Original Article

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DOI: 10.4103/ijawhs.ijawhs_125_25

Shear-wave elastography assessment of the linea alba mechanical properties in individuals with obesity versus normal-weight: A pilot study

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Abstract

BACKGROUND: Diastasis recti abdominis (DRA) is characterized by a widened linea alba, but its pathophysiology may involve complex biomechanical failure. This pilot study utilized shear-wave elastography (SWE) to characterize the mechanical properties of the abdominal wall in healthy adults and investigate the influence of obesity on DRA presentation.

MATERIALS AND METHODS: The study was conducted on a group of 10 healthy adult volunteers. All participants underwent ultrasonographic assessment. Morphological measurements and SWE of the linea alba, rectus sheaths, and lateral fasciae were performed at rest and during three maneuvers: Valsalva, curl-up, and side plank.

RESULTS: Four participants had DRA. A divergent biomechanical response was observed: during an isolated curl-up, the linea alba stiffened in obese individuals with DRA but softened in non-obese individuals. A visible epigastric bulge was universally linked to DRA, but its manifestation depended on body habitus and the type of muscle activation. Obese individuals exhibited bulging during global maneuvers (Valsalva, side plank), whereas non-obese individuals showed bulging only during the curl-up.

CONCLUSION: Obesity fundamentally alters the abdominal wall's response to load, suggesting a dual pathophysiology for DRA-related bulging. These preliminary findings highlight that management strategies, including physical therapy, may need to be tailored based on patient body habitus.

Keywords:

Abdominal wall mechanics, diastasis recti abdominis, linea alba, obesity, shear-wave elastography

Introduction

Of the many conditions affecting the abdominal wall, diastasis recti abdominis (DRA) presents a particularly intriguing clinical picture, straddling the line between a cosmetic concern and a potential biomechanical dysfunction. Traditionally, DRA has been defined by its morphology: an abnormal separation of the two bellies of the rectus abdominis muscle, most commonly observed in the supraumbilical region. Diagnosis is often confirmed quantitatively using ultrasonography, with a separation exceeding 20 mm at or above the umbilicus serving as a common diagnostic criterion. Clinically, DRA typically presents as a characteristic midline bulge or protrusion that becomes evident during straining or trunk flexion. For many years, this presentation was largely considered an aesthetic issue, with the prevailing view being that, beyond the visible bulge, it did not cause significant pain or functional core weakness.[1-3]

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Submitted: 03-Dec-2025
Revised: 23-Jan-2026
Accepted: 02-Feb-2026
Published: 18-Apr-2026

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How to cite this article: Bielaczyc G, Simka M. Shear-wave elastography assessment of the linea alba mechanical properties in individuals with obesity versus normal-weight: A pilot study. Int J Abdom Wall Hernia Surg 2026;9:36-42.

However, this foundational understanding of DRA as a mere anatomical gap is being challenged by research into the dynamic mechanical properties of the abdominal wall's constituent tissues. To move beyond simple linear measurements and investigate this complex problem more thoroughly, we conducted a pilot study utilizing advanced ultrasonographic techniques. Our research aimed to characterize not just the morphology, but also the functional properties of the abdominal wall structures. We performed shear-wave elastography (SWE) on a cohort of 10 healthy individuals. This noninvasive technology allows for the quantitative, real-time measurement of tissue stiffness by tracking the speed of shear-waves propagating through the tissue. Our analysis specifically focused on the elastographic characteristics of the linea alba, the adjacent rectus abdominis and oblique abdominis muscles, and their enveloping fascial sheaths.

Materials and Methods

This pilot study was conducted on a cohort of 10 healthy adult volunteers. The study protocol was approved by the bioethical committee of our university (Approval No. UO/0008/KB/2024) and was performed in accordance with the ethical standards outlined in the Declaration of Helsinki. Informed consent was obtained from all individual participants.

The inclusion criteria were as follows: age over 18 years and a physical condition sufficient to participate in abdominal muscle testing. Key exclusion criteria were designed to eliminate confounding factors affecting the abdominal wall and included a current or history of linea alba hernia, a current or history of other abdominal hernias, clinically significant cardiopulmonary insufficiency, and any other systemic conditions that would preclude physical exercise. Basic anthropometric data were collected for all participants, including age, sex, body height, body weight, body mass index (BMI), and waist circumference.

All ultrasonographic assessments were performed by a single physician to ensure consistency. Examinations were carried out using the Samsung V8 ultrasound system (Samsung Medison, Seoul, Republic of Korea), equipped with a 10 MHz linear probe and a dedicated elastographic preset. The protocol consisted of two parts: a morphological (B-mode) assessment and a functional (elastographic) assessment.

Morphological assessment

The following morphological measurements were taken bilaterally (except for the linea alba) at a standardized location: halfway between the umbilicus and the xiphoid process [Figure 1].

- Linea alba width.
- Linea alba thickness.
- Rectus abdominis muscle width.
- Rectus abdominis muscle thickness.
- Thickness of the oblique and transversus abdominis muscles (measured in the midclavicular line).
- Thickness of the transversalis fascia (measured in the midclavicular line).

Elastographic assessment

SWE was utilized to quantitatively measure tissue stiffness. Elastographic measurements were performed under four different conditions of abdominal wall activation to assess dynamic changes in tissue tension:

1. At rest.
2. During the Valsalva maneuver.
3. During curl-up (head-lift), selectively engage the rectus abdominis.
4. In a side plank position, primarily engaging the oblique and transversus abdominis muscles.

The following structures were evaluated elastographically [Figure 2]:

- Linea alba.
- Linea alba-rectus abdominis junction.
- Anterior rectus sheath.
- Posterior rectus sheath.



Figure 1: Ultrasonography of the anterior abdominal wall: 1. linea alba; 2. rectus abdominis muscle belly; 3. anterior rectus sheath

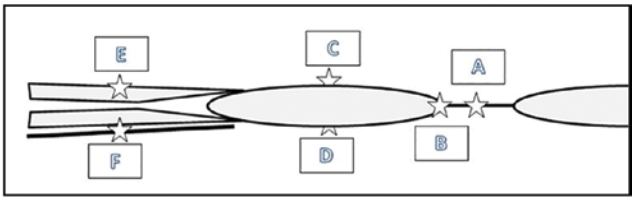


Figure 2: The sites of the abdominal wall assessed elastographically: A. linea alba; B. linea alba-rectus abdominis junction; C. anterior rectus sheath; D. posterior rectus sheath; E. external oblique muscle fascia; F. transversalis fascia

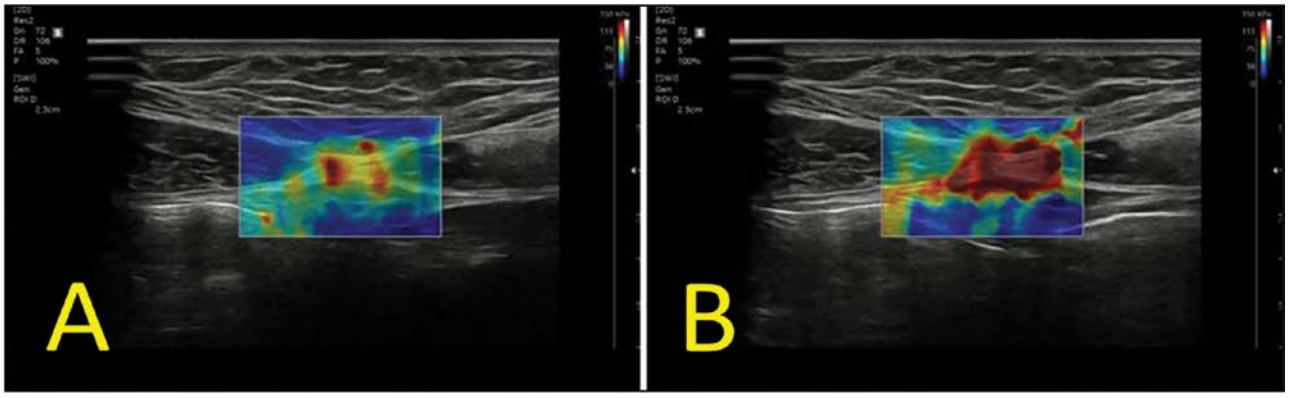


Figure 3: Ultrasonography with elastographic imaging of the linea alba area: A. at rest, B. during Valsalva maneuver

- Fascia covering the external oblique muscle.
- Transversalis fascia.

For this purpose, SWE was performed using the ultrasonographic system. The areas of interest were first visualized, and the shear-wave velocity was then automatically converted into an elastic modulus, providing a measurement of local tension in kilopascals [Figure 3]. Statistical comparisons between groups were conducted with an independent two-sample *t* test. A two-sided *P*-value of less than 0.05 was defined as the threshold for statistical significance.

Table 1: Morphological characteristics of the anterior abdominal wall

	Range	Mean
Linea alba width [mm]	13–70	33.1
Linea alba thickness [mm]	1.0–1.3	1.14
Left rectus abdominis muscle width [mm]	32–42	36.4
Right rectus abdominis muscle width [mm]	30–40	33.9
Left rectus abdominis muscle thickness [mm]	6–31	17.6
Right rectus abdominis muscle thickness [mm]	6–27	14.9
Left lateral abdominal muscle thickness [mm]	11–27	19.4
Right lateral abdominal muscle thickness [mm]	12–26	19.0
Left transversalis fascia thickness [mm]	0.8–1.2	1.01
Right transversalis fascia thickness [mm]	0.9–1.3	1.03

Results

The study cohort consisted of 10 individuals (4 females, 6 males) with a mean age of 43.7 years (range: 20–67). The mean height was 180.1 cm (range: 161–199 cm), and the mean weight was 89.8 kg (range: 52–118 kg). This resulted in a mean BMI of 27.7 (range: 20–39) and a mean waist circumference of 99.8 cm (range: 60–130 cm). Three participants (30%) were classified with obesity (BMI ≥ 30).

The width of the linea alba at the measurement point ranged from 13 to 70 mm (mean: 33.1 mm). DRA, defined as a linea alba width >20 mm, was present in four individuals. In all cases with DRA, a palpable or visible bulge in the epigastrium was observed in at least one body position. Detailed morphological characteristics of the anterior abdominal wall in the epigastrium are provided in Table 1.

The presence of DRA was not consistently associated with an epigastric bulge. Whereas obese individuals exhibited a bulge in three of the assessed positions, a bulge was observed in only one non-obese individual with DRA (during an abdominal crunch). Detailed findings are presented in Table 2.

SWE revealed that local tension approximately doubled at all measured points during the Valsalva maneuver compared to the resting state. While this Valsalva-induced increase was consistent, its magnitude differed by patient group at specific locations. No significant differences were found between obese and non-obese participants at the linea alba, the linea alba-rectus abdominis junctions, or the rectus abdominis sheaths. However, a significantly greater increase in tension was observed in obese individuals at the external oblique muscle fascia and the transversalis fascia. Elastographic measurements during the curl-up and side plank positions showed considerable heterogeneity, which was largely attributed to obesity. A divergent response was observed at the linea alba and its junction with the rectus abdominis: during an abdominal crunch, normal-weight subjects exhibited a decrease in local tension, whereas obese individuals demonstrated an increase. Similarly, during a side plank, tension remained at resting levels in normal-weight subjects but increased in the obese group. Furthermore, obese individuals exhibited significantly higher tension at the external oblique muscle fascia and transversalis fascia across all three dynamic maneuvers—Valsalva, curl-up, and side plank (with the exception of the right external oblique fascia during a right side plank). Detailed results of this analysis for specific measurement points and positions are provided in Table 3.

Table 2: Presence of a visible epigastric bulge under different abdominal wall conditions in 10 individuals, categorized by diastasis recti and obesity status

	Linea alba width >20 mm	BMI ≥ 30	Bulge in epigastrium			
			At rest	Valsalva maneuver	Curl-up	Side plank position
1	No	No	No	No	No	No
2	No	No	No	No	No	No
3	No	No	No	No	No	No
4	No	No	No	No	No	No
5	No	No	No	No	No	No
6	No	No	No	No	No	No
7	Yes	No	No	No	Yes	No
8	Yes	Yes	No	Yes	Yes	Yes
9	Yes	Yes	No	Yes	Yes	Yes
10	Yes	Yes	No	Yes	Yes	Yes

BMI = body mass index

Table 3: Local tension values measured by shear-wave elastography across four abdominal wall conditions. Data are expressed as mean ± standard deviation for the entire study group and after categorization into normal-weight and obese individuals. Statistically significant differences between normal-weight and obese individuals ($P < 0.05$) are indicated by bold font

	At rest [kPa]		Valsalva maneuver [kPa]		Curl-up [kPa]		Right side plank position [kPa]	
	Normal-weight	Obesity	Normal-weight	Obesity	Normal-weight	Obesity	Normal-weight	Obesity
Linea alba	82.2 ± 16.2		213.1 ± 65.9		114.9 ± 126.3		118.6 ± 58.3	
	75.9 ± 13.1	97.0 ± 14.1	184.1 ± 48.4	280.7 ± 52.2	37.0 ± 16.2	296.7 ± 14.6	83.7 ± 16.5	200.0 ± 16.5
Linea alba-rectus abdominis junction – left	78.1 ± 13.9		159.1 ± 32.0		86.0 ± 89.3		130.7 ± 63.3	
	76.1 ± 15.6	82.7 ± 10.1	148.3 ± 31.5	184.3 ± 16.2	30.9 ± 8.2	214.7 ± 15.0	93.7 ± 24.7	217.0 ± 15.7
Linea alba-rectus abdominis junction – right	77.6 ± 9.9		166.9 ± 39.4		78.3 ± 79.5		133.7 ± 40.9	
	76.3 ± 11.9	80.7 ± 1.2	153.0 ± 32.9	199.3 ± 38.2	29.1 ± 7.9	193.0 ± 6.1	108.4 ± 7.2	191.3 ± 12.1
Anterior rectus sheath – left	49.8 ± 17.6		141.3 ± 46.3		170.2 ± 35.2		124.1 ± 47.8	
	63.4 ± 16.6	84.7 ± 9.7	129.1 ± 50.1	169.7 ± 20.2	162.0 ± 38.9	189.3 ± 15.3	97.1 ± 23.7	187.0 ± 11.5
Anterior rectus sheath – right	69.7 ± 19.5		143.5 ± 56.0		160.7 ± 43.2		148.5 ± 34.0	
	62.0 ± 18.0	87.7 ± 6.8	124.7 ± 57.0	187.3 ± 15.1	144.9 ± 40.9	197.7 ± 21.1	131.1 ± 23.7	189.0 ± 1.7
Posterior rectus sheath – left	39.8 ± 5.5		95.7 ± 36.7		74.7 ± 11.8		79.4 ± 11.1	
	40.3 ± 4.2	38.7 ± 9.0	101.4 ± 43.3	82.3 ± 6.5	69.9 ± 9.3	86.0 ± 9.6	80.1 ± 8.9	77.7 ± 17.8
Posterior rectus sheath – right	41.7 ± 6.1		91.3 ± 30.7		70.3 ± 13.8		70.0 ± 8.1	
	42.7 ± 4.3	39.3 ± 10.0	98.3 ± 34.9	75.0 ± 5.0	64.6 ± 12.3	83.7 ± 5.1	66.3 ± 4.0	78.7 ± 9.3
External oblique muscle fascia – left	75.7 ± 15.4		126.8 ± 41.5		139.8 ± 34.9		133.2 ± 39.2	
	72.6 ± 16.1	83.0 ± 13.2	103.4 ± 20.8	181.3 ± 9.9	122.0 ± 20.9	181.3 ± 21.4	115.4 ± 30.3	174.7 ± 21.6
External oblique muscle fascia – right	75.8 ± 15.0		135.0 ± 38.6		142.7 ± 37.9		165.8 ± 28.9	
	72.1 ± 15.8	84.3 ± 10.8	114.7 ± 23.7	182.3 ± 15.3	124.3 ± 28.8	185.7 ± 5.1	162.1 ± 33.7	174.3 ± 14.0
Transversalis fascia – left	37.7 ± 8.4		58.2 ± 13.0		61.9 ± 18.1		59.9 ± 17.4	
	37.6 ± 9.9	38.0 ± 5.3	53.0 ± 11.3	70.3 ± 8.1	53.0 ± 13.4	82.7 ± 3.5	50.9 ± 10.8	81.0 ± 8.2
Transversalis fascia – right	39.1 ± .62		55.9 ± 12.7		58.3 ± 15.2		53.4 ± 11.5	
	38.0 ± 7.9	41.7 ± 10.3	49.6 ± 7.4	70.7 ± 9.5	50.6 ± 8.1	76.3 ± 11.8	47.3 ± 5.0	67.7 ± 9.3

kPa = kilopascals

Discussion

This pilot study utilized SWE to characterize the mechanical properties of the anterior abdominal wall, revealing distinct patterns of linea alba stiffness that were significantly influenced by obesity and the presence of DRA. The central finding was a contrasting biomechanical behavior between normal-weight and obese individuals. A key observation was the divergent response of the linea alba to an isolated rectus abdominis contraction (curl-up maneuver). In non-obese individuals, this maneuver resulted in decreased stiffness of the linea alba and its junctions with the rectus abdominis. Conversely, in obese individuals with DRA, the same action provoked a significant increase in stiffness in these structures. In contrast, global abdominal engagement during the Valsalva maneuver produced a uniform increase in stiffness across all measurement points in both groups.

These elastographic findings provide a potential mechanistic explanation for the clinical presentation of epigastric bulging in patients with DRA. The occurrence of a visible bulge was universally linked to diastasis, but its manifestation depended on the type of muscle activation and body habitus. While a midline bulge was observed in all participants with DRA during an isolated head-lift, it was exclusively observed in obese individuals with DRA during global maneuvers like the Valsalva and side plank. Synthesizing these observations, our results suggest a dual pathophysiology for diastasis-related bulging, in which obesity fundamentally alters the mechanical response of the linea alba to specific loads.

It is essential to interpret these results with caution. As a pilot study, our findings are derived from a relatively small number of participants. Larger-scale investigations in more diverse and extensive cohorts are necessary to confirm these patterns and enhance their generalizability. Differences in biomechanical behavior may emerge with a greater sample size or different population demographics. Nonetheless, these preliminary findings provide a useful framework and generate important hypotheses for future studies on DRA, particularly in obese individuals. They highlight the critical interaction between body habitus, fascial mechanics, and muscle activation strategy—a perspective that should guide further research into the pathophysiology and management of DRA across different patient populations.

In non-obese individuals, an isolated rectus contraction reduces tension in the linea alba. In the context of a preexisting diastasis, this loss of tension permits the protrusion of preperitoneal adipose tissue, creating the characteristic midline bulge. Our finding aligns with the work of Beamish *et al.*, who similarly reported a decrease in linea alba stiffness during head-lift and curl-up maneuvers in non-obese women.[4] Their study concluded that the primary characteristic of DRA was a failure of the linea alba to stiffen under load. This was further supported by Lee *et al.*,[5] who described a similar distortion of the linea alba during curl-ups, suggesting a decrease in tension, albeit without using elastography. Our results largely corroborate this model in normal-weight individuals. This mechanism is responsible for the unaesthetic bulging associated with DRA suggests that exercises inducing such a tension reduction may be counterproductive in physiotherapeutic management, especially if they were the only exercises prescribed.

However, a critical distinction emerges from our data regarding the role of obesity. In our obese participants with DRA, the linea alba demonstrated an increase in stiffness during the curl-up. Thus, in obese individuals, the primary mechanism responsible for bulging in the epigastrium appears to differ. This bulging is likely driven by the direct pressure from intra-abdominal contents against the abdominal wall during muscle activation, leading to protrusion rather than passive stretching of the linea alba. This is corroborated by the observed increase in linea alba stiffness during the head-lift maneuver in this group. This suggests that the pathophysiology of DRA is not uniform and is fundamentally modulated by abdominal contents. Furthermore, it is likely that this constant tension across the linea alba is similar to the pathomechanism responsible for DRA formation during pregnancy—albeit without the concomitant action of relaxin, which in pregnant women loosens fibrous connective tissue structures, including the linea alba.

In summary, our findings suggest that obesity fundamentally alters the abdominal wall's mechanical response to loading, with significant implications for the management of DRA. The presence of obesity appears to create a distinct biomechanical state in which the abdominal wall responds to load with heightened tension, likely due to the dominant effect of intra-abdominal pressure. Therefore, while the model from Beamish *et al.* and Lee *et al.* aptly describes the mechanics in non-obese populations,[4,5] our findings indicate that a separate mechanistic model is necessary to understand DRA in the context of obesity.

Contemporary studies suggest that the pathology of DRA is not merely a widening of the linea alba, but rather a complex biomechanical failure. This paradigm posits that DRA results from an awry interplay between the abdominal muscles and fascial sheaths, where midline integrity depends not only on width but also on the linea alba's intrinsic stiffness and resilience. A thinned, compliant linea alba may fail as a stable central fibrous structure even within traditional width thresholds, leading to a visible bulge that signifies a deeper compromise in force transmission and trunk stability. This broader dysfunction is supported by findings such as reduced trunk rotation torque in women with DRA,[6] indicating impaired oblique muscle function. Furthermore, the mechanical interplay is critically influenced by body habitus. A higher incidence of DRA in obese women[7] and our findings suggest that increased intra-abdominal volume—from fat deposits or pregnancy—likely alters the delicate balance between the muscular and fibrous components of the abdominal wall.[8-10] Importantly, a bulging in the epigastrium is not pathognomonic for DRA. It can also occur in individuals with a normal linea alba width but thin and weakened rectus abdominis muscles. A hernia of the linea alba can also present with similar bulging. Therefore, a thorough diagnostic workup, preferably using ultrasonography to visualize the subcutaneous and fascial anatomy, is essential. Of note, all participants in our study who

presented with epigastric bulging also had a widened linea alba. However, as previously discussed, this was a small sample study, and all observations should be interpreted with caution.

Currently, there is no universal or strongly evidence-based protocol for managing diastasis DRA, with the European Hernia Society noting limited evidence and weak recommendations.[2] While physiotherapy may reduce abdominal separation,[11-14] no specific exercise program is endorsed, and its symptomatic benefit remains unproven. However, dedicated physical therapy—widely recommended for post-partum DRA—could be optimized. Our results and prior studies suggest that while strengthening the rectus abdominis can be valuable, it should not be done in isolation. An effective protocol should include a set of exercises targeting all abdominal wall muscles, particularly the obliques. A strong external and internal oblique and transversus abdominis complex stabilizes the midline by tensioning the linea alba, reducing unaesthetic bulging, and improving lumbar stability—potentially alleviating the increased lordosis and back pain often associated with DRA. A dedicated, evidence-based exercise regimen could reduce the need for surgical intervention, which currently lacks standardization and robust evidence.

The management of DRA in obese individuals, however, may differ. Given the altered biomechanics of the abdominal wall in obesity, physiotherapy alone may be insufficient, and treatment should likely begin with weight reduction. While physical exercises—emphasizing global abdominal engagement—can be a valuable component of a broader plan that includes diet and pharmacological management, surgical correction (e.g., linea alba plication with or without mesh) carries higher risks in this population and is generally not a preferred first-line option. Alternatively, surgical plication could be considered as a combined procedure with bariatric surgery. Ultimately, if surgery for isolated DRA is considered, the decision and technique should follow a thorough shared decision-making process between patient and surgeon, acknowledging the absence of strong evidence favoring any single approach. It is critical to recognize that research on DRA has historically focused almost exclusively on post-partum women, leaving other patient groups largely neglected. Obese patients represent one such understudied population that could particularly benefit from a better understanding of abdominal wall biomechanics in the context of DRA. Therefore, dedicated research on larger cohorts of obese individuals is not only necessary to fully understand the unique biomechanics but is essential to establish safe, effective, and evidence-based management protocols.

Author contributions

We certify that we have participated sufficiently in the intellectual content, conception and design of this work or the analysis and interpretation of the data (when applicable), as well as the writing of the manuscript, to take public responsibility for it and have agreed to have our name listed as a contributor.

Ethical policy and institutional review board statement

The study protocol was approved by the bioethical committee of our university (Approval No. UO/0008/KB/2024) and was performed in accordance with the ethical standards outlined in the Declaration of Helsinki.

Declaration of patient consent

Informed consent was obtained from all individual participants.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Acknowledgments

Not applicable.

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