

## ORIGINAL COMMUNICATION

# The Normal Width of the Linea Alba in Nulliparous Women

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The function of the linea alba is to maintain the abdominal muscles at a certain proximity to each other. In the case of long-lasting increased intra-abdominal pressure, the linea alba widens. Yet, as the existence of the linea a priori implicates a physiological distance between the two rectus muscles, the question arises as to what the normal width of the linea alba is. To evaluate the normal width of the linea alba, we examined 150 nulliparous women between 20 and 45 years of age with a body mass index  $< 30 \text{ kg m}^{-2}$  by ultrasound at three reference points: the origin at the xiphoid and 3 cm above and 2 cm below the umbilicus. The examination revealed a broad range of widths at the three reference points. The linea was widest at 3 cm above the umbilicus (–35 mm), followed by the reference point 2 cm below the umbilicus (–31 mm) and the origin at the xiphoid (–31 mm). The mean width was  $7 \pm 5 \text{ mm}$  at the xiphoid and  $13 \pm 7 \text{ mm}$  above and  $8 \pm 6 \text{ mm}$  below the umbilicus. For the definition of the normal width of the linea, the 10th and 90th percentiles were taken. The linea alba can be considered “normal” up to a width of 15 mm at the xiphoid, up to 22 mm at the reference point 3 cm above the umbilicus and up to 16 mm at the reference point 2 cm below the umbilicus in nulliparous women. Clin. Anat. 22:706–711, 2009. © 2009 Wiley-Liss, Inc.

**Key words:** linea alba; normal breadth; abdominoplasty; ultrasound

## INTRODUCTION

The linea alba reaches from the xiphoid process to the pubic symphysis and shows an inferior triangular reinforcement, referred to as the “Adminiculum lineae albae.” The linea alba is defined as the fusion of aponeuroses of the external abdominal oblique, internal abdominal oblique, and transversus abdominis and consists of a three-dimensional, highly structured meshwork of collagen fibers (Axe et al., 2001) with some additional circular fibers interwoven in the region of the umbilicus.

Above the umbilicus, the linea is wide and thin; below the umbilicus, it is small and thick (Waldeyer, 1974), although this simplified description has not

remained unquestioned (Hagentorn, 1902; Eiseler, 1912; Nahas, 2001).

The clinical function of the linea alba is to maintain the abdominal muscles, particularly the rectus muscles, at a certain proximity to each other. Yet, when the strain and the direction-specific compliance

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are measured in strips of collagen tissue from the linea (Grassel et al., 2005), it can be shown that the compliance is highest in the longitudinal direction and smallest in the transverse direction. In the infraumbilical region of the female linea alba, the compliance is still smaller in the transverse direction than in the oblique direction. This complex but flexible structural composition of the linea alba makes it prone to fatigue in the case of a long-lasting increased intra-abdominal pressure, such as that resulting from pregnancy (Boissonnault and Blaschak, 1988; al-Qattan, 1997) or obesity. Consequently, the rectus muscles will separate, leading to a rectus diastasis with a widened linea alba. Persistent pronounced rectus diastasis can contribute to a bulging of the anterior abdominal wall (Brauman, 2008), which leads women and men alike to seek correction.

In plastic and reconstructive surgery, several techniques have been developed to restore or improve abdominal bulging. One of these techniques consists of correcting a rectus diastasis during abdominoplasties. The most common method involves repositioning the rectus muscles and advancing them by plication of the anterior sheath of the fascia and invagination of the linea alba. While some authors have stated that a successful plication leaves no distance between the rectus muscles (Nahas et al., 2001), other authors have found that such a repair is impossible (al-Qattan, 1997) and unnecessary, as there is a physiological distance between the two rectus muscles—the linea alba. Thus far, no consensus has been reached regarding a feasible and desirable distance of the rectus muscles after rectus fascia plication.

Given this controversy, the question arises as to what the normal width of the linea alba is (Rath et al., 1996) and from which width on a physiological rectus diastasis can be addressed as a myoaponeurotic deformity (Nahas, 2001).

The aim of this study was to evaluate the normal width of the linea alba at three reference points in a homogeneous group of women.

## METHODS

We enrolled 150 healthy nulliparous female volunteers in this study. The exclusion criteria included an age of under 20 or above 45 years, a body mass index  $>30 \text{ kg m}^{-2}$ , previous weight loss  $>10 \text{ kg}$ , and previous operations on the abdominal wall or abdominal wall hernias.

The width of the linea alba was evaluated in a supine position, with the neck slightly flexed and the legs fully extended with relaxed rectus muscles and normal breathing. Three representative measurements (Nahas et al., 2005) were taken on a high-end ultrasound machine, using a high-resolution linear array transducer: the distance of the medial borders of the rectus muscles at the origin at the xiphoid, 3 cm above the umbilicus and 2 cm below the umbilicus. The focus and depth were adjusted to the individual patient size, and the focus was placed at the depth of interest. Automatic time gain control was utilized, and the width of the linea was indicated

by an automatic ruler. Standardized machine settings were used and remained unchanged throughout all examinations. Plastic surgeons, general surgeons, and an experienced musculoskeletal ultrasonographer carried out the examinations.

At the xiphoid, the type of insertion of the rectus muscles was indicated according to the four types A–D of myofascial deformities of the abdomen described by Nahas (2001). According to this classification, Type A represents a rectus diastasis secondary to pregnancy, Type B a rectus diastasis and laxity of the lateral and infraumbilical aponeurotic layer, Type C a congenital lateral insertion of the rectus muscles at the costal margins with a broadened linea alba, and a Type D represents a rectus diastasis with a poor waistline.

Statistical analysis was carried out using SPSS 13.0 (SPSS, Chicago, IL). Continuous variables were summarized as the mean  $\pm$  standard deviation. Comparison of the widths of the linea alba at the three reference points was carried out by using the Wilcoxon signed rank test. To address the problem of multiple comparisons, we utilized the Bonferroni correction and considered tests with  $P$ -values less than or equal to 0.017 as statistically significant. Correlations between continuous variables were analyzed using the Pearson correlation.

## RESULTS

The examination revealed a broad range of values at the three reference points measured (Table 1), (Figs. 1 and 2). There was no significant correlation of age or body height with the widths of the linea alba. There was a weak, positive correlation between body weight and body mass index with the widths of the linea measured at 3 cm ( $r = 0.3$ ) above and 2 cm ( $r = 0.2$ ) below the umbilicus, which was only significant at the 0.01 level.

The linea alba was widest at the reference point 3 cm above the umbilicus ( $-35 \text{ mm}$ ), followed by the reference point 2 cm below the umbilicus ( $-31 \text{ mm}$ ) and the origin at the xiphoid ( $-31 \text{ mm}$ ). The width at 3 cm above the umbilicus was significantly greater than that at 2 cm below the umbilicus and the origin at the xiphoid ( $P \leq 0.0001$ ). Two centimeters below the umbilicus, the linea alba was generally smaller than at the xiphoid (90th percentile, 16 mm below the umbilicus vs. 15 mm at the xiphoid), but the difference was not significant ( $P = 0.034$ ). In 23 women (15%), the width of the linea alba 2 cm below the umbilicus was larger than that at the xiphoid.

At the origin at the xiphoid in nine women (6%), the linea alba was not present. This was also the case in one woman at 2 cm below the umbilicus. At 3 cm above the umbilicus, the linea alba was always present.

In 21 cases (14%), the linea alba was wider at the xiphoid than at 3 cm above the umbilicus, and in one case, the widths were identical. The additional width at the xiphoid ranged from 1 to 10 mm, yet the distance was greater than 5 mm in only two cases and greater than 10 mm in only one case (16 mm vs. 5 mm).

**TABLE 1. Characteristics of the 150 Nulliparous Women and Width of the Linea Alba at Three Characteristic Reference Points**

	Mean $\pm$ SD	Range	Percentiles				
			5%	10%	50%	90%	95%
Age (years)	29 $\pm$ 6	(20–45)					
Weight (kg)	61 $\pm$ 9	(43–88)					
Height (cm)	169 $\pm$ 6	(156–190)					
Body mass index (kg m <sup>-2</sup> )	21.4 $\pm$ 2.7	(16.6–29.0)					
Width at xiphoid (mm)	7 $\pm$ 5	(0–31)	0	2	5	15	17
Width 3 cm $\uparrow$ umbilicus (mm)	13 $\pm$ 7	(1–35)	5	6	11	22	28
Width 2 cm $\downarrow$ umbilicus (mm)	8 $\pm$ 6	(0–31)	2	2	6	16	20

The 5th, 10th, 90th, and 95th percentiles are listed in Table 1. The 10th and 90th percentiles were calculated to define the normal width of the linea alba. These values indicate that the linea alba width can be considered “normal” from 2 to 15 mm at the xiphoid, from 6 to 22 mm at 3 cm above the umbilicus and from 2 to 16 mm at 2 cm below the umbilicus.

## DISCUSSION

This ultrasonographic study measured the width of the linea alba in 150 nulliparous women at three representative positions, at the origin at the xiphoid, at 3 cm above the umbilicus and at 2 cm below the umbilicus. When the 90th percentile is used to define the “normal” width of the linea alba, the normal width is designated as 15 mm at the xiphoid, 22 mm above the umbilicus and 16 mm below the umbilicus.

In 21 of the women examined (14%), the linea alba was wider at the xiphoid than at 3 cm above the umbilicus, as the rectus muscles showed a small divergent, lateral insertion at the costal margins. Yet, in only one woman did the width of the linea alba surpass that of the supraumbilical reference point by 10 mm. We would not consider such a divergence to be a congenital myoaponeurotic deformity C (Nahas, 2001), as Nahas did not define the quantitative border between the physiological breadth of the linea alba at the xiphoid and a congenital deformity C.

Our decision to include only women 20 to 45 years of age and to exclude women with a body mass index  $>30$  kg m<sup>-2</sup> and a weight loss  $>10$  kg was based on the literature. Rath et al. (1996) found a significantly wider linea alba above and below the umbilicus in subjects beyond the age of 45 years, and Hagentorn (1902) reported a pronounced accumulation of rectus diastases of up to 40–50 mm or more in children.

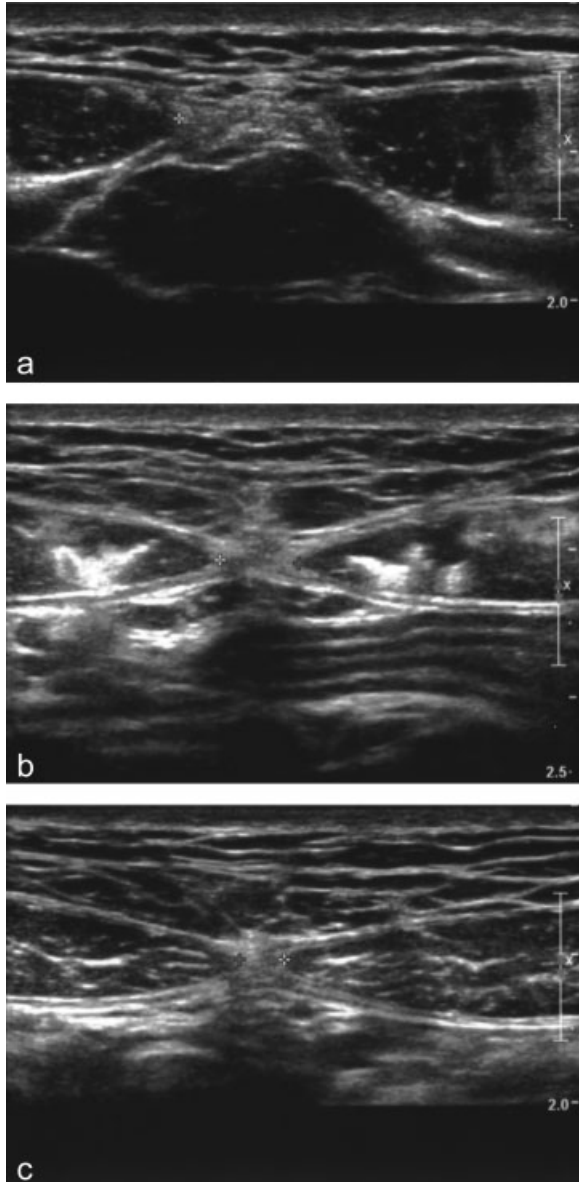
The correlation of the width of the linea alba with increasing weight is less established than that of age. Mendes et al. (2007), for example, correlated body weight with rectus diastasis, as they stated that diastasis occurs after major weight loss. On the other hand, Nahas et al. (1997) found no relevant correlation between weight gain and rectus diastasis. This led the authors to conclude that women gain most of their weight in areas outside of the abdominal cavity, so

tension on the abdominal wall and the linea alba does not necessarily increase with weight gain. Despite these conflicting theories, we excluded women with a body mass index of  $>30$  kg m<sup>-2</sup>, as we recognized that, in the case of obesity, fat tissue can accumulate between the linea alba and the rectus muscles within the most medial regions of the rectus sheath, laterally displacing the muscles and leading to a wider distance between both rectus muscles (Fig. 3).

When defining the normal width of the linea alba, the question arises as to which method is optimal and whether ultrasound is a valid means for examination. The validity of ultrasound in examining the anterior abdominal wall is well established (Hodgson et al., 2000). Although only a few studies have used ultrasound for determining the width of the linea alba and rectus diastasis, ultrasound use was validated in a recent study by Mendes et al. (2007). In this study, rectus diastasis was measured by preoperative ultrasonography in 20 females at different levels, 3, 6, 9, and 12 cm above the umbilicus, at the umbilicus and at 2 and 4 cm below the umbilicus. The authors found the greatest width of the linea alba at 3 cm above the umbilicus and 2 cm below the umbilicus. These findings were the basis for our choice of measurement locations. Matarasso et al. (2005) also found that the central periumbilical area is the region of maximum width of the linea alba.

In the cited ultrasonographic study of Mendes, all the levels measured preoperatively were also measured after exposition during abdominoplasty. The examiners found no significant difference between the values obtained by ultrasound and those measured during surgery in the supra-umbilical levels and at the level of the umbilicus. However, below the umbilicus, these values differed significantly, showing smaller values in the imaging evaluation. This may be due to the fact that all of the examined women had experienced at least one pregnancy, and 19 of the 20 women had undergone a previous Caesarean section with resulting fibrosis in the infra-umbilical area, which may have led to difficulties in identifying the rectus muscles inferiorly and may have negatively affected the accurate measurements. The authors concluded that ultrasonography is an accurate method to measure rectus diastasis above the umbilicus and at the umbilical level.

Van Uchelen et al. (2001a) used ultrasound for the evaluation of long-term durability of plication of

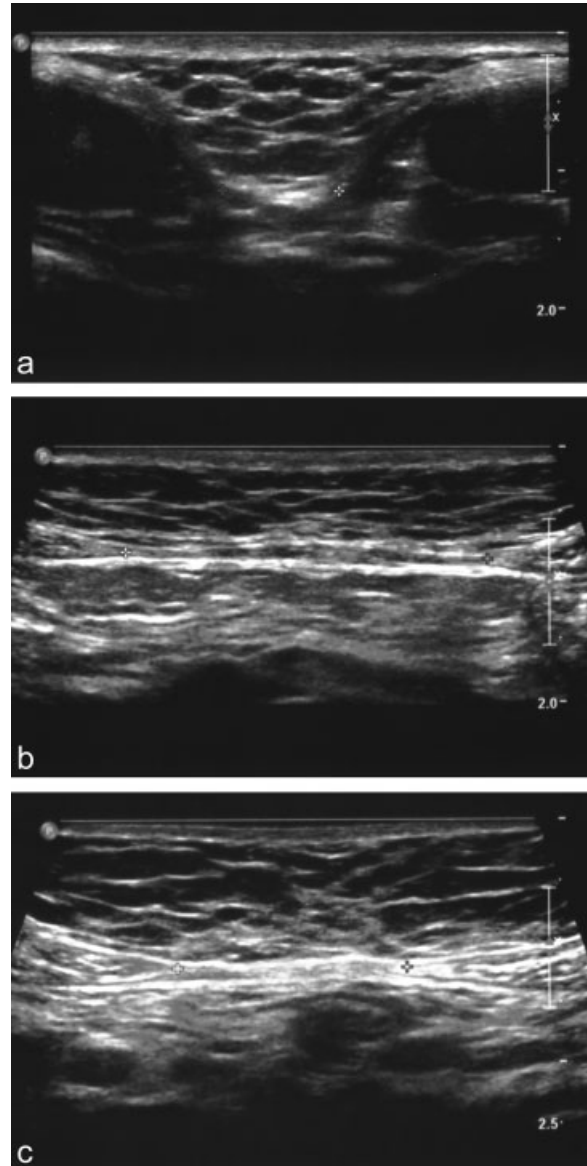


**Fig. 1.** Representative ultrasonographic images of the linea alba and the rectus muscles in a woman with a small linea alba, 26 years of age, body mass index  $18.4 \text{ kg m}^{-2}$ . **(a)** Transverse scan at the origin at the xiphoid (10 mm), **(b)** 3 cm above the umbilicus (5 mm), and **(c)** 2 cm below the umbilicus (3 mm). There is an excellent visualization of the hypoechogenic rectus muscles in contrast to the hyperechogenic linea alba. The asterisks show the width of the linea alba. There is no difficulty in identifying the medial margins of the rectus muscles. The anterior and posterior sheaths of the rectus fascia are thick and clearly visible. There are no difficulties in identifying the rectus muscles infraumbilically.

the anterior rectus sheath in 40 women and also considered it as a valid means of examination for assessing rectus diastasis.

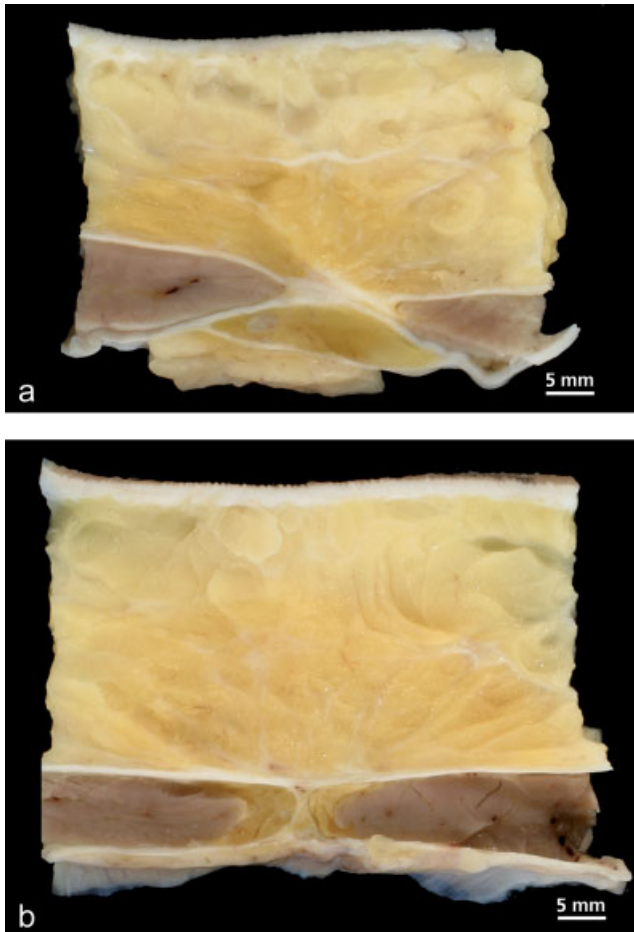
Recently, ultrasound has replaced computed tomography as the method of choice in examining the

abdominal wall. Compared to the expense and radiation exposure of computed tomography, ultrasound is a simple, noninvasive and inexpensive technique that may be repeated as often as necessary. However, a correct evaluation depends on the examiners' skill and training and the quality of the equipment, as ultrasound has a small field of view, which is limited to the width of the transducer (in general, 4–6 cm). To overcome such disadvantages, sophisticated techniques such as an extended field of view and echo filters have been developed, and image quality has been



**Fig. 2.** Representative ultrasonographic images of the linea alba and the rectus muscles in a woman with a wide linea alba, 31 years of age, body mass index  $21.7 \text{ kg m}^{-2}$ . **(a)** Transverse scan at the origin at the xiphoid (8 mm), **(b)** 3 cm above the umbilicus (28 mm), and **(c)** 2 cm below the umbilicus (19 mm).





**Fig. 3.** Cross-section of the linea alba and the rectus muscles (**a**) 3 cm above and (**b**) 2 cm below the umbilicus in a fresh unfixed, obese female cadaver (body mass index  $31.2 \text{ kg m}^{-2}$ ). Notice the accumulation of additional fat tissue in the subperitoneal median in (a) and the accumulation of fat within the medial regions of both rectus sheaths, laterally displacing the rectus muscles and mimicking a rectus diastasis, in (b).

improved. Thus, the evaluation of the linea alba in our study yielded no major problems.

Irrespective of the means used in evaluating the linea alba, there are only very few studies that have attempted to define the normal width of the linea alba and, thus, define rectus diastasis. The most extensive work is that of Rath et al. (1996). They defined rectus diastasis after studying the linea alba in 40 fresh cadavers and 40 abdominopelvic computed tomography scans. The cadavers of 20 women and 20 men studied had lean to obese body builds and were aged an average of 83 years (range: 62–99 years) and thus cannot be compared with our study. In the computed tomography portion of the study, there was also a mixture of men and women (16 women and 24 men) with a broad range of ages from childhood to seniority. Additionally, information regarding the weight of all cadavers and the number of pregnancies in the women is missing. Two reference

points were measured: the supra-umbilical reference point was halfway between the umbilical ring and the xiphoid process, and the infra-umbilical point was halfway between the umbilical ring and the pubic symphysis. In subjects younger than 45 years of age (19 of the 40 subjects), the mean width of the linea alba above and below the umbilicus was indicated at 5 mm. From these numbers, the authors defined rectus diastasis as a separation of rectus muscles exceeding 10 mm above the umbilicus and 9 mm below the umbilicus. Whether these values represent the standard deviation or some other standardized measuring unit is not indicated. We do not wish to define the “normal” width of the linea alba from such a nonhomogeneous patient population, particularly as the authors themselves stated that the width of the linea alba differs significantly with age and sex.

Three other studies from the research group of Nahas et al. (1997, 2001, 2005) also provide information regarding the width of the linea alba. In these studies with 12–20 women, the average width of the linea alba, was 24–26 mm above the umbilicus and 12–14 mm below the umbilicus. The figures of these studies are considerably higher at both representative positions, as compared with our average widths of 13 and 8 mm. The difference in the figures seems to be due to the fact that in the cited studies, all women had experienced previous pregnancies, suggesting that gravity is likely to lead to a persistent widening of the linea alba. Consequently, Nahas et al. (2005) stated that all examined women had a rectus diastasis despite the authors never attempting to define the normal width of the linea alba. Yet, when evaluating the widths of their third study in detail, 5 of the 12 women had a supraumbilical width of the linea alba smaller than 22 mm, and 9 of the 12 women had an infraumbilical width equal to or smaller than 16 mm, numbers that we would not automatically define as rectus diastasis per se, as they are within the range of our 90th percentile, which represents the “normal” width of the linea alba. In all three studies, only two women had a width of the linea alba above the umbilicus  $>35$  mm, and no women had a width  $>31$  mm below the umbilicus, with 35 and 31 mm being the extremes in our study of normal widths. Nevertheless, Nahas (2001) aimed at complete rectus muscle closure in any of their cases. Because of such aims, the question arises as to whether correction of a normal width of the linea alba and thus a “normal” rectus diastasis is desirable and worthwhile in women, as rectus diastasis is only one symptom of a stretched abdominal wall (Brauman, 2008). In addition, it should be considered whether the potential complications of complete invagination of the linea alba and approximation or complete advancement of the rectus muscles, with enhanced pain, enhanced morbidity with difficulties in mobilizing women, and the danger of fistula and palpable suture knots due to the suture material, are justified. Furthermore, the question arises as to whether complete advancement of those rectus muscles, which were never driven apart, will last over time, as repeated contraction will probably force the muscles back to their original, more lat-

eral position. In addition to contraction, several other forces could act against such a plication, i.e., intra-abdominal pressure and the tissue elasticity of the linea alba and thus surgeons should respect the natural diastasis between the two rectus muscles. Regarding this issue, Birdsell et al. (1981), Netscher et al. (1995), al-Qattan (1997), and van Uchelen et al. (2001a), found a residual or recurrent rectus diastasis from 40 to 100% in their patients after correction. Only in the three above cited studies of Nahas et al. was the recurrence rate of rectus diastasis zero.

Taking into account all the cited studies and comparing them with our study, we can conclude that the width of the linea alba has a broad range of values.

The normal width of the linea in our nulliparous women from 20 to 45 years of age with a body mass index  $<30 \text{ kg m}^{-2}$  is up to 15 mm at the xiphoid, up to 22 mm at 3 cm above the umbilicus and up to 16 mm at 2 cm below the umbilicus. Beyond these values a rectus diastasis can be anticipated with an error quote of 10% and beyond the extreme widths of 31, 35, and 31 mm a rectus diastasis can be anticipated for sure.

Ultrasonography is a validated noninvasive, repeatable method used to preoperatively measure rectus diastasis and can be helpful in developing an accurate operative plan.

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