Diastasis rectus abdominis (DRA), the abnormal separation of the right and left rectus abdominis, appears as an increase in the width of the linea alba, or interrecti distance (IRD). The linea alba is a meshwork of connective tissue in which the tendinous insertions of the external oblique, internal oblique, and transversus abdominis muscles intermingle, providing structure and stability to the abdominal wall and trunk. A DRA can indicate connective tissue alterations of the linea alba, an increase in muscle length with consequent altered line of muscle pull, damage of the fixation of the rectus muscles in their sheaths, or a disruption of the entire musculofascial abdominal wall. The anisotropic, directionally dependent behavior of the linea alba, in conjunction with craniocaudal differences in the width and thickness of the linea alba, necessitates IRD measurements both above and below the umbilicus to document the DRA width. Compromising the mechanical function of the trunk, a DRA has been associated with decreased muscle strength and endurance, reduced capacity of abdominal musculature to stabilize the pelvis, related pelvic floor dysfunction, posture abnormalities, and lumbopelvic pain.

Development of a DRA may be due to failure of the abdominal wall to withstand extreme overloading and may stem from different causes in males and females. In males, factors that appear to be related to DRA include increasing age, greater abdominal circumference, weight training, hernia, abdominal aortic aneurysm, and lipodystrophy in HIV-infected men. In addition to these same factors, in females abdominal wall stress frequently begins due to the uterus enlarging during pregnancy, with 27% of women exhibiting a DRA during their second trimester and 66% during the third trimester.
third. Although IRD decreases during the initial postpartum months, it does not completely resolve and typically remains significantly larger than IRD in nulliparous women. In postpartum women, Liaw et al. found that abdominal muscle function and IRD improved at 6 months but were not restored to nulliparous values. At 12 months postpartum, Coldron et al. reported that 48% of women had a significantly larger IRD than nulliparous controls. Ranney found that 39% of 1738 parous women undergoing a hysterectomy several years postpartum still exhibited a DRA. Other reported risk factors for DRA in women include multiparity, multiple gestation, older maternal age, large pregnancy weight gain, and larger babies.

Although there is agreement that a DRA is abnormal, there is no consensus in the literature on the optimal IRD for all adults. Documentation of the size and location of a DRA is important in examining patients with any type of musculoskeletal trunk dysfunction to determine stability and load acceptance, the efficacy of exercise intervention programs, as well as the need for abdominoplasty. Typically, DRA is measured by placing palpat ing fingers between the medial borders of the right and left rectus abdominis muscles, parallel to the linea alba. DRA size is determined by indicating the number of fingers that fit between the 2 muscle bellies at locations above, below, and at the umbilicus while the individual performs a partial curl-up. Clinically, this palpation technique is easy to perform but has not demonstrated adequate reliability and validity. A modification of this palpation technique using nylon dial or digital calipers to measure the IRD has been shown to be reliable in pregnant and postpartum women.

The validity of ultrasound imaging (USI) to measure IRD above the umbilicus has been established. Mendes et al. found no statistically significant difference between suprapubic measurements taken with USI and those directly measured during surgery for abdominoplasty. Good intrarater reliability of IRD measurements made with USI in females has also been demonstrated. Therefore, USI is an accurate and valid method of measuring IRD size and location; however, it requires expensive equipment and extensive examiner training and expertise.

Given the importance of measuring IRD during an examination of abdominal function, an inexpensive, accessible, and easy-to-use tool is necessary. Digital nylon calipers meet the criteria of reliability and ease of use; however, to date, there have found no studies validating digital nylon calipers for measuring IRD. The primary purpose of this investigation was to determine the concurrent validity of digital nylon calipers in comparison to USI for the measurement of IRD. For calipers to be clinically useful tool, they must be valid across gender, parity, and size of the IRD. A secondary purpose of the study was to describe the IRD seen in typical adult males and females.

### METHODS

#### Participants

A sample of convenience, consisting of an ethnically diverse group of 56 English-speaking individuals (11 men, 22 nulliparous women, 23 parous women) between 19 and 64 years of age (Table 1), was recruited from physical therapy private practices in New York City and the student populations at Columbia University and Touro College. The ethnicity of the sample was 66% Caucasian, 12% Asian, 9% Hispanic, 9% mixed, 2% African American, and 2% Middle Eastern. Participants were excluded if they were pregnant; had scarring from previous abdominal surgery such that, on observation of the abdomen, the linea alba or umbilicus was obscured or deformed; had rheumatological or connective tissue disease; or had any medical condition that would prohibit active abdominal muscle contraction. The study protocol was approved by the Columbia University Medical Center Institutional Review Board, and participants signed an informed-consent form following a detailed explanation of all study procedures.

#### Instrumentation and Examiners

Each tool was used by 1 examiner for all data collection, and each examiner was blinded to the measurements by the other examiner with the other tool. The measurements of IRD using the nylon digital calipers (Mitutoyo America Corporation, Aurora, IL) were made by 1 examiner.

### TABLE 1

<table>
<thead>
<tr>
<th>Participant Characteristics*</th>
<th>Men (n = 11)</th>
<th>Nulliparous (n = 22)</th>
<th>Parous (n = 23)</th>
<th>Total (n = 56)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>37.5 ± 9.8 (33.1-56.3)</td>
<td>28.5 ± 6.0 (23.0-49.9)</td>
<td>39.6 ± 9.8 (25.8-64.0)</td>
<td>34.8 ± 9.8 (19.8-64.0)</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.80 ± 0.09 (1.63-1.92)</td>
<td>1.63 ± 0.06 (1.53-1.76)</td>
<td>1.62 ± 0.06 (1.47-1.74)</td>
<td>1.67 ± 0.10 (1.47-1.92)</td>
</tr>
<tr>
<td>Mass, kg</td>
<td>91.2 ± 13.7 (74.5-119.3)</td>
<td>62.2 ± 11.7 (45.8-94.4)</td>
<td>59.5 ± 6.7 (49.0-72.7)</td>
<td>67.9 ± 17.8 (45.8-119.3)</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>30.0 ± 3.9 (23.7-33.9)</td>
<td>23.4 ± 4.0 (17.2-34.1)</td>
<td>22.6 ± 1.8 (20.1-27.8)</td>
<td>24.3 ± 4.3 (17.2-34.1)</td>
</tr>
</tbody>
</table>

*Values are mean ± SD (range).
who had 10 years of experience with this tool. The USI measurements of IRD were performed using the LOGIQ Book XP ultrasound unit (GE Healthcare, Waukesha, WI), with a 5-MHz curvilinear transducer, by 1 examiner with advanced training and 7 years of clinical USI use. High intrarater reliability for measuring IRD for both USI and the calipers has previously been reported.21

To establish our own reliability, a separate study was performed, in which 8 subjects were measured with calipers and 6 subjects with USI. Three measurements for each location (above and below the umbilicus) and each condition (abdominal muscles at rest and contracted) were performed on the same day. Intrarater reliability for USI was assessed by measuring 3 separate images for each location and condition. In this preliminary work, intrarater reliability was found to be very high for each tool-examiner combination, with intraclass correlation coefficients (ICCs) ranging from 0.90 to 0.99. The minimal detectable difference (MDD) for each tool-examiner combination ranged from 0.003 to 0.113 cm (Table 2).

**Procedures**

IRD measurements using both tools were made during a single session. To ensure that both tools measured IRD at precisely the same location, the participant was positioned comfortably in supine and the desired measurement locations were marked with a water-soluble pen 4.5 cm above the umbilical midpoint and 4.5 cm below the umbilical midpoint. These specific locations along the linea alba have previously been used to measure IRD with 3-D photography.24 We also selected 4.5 cm above and below the umbilicus because measurements at these locations have previously been reported.3,11,12,29 No IRD measurements were made at the umbilicus due to technical difficulties with USI, which is consistent with other USI studies that have not reported measurements at the level of the umbilicus.3,13 Because the ultrasound gel can blur the water-soluble markings, making future measurements in the same location difficult, the caliper measurements always preceded the USI measurements.

Previous investigations of DRA using USI have measured IRD with the abdominal muscles at rest,3,14 whereas previous studies using palpation and caliper techniques12 have reported IRD measurements in a hook-lying test position, with the subject actively performing a partial curl-up. In this study, we elected to perform the measurements with the abdominals both at rest and activated. For the caliper measurements with the abdominal muscles at rest, the participant was positioned in hook-lying, arms down by the side, with 1 pillow placed beneath the head. The examiner palpated the medial borders of the right and left rectus abdominis muscle bellies at the marked locations. The inside measurement jaws of the digital nylon calipers were positioned at the locations of the palpating fingers, perpendicular to the direction of the muscles, and adjusted to the perceived IRD width (Figure 1). The palpation and caliper measurement procedure was the same for both measurement locations, above and below the umbilicus. To measure the IRD with abdominal muscles contracted, each participant crossed the arms over the chest and raised the head until the spine of the scapulae was off the table surface. The participant maintained this partial curl-up while the examiner palpated and measured the IRD with the calipers, as described just above. Once the caliper measurements were completed, the participant remained in the same hook-lying position and the first examiner left the room.

Upon entering the room, the second examiner placed the 5-MHz curvilinear

---

**TABLE 2**

<table>
<thead>
<tr>
<th>Measurement Condition and Location</th>
<th>Ultrasound Imaging (n = 6)</th>
<th>Calipers (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC, *</td>
<td>SEM, cm</td>
</tr>
<tr>
<td>PAU</td>
<td>0.97 (0.95, 0.99)</td>
<td>0.005</td>
</tr>
<tr>
<td>AAU</td>
<td>0.98 (0.92, 0.99)</td>
<td>0.012</td>
</tr>
<tr>
<td>PBU</td>
<td>0.90 (0.89, 0.99)</td>
<td>0.017</td>
</tr>
<tr>
<td>ABU</td>
<td>0.94 (0.93, 0.99)</td>
<td>0.009</td>
</tr>
</tbody>
</table>

Abbreviations: AAU, activated abdominal muscles above umbilicus; ABU, activated abdominal muscles below umbilicus; ICC, intraclass correlation coefficient; MDD, minimal detectable difference; PAU, passive abdominal muscles above umbilicus; PBU, passive abdominal muscles below umbilicus; SEM, standard error of measurement.

*Values in parentheses are 95% confidence interval.
TABLE 3  Descriptive Data for Interrecti Distance*

<table>
<thead>
<tr>
<th></th>
<th>Men (n = 11)</th>
<th>Women: Nulliparous (n = 22)</th>
<th>Women: Parous (n = 23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5 cm above umbilical midpoint</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultrasound imaging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAU</td>
<td>1.45 ± 0.95</td>
<td>0.88 ± 0.45</td>
<td>1.69 ± 0.92</td>
</tr>
<tr>
<td>PAU</td>
<td>1.62 ± 1.04</td>
<td>0.75 ± 0.43</td>
<td>2.03 ± 1.05</td>
</tr>
<tr>
<td>Calipers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAU</td>
<td>1.54 ± 0.76</td>
<td>0.84 ± 0.30</td>
<td>1.60 ± 0.96</td>
</tr>
<tr>
<td>PAU</td>
<td>1.63 ± 0.69</td>
<td>0.81 ± 0.53</td>
<td>2.04 ± 1.61</td>
</tr>
<tr>
<td>4.5 cm below umbilical midpoint</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultrasound imaging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABU</td>
<td>0.48 ± 0.58</td>
<td>0.34 ± 0.36</td>
<td>0.72 ± 0.45</td>
</tr>
<tr>
<td>PBU</td>
<td>0.74 ± 0.89</td>
<td>0.22 ± 0.29</td>
<td>1.05 ± 0.65</td>
</tr>
<tr>
<td>Calipers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABU</td>
<td>1.39 ± 0.37</td>
<td>1.18 ± 0.33</td>
<td>1.63 ± 1.04</td>
</tr>
<tr>
<td>PBU</td>
<td>1.68 ± 0.54</td>
<td>1.69 ± 0.68</td>
<td>2.36 ± 1.13</td>
</tr>
</tbody>
</table>

Abbreviations: AAU, activated abdominal muscles above umbilicus; ABU, activated abdominal muscles below umbilicus; IRD, interrecti distance; PAU, passive abdominal muscles above umbilicus; PBU, passive abdominal muscles below umbilicus.

*Values are mean ± SD cm.

**Statistically different between measurement tools (P<.0001).

**The concurrent validity of the digital nylon calipers was compared to USI. Furthermore, the intraclass correlation coefficient (ICC) was calculated to measure the reliability of the measurement tools. The ICC was interpreted as follows: low, 0.0 to 0.5; moderate, 0.5 to 0.7; high, 0.7 to 0.9; and very high, greater than 0.9. For descriptive purposes and to ensure that the validation of measurements using calipers was generalizable to a greater population, the participants were divided post hoc into male, nulliparous female, and parous female subgroups.

RESULTS

Interrecti Distance

The mean IRDs for all subjects, as measured by both USI and calipers for each measurement condition and location, are depicted in FIGURE 3. Parous women exhibited the largest IRD above and below the umbilicus, both with and without an active abdominal muscle contraction. Nulliparous women exhibited the smallest IRD for all conditions and locations, except for the measurement with calipers below the umbilicus with the abdominal muscles at rest. Men
exhibited the smallest IRD for the measurement with calipers below the umbilicus with the abdominal muscles at rest (TABLE 3).

Validity
The validity of the measurements made with the digital nylon calipers, as compared to those made with USI, was different above and below the umbilicus. Above the umbilicus, there was no statistically significant difference (P>.05) in IRD values between the 2 tools under either the contracted or at-rest condition (FIGURE 3). As illustrated in the Bland-Altman plots, for measurements made above the umbilicus, the majority of the data points fell within the limits of agreement (FIGURES 4A and 4B). On average, compared to the calipers, the IRD measured with USI was 0.03 cm larger with the abdominal muscles at rest and 0.03 cm smaller with the abdominal muscles contracted (FIGURE 4). Above the umbilicus, there was a high level of agreement between IRD measurements made with calipers and USI with the abdominal muscles at rest (ICC3,2 = 0.79, P<.0001) and contracted (ICC3,2 = 0.71, P<.0001) (TABLE 4).

Below the umbilicus, IRD measurements using calipers were significantly larger (P<.0001) than those using USI for both abdominal muscles at rest and contracted (FIGURE 3). As indicated in the Bland-Altman plots, below the umbilicus, the mean difference in IRD between the tools was 1.43 cm with abdominal muscles at rest (FIGURE 4C) and 0.74 cm with abdominal muscles contracted (FIGURE 4D). Systematic bias was seen for measurements made below the umbilicus, as most points were located above the zero line, indicating that the calipers consistently overestimated IRD when compared to USI (FIGURES 4C and 4D). There was low agreement between the 2 measurement tools for IRD measurements below the umbilicus under both the at-rest and contracted conditions of the abdominal muscles (TABLE 4).

DISCUSSION
To our knowledge, this is the first study to examine the concurrent validity of measuring IRD with digital nylon calipers compared to the best available clinical tool, USI. Caliper measurements above the umbilicus were comparable to the USI measurements, TABLE 4

<table>
<thead>
<tr>
<th>Measurement Condition/Location</th>
<th>ICC3,2</th>
<th>SEM, cm</th>
<th>MDD95, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAU</td>
<td>0.79†</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>AAU</td>
<td>0.71†</td>
<td>0.17</td>
<td>0.48</td>
</tr>
<tr>
<td>PBU</td>
<td>0.40†</td>
<td>0.52</td>
<td>1.46</td>
</tr>
<tr>
<td>ABU</td>
<td>0.43†</td>
<td>0.50</td>
<td>1.38</td>
</tr>
</tbody>
</table>

Abbreviations: AAU, activated abdominal muscles above umbilicus; ABU, activated abdominal muscles below umbilicus; ICC, intraclass correlation coefficient; MDD95, minimal detectable difference at the 95% confidence level; PAU, passive abdominal muscles above umbilicus; PBU, passive abdominal muscles below umbilicus; SEM, standard error of measurement.

*Values in parentheses are 95% confidence interval.

†P<.0001.

FIGURE 4. Bland-Altman plots of interrectus distance (cm), with difference in values between ultrasound imaging and caliper techniques on the y-axis and the average between ultrasound imaging and caliper values on the x-axis. Lines are mean differences and 95% limits of agreement. (A) PAU, (B) AAU, (C) PBU, (D) ABU. Abbreviations: AAU, activated abdominal muscles above umbilicus; ABU, activated abdominal muscles below umbilicus; PAU, passive abdominal muscles above umbilicus; PBU, passive abdominal muscles below umbilicus.
whereas below the umbilicus there was overestimation of the IRD size when measured with the calipers.

We found good to excellent validity of measurements with the calipers when performed above the umbilicus, both with abdominal muscles at rest and contracted. The mean difference in IRD between methods was 0.03 cm, which is less than the MDD and not likely clinically significant. Although almost all data points were within the limits of agreement, a slightly higher measurement error was seen when IRD was measured with the abdominal muscles at rest, as a third of the points on the corresponding Bland-Altman plot were outside the limits of agreement (FIGURE 4C). Using the calipers, there may be a greater tendency to overestimate IRD for widths greater than 2.5 cm (FIGURE 4C). However, as only a few subjects exhibited such a large IRD, this requires further investigation.

We initially thought that using calipers would lead to smaller IRD values than those obtained with USI, due to overlying skin and subcutaneous tissue. But the measurements made with the calipers were, on average, 1.43 cm greater than those made with USI with the abdominal muscles at rest (FIGURE 4C) and 0.74 cm greater with the abdominal muscles contracted (FIGURE 4D). These larger IRD measurements when using calipers may be due to the inaccurate identification of the medial edges of the right and left rectus abdominis muscles using manual palpation. It is possible that the USI and caliper measurements were not taken at equivalent depths. The measurement of IRD with USI is of the closest distance between the muscle bellies, regardless of depth from the skin. Below the umbilicus, there may be more subcutaneous tissue interfering with the examiner’s ability to detect the medial borders of the muscle by palpation. Consequently, the palpating fingers may be at a more superficial location and more lateral than the most medial aspect of the muscles (FIGURE 5). It is also possible that the caliper jaws produce a slight outward pressure against the muscle belly, thus increasing IRD—particularly if the tissue is more extensible, as is likely in those with greater IRD. This slight outward pressure may also explain why the caliper measurements were larger than the USI measurements when taken with the abdominal muscles at rest. Our results are in agreement with those by Mendes et al., who compared USI to direct surgical measurement and found excellent validity for measurements above the umbilicus and poor validity for those below the umbilicus. In women who had undergone a cesarean delivery, Mendes et al. found a significantly larger IRD below the umbilicus at surgery than IRD measured with USI, which they attributed, in part, to a loss of definition of the posterior layer of the recti muscles and fibrosis, leading to difficulty in determining the medial rectus borders with USI.

Gender differences in the architech-
ture3 and width12,31 of the linea alba in cadavers have been reported. The effect of gender on IRD has not yet been explored in living individuals. An increase in IRD postpartum compared to nulliparous women has been shown.6,12 To our knowledge, this is the first investigation to describe IRD with respect to both gender and parity. For the calipers to be clinically useful to detect a DRA, gender variation in the width of the linea alba must be considered. To facilitate comparison of our data to the few published reports on the typical IRD in adults, we chose to describe our sample by gender and parity. Modeling clinical practice, we measured IRD with the abdominal muscles under 2 conditions, at rest and contracted.

To our knowledge, the only other investigation of IRD size that has included both males and females was conducted by Rath et al,12 with 60% of the 40 participants being males. However, Rath et al12 did not specifically report IRD values by gender or parity but, rather, reported a composite mean IRD of 8.3 mm midway between the umbilicus and xiphoid and 9.3 mm midway between the umbilicus and pubic symphysis, taking all measurements with the abdominal muscles at rest. The IRD values for men in our study appear similar to those reported by Rath et al12 for the location below the umbilicus, but not for the location above the umbilicus (TABLE 3). For the parous women in our study, in which 3 of the 23 participants were less than 1 year postpartum, IRD was more than double the values reported by Rath et al12 above the umbilicus and only slightly larger below the umbilicus (TABLE 3). This comparison should be made with respect to the present study’s sample of adults without disease, measured using USI, whereas the Rath et al12 study used computerized scans to measure individuals with intra-abdominal disease.

The IRD in women within their first postpartum year has been shown to exceed that which is considered normal in nulliparous women.13,21 The nulliparous women in this study exhibited IRD values comparable to those previously reported (TABLE 3). To identify the normal width of the linea alba in nulliparous females, Beer et al2 measured 150 women between 20 and 45 years of age. In the study by Beer et al,2 normal IRD was defined as any value between the 10th and 90th percentile, or greater than 22 mm at 3 cm above the cranial margin of the umbilicus and any value up to 16 mm at 2 cm below the caudal margin of the umbilicus. IRD measurements reported by Liaw et al21 at 2.5 cm above and below the umbilical ring in 20 nulliparous females also fell within the normal IRD range defined by Beer et al.2 The individuals in our study, and those in the study by Liaw et al,21 were within the same age range and were measured at a similar location along the linea alba.21 Coldron et al19 reported a larger IRD measurement with abdominal muscles at rest for 69 nulliparous females, using measurements immediately cranial to the umbilicus, where IRD is expected to be larger. Similar findings in our sample of nulliparous women give credence to the validity data for this group and provide further evidence that parity and location along the linea alba are important factors to consider when reporting IRD values.

Boissonnault and Blaschak’s seminal research described the active curl-up assessment technique for a DRA, which is now used in common clinical practice. However, most subsequent investigations using objective measurement tools have just reported the IRD with the abdominal muscles at rest.3,13,31,30,31 IRD measured with the abdominal muscles at rest with calipers has been shown to be more than twice the width of that measured during an active muscle contraction in women who were 11 weeks postpartum.7 In our study, to mimic clinical examination, participants were not instructed on a specific recruitment pattern or effort during the curl-up. While it was necessary to measure IRD during an active muscle contraction to validate the calipers as a clinical tool, this study was not designed to examine the variation of IRD at rest and during abdominal muscle contraction.

Based on the results of this investigation and on our interpretation of the literature, we recommend that clinicians examine patients for the presence of a DRA when presenting with abdominal or lumbopelvic dysfunction. Keeler et al18 reported that 96.6% of women’s health clinicians used the finger-width technique for measuring a DRA. Finger palpation is not accurate and reliable.9 We recommend using USI when equipment and training are available. In the absence of USI, the easily obtainable and inexpensive calipers are a good alternative. Both of these tools are reliable for measuring IRD along the linea alba and lead to similar values for measurements made above the umbilicus. For measurements below the umbilicus, while recognizing that measurements made with the calipers will be greater than those made with USI, clinicians should not preclude the use of either tool at this time.

To date, there is no universally agreed-upon definition for DRA. It appears that measurement location, level of activation of the abdominal musculature, gender, parity, and measurement tool must be considered for the interpretation of IRD values. Future research should be designed to define DRA with respect to these variables.

Limitations
Measurement error may account for some of the inconsistency found below the umbilicus between the 2 tools. Measurement error might have occurred with either examiner. Though all efforts were made to minimize examiner error, our results represent not only the measurement tool but also the raters, and results may differ among raters. The results represent a first step in determining the validity of caliper measurement of IRD. Future studies should examine this technique with additional raters with varying amounts of clinical experience.

Related to error among raters is
sample size, and we recognize that a sample size of 20 or more is necessary to determine intrarater reliability for a novel tool. As the reliability of each tool has been previously reported in the literature, in our preliminary work we used a small but statistically appropriate sample size to determine our intrarater reliability.

To accurately perform IRD measurement with calipers, the examiner must palpate the medial borders of both rectus abdominis muscles and place the calipers at the precise IRD locations palpated. The examiner perceives the edges of the muscle belly through subcutaneous tissue. If the individual has excessive subcutaneous tissue, adiposity, or a thick and rounded muscular configuration, it may be difficult to identify the actual medial extent of the muscle. When IRD is measured with USI, the examiner delineates a line between the most medial aspects of the muscle bellies, and the computer determines this exact distance. The subumbilical morphological variability previously described, along with these palpation issues, can explain how we achieved accurate measurements with each tool but how the measurements between the calipers and USI were only comparable above the umbilicus.

In the design of this study, the USI examiner measured IRD without any palpation of the linea alba to most accurately represent USI. This does not represent clinical practice, and future studies may include palpation prior to transducer placement. When evaluating IRD with USI, examiner judgment, training, and consistent USI usage are vital to accurate assessment. The fascial sheaths of the rectus appear on the USI monitor as white, hyperechoic outlines, which demarcate the conical borders of the muscles against the darker, hypoechoic muscle bellies. The quality of this visual image can be affected by age and musculoskeletal dysfunctions such as atrophy, which produce a fatty fibrous muscle with diminished water content. Thus, the muscle appears whiter throughout or presents with greater echogenicity. The participants in our study represented a range of ages and muscular development, some of which produced very poor images. In the participants with hard-to-distinguish muscle edges, measurement error could have been introduced.

Accurately placing the ultrasound transducer at measurement sites identical to those of the calipers was vital to ensure that IRD measurements were made by both tools in precisely the same locations. As the ultrasound gel removed skin markings, we chose to perform the caliper measurements first. Although randomized testing conditions are preferable, these would have necessitated re-marking the measurement location with the use of each tool, introducing an additional source of measurement error.

CONCLUSION

This concurrent validity study comparing IRD measurements made with digital nylon calipers to those made with USI offers preliminary evidence to support the validity of using calipers in both males and females when measuring IRD above the umbilicus with the abdominal muscles both at rest and during contraction. Measurements with calipers, although reliable, were not comparable to those made with USI at a location 4.5 cm below the umbilicus, which may reflect anatomical variation of the linea alba or a limitation of the calipers to measurements made below the umbilicus.

CAUTION: Interpretation of these results should consider that only 2 examiners, with extensive experience with these measurements, collected data for this study.

ACKNOWLEDGEMENTS: The authors thank Dr. David Madigan for his assistance in statistical analyses, and Drs Susan Ohlsen and Loretta Verma for assistance with data collection. We also acknowledge KIMA Center for Physiotherapy and Wellness for the use of space and equipment, as well as the support of Touro College in New York, NY, where Dr McAuley served as faculty during much of the time devoted to this project.

REFERENCES


