Chison Medical Imaging Co. Ltd., China) ultrasound machine (low-resolution) and Phillips iU22 (Royal Philips Electronics, The Netherlands) ultrasound machine (high-resolution). Although the use of both curvi-linear transducers (Chiarello and McAuley 2013) and linear transducers (Barbosa et al 2013, Mota et al 2012, Mota et al 2013) have been reported for IRD measurement, it was decided to use linear transducers as these gave the clearest images during pilot testing. A 12-5 MHz linear transducer was used for the high-resolution scanning whilst a 7.5 MHz linear transducer was used for the low-resolution scanning.

The linear transducer was aligned over the marking made on the participant's abdomen. The examiners adjusted the orientation of the transducer and positioned this on the participant's abdomen until the medial borders of both rectus abdominis muscles were clearly visualised (Mota et al 2012) (Figure 4, Figure 5). Ample amounts of transmission gel was applied by the sonographer to ensure that the least amount of transducer pressure was used in order to clearly visualise the medial borders of both rectus abdominis muscles. Once the examiner was satisfied, a static image was captured, allowing calculation of the IRD using the digital measurement caliper setting on the machine (Figure 4, Figure 5).

Two images were captured for each of the testing conditions. There was a one minute rest period between the two images captured. All images were captured at the end of expiration for both the rested and contracted conditions. The focus, depth,

Figure 4: Inter-recti distance (IRD) as seen with low-resolution ultrasound imaging

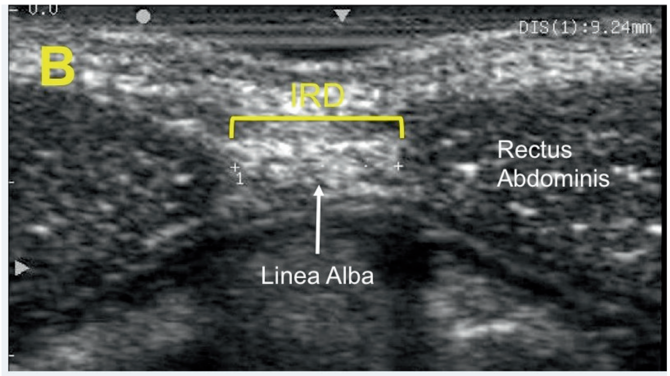
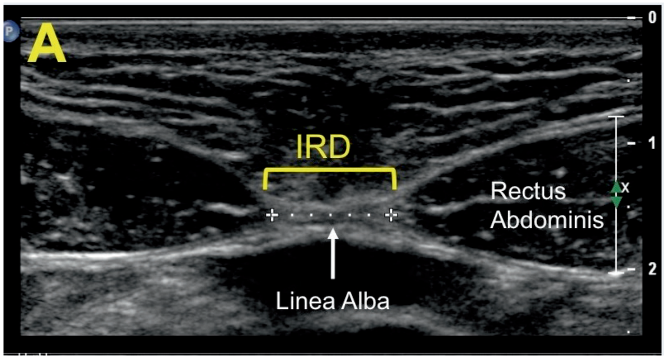


Figure 5: Inter-recti distance (IRD) as seen with high-resolution ultrasound imaging



and contrast settings were manipulated individually to increase image clarity of the rectus abdominis borders and IRD and to differentiate from surrounding anatomical structures.

Statistical analysis

In order to allow ease of comparison of reliability studies which examine USI, it has been advocated that the following statistical analyses are performed: intra-class correlation coefficients (ICC), standard error of measurement (SEM), minimal detectable change score (MDC) and Bland-Altman plots (Whittaker and Stokes 2011, Whittaker et al 2007).

The first aim of the present study was to establish the intra-session and inter-session reliability of an experienced versus a novice sonographer to measure the IRD. For the measurement of intra-session reliability of the experienced and novice sonographer individually, two-way random, single measures ICC (2,1), with 95% confidence intervals (CI) were calculated. Standard error of measurement (SEM) ($SEM=StandardDeviation_{pooled} \times \sqrt{1-ICC}$) and minimal detectable change (MDC) at the 95% CI ($MDC=1.96 \times \sqrt{2} \times SEM$) were also calculated. These calculations were made across the different variables: high-resolution versus low-resolution USI; SU versus IU IRD; and rested versus contracted state.

The second aim of the present study was to establish the intra-session reliability of using a high-resolution versus a low-resolution ultrasound machine to measure the IRD. To achieve this two-way random, average measures ICC (2,k) (therefore taking into account both sonographers), with 95% CI were calculated. SEM and MDC values were also calculated as previously described.

For qualitative assessment of the reliability results, ICC values of less than 0-0.5 represent very low reliability, 0.5-0.7 low, 0.7-0.9 high, and greater than 0.9 represent very high reliability (Hides et al 2009, Mota et al 2012).

As a measure of construct validity, student t-tests were conducted to conclude if there were statistical differences in IRD measurements, 1) between the experienced and novice sonographer and, 2) between the high-resolution versus a low-resolution USI. The statistical significance level was set $p < 0.05$.

Bland-Altman plots were used to provide a graphical representation of some of the key reliability findings (Bland and Altman 1986). All statistical analysis was performed using SPSS statistical software package, version 21 (SPSS Inc., Chicago, IL, USA).

RESULTS

Thirty healthy volunteers (14 male and 16 female) participated in this study (Table 1). The mean age and body mass index (BMI) of all participants was 24.37 years (range 20-53 years) and 23.89 kg/m^2 respectively. Of the 14 male participants, the mean age was 24.21 years (range 20-53 years) with a BMI of 24.38 kg/m2. Of the 16 female participants, three had had previous pregnancies (range 1-4 children), mean age of 36 years (range 27-43) and mean BMI 21.47 kg/m2. The additional 13 participants were nulliparous females, mean age of 21.85 years (range 20- 26 years) and mean BMI of 23.92 kg/m2.

presented in Table 2. There was no significant difference seen when comparing high- versus low-resolution USI (SU p=0.91, IU p=0.11) at both anatomical locations (Table 2).

Pooled data of the HRUS and LRUS machines in the measurement of the IRD at the SU and IU locations during the concentric contraction are presented in Table 3. There was no significant difference seen when comparing high- versus low-resolution USI (SU p=0.35, IU p=0.68) at both anatomical locations.

Intra-rater, within-session reliability

Generally the intra-rater, within session reliability of measuring IRD, irrespective of the condition (i.e. novice versus experienced sonographer, SU versus IU measurement, rest versus contracted), was very high (ICC>0.91). The exception was the reliability of the novice sonographer measuring IRD at the IU location with the LRUS, which showed good reliability (ICC=0.89) (Table 4).

Confirmation of the excellent levels of reliability recorded were the small measurement error that was evident with small SEM values (range 0.02cm - 0.17cm) and MDC values (0.05cm - 0.48cm) indicating good precision. In order to assess whether there was a difference in mean measures between the novice's and experienced sonographer's, student t tests (p<0.05), were calculated for the different conditions. These results demonstrated no significant differences between the novice's and experienced sonographer's measurements across all conditions (p>0.14) (Table 4).

Table 1: Demographic information

	All (n=30)	Men (n=14)	Female (Nulliparous) (n=13)	Female (Postpartum) (n=3)
Age (years)	24.37 SD 7.40	24.21 SD 8.35	21.85 SD 1.88	36 SD 6.68
Height (cm)	173.13 SD 8.26	178.73 SD 5.98	168.66 SD 7.39	166.33 SD 0.47
Weight (kg)	72.02 SD 12.33	78.21 SD 11.37	68.28 SD 10.49	59.37 SD 6.45
BMI (kg/m^2)	23.89 SD 2.76	24.38 SD 2.5	23.92 SD 2.81	21.47 SD 2.44

Note. BMI = Body mass index, n = participant numbers; [a]Data are mean and standard deviation (SD).

Table 2: High and low Resolution USI of IRD at rest (Pooled Data)

	SU IRD (cm)	95% CI (cm)	ICC(2,k) (95% CI)	IU IRD (cm)	95% CI (cm)	ICC(2,k) (95% CI)
HRUS	1.46 SD 0.57	1.36 - 1.56	0.97 (0.94-0.98)	0.53 SD 0.28	0.48-0.58	0.98 (0.96-0.99)
LRUS	1.47 SD 0.57	1.37 - 1.57	0.97 (0.94-0.98)	0.59 SD 0.32	0.53-0.65	0.76 (0.58-0.87)
T-test	0.91*			0.11*		

Note. SU = supra umbilicus. IU = infra umbilicus. IRD = inter recti distance. HRUS = high-resolution ultrasound. LRUS = low-resolution ultrasound. CI = confidence interval. ICC = intraclass correlation coefficient; [a]Data are mean and standard deviation (SD), except where otherwise indicated. * p<0.05

Ultrasound Measurements at Rest and During Concentric Contraction

Pooled data (i.e. for both sonographers) for the high-resolution ultrasound (HRUS) and low-resolution ultrasound (LRUS) measurement of IRD at rest at both the SU and IU locations are

Bland-Altman plots representing some of the key within-session analyses (comparing the difference between the results, plotted against their average) are shown in Figures 6, 7, 8 and 9.

Intra-rater, between-session reliability

The ICC values representing intra-rater, between-session reliability of measuring the IRD at rest and during contraction

Table 3: High and low Resolution USI of IRD whilst contracted (Pooled Data)

	SU IRD (cm)	95% CI (cm)	ICC(2,k) (95% CI)	IU IRD (cm)	95% CI (cm)	ICC(2,k) (95% CI)
HRUS	1.40 SD 0.54	1.30-1.50	0.94 (0.90-0.97)	0.84 SD 0.48	0.76-0.93	0.80 (0.65-0.90)
LRUS	1.33 SD 0.51	1.24-1.42	0.92 (0.86-0.96)	0.82 SD 0.38	0.75-0.89	0.91 (0.84-0.95)
T-test	0.35*			0.68*		

Note. SU = supra umbilicus. IU = infra umbilicus. IRD = inter recti distance. HRUS = high-resolution ultrasound. LRUS = low-resolution ultrasound. CI = confidence interval. ICC = intraclass correlation coefficient; [a]Data are mean and standard deviation (SD), except where otherwise indicated. * p<0.05

Table 4: Intra-rater, within-session reliability of measuring IRD at rest and contracted (HRUS vs. LRUS) (n=30)

Location	Sonographer	Mean IRD SD (cm)	ICC (2,1)	ICC 95% CI	SEM (cm)	MDC (cm)	T-test
SU rest							
HRUS	Experienced	1.49 SD 0.65	0.97	0.94-0.99	0.11	0.31	0.57*
	Novice	1.43 SD 0.59	0.98	0.97-0.99	0.07	0.19	
LRUS	Experienced	1.46 SD 0.56	0.92	0.84-0.96	0.16	0.45	0.85*
	Novice	1.48 SD 0.56	0.95	0.90-0.98	0.13	0.35	
IU rest							
HURS	Experienced	0.50 SD 0.37	0.98	0.96-0.99	0.05	0.14	0.34*
	Novice	0.55 SD 0.11	0.98	0.96-0.99	0.02	0.05	
LRUS	Experienced	0.61 SD 0.46	0.96	0.92-0.98	0.08	0.23	0.20*
	Novice	0.63 SD 0.17	0.89	0.78-0.95	0.06	0.16	
SU contracted							
HRUS	Experienced	1.47 SD 0.61	0.96	0.91-0.98	0.12	0.34	0.15*
	Novice	1.33 SD 0.46	0.96	0.92-0.98	0.09	0.25	
LRUS	Experienced	1.36 SD 0.56	0.91	0.82-0.96	0.17	0.47	0.53*
	Novice	1.3 SD 0.44	0.95	0.89-0.97	0.10	0.28	
IU contracted							
HRUS	Experienced	0.91 SD 0.57	0.91	0.81-0.95	0.17	0.48	0.14*
	Novice	0.78 SD 0.33	0.93	0.86-0.97	0.09	0.25	
LRUS	Experienced	0.84 SD 0.44	0.92	0.84-0.96	0.12	0.34	0.53*
	Novice	0.79 SD 0.31	0.94	0.89-0.97	0.08	0.21	

Note. SU = supra umbilicus. IU = infra umbilicus. IRD = inter recti distance. HRUS = high-resolution ultrasound. LRUS = low-resolution ultrasound. cm = centimetres. SD = standard deviation from the mean. CI = confidence interval. ICC = Intra-class correlation coefficient. SEM = standard error of measurement. n = participant numbers; * For differences in mean values, p<0.05

(HRUS vs. LRUS) are presented in Table 5. There was a five week period between the initial measurement and follow up session. Ten participants attended the first and second testing sessions for between-session analysis.

The between-session reliability of measuring IRD, irrespective of condition, for the experienced sonographer demonstrated good to very good levels of reliability (ICC 0.79-0.98) with a low SEM (0.09-0.30cm) and MDC (0.25-0.82cm). However, the novice sonographer demonstrated between low to high reliability (ICC -0.51-0.88) for

Figure 6: Bland-Altman graph (difference versus average) for both sonographers (pooled data) for measurement of the IRD at the supra-umbilical location during the rested condition using high-resolution USI. Hashed line indicates bias. Solid lines indicate limits of agreement (95%)

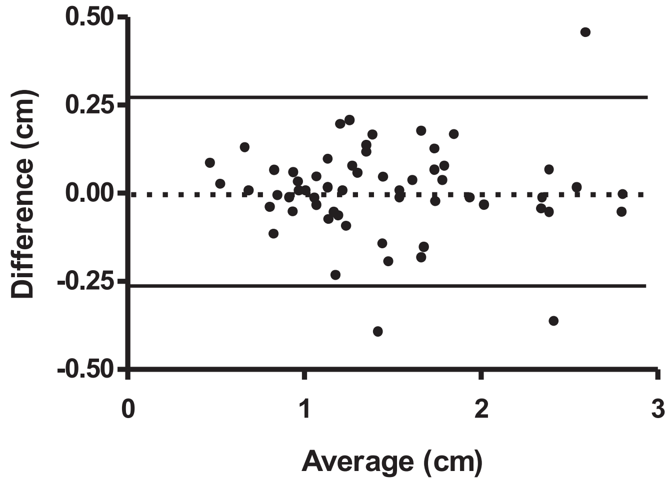
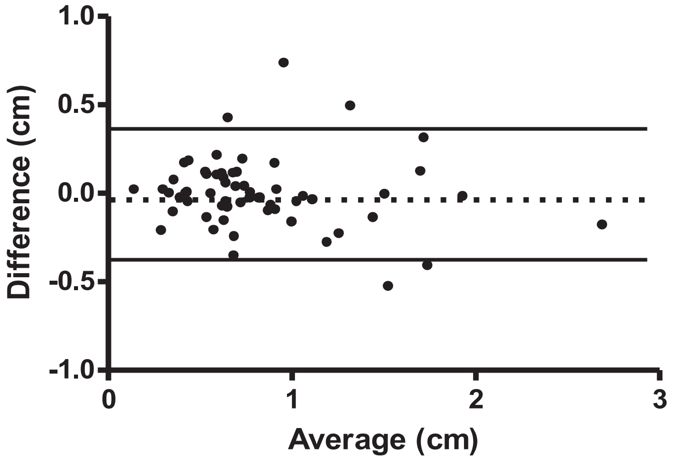


Figure 7: Bland-Altman graph (difference versus average) for both sonographers (pooled data) for measurement of the IRD at the infra-umbilical location during the contracted condition using high-resolution USI. Hashed line indicates bias. Solid lines indicate limits of agreement (95%)



IRD measurements depending on the different conditions (Table 5). Furthermore, the SEM (0.15-0.95cm) values for the novice sonographer's measurements of the IRD illustrated greater variance compared to the experienced sonographer (Table 5). For the mean IRD measurement, no significant differences between the novice's and experienced sonographers' measurements across all conditions were seen (p>0.17) (Table 5).

Inter-rater, Between-session Reliability

The ICC values representing inter-rater, between-session reliability of measuring the IRD at rest and during contraction (HRUS vs. LRUS) are presented in Table 6. The results for both high- and low-resolution USI, demonstrated excellent reliability for the SU and IU IRD measurements (Table 6). The low SEM values (HRUS 0.14-0.27 and LRUS 0.07-0.60) indicate low measurement error (Table 6). At the SU location measurements

Figure 8: Bland-Altman graph (difference versus average) for both sonographers (pooled data) for measurement of the IRD at the infra-umbilical location during the contracted condition using low-resolution USI. Hashed line indicates bias. Solid lines indicate limits of agreement (95%)

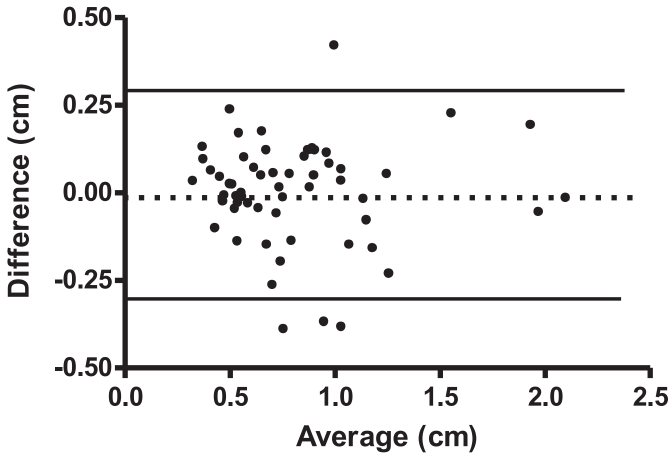
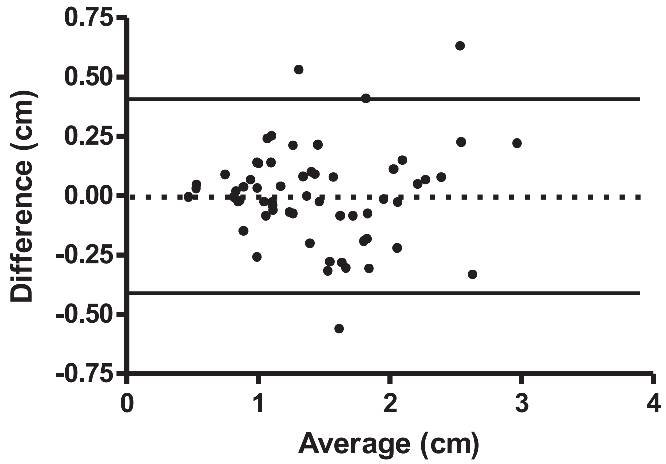


Figure 9: Bland-Altman graph (difference versus average) for both sonographers (pooled data) for measurement of the IRD at the supra-umbilical location during the rested condition using low-resolution USI. Hashed line indicates bias. Solid lines indicate limits of agreement (95%)



demonstrated excellent reliability (ICC >0.94) for high- and low-resolution USI (Table 6). At the IU location measurements demonstrated moderate to high reliability (ICC range 0.65-0.83) for high- versus low-resolution USI.

DISCUSSION

This present study examined many aspects of reliability of IRD measurement, in healthy participants, including the intra-session and inter-session reliability of an experienced versus a novice sonographer. The intra-rater, within-session reliability of measuring the IRD irrespective of the condition was very high. These results demonstrated no significant differences between both sonographers' measurements. Whereas the intra-rater, between-session reliability of measuring the IRD for the experienced sonographer demonstrated good to very good

Table 5: Intra-rater, between-session reliability of measuring IRD at rest and contracted (HRUS vs. LRUS) (n=10)

Location	Sonographer	Mean IRD SD (cm)	ICC(2,1)	ICC 95% CI	SEM (cm)	MDC (cm)	T-test
SU rest							
HRUS	Experienced	1.61 SD 0.66	0.93	0.75-0.98	0.17	0.48	0.72*
	Novice	1.54 SD 0.52	0.88	0.58-0.97	0.18	0.50	
LRUS	Experienced	1.53 SD 0.63	0.98	0.93-0.99	0.09	0.25	0.51*
	Novice	1.64 SD 0.59	0.88	0.59-0.97	0.20	0.56	
IU rest							
HRUS	Experienced	0.72 SD 0.52	0.79	0.36-0.94	0.24	0.66	0.87*
	Novice	0.71 SD 0.40	0.04	-0.32-0.54	0.39	1.08	
LRUS	Experienced	0.78 SD 0.54	0.97	0.87-0.99	0.09	0.25	0.53*
	Novice	0.68 SD 0.22	-0.51	-0.63-0.57	0.95	2.61	
SU contracted							
HRUS	Experienced	1.68 SD 0.65	0.94	0.78-0.98	0.16	0.44	0.25*
	Novice	1.46 SD 0.58	0.59	-0.07-0.89	0.40	1.10	
LRUS	Experienced	1.51 SD 0.59	0.87	0.57-0.97	0.21	0.59	0.96*
	Novice	1.51 SD 0.60	0.85	0.51-0.96	0.23	0.64	
IU contracted							
HRUS	Experienced	1.02 SD 0.74	0.92	0.7-0.98	0.21	0.57	0.17*
	Novice	0.78 SD 0.37	0.2	-0.17-0.65	0.33	0.91	
LRUS	Experienced	0.99 SD 0.65	0.79	0.36-0.94	0.30	0.82	0.22*
	Novice	0.82 SD 0.35	0.26	-0.4-0.75	0.30	0.83	

Note. SU = supra umbilicus. IU = infra umbilicus. IRD = inter recti distance. HRUS = high-resolution ultrasound. LRUS = low-resolution ultrasound. cm = centimetres. SD = standard deviation from the mean. CI = confidence interval. ICC = Intra-class correlation coefficient. SEM = standard error of measurement. n = participant numbers; * For differences in mean values, $p<0.05$

levels of reliability, the novice sonographer demonstrated low to high reliability with a greater variance.

Furthermore, our study examined the intra-session reliability of using high-resolution versus low-resolution USI to measure IRD. The results for both resolution qualities, demonstrated excellent reliability for the SU and IU IRD measurements. Pooled data for both sonographers for measurement of IRD during the resting and contracted conditions at both locations (SU and IU) revealed strong agreement between both HRUS and LRUS for both anatomical positions tested. No significant differences were recorded for the SU and IU locations.

In this present study, measurement of the IRD at the SU location revealed very high intra-session and inter-rater reliability (ICC 0.91-0.98). The intra-rater, within session IU ICC values were very good (0.89-0.98) but slightly lower than SU measurements. These findings are consistent with those of previous studies measuring IRD using USI (Liaw et al 2011, Mota et al 2012, Mota et al 2013). Mota et al (2012) demonstrated excellent reliability 2cm above the umbilicus (ICC 0.87) and moderate-good reliability at 2cm below the umbilicus (ICC 0.78). Further to this finding, de Almeida Mendes et al (2007) have stated that it is more difficult to attain clear, consistent measures of the IRD at the IU location with USI. This decreased accuracy at the IU location has been suggested to occur due to the constitution of the rectus sheath affecting the formation of the linea alba and making identification of the borders more challenging (Barbosa et al 2013). It has also been suggested that at the IU location there is reduced definition of the posterior layer of recti muscles and the presence of large abdominal laxity. For example, amongst humans there is typically greater subcutaneous fat in this region (Barbosa et al 2013, de Almeida Mendes et al 2007). The fatty deposits at the IU location may attenuate the sound beam more, which can lead to reduced clarity of image.

In this present study we found that there were no significant differences for the measurement of IRD, across all conditions, between the high and low-resolution USI, both demonstrated good to very good reliability. In regard to the comparison of high-resolution versus low-resolution USI, Hing et al (2009) demonstrated similar results. They found that LRUS is an

Table 6: Inter-rater, between-session reliability of measuring IRD at rest and contracted (HRUS vs. LRUS) (n=10)

Location	ICC(2,1)	95% CI	SEM (cm)	MDC (cm)
SU rest				
HRUS	0.94	0.85-0.98	0.14	0.40
LRUS	0.99	0.96-0.99	0.07	0.20
IU rest				
HRUS	0.65	0.08-0.90	0.27	0.75
LRUS	0.65	0.09-0.90	0.60	1.67
SU contract				
HRUS	0.94	0.84-0.98	0.11	0.31
LRUS	0.97	0.73-0.97	0.10	0.28
IU contract				
HRUS	0.83	0.56-0.95	0.24	0.67
LRUS	0.83	0.56-0.95	0.22	0.60

Note. SU = supra umbilicus. IU = infra umbilicus. HRUS = high resolution ultrasound. LRUS = low resolution ultrasound. CI = confidence interval. ICC = Intra-class correlation coefficient. SEM = standard error of measurement. MDC = minimal detectable change. n = participant numbers

effective and reliable tool for measuring lower extremity muscle parameters. These authors reported very good within-session reliability for all lower limb measurements of dorsal plantar thickness and medial-lateral length of abductor hallucis, using similar machines for both HRUS (ICC 0.95-0.99) and LRUS (0.92-0.99). Regardless of the type of resolution quality, intra-tester reliability was found to be very high (Hing et al 2009).

Our results demonstrated very good intra-rater, between-session reliability for the experienced sonographer for IRD measurement. However; the intra-rater, between-session reliability of IRD measurements by the novice sonographer ranged from low to high and were not consistent for the rest and contracted conditions (Table 5). The lack of precision and wide 95% confidence intervals confirm the low intra-rater, between-session reliability of the novice sonographer for these measurements. Hides et al (2007) demonstrated similar findings for novice sonographers. The reliability of measuring the slide of the anterior abdominal fascia by the novice sonographer was poor within-session (ICC=0.44) and between-session (ICC =0.36) (Hides et al 2007). In addition to this, Teyhen et al (2005) reported very good intra-rater reliability for measurement of two ultrasound images of the transverse abdominis and a combined measure of the antero-lateral abdominal muscles. However the novice sonographer demonstrated variable reliability for attainment of images and subsequent measurement at both rest and contraction (Teyhen et al 2005).

Hides et al (2007) suggested these poor reliability results were a reflection of the amount of training undertaken by the novice sonographer. In their study, the novice sonographer received eight hours of training of the anterolateral abdominal muscles with USI (Hides et al 2007). Inconsistencies in the pattern of results suggest that for a novice sonographer, this training was inadequate. Our study suggested that the amount of training received by the novice sonographer may not have transferred well across the five week delay between testing sessions. Although previous studies (Hides et al 2007, Teyhen et al 2005) used novice sonographers in conducting abdominal measurements, we acknowledge that these are very different measurements from ours.

The implications of this present study include the potential of utilising low-resolution USI in the clinical environment more regularly. The results of this present study indicate that images obtained from both the high-resolution (Phillips IU22) and low-resolution (Chison) machines displayed consistent, highly comparable results across all measurements examined. There was no significant difference calculated for the measurement of IRD between the machines, therefore validating the use of either ultrasound machine within the clinical setting for examination of muscle morphology and activation.

There were several limitations to this study that should be considered. We recruited a convenience sample of healthy participants with a small number of postpartum women being examined. It may be more challenging to reliably measure the IRD of symptomatic participants with abdominal impairments. Future research should include testing a wide spectrum of participants, as results illustrated in this study may not necessarily generalise to pathological populations.

A potential source of error was the performance of the abdominal contraction during the "contracted" IRD measurements. Although the instruction of how to perform the abdominal contraction was standardised, the end position was not standardised. The performance may have varied due to factors such as participant motivation, motor control, and skill during the curl-up contraction. The intensity of abdominal contraction and varied effort made by the participants may have induced movements under the transducer and may have varied the relevant morphology of the underlying abdominal musculature and linea alba. For example, during the curl-up contraction the contours of the abdominal wall may have varied between participants. Accurate IRD interpretation depends upon maintaining a relatively stationary transducer position during abdominal contraction. To mitigate some of the potential sources of error, the transducer location on the abdominal wall, room temperature, position of the participant on the plinth were standardised.

CONCLUSION

Low-resolution USI has shown promise as a reliable and valid tool for measuring the IRD in healthy participants. Low-resolution USI has advantages as a cost-effective, portable, safe and clinically accessible method of examination for static and dynamic muscle assessment. There is growing access to low-resolution USI and burgeoning evidence in support of its use by physiotherapists in clinical practice. While the experienced sonographer maintained high between-session reliability, the novice sonographer was unable to maintain this over time. Inconsistencies in the novice sonographer inter-session results suggest that revision of ultrasound training should be undertaken to ensure the consistency of IRD measurements remains high. The potential benefits of low-resolution USI are appealing, and the results of the present study indicate its potential to be implemented clinically in the future.

KEY POINTS

- Both low-resolution and high-resolution USI demonstrate good to very good reliability in the measurement of IRD in healthy participants. There does not appear to be differences in IRD measurements between both resolution qualities. This is of benefit to clinicians where access to low-resolution USI is greater.
- Novice and experienced sonographers demonstrate good to very good reliability in the measurement of IRD within a single scanning session
- Although the reliability for the experienced sonographer remained high across scanning sessions, the reliability for the novice sonographer decreased. This indicates that ultrasound training for the novice sonographer needs to be maintained across time to potentially improve reliability.

ACKNOWLEDGEMENTS

The authors thank the participants in this study. The authors would also like to thank the staff of Horizon Radiology (AUT Campus) for their assistance with this project.

PERMISSIONS

This study was approved by the Auckland University of Technology Ethics Committee (AUTEC) (Authorisation reference 13/132). Signed written informed consent was obtained before participation in this study.

The photographs used do not identify the participant as all facial features have been removed.

DISCLOSURES

No specific funding was sought for this project. No conflicts of interest have been identified for this research.

ADDRESS FOR CORRESPONDENCE

Dr Richard Ellis, Senior Lecturer, Health & Rehabilitation Research Institute, School of Rehabilitation and Occupation Studies, Faculty of Health and Environmental Sciences, AUT University, Private Bag 92006, Auckland 1142, New Zealand.
Email: richard.ellis@aut.ac.nz

REFERENCES

Barbosa S, Moreira RA, Coca Velarde LG (2013) Diastasis of rectus abdominis in the immediate puerperium: Correlation between imaging diagnosis and clinical examination. *Archives of Gynecology and Obstetrics* 288: 1-5. http://dx.doi.org/10.1007/s00404-013-2725-z

Bland J, Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *The Lancet* 327: 307-310. http://dx.doi.org/10.1016/S0140-6736(86)90837-8

Boissonnault JS, Blaschak MJ (1988) Incidence of diastasis recti abdominis during the childbearing year. *Cochrane Database of Systematic Reviews*: 1082-1086.

Boxer S, Jones S (1997) Intra-rater reliability of rectus abdominis diastasis measurement using dial calipers. *Cochrane Database of Systematic Reviews*: 109-114.

Bursch SG (1987) Interrater reliability of diastasis recti abdominis measurement. *Cochrane Database of Systematic Reviews*: 1077-1079.

Chiarello CM, Falzone LA, McCaslin KE, Patel MN, Ulery KR (2005) The effects of an exercise program on diastasis recti abdominis in pregnant women. *Cochrane Database of Systematic Reviews*: 11-16.

Chiarello CM, McAuley JA (2013) Concurrent validity of calipers and ultrasound imaging to measure inter-recti distance. *Journal of Orthopaedic & Sports Physical Therapy* 43: 495-503. http://dx.doi.org/10.2519/jospt.2013.4449

Chiarello CM, Zellers JA, Sage-King FM (2012) Predictors of inter-recti distance in cadavers. *Journal of Women's Health Physical Therapy* 36: 125-130. http://dx.doi.org/10.1097/JWH.0b013e318276f60e

Coldron Y, Stokes MJ, Newham DJ, Cook K (2008) Postpartum characteristics of rectus abdominis on ultrasound imaging. *Manual Therapy* 13: 112-121. http://dx.doi.org/10.1016/j.math.2006.10.001

de Almeida Mendes D, Nahas F, Veiga D (2007) Ultrasonography to measure the width of rectus abdominis muscle diastasis. *Acta Cirurgica Brasileira* 22: 182-186. http://dx.doi.org/10.1590/S0102-86502007000300005

Ghamkhar L, Emami M, Mohseni-Bandpei MA, Behtash H (2010) Application of rehabilitative ultrasound in the assessment of low back pain: A literature review. *Journal of Bodywork and Movement Therapies* 15: 465-477. http://dx.doi.org/10.1016/j.jbmt.2010.07.003

Gilleard WL, Brown JMM (1996) Structure and function of the abdominal muscles in primigravid subjects during pregnancy and the immediate postbirth period. *Cochrane Database of Systematic Reviews*: 750-762.

Hides JA, Belavý DL, Cassar L, Williams M, Wilson SJ, Richardson CA (2009) Altered response of the anterolateral abdominal muscles to simulated weight-bearing in subjects with low back pain. *European Spine Journal* 18: 410-418. http://dx.doi.org/10.1007/s00586-008-0827-2

Hides JA, Miokovic T, Belavy DL, Stanton WR, Richardson CA (2007) Ultrasound imaging assessment of abdominal muscle function during drawing-in of the abdominal wall: An intrarater reliability study. *Journal of Orthopaedic & Sports Physical Therapy* 37: 480-486. http://dx.doi.org/10.2519/jospt.2007.2416

Hides JA, Richardson CA, Jull GA (1998) Use of real-time ultrasound imaging for feedback in rehabilitation. *Cochrane Database of Systematic Reviews*: 125-131.

Hing WA, Rome K, Cameron AF (2009) Reliability of measuring abductor hallucis muscle parameters using two different ultrasound machines. *Journal of Foot and Ankle Research* 2: 1757-1146. http://dx.doi.org/10.1186/1757-1146-2-33

Hsia M, Jones S (2000) Natural resolution of rectus abdominis diastasis: Two single case studies. *Cochrane Database of Systematic Reviews*: 301-307.

Liaw LJ, Hsu MJ, Liao CF, Liu MF, Hsu AT (2011) The relationships between inter-recti distance measured by ultrasound imaging and abdominal muscle function in postpartum women: A 6-month follow-up study. *Journal of Orthopaedic & Sports Physical Therapy* 41: 435-443. http://dx.doi.org/10.2519/jospt.2011.3507

Lockwood D, Einstein D, Davros W (2006) Diagnostic imaging: Radiation dose and patients' concerns. *Cleveland Clinic Journal of Medicine* 73: 583-586. http://dx.doi.org/10.3949/ccjm.73.6.583

McPhail I (2009) Abdominal aortic aneurysm and diastasis recti. *Angiology* 56: 736-739.

Mota P, Pascoal AG, Sancho F, Bø K (2012) Test-retest and intrarater reliability of 2-dimensional ultrasound measurements of distance between rectus abdominis in women. *Journal of Orthopaedic & Sports Physical Therapy* 42: 940-946. http://dx.doi.org/10.2519/jospt.2012.4115

Mota P, Pascoal AG, Sancho F, Carita AI, Bø K (2013) Reliability of the inter-rectus distance measured by palpation: Comparison of palpation and ultrasound measurements. *Cochrane Database of Systematic*.

Rankin G, Stokes M, Newham DJ (2006) Abdominal muscle size and symmetry in normal subjects. *Muscle & Nerve* 34: 320-326. http://dx.doi.org/10.1002/mus.20589

Rath AM, Attali P, Dumas JL, Goldlust D, Zhang J, Chevrel JP (1996) The abdominal linea alba: An anatomo-radiologic and biomechanical study. *Surgical and Radiologic Anatomy* 18: 281-288. http://dx.doi.org/10.1007/BF01627606

Spitznagle TM, Leong FC, Van Dillen LR (2012) Reliability and validity of panoramic ultrasound for muscle quantification. *Ultrasound in medicine & biology* 18: 321-328.

Teyhen DS, Miltenberger CE, Deiters HM, Del Toro YM, Pulliam JN, Childs JD, Boyles RE, Flynn TW (2005) The use of ultrasound imaging of the abdominal drawing-in maneuver in subjects with low back pain. *Cochrane Database of Systematic Reviews*: 346-355. http://dx.doi.org/10.2519/jospt.2011.3682

Whittaker JL, Stokes M (2011) Ultrasound imaging and muscle function. *Journal of Orthopaedic & Sports Physical Therapy* 41: 572-580. http://dx.doi.org/10.2519/jospt.2011.3682

Whittaker JL, Teyhen DS, Elliott JM, Cook K, Langevin HM, Dahl HH, Stokes M (2007) Rehabilitative ultrasound imaging: Understanding the technology and its applications. *Journal of Orthopaedic & Sports Physical Therapy* 37: 434-449. http://dx.doi.org/10.2519/jospt.2007.2350