Influence of Ultrasound Transducer Tilt in the Cranial and Caudal Directions on Measurements of Inter-Rectus Distance in Parous Women

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ABSTRACT

Purpose: An increased inter-rectus distance (IRD) can persist after a pregnancy and may be associated with lumbopelvic dysfunction. Ultrasound imaging (USI) is currently the gold standard for measuring IRD; however, no study has explored the need to standardize the transducer angle during these evaluations. The purpose of this study was to determine whether the angle of the ultrasound transducer relative to the underlying abdominal wall has an effect on measurements of IRD in parous women. **Method:** Ultrasound images of the linea alba (LA) were captured from 15 women, at rest and during a head lift, beginning with images acquired perpendicular to the LA at the midline, then tilted in 5° increments to 15° in both the cranial and the caudal directions. Repeated-measures analyses of variance were used to test for systematic differences in IRD measurements among the transducer angles in both the rest and the head-lift conditions. An α of 0.05 was used for all tests. **Results:** No significant effect of transducer angle was found in IRD measurements acquired with participants at rest ($F_{2,24,31.3} = 1.814$; $p = 0.18$) or during a head lift ($F_{3,15,44.1} = 1.315$; $p = 0.28$). **Conclusion:** When using USI, cranial or caudal tilt errors in transducer angle do not appear to pose a problem when measuring IRD.

Key Words: abdominal wall; linea alba; parity; ultrasonography.

RÉSUMÉ

Objectif : une diastase des grands droits (DGD) peut persister après la grossesse et s'associer à une dysfonction lombo-pelvienne. L'échographie est actuellement la norme pour mesurer la DGD, mais aucune étude n'a porté sur la standardisation de l'angle du transducteur pendant ces évaluations. La présente étude visait à déterminer si l'angle du transducteur échographique par rapport à la paroi abdominale sous-jacente influe sur les mesures de la DGD chez les femmes primipares. **Méthodologie :** les chercheurs ont utilisé les images échographiques de la ligne blanche (LB) de 15 femmes, au repos et pendant qu'elles soulevaient la tête, à commencer par des images acquises perpendiculairement à la ligne médiane de la LB, puis inclinées par incréments de cinq degrés jusqu'à concurrence de 15 degrés dans une orientation crânienne, puis caudale. Ils ont utilisé les analyses de mesures de variance répétées pour vérifier les différences systématiques entre les mesures de DGD selon les divers angles du transducteur, à la fois au repos et au moment de soulever la tête. Ils ont privilégié un taux alpha de 0,05 pour tous les tests. **Résultats :** l'angle du transducteur n'avait pas d'effet significatif sur les mesures de la DGD prises chez des participantes au repos ($F_{2,24,31.3} = 1,814$; $p = 0,18$) ou qui soulevaient la tête ($F_{3,15,44.1} = 1,315$; $p = 0,28$). **Conclusion :** à l'échographie, les erreurs d'inclinaison de l'orientation crânienne ou caudale de l'angle du transducteur ne semblent pas poser problème lors de la mesure de la DGD.

Ultrasound imaging (USI) is the gold standard for evaluating abdominal muscle separation, particularly in women after pregnancy.¹ By mid- to late pregnancy, the rectus abdominus (RA) muscle bellies must move laterally to compensate for the expansion of the abdomen, and this lengthens the linea alba (LA). The distance between the RA muscle bellies is referred to as the inter-rectus distance (IRD) and can be measured using USI.^{2,3} There is ambiguity about what constitutes an abnormal IRD, known as diastasis recti (DR). However, research has

suggested that IRD values greater than 2 centimetres at the level of the umbilicus define DR.⁴ DR is estimated to be present in 35%–68% of women in the early postpartum period,^{5,6} and it can persist in the years after a pregnancy.⁷ Currently, only limited information is available regarding the health implications of DR. Research has suggested that an association may exist between DR and reduced abdominal muscle strength and endurance,⁸ lumbopelvic dysfunction, and pain;⁶ however, results are not definitive.⁹ Clinicians currently monitor changes in

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IRD associated with DR recovery, either naturally or in response to interventions.^{7,10}

USI has been shown to provide reliable measurements of IRD.^{11,12} Keshwani and McLean¹¹ found the between-session reliability of IRD measured at or above the level of the umbilicus to be high (intra-class correlation coefficients > 0.90), with a minimal detectable change of less than 0.46 centimetre and a standard error of measurement of less than 0.17 centimetre.¹¹ IRD measured using USI at and above the umbilicus was found to be valid compared with measurements obtained with a surgical compass,¹ and IRD measured below the umbilicus was found to be both less valid¹ and less reliable.¹¹

It is evident from the literature that the angle of the transducer relative to the tissue of interest can affect the validity of the morphologic measurements made using USI.¹³ For example, Whittaker and colleagues¹⁴ found significant differences in the thickness of the transversus abdominus muscle if the transducer was rotated more than 9° in the *z*-direction (rotation) or tilted more than 5° in the cranial–caudal or medial–lateral direction. These researchers also found differences in bladder base position when they tilted the transducer more than 10° in either the cranial or the caudal direction.¹⁴ Investigating the shoulder musculature, Dupont and colleagues¹⁵ found up to a 15% measurement error induced by varying the transducer angle by 30°. These studies suggest that it is important to carefully control the tilt and rotation of the transducer when using USI for musculoskeletal applications.

When measuring IRD in healthy individuals, the sound waves emitted from the ultrasound transducer remain relatively perpendicular to the LA, regardless of the amount of cranial or caudal tilt of the transducer head. However, after childbirth, there is often distortion in the abdominal muscles and fascia,¹⁶ and the sound waves may no longer run perpendicular to the LA. Therefore, the transducer must be held in either the cranial or the caudal direction to acquire a clear image. The amount of tilt used is often a compromise between clearly visualizing the fascial margins on one head of the RA and visualizing both fascial margins simultaneously. When using a linear transducer to optimize image resolution, it is possible to tilt the transducer laterally or rotate it on its axis, but only minimally. The image quality quickly deteriorates because the transducer loses contact with the skin. These errors are unlikely to occur when measuring IRD.

Studies to date have not reported the orientation of the transducer when measuring IRD or the controls in place to ensure that the imaging angle was consistent.^{17–19} It has been recommended to image IRD by holding the transducer perpendicular to the LA and then incorporating tilting until there is a clear transverse image of both RA heads.¹⁰ Currently, we do not know whether transducer angle has an effect on IRD measurements, and

such an investigation has important implications for clinical practice and research. Specifically, physiotherapists who intend to measure changes in IRD over time need to know whether it is necessary to replicate the transducer angle from one day to another. Therefore, the objective of this study was to determine the effect of tilting the transducer cranially or caudally on the resulting IRD, measured using USI in parous women. We hypothesized that there would be a systematic difference in IRD measurements with the application of a cranial or a caudal directional to the transducer.

METHODS

The Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board approved this study (REH-559–13), and all volunteers provided written informed consent before participating.

Participants

A total of 15 parous female participants aged older than 18 years were recruited from the Kingston, Ontario, area and participated in the study through convenience sampling. Our exclusion criteria consisted of women who were pregnant at the time of recruitment and women who reported persistent low back or neck pain.

Ultrasound imaging system specifications

A General Electric Voluson-i ultrasound system (GE Healthcare, Mississauga, ON) was used, and static two-dimensional images were recorded in B-mode using a 10-megahertz linear transducer with a width of 53 millimetres (Model 9L-RS). A trapezoid mode was chosen because it allows the investigator to enlarge the field of view. The output power and gain were adjusted to capture a clear image using the least amount of power.¹⁰ Images were taken with the transducer centred between the bellies of the RA at 3 centimetres and 5 centimetres above the umbilicus, as per previously published protocols.^{1,11} The depth of the image captured was adjusted so that the RA heads could clearly be seen, and the focal point was customized to be just under the LA on each participant.¹⁰ A triaxial accelerometer was attached to the head of the transducer to assess the cranial and caudal angles at which the probe was held (*y*-axis) relative to perpendicular.

Procedure

The same examiner performed all imaging and image processing. The examiner was a physiotherapist with formal postgraduate training in musculoskeletal USI and more than 50 hours of clinical or research experience using USI to evaluate the abdominal musculature. Before testing, the examiner determined which image site (3 cm or 5 cm above the umbilicus) produced the clearest images for each participant and used this site for the study. The clearest image was defined as the location on each participant's abdominal wall that produced images

in which both fascial boundaries of the RA muscles were clearly defined, presumably the angle at which the sound waves emitted from the transducer were relatively perpendicular to most of the LA.

The reference image (considered to be 0° of tilt, or perpendicular to the LA) was the first image captured. Subsequent images were recorded with the transducer head tilted 5°, 10°, and 15° from perpendicular in both the cranial and the caudal directions while the participant remained at rest in a supine position (legs extended); the angles were verified using real-time accelerometer data. The protocol was then repeated while the participant isometrically held a head lift. For the head lift task, participants were instructed to keep their neck in line with their spine and slowly lift their head off a thin pillow; the researcher palpated to verify that their scapula remained in contact with the plinth. A minimum of 1-minute rest was provided between repetitions of the head-lift task.²⁰ Two images were captured at each angle during each task.

Data processing and analysis

The IRD was measured on all images off-line using ImageJ, version 1.46r (National Institutes of Health, Bethesda, MD). It was measured as the linear distance between the posterior–medial fascial borders of each RA head.¹⁰

All data were first confirmed to be normally distributed using the Shapiro–Wilk test. We then used separate repeated-measures analysis of variance models using SPSS, version 14.2 (SPSS Inc., Chicago, IL) to test for systematic differences among trials and transducer angles. An α level of 0.05 was used for all statistical tests.

RESULTS

Complete data sets were acquired from all 15 women. They had a mean age of 39.4 (SD 8.0) years, a mean height of 161.6 (SD 5.7) centimetres, and a mean weight of 76.2 (SD 25.7) kilograms. Five of the women had experienced one term pregnancy, and 10 had experienced two or three term pregnancies. The mean age at birth of their first child was 32.1 (SD 4.7) years. Nine of the women had delivered vaginally, and 6 had delivered by Cesarean section. Seven of the women presented with DR, as defined by an IRD of more than 2.0 centimetres.⁴ For 7 of the participants, the clearest images of the LA were captured at 3 centimetres above the umbilicus; for the other 8 participants, the clearest images were those captured at 5 centimetres above the umbilicus. The difference in anatomical measurement site produced no significant difference in IRD, and there was no significant trial effect that might have indicated fatigue-induced effects.

Table 1 presents the mean (SD) IRDs measured at each transducer angle during each task. The analysis of variance revealed no significant effect of transducer angle

Table 1 Inter-Rectus Distance by Transducer Angle at Rest and during a Head Lift ($n = 15$)

Tilt direction and angle	Mean (SD) cm	
	Rest	Head lift
Cranial		
15°	2.04 (0.68)	1.62 (0.50)
10°	2.05 (0.69)	1.57 (0.51)
5°	2.05 (0.70)	1.65 (0.55)
Perpendicular		
0°	2.03 (0.90)	1.62 (0.52)
Caudal		
5°	2.03 (0.87)	1.64 (0.58)
10°	2.01 (0.89)	1.61 (0.53)
15°	2.02 (0.87)	1.61 (0.56)

at rest ($F_{2,24,31.3} = 1.814$; $p = 0.18$) or during the head lift ($F_{3,15,44.1} = 1.315$; $p = 0.28$).

DISCUSSION

The results of this study suggest that changes in ultrasound transducer angle of up to 15° in the cranial or caudal direction have no significant systematic impact on IRD measured from static ultrasound images recorded from parous women, either when they remain at rest or when they perform a head lift. The largest difference in IRD induced by tilting the transducer away from perpendicular was 0.05 centimetre; this occurred when the transducer was tilted 15° in the cranial direction while the women remained at rest. The magnitude of this error is much smaller than the previously reported minimal detectable change at 3 centimetres and 5 centimetres above the umbilicus (0.31 cm and 0.29 cm, respectively).¹¹ Thus, measurements of IRD obtained by tilting the transducer cranially or caudally to achieve the best possible image quality are unlikely to result in clinically important errors.

Although our results differ from those of Dupont and colleagues¹⁵ and Whittaker and colleagues,¹⁴ this accurately reflects the morphology of the LA. For example, Whittaker and colleagues¹⁴ found that tilting the transducer in the cranial or caudal direction by more than 10° introduced an unacceptable level of error into measurements of the thickness of the muscles of the lateral abdominal wall¹⁴ because the axis of measurement was no longer perpendicular to the tissue of interest. We also angled the transducer in the caudal and cranial directions; however, unlike Whittaker and colleagues,¹⁴ we measured the LA on the plane perpendicular to the axis of the transducer. Measures taken on this plane should not be affected by transducer tilt as long as the distortion of the LA is not too great.

The mean IRD value measured at rest from this sample of 15 women—2.03 (SD 0.66) centimetres—is similar to that described by Coldron and colleagues,⁷ who reported

a mean IRD of 2.33 (SD 0.83) centimetres in women who were 1 year postpartum. Coldron and colleagues⁷ also reported that IRD decreased over the first postpartum year, with an estimated reduction of 0.15 centimetre per month. On the basis of our data, errors in transducer angle were much smaller (0.05 cm) than the expected monthly reduction in IRD over the first 6 months postpartum. Therefore, errors in transducer angle are unlikely to contribute significantly to error when investigating changes in IRD during the acute phase of recovery in postpartum women, particularly if the examiner is kept constant.

This study has several limitations. To begin with, we did not measure or standardize the amount of pressure on the ultrasound transducer while capturing the images. Changing the amount of pressure at the transducer–tissue interface may significantly affect IRD measurements by varying the amount of strain on the tissues. Second, we did not explore the effect of changes in transducer angle on the *x*-plane (lateral and medial tilting) or the *z*-plane (rotation). Although it is possible that errors on these planes could affect IRD measurements, our pilot work suggested that slight errors on these planes ($<5^\circ$) resulted in such poor image quality that they were unlikely to occur in practice. Third, our small sample size may limit the generalizability of our results. On the basis of previous psychometric studies, we advise against taking IRD measurements below the umbilicus,^{1,11} and our results should not be generalized to this position. Finally, to limit the effect of fatigue, we recorded only two images at each transducer tilt angle. Recent reliability analyses have reported results using an average of five images at each measurement site to quantify IRD, so it would have been prudent to measure five images at each transducer tilt angle, at least while the women remained at rest.

CONCLUSION

Errors in transducer angle of up to 15° in both the caudal and the cranial directions are not significant when measuring IRD in parous women using trans-abdominal USI with a high-frequency linear probe. Clinicians and researchers can be confident that tilting the USI transducer to achieve the clearest image of the LA will not reduce their capacity to evaluate changes in IRD over time.

KEY MESSAGES

What is already known on this topic

Ultrasound imaging (USI) has been shown to provide reliable^{11,12} and valid measurements of inter-rectus distance (IRD) when measured at and above the level of the umbilicus.¹ It is evident from the literature that the angle of the transducer relative to the tissue of interest can affect the validity of morphologic measurements made from ultrasound images.^{13,14}

What this study adds

Cranial or caudal variation in transducer angle of 15° or less does not introduce systematic error into IRD measurements made using a high-frequency linear transducer when the researcher measuring the images is kept constant. However, the results of this study should not be generalized to other musculoskeletal structures when conducting USI studies; they apply only to the measurement of IRD.

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