Predictors of Inter-recti Distance in Cadavers

Cynthia M. Chiarello, PT, PhD
Jennifer A. Zellers, DPT
Francine M. Sage-King, DPT, ATC

ABSTRACT

Objective: Examine embalmed human cadavers for diastasis rectus abdominis by measuring inter-recti distance (IRD) at 3 locations: supraumbilical, umbilical, and infraumbilical. Factors examined that can influence IRD included gender, waist girth, subcutaneous fat, waist-hip ratio (WHR), abdominal scarring, and age.

Study Design: Basic science.

Background: Diastasis rectus abdominis is an abnormal separation of the rectus abdominis muscles at the linea alba. The criteria for and factors that predispose an individual to diastasis rectus abdominis remain unclear in the literature.

Methods and Measures: Thirty-four embalmed cadavers (16 women and 18 men) between 47 and 99 years of age were included. Morphological measures—waist and hip girth—were taken, followed by dissection of the rectus sheath/rectus abdominis muscles. Digital calipers were used to measure IRD at the umbilicus and 4.5 cm above and below the umbilicus; the depth of subcutaneous fat was recorded. Regression analysis was used to determine whether gender, waist girth, subcutaneous fat, WHR, abdominal scarring, or age influenced maximal IRD.

Results: Upon optimizing the mathematical model, a 102-cm threshold was identified and included in the regression as “waist index” (R² = 0.539). This threshold indicates that at more than 102 cm, waist girth has a greater contribution to IRD. Factors increasing IRD were waist girth (P = .0016) and scarring (P = .0222) in the supraumbilical region, waist index (P = .0100) and scarring (P = .0131) at the umbilicus, and WHR (P = .0169) and gender (P = .0000) in the infraumbilical region. Age did not increase IRD.

Conclusions: Waist girth more than 102 cm, female gender, abdominal scarring, and increased WHR are predictors of increased IRD in cadavers.

Key Words: diastasis rectus abdominis, linea alba, rectus abdominis, rectus sheath

INTRODUCTION

The midline linea alba represents the meshwork of connective tissue containing the tendinous insertion of the abdominal muscles as well as the anterior and posterior rectus sheath and is a part of the cooperating system of collagenous fibers providing structure and stability to the abdominal wall and trunk.1 Diastasis rectus abdominis (DRA) is an abnormal separation of the rectus abdominis muscles along the linea alba and is determined by measuring the inter-recti distance (IRD). The presence of a DRA may represent connective tissue alterations of the linea alba2 and an increase in muscle length with an altered line of muscle pull,3 which has been negatively correlated with abdominal muscle strength and endurance.4 Pregnancy,5 waist girth,6 obesity,7,8 gender,6 and age9,9 contribute to a DRA. Clinically, DRA has also been linked with low back pain,10,11 pelvic floor dysfunction,12 and pelvic pain.10 It is important to identify the range of normal IRD in order to determine the efficacy of corrective intervention programs.

Clinically, measuring DRA relies on the examiner’s ability to palpate the medial edges of the rectus abdominis muscles and record the IRD with fingers or calipers. Palpation techniques are subject to error because of examiner skill and the amount of overlying skin and subcutaneous tissue. Real-time ultrasound imaging can be used to measure IRD, but it requires expensive equipment, entails significant operator training, and exhibits diminished accuracy in the presence of poorly defined, scarred, or fibrotic musculature.4,13 Directly measuring IRD in cadavers allows for defining the exact distance between the rectus abdominis muscle bellies along the linea alba with less chance for error.

To date, only a single study has examined IRD in cadavers. Rath and colleagues9 have reported direct measurements of IRD in 40 cadavers ranging in age from 62 to 99 years. Rath et al9 identified a DRA as an IRD of at least 15 mm in the region 4.5 cm above the umbilicus, 27 mm at the level of the umbilicus, and 14 mm at the level of 4.5 cm below the umbilicus for subjects older than 45 years.9 Thus, the description of IRD by Rath et al9 has been used as the normal width of the linea alba; however, it does...
not account for important morphological factors that may impact on the size of the IRD. Therefore, more research is needed to investigate IRD in cadavers that accounts for characteristics that impact the width of IRD and, consequently, what constitutes a DRA in the general population.

The purpose of this study was to examine embalmed human cadavers for DRA by directly measuring IRD. In addition, we sought to examine the following factors, which could influence IRD: gender, waist girth, subcutaneous fat, waist-hip ratio (WHR), abdominal scarring, and age. An increase in abdominal girth, as in pregnancy, and obesity, as well as gender may contribute to DRA. Subcutaneous fat distribution (intra-abdominal fat vs subcutaneous fat) could play a role in whether or not a DRA is present with increased waist girth. The WHR is a measure for obesity as well as its predictive value for cardiac risk. Abdominal scarring was included as it might be an indication of a disruption to the abdominal musculature, resulting in altered biomechanics and inefficient muscle use. Rath and colleagues suggested that increasing age is associated with increased IRD. We propose that an increase in waist girth and WHR would result in an overall increase in IRD. In addition, we propose that DRA is equally prevalent in men and women and that the presence of abdominal scarring results in a greater likelihood of developing DRA.

**METHODS AND MEASURES**

A convenience sample of 34 embalmed cadavers (16 women and 18 men) between the ages of 47 and 99 years was included in the study; all were donated to the Columbia University’s medical, dental, and physical therapy programs. The only criterion for exclusion was postmortem visual disruption of the linea alba, and on the basis of the criteria, one cadaver was excluded. Forty-four percent of subjects presented with visual abdominal scarring. The location, size, and description of the scar were recorded.

Morphological measures, including waist- and hip-girth measurements, were performed before dissection using a tape measure and recorded in centimeters. **Waist girth** was defined as the circumferential measurement directly over the umbilicus. Because of tissue changes that occur with the embalming process, accurate identification of the anterior superior iliac spine (ASIS) was not possible. For consistency in hip landmark identification, **hip girth** was defined as the circumferential measurement midway between the inferior umbilicus and superior pubic symphysis (Figure 1). Using these 2 measurements, a WHR was calculated as the quotient of the waist and hip measurements.

Dissection of the abdominal region was divided into 3 separate phases: window exposure, gross dissection, and fine dissection. Window exposure outlined the dimensions of the area to be examined surrounding the umbilicus. Using a scalpel, an “I” incision (12 cm in length by 4 cm in width) was made spanning the umbilicus. Through gross dissection, the abdominal subcutaneous fat was removed and the underlying rectus sheath uncovered. Fine dissection was performed to remove the rectus sheath and expose the insertion of the abdominal musculature to the linea alba. Pins were placed perpendicularly at the right and left medial edges of the rectus abdominis muscle belly at 3 locations: 4.5 cm above the umbilicus (supraumbilical), at the umbilicus, and 4.5 cm below the umbilicus (infraumbilical). Using metal digital calipers (CMT12, Neiko 12-inch digital caliper, Neiko Tools, Zhejiang, China), the distance between the medial aspect of the rectus muscle bellies was measured (IRD) by placing the inside measuring arm of the caliper between the pins (Figure 2). Following the IRD measurement, subcutaneous fat measurements were taken using the depth portion of the digital calipers along the inferior border of the dissection window (Figure 3).

Upon completion of data collection, statistical analysis was performed in consultation with the Columbia University Center for the Social Sciences and the Department of Biostatistics. Data analysis included intrarater reliability of caliper measurements, descriptive statistics for all variables, and test comparisons between the IRDs for men and women. A stepwise multiple regression, which included all variables of interest, was also used to identify variables that had the greatest impact on IRD. The P value was set at less than .05. Intrarater
and intrarater reliabilities for this dissection technique were found to be excellent as reported in a previous investigation.\textsuperscript{16} For the purposes of this study, only 1 examiner was taking measurements; thus, the Cronbach $\alpha$ was used to confirm intrarater reliability. The data used for the reliability study were taken at the same time as the data for the study itself, and all of the cadavers were used in calculating the Cronbach $\alpha$. A single examiner, blinded to the caliper reading, took 3 measures each of waist girth, hip girth, subcutaneous fat depth, and IRD. The results of that Cronbach $\alpha$ indicate 99% reliability for these measurements, indicating high intrarater reliability.

**RESULTS**

Girth, subcutaneous fat, and IRD measures for all subjects ($n = 34$) are delineated in Table 1. As can be seen in Figure 4, women exhibited a larger IRD than men. To compare IRD at all locations for men and women, $t$ tests were performed as shown in Table 2. The results of the $t$ tests indicate that women, in general, demonstrate larger IRD values that reach statistical significance inferior to the umbilicus (Table 2).

Using the definition of DRA by Rath et al,\textsuperscript{9} we found that 29% of the subjects exhibited a DRA at all 3 measurement locations, 24% at 2 sites, and 21% at 1 site. Therefore, 74% of the cadavers met the criteria for DRA on the basis of at least 1 measurement.

Variables having the greatest impact on IRD were identified by stepwise multiple regression analysis. For the maximal IRD, or the largest IRD at any of the 3 sites, a stepwise regression was completed including the factors of waist girth, hip girth, subcutaneous fat depth, and IRD. The results of that Cronbach $\alpha$ indicate 99% reliability for these measurements, indicating high intrarater reliability.

![Figure 2. The metal digital caliper being used to measure inter-recti distance.](image)

![Figure 3. The metal digital caliper being used to measure subcutaneous fat.](image)

![Figure 4. Although women tended to have larger inter-recti distance than men, gender differences were only statistically significant in the infraumbilical region ($P = .001$). Bars indicate standard deviation. Abbreviation: IRD, inter-recti distance.](image)

<table>
<thead>
<tr>
<th>Table 1. Subject Characteristics for Total Subjects ($n = 34$)</th>
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<tbody>
<tr>
<td><strong>Mean</strong></td>
</tr>
<tr>
<td>Waist girth, cm</td>
</tr>
<tr>
<td>Hip girth, cm</td>
</tr>
<tr>
<td>Subcutaneous fat, mm</td>
</tr>
<tr>
<td>IRD supraumbilicus, mm</td>
</tr>
<tr>
<td>IRD at umbilicus, mm</td>
</tr>
<tr>
<td>IRD infraumbilicus, mm</td>
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</tbody>
</table>

Abbreviation: IRD, inter-recti distance.
Incorporating the variable waist index into the regression analysis further optimized the mathematical model (Figure 6). Optimization of the model was determined by calculating the Akaike Information Criterion and Bayesian Information Criterion. These values were used to determine the best-fit model. Therefore, 53.9% of the variance in maximal IRD can be explained by scarring, waist girth, and waist index ($R^2 = 0.539$).

Following the same stepwise regression procedure used to determine factors impacting maximal IRD, stepwise regressions were completed for the supraumbilical, umbilical, and infraumbilical regions (Table 3). In the supraumbilical region, waist girth ($P = .0016$) and scarring ($P = .0222$) were found to be significant, explaining 36.3% of the variance ($R^2 = 0.363$). At the level of the umbilicus, waist index ($P = .0100$) and scarring ($P = .0131$) were found to be significant, explaining 53.9% of the variance ($R^2 = 0.5390$). Waist girth was included in the stepwise regression but was not found to be statistically significant ($P = .1704$). In the infraumbilical region, WHR ($P = .0169$) and gender ($P = .0000$) were found to be significant, explaining 44.2% of the variance ($R^2 = 0.4421$). Age was not found to be significant at any location along the linea alba.

**DISCUSSION**

The principal aims of this study were to measure IRD in embalmed human cadavers to detect the presence of DRA and to establish which subject characteristics are associated with a larger IRD. Our values for IRD of 23.2 mm above and 31.8 mm at the umbilicus were larger than those reported by Rath and colleagues by 8.2 mm and 4.8 mm, respectively, and similar below the umbilicus. Using the definition by Rath et al, we found that 29% of our subjects had a DRA in all the 3 measurement locations and 74% exhibited a DRA in at least 1 location. The IRD measurements made in this study used the same locations as those chosen by Rath et al, at 4.5 cm above and below the umbilicus and directly at the umbilicus.

Other studies that have attempted to define the normal IRD have reported a much smaller IRD in nulliparous women, using ultrasound imaging. Beer and colleagues defined normal IRD in nulliparous women with an average age of 29 years as 22 mm located 3 cm above the umbilicus and 16 mm below the umbilicus. Similarly, Coldron and colleagues found an IRD of 11.17 mm just above the umbilicus in nulliparous women with an average age of 27 years. These reported smaller IRD values, taken collectively with the findings of Rath et al, provide evidence that a DRA existed in a large proportion of our subjects and that factors other than location along the linea alba play an important role in determining the normal IRD.

Forty-four percent of our subjects had some type of abdominal scar. We determined that the presence of scarring was predictive of a larger IRD at the supraumbilical and umbilical levels. This study is the first to link abdominal scarring with an increased IRD. We postulate that surgical or traumatic disruption of the abdominal wall may result in altered biomechanics and diminished function of the abdominal musculature post-surgery. Mendes and colleagues intraoperatively measured IRD in 20 women, 19 of whom had previously undergone cesarean delivery,
and found a loss of definition of the rectus abdominis and increasing fibrosis below the umbilicus.

As our IRD size is within 1 standard deviation of Rath’s study, we believe that we have sampled a similar population of cadavers with regard to age range and gender distribution. The exception is that our study took into account the presence of abdominal scarring, giving support to the findings that abdominal wall disruption contributes to an increased IRD and a possible DRA as evidenced by our larger IRD values. Future research should examine the relationship between abdominal surgery, which disrupts the abdominal wall and the presence of DRA.

Another major finding of this study is that there is a 102-cm threshold for waist girth suggesting that abdominal circumferences exceeding this measurement have a greater contribution to an increasing IRD. Exhibited in Figure 6, as waist girth increases past 102 cm, the slope of the line increases dramatically, indicating increased IRD. For each centimeter of waist girth more than 102 cm, there was a corresponding increase of 1.44 mm in IRD. This finding corresponds to the increase seen in DRA during pregnancy and with obesity. It can also help explain the relatively small IRD found in nulliparous women with a body mass index of less than 30. Interestingly, the subcutaneous fat measurement did not appear to significantly affect IRD, suggesting that increases in the size of the abdominal cavity originating deep to the linea alba can compromise the IRD. The IRD of postpartum women has been shown to consistently exceed that of nulliparous women throughout the length of the linea alba. This threshold has not been reported in previous studies regarding DRA. It is interesting to note, though, that there are studies in the cardiac literature that suggest that a waist girth of greater than 40 inches (or 102 cm) is a positive cardiac risk factor. With an appreciation for the complexity of tissue mechanics and the anisotropic connective tissue of the linea alba, this waist girth threshold may be indicative that the abdominal wall has exceeded its elastic limit. Further study is necessary to determine when an increase in IRD represents connective tissue plastic deformation indicative of surgical correction versus tissue that has retained enough elasticity to benefit from exercise and motor control training.

Below the umbilicus, we found gender and WHR to be predictors of IRD. The WHR may be a further indicator of gender differences. When we specifically compared the IRD of men with that of women, women tended to have larger IRD than men, which was only statistically significant in the infraumbilical region. Axer and colleagues also reported statistically significant gender differences, noting that the linea alba of women was wider and thinner than that of men in the infraumbilical region. They also discovered architectural gender differences in the linea alba, as there were more layers of fiber bundles per segment in men and infraumbilical differences in fiber orientation in which women had a larger amount of transverse fibers relative to oblique fibers. It is noteworthy that 5 of the 6 female subjects in Axer’s study were parous, while the linea alba of nulliparous female subjects resembled that of the male subjects. Furthermore, both Coldron and colleagues and Liaw and colleagues have noted that the linea alba in postpartum women did not return to the pre-pregnancy width. We do not know the parity status of our female subjects

<table>
<thead>
<tr>
<th>Location</th>
<th>Waist Girth</th>
<th>Waist Index</th>
<th>Waist-Hip Ratio</th>
<th>Gender</th>
<th>Scar</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supraumbilical</td>
<td>0.51</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>8.93$^b$</td>
<td>0.363$^b$</td>
</tr>
<tr>
<td>Umbilical</td>
<td>0.28</td>
<td>1.60$^b$</td>
<td>...</td>
<td>...</td>
<td>10.25$^b$</td>
<td>0.556$^b$</td>
</tr>
<tr>
<td>Infraumbilical</td>
<td>...</td>
<td>...</td>
<td>71.29$^b$</td>
<td>Men: −26.06$^b$</td>
<td>...</td>
<td>0.442$^b$</td>
</tr>
</tbody>
</table>

$^a$This table depicts the factors included in the stepwise regression with the associated $\beta$ value and resultant $R^2$ values for the 3 locations along the linea alba.

$^b$Statistical significance.

Figure 6. Graphical representation of the stepwise regression for maximal inter-recti distance with predicted value of inter-recti distance (mm) plotted against waist range (cm). Scarring increases the predicted inter-recti distance and the slope increases at a 102-cm threshold.
and are thus limited in drawing conclusions regarding the parity as the reason for our difference in IRD between genders.

Using cadavers as subjects affords making accurate, direct measurements of IRD and subcutaneous fat possible. A limitation of this study, however, is the relevance of extrapolating data gleaned from cadavers to living subjects. Results of prior cadaver studies, in addition to those of this study, have formed a basis for future investigations and can assist researchers in selecting appropriate variables to examine DRA in both living and cadaveric studies.

The statistical analyses performed in this study were limited because of the large number of variables included, the interrelatedness of some of the variables (e.g., waist girth would certainly impact WHR), and the relatively small number of subjects. It appears that IRD is affected by many factors that were not amenable to measurement in the investigation on cadavers. Some of these factors may include parity, individual connective tissue properties, and medical history. Therefore, relatively low $R^2$ values reported in this study suggest that additional factors are implicated. Future studies with a larger number of subjects would be beneficial in supporting the conclusions reported in this study. Incorporating information obtained from a medical history such as a pregnancy history may also be useful in identifying additional factors that contribute to an increased IRD. In addition, performing a similar study with living subjects, using ultrasound measurement of IRD, and broad inclusion criteria may contribute to the clinical generalizability of the conclusions presented in this study.

CONCLUSION

This study identified waist girth more than 102 cm, female gender, abdominal scarring/history of abdominal surgery, and increased WHR to be predictors of increased IRD in cadavers. Being cognizant of these risk factors may assist clinicians in identifying individuals at risk of having increased IRD to more efficiently address abdominal stability. Future studies such as ultrasound studies in living subjects may be useful to support the conclusions found in this study and aid in clinical application of these findings.

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REFERENCES