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Warping of the levator hiatus: how significant is it?

H. P. DIETZ*, M. SEVERINO*, I. KAMISAN ATAN*†, K. L. SHEK*‡ and R. GUZMAN ROJAS§¶

**Department of Obstetrics and Gynecology, Sydney Medical School Nepean, University of Sydney, Penrith, Australia; †Universiti Kebangsaan Malaysia Medical Centre (UKMMC), Kuala Lumpur, Malaysia; ‡Department of Obstetrics and Gynecology, Liverpool Hospital, University of Western Sydney, Richmond, NSW, Australia; §Departamento de Ginecología y Obstetricia, Facultad de Medicina, Clínica Alemana – Universidad del Desarrollo, Santiago, Chile; ¶Departamento de Ginecología y Obstetricia, Hospital Clínico de la Universidad de Chile, Santiago, Chile*

KEYWORDS: 4D ultrasound; female pelvic organ prolapse; levator hiatus; measurement; translabial ultrasound

ABSTRACT

Objectives *The levator hiatus is the largest potential hernial portal in the human body. Excessive distensibility is associated with female pelvic organ prolapse (POP). Distension occurs not just laterally but also caudally, resulting in perineal descent and hiatal deformation or 'warping'. The aim of this study was to quantify the warping effect in symptomatic women, to validate the depth of the rendered volume used for the 'simplified method' of measuring hiatal dimensions and to determine predictors for the degree of warping.*

Methods *This was a retrospective study utilizing records of patients referred to a tertiary urogynecological service between November 2012 and March 2013. Patients underwent a standardized interview, clinical assessment using the POP quantification system of the International Continence Society and four-dimensional translabial ultrasound. The craniocaudal difference in the location of minimal distances in mid-sagittal and coronal planes was determined by offline analysis of ultrasound volumes, and provided a numerical measure of warping. We tested potential predictors, such as demographic factors, signs and symptoms of prolapse, levator avulsion and levator distensibility, for an association with warping.*

Results *Full datasets were available for 190 women. The mean craniocaudal difference in location of minimal distances in mid-sagittal and coronal planes was −1.26 mm (range, −6.7 to 4.6 mm; $P < 0.001$). This measure of warping was associated with hiatal area on Valsalva maneuver ($r = -0.284$; $P < 0.0001$) and signs of significant prolapse on clinical and ultrasound examination (both $P < 0.0001$).*

Conclusions *The plane of minimal dimensions of the levator ani hiatus is non-Euclidean, i.e. warped, and the degree of warping is associated with hiatal distension, or 'ballooning', and with POP. However, the degree of warping is minor, the largest difference we found in the location of the plane of minimal dimensions being 6.7 mm. Hence, our results support the determination of hiatal area in a rendered volume of 1–2 cm in depth. Copyright © 2015 ISUOG. Published by John Wiley & Sons Ltd.*

INTRODUCTION

Pelvic organ prolapse (POP) is a common condition that conveys substantial bother and is associated with a lifetime risk of surgical intervention of 10–20% in developed countries[1–3]. POP may be described as herniation of pelvic organs through the levator hiatus, the largest potential hernial portal in the human body. The conditions subsumed under the term 'POP' vary considerably in etiology and functional impact, as POP may involve multiple organ systems, singly or in combination, such as the lower urinary tract, the lower aspects of the reproductive tract and the lower gastrointestinal tract.

Excessive distensibility of the hiatus is a common observation in women complaining of prolapse. It can be determined clinically, by measuring the length of the genital hiatus (gh) and perineal body (pb) on Valsalva maneuver as part of the Pelvic Organ Prolapse Quantification (POP-Q) system of the International Continence Society (ICS)[4,5], and on imaging, by determining the levator hiatus, i.e. the space between the inferior pubic rami and the puborectalis component of the levator ani muscle, in the plane in which this structure is the narrowest, i.e. the 'plane of minimal hiatal dimensions'[6]. Clinical (gh and pb) and sonographic measures of hiatal dimensions have been shown to be strongly associated with each other[7].

The area of the levator hiatus on maximal Valsalva is a predictor of prolapse and its recurrence[8,9]. Distension occurs not just laterally but also caudally, resulting in perineal descent and substantial deformation of the hiatus. This implies that the levator outlet, i.e. the true plane

Correspondence to: Prof. H. P. Dietz, Sydney Medical School Nepean, Nepean Hospital, Penrith, NSW 2750, Australia (e-mail: hpdietz@bigpond.com)

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of minimal dimensions, may not remain a 'Euclidean' (i.e. flat) plane but may become warped, to a greater or lesser degree. This phenomenon has been described previously in a study using magnetic resonance imaging in a small number of patients[10]. Prompted by this finding, a simplified method for the determination of hiatal dimensions has been described using a 'rendered volume', i.e. a semitransparent representation of a box-like volume of imaging data[11]. The original description of this technique uses a box of an arbitrarily defined depth of 1–2 cm[11].

The aim of this study was to quantify the warping effect described above in a larger series of symptomatic women, validate the box depth used for the 'simplified method' of measuring hiatal dimensions and determine predictors for the degree of warping.

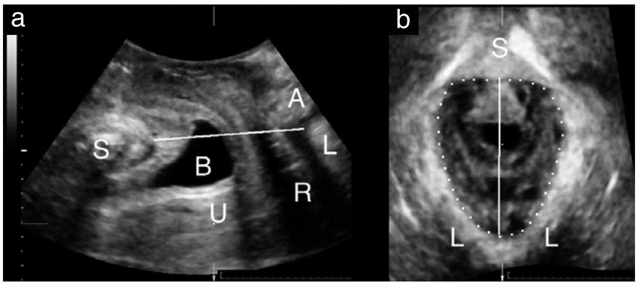

Figure 1 Translabial ultrasound images showing determination of the plane of minimal hiatal dimensions on Valsalva maneuver in mid-sagittal (a) and axial (b) planes. Location of this plane is indicated by oblique line in (a) and vertical line in (b). A, anal canal; B, bladder; L, levator ani; R, rectal ampulla; S, symphysis pubis; U, uterus.

METHODS

This was a retrospective study utilizing records of patients referred to a tertiary urogynecological service between November 2012 and March 2013. Patients underwent a standardized interview, clinical assessment and four-dimensional (4D) translabial ultrasound, as described previously, to assess pelvic organ descent, hiatal dimensions and pelvic floor trauma[12]. As part of a standardized protocol, we obtained series of ultrasound volume data, at rest, during at least three Valsalva maneuvers lasting at least 6 s and during pelvic floor muscle contraction[13]. Care was taken to avoid false-negative results due to levator co-activation or suboptimal Valsalva, a method that results in a high degree of repeatability[14]. On prolapse assessment, pressure on the perineum was kept to a minimum to allow full development of the prolapse. All volume datasets were obtained using a Voluson 730 Expert system with a RAB 4–8-MHz volume transducer (GE Medical Systems, Zipf, Austria), set at an acquisition angle of 85°. Volumes were obtained by approximately 10 different trainees under the direct supervision of the senior author. We use a 'Pelvic Floor' preset, which specifies maximum aperture and acquisition angles (70° and 85°, respectively), a depth of 8 cm, two focal zones at 1.5 cm and 4.5 cm, high quality, low or medium harmonics, speckle reduction 5 and crossbeam 2.

Archived ultrasound volume datasets were analyzed at a later date by M.S., blinded to all clinical data, using proprietary software (4DView v10, GE Medical Systems) on a PC. M.S. had undertaken a test–retest series for the primary outcome measure, a numerical measure of warping (difference in coronal minimal hiatal diameters determined in single axial planes), achieving an intraclass correlation coefficient (single measures, absolute agreement definition) of 0.683 (95% CI, 0.349–0.862), signifying fair to good agreement without significant bias.

Significant pelvic organ descent on ultrasound is defined as bladder descent to at least 10 mm below the symphysis pubis and descent of the rectal ampulla to at least 15 mm below the symphysis pubis. Significant uterine descent was rated positive if the uterus descended to the level of the pubic symphysis. We determined the craniocaudal difference in the location of minimal distances in mid-sagittal and in coronal planes as a numerical measure of warping as follows: first, the location of the plane of minimal hiatal dimensions was determined in the mid-sagittal plane (Figures 1a and 2a), as described previously[6]. The resulting axial plane (Figure 1b) was adjusted as much as necessary until the same location was identified in the coronal plane (Figure 2b). The plane was then adjusted in a craniocaudal direction to show again the minimal hiatal dimensions (Figure 2c). Finally, the craniocaudal distance between the location of the plane of minimal hiatal dimensions shown in Figure 2b and c was determined as a numerical measure of hiatal warping, i.e. as a measure of the degree to which the lateral aspects of the levator hiatus descended more than its most posterior aspect, resulting in a plane of minimal dimensions that is not 'Euclidean' or flat but rather 'warped', i.e. lower in its lateral aspects than in its most ventral and dorsal aspects.

We then tested potential predictors, such as demographic factors, signs and symptoms of prolapse, levator avulsion and levator distensibility, for any association with the numerical measure of warping. Significant clinical prolapse was defined as ICS POP-Q Stage 2 or worse. Avulsion was defined on tomographic imaging as requiring abnormal insertions of the puborectalis muscle in the axial plane of minimal dimensions and the two planes cranial to this plane, at an interslice interval of 2.5 mm, as described previously[15]. In difficult cases, we used the 'levator–urethra gap' (LUG), for the assessment of avulsion, a LUG of ≥ 2.5 cm being regarded as abnormal[16].

Approval for this retrospective study had been obtained from the local human research ethics committee (ref. NBMLHD HREC 13–31). Statistical analysis was undertaken using the software Minitab version 13 (Minitab Inc., State College, PA, USA) and SAS V 9.2 (SAS Institute Inc., Cary, NC, USA). All parameters used for comparative statistical analysis were tested for normality using Kolmogorov–Smirnov testing and all proved to be normally or near-normally distributed. Our numerical measure of warping was tested against potential predictors using Pearson's correlations for continuous data (such as hiatal area, gh, pb) and *t*-tests for categorical data (such as avulsion, significant prolapse).

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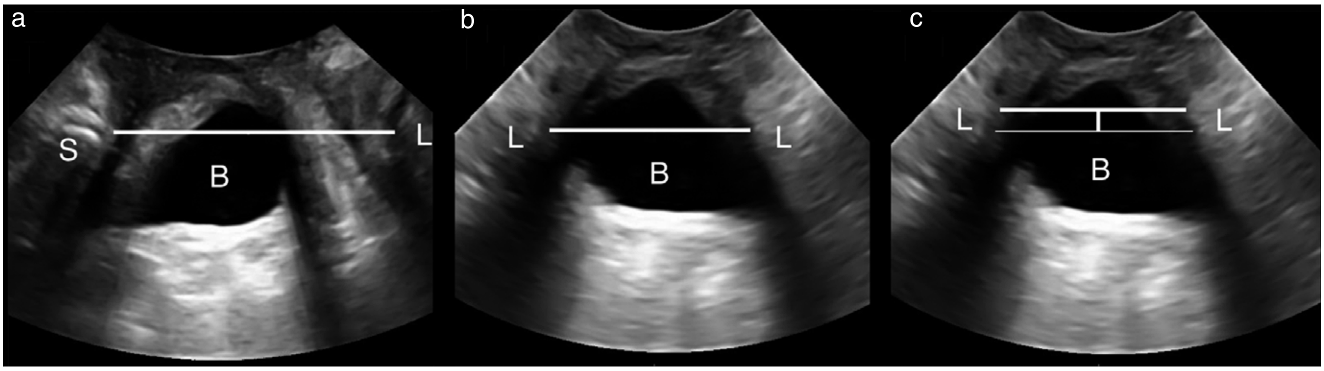

Figure 2 Quantification of hiatal warping by four-dimensional ultrasound. (a) Plane of minimal hiatal dimensions (horizontal line) in mid-sagittal plane on maximal Valsalva maneuver. (b) Same location (horizontal line) as that in (a), in the coronal plane. (c) Coronal plane in (b) is then adjusted in a craniocaudal direction until minimal dimensions (bold horizontal line) are again obtained. Location of plane of minimal dimensions in (a) and (b) is illustrated by thin horizontal line in (c). The craniocaudal distance between the two horizontal lines (vertical line in (c)), which in this case is 5 mm, is recorded by postprocessing software. B, bladder; L, levator ani; S, symphysis pubis.

RESULTS

During the inclusion period, 203 patients were seen at our tertiary unit. Of those, 190 patients had ultrasound volumes available for review; 13 cases had volumes missing owing to unavailability of equipment and were excluded.

The mean age of the women was 54 ± 14.6 (range, 18–87) years and average body mass index was 28.6 ± 6.3 (range, 17–55) kg/m^2. Of the 190 women, 108 (57%) were postmenopausal with an average interval since menopause of 9 years, and 82 were still menstruating regularly. Mean parity was 2.5, 165 (87%) women were vaginally parous and 48 of those had had a vaginal operative delivery. Fifty-five women had undergone a hysterectomy and 42 had a history of prolapse and/or incontinence surgery. One hundred and thirty-four (71%) women presented with stress urinary incontinence, 122 (64%) with urge incontinence, 70 (37%) with urinary frequency, 87 (46%) with nocturia and 68 (36%) with symptoms of voiding dysfunction. Prolapse symptoms were reported by 103 (54%), obstructed defecation by 108 (57%) and fecal incontinence by 21 (11%) women.

On clinical examination, 144 (76%) patients had significant prolapse of Stage 2 or above. This was due to a cystocele in 105, uterine prolapse in 13 and/or a rectocele in 112. Significant prolapse on ultrasound was found in 115 (61%) cases. This was due to a cystocele in 74 (39%), significant uterine descent in 37 (19%), an enterocele in 17 (9%) and significant rectocele in 70 (37%).

On postprocessing of ultrasound volume datasets, the mean anteroposterior diameter in the plane of minimal hiatal dimensions on Valsalva maneuver was 6.2 ± 1.1 cm (range, 3.6–9.8 cm) and mean coronal diameter in the same plane was 5.4 ± 0.9 cm (range, 3.4–8.6 cm). The mean minimal coronal diameter as determined in coronal sections was 5.0 ± 0.9 cm (range, 3.0–7.9 cm) and the mean craniocaudal difference in location of the minimal distances in the mid-sagittal and coronal planes was −1.26 ± 2.7 mm (range, −6.7 to 4.6 mm; $P < 0.001$ on *t*-test). Mean hiatal area on Valsalva was 28.7 ± 9.7 cm^2 (range, 10.4–61.1 cm^2). Fifty-one (27%) patients were diagnosed with levator avulsion, and in 10 (5%) this was bilateral.

Our numerical measure of warping (the distance between the location of the plane of minimal dimensions as determined in the mid-sagittal and in the coronal planes) was significantly associated with hiatal area on Valsalva ($r = -0.284$; $P < 0.0001$). It was associated with signs of significant prolapse, both on clinical examination and on ultrasound (both $P < 0.0001$), the sum of gh and pb ($r = -0.278$; $P < 0.0001$), with gh ($r = -0.239$; $P < 0.0001$) and with pb ($r = -0.17$; $P = 0.019$) individually, and also with avulsion ($P = 0.025$).

There was a systematic difference in the location of minimal hiatal dimensions in the coronal compared with the mid-sagittal plane, with the coronal minimal dimension being located more caudally, although this difference was on average only 1.26 mm; the largest such difference was measured as 6.7 mm.

DISCUSSION

POP is a form of hernia in which pelvic organs herniate into and/or out of the vagina through the levator hiatus. The size of the hiatus has been shown to be strongly associated with both symptoms and signs of POP[6,8]. While it may be argued that the size of the levator hiatus is secondary to distension by POP, the observation showing only a minor reduction in hiatal size after prolapse surgery argues against this[17]. The gh is also associated with POP and has the advantage of being easily measured clinically[18]. We believe that the hiatus of the levator ani seems to be a more relevant and appropriate measure of the hernial portal, given that rectal intussusception and rectal prolapse clearly are forms of POP. In fact, rectal intussusception has been shown to be significantly associated with the area of the levator hiatus[19]. Assessment of the levator hiatus therefore is likely to be relevant for the understanding of the pathophysiology of POP[6,8].

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The original method for the assessment of hiatal dimensions relied on identifying a single axial plane of minimal hiatal dimensions, assuming that this plane is flat[6]. Both measurement of hiatal dimensions and volume acquisition have been shown to be highly repeatable[14], by us and by other groups[6,20–24]. However, it has since become apparent that the true plane of the levator hiatus is not flat or Euclidean, but is in fact warped[10]. This was first shown by analyzing hiatal measurements on both magnetic resonance imaging and translabial three-dimensional (3D) ultrasound in a small series of patients. One way to avoid the potential confounding effect of warping is to measure hiatal dimensions in a 'rendered volume', i.e. a semitransparent representation of a flat, box-shaped 3D volume encompassing the true, warped plane of minimal hiatal dimensions. This is not possible on all 3D/4D-capable ultrasound systems since such measurements are impermissible under the rules of Euclidean geometry, which requires a plane to be flat. On Voluson systems, such as the ones used by us, the rendered-volume option exists and allows for faster determination of hiatal area, a method that is at least as repeatable and valid as the original single-plane method[11]. This method arbitrarily uses a rendered volume with a depth of 1–2 cm. Other authors have recently proposed using volume contrast imaging (VCI), i.e. thick-slice techniques, which are similar to using rendered volumes[24].

In the present study, we set out to define the degree of hiatal warping in women with symptoms of pelvic floor dysfunction in order to validate the simplified method and any other methods that use thick-slice imaging of the levator hiatus, and to estimate the thickness required for a rendered volume to reliably encompass the entire plane of minimal dimensions.

We were able to detect clear evidence of warping of the plane of minimal dimensions. The mean craniocaudal difference in the location of minimal dimensions in the mid-sagittal and coronal planes was -1.26 ± 2.7 mm (range, -6.7 to 4.6 mm; $P < 0.001$), with the minimal dimension in the coronal plane located more caudally than the same dimension in the mid-sagittal plane. This implies that lateral aspects of the hiatus tend to be situated more caudally than anterior and posterior aspects, in agreement with data from the literature[10]. Our measure of warping was associated with hiatal area on Valsalva ($r = -0.284$; $P < 0.0001$) and signs of significant prolapse on clinical examination and ultrasound (both $P < 0.0001$), which is consistent with the assumption that warping is an expression of hiatal overdistensibility due to the levator stretching not just laterally but also in a caudal direction. In most patients this warping is rather minor and unlikely to introduce a clinically relevant error. The range of measurements suggests that the arbitrarily defined box depth of 1–2 cm described for the simplified method[11] or VCI (thick slice) imaging of 1–2-cm thickness[24] will encompass the entire plane of minimal dimensions even in patients with the most marked degree of hiatal warping seen in this study.

In conclusion, the plane of minimal dimensions of the levator ani hiatus is non-Euclidean (warped), and the degree of warping is highly significantly associated with the degree of hiatal distension or 'ballooning'. However, the degree of warping is relatively minor, the largest difference seen in the location of planes of minimal dimensions being 6.7 mm. Hence, the results of this study support the determination of hiatal area in a rendered volume of 1–2 cm in depth, or any other technique that uses 'thick slices' of 1 cm or more.

DISCLOSURE

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REFERENCES

1. Ulrich D, Guzman Rojas R, Dietz H, Trutnovsky G. Use of a visual analog scale for evaluation of bother from pelvic organ prolapse. *Ultrasound Obstet Gynecol* 2014; **43**: 693–697.
2. Olsen AL, Smith VJ, Bergstrom JO, Colling JC, Clark AL. Epidemiology of surgically managed pelvic organ prolapse and urinary incontinence. *Obstet Gynecol* 1997; **89**: 501–506.
3. Smith F, Holman D, Moorin R, Tsokos N. Lifetime risk of undergoing surgery for pelvic organ prolapse. *Obstet Gynecol* 2010; **116**: 1096–1100.
4. Bump RC, Mattiasson A, Bo K, Brubaker LP, DeLancey JO, Klarskov P, Shull BL, Smith AR. The standardization of terminology of female pelvic organ prolapse and pelvic floor dysfunction. *Am J Obstet Gynecol* 1996; **175**: 10–17.
5. Gerges B, Kamisan Atan I, Shek KL, Dietz HP. How to determine "ballooning" of the levator hiatus on clinical examination: a retrospective observational study. *Int Urogynecol J* 2013; **24**: 1933–1937.
6. Dietz HP, Shek C, Clarke B. Biometry of the pubovisceral muscle and levator hiatus by three-dimensional pelvic floor ultrasound. *Ultrasound Obstet Gynecol* 2005; **25**: 580–585.
7. Khunda A, Shek KL, Dietz HP. Can ballooning of the levator hiatus be determined clinically? *Am J Obstet Gynecol* 2012; **206**: 246.e1–4.
8. Dietz HP, Shek C, De Leon J, Steensma AB. Ballooning of the levator hiatus. *Ultrasound Obstet Gynecol* 2008; **31**: 676–680.
9. Rodrigo N, Wong V, Shek K, Martin A, Dietz HP. The use of 3-dimensional ultrasound of the pelvic floor to predict recurrence risk after pelvic reconstructive surgery. *Aust N Z J Obstet Gynaecol* 2014; **54**: 206–211.
10. Kruger J, Heap S, Murphy B, Dietz H. How best to measure the levator hiatus: evidence for the non-Euclidean nature of the 'plane of minimal dimensions'. *Ultrasound Obstet Gynecol* 2010; **36**: 755–758.
11. Dietz HP, Wong V, Shek KL. A simplified method for determining hiatal biometry. *Aust N Z J Obstet Gynaecol* 2011; **51**: 540–543.
12. Dietz HP. Pelvic floor ultrasound in prolapse: what's in it for the surgeon? *Int Urogynecol J* 2011; **22**: 1221–1232.
13. Orejuela FJ, Shek KL, Dietz HP. The time factor in the assessment of prolapse and levator ballooning. *Int Urogynecol J* 2012; **23**: 175–178.
14. Tan L, Guzman Rojas R, Dietz H. The repeatability of sonographic measures of functional pelvic floor anatomy. *Neurourol Urodyn* 2014; **33**: 1058–1060.
15. Dietz H, Bernardo M, Kirby A, Shek K. Minimal criteria for the diagnosis of avulsion of the puborectalis muscle by tomographic ultrasound. *Int Urogynecol J* 2011; **22**: 699–704.
16. Dietz HP, Abbu A, Shek KL. The levator-urethral gap measurement: an objective means of determining levator avulsion? *Ultrasound Obstet Gynecol* 2008; **32**: 941–945.
17. Andrew B, Shek K, Chantarasorn V, Dietz H. Enlargement of the levator hiatus in female pelvic organ prolapse: cause or effect? *Aust N Z J Obstet Gynaecol* 2013; **53**: 74–78.
18. DeLancey JO, Hurd WW. Size of the urogenital hiatus in the levator ani muscles in normal women and women with pelvic organ prolapse. *Obstet Gynecol* 1998; **91**: 364–368.
19. Rodrigo N, Shek KL, Dietz HP. Rectal intussusception is associated with abnormal levator ani muscle structure and morphometry. *Tech Coloproctol* 2011; **15**: 39–43.
20. Siafarikas F, Staer-Jensen J, Braekken I, Bo K, Engh M. Learning process for performing and analyzing 3D/4D transperineal ultrasound imaging and interobserver reliability study. *Ultrasound Obstet Gynecol* 2013; **41**: 312–317.
21. Cheung R, Shek K, Chan S, Dietz H. Pelvic floor biometry and pelvic organ mobility in Asian and Caucasian nulliparae. *Int Urogynecol J* 2013; **24**: S53–S55.
22. van Veelen GA, Schweitzer KJ, van der Vaart CH. Reliability of pelvic floor measurements on three- and four-dimensional ultrasound during and after first pregnancy: implications for training. *Ultrasound Obstet Gynecol* 2013; **42**: 590–595.
23. Yang JM, Yang SH, Huang WC. Biometry of the pubovisceral muscle and levator hiatus in nulliparous Chinese women. *Ultrsound Obstet Gynecol* 2006; **28**: 710–716.
24. Youssef A, Montaguti E, Sanlorenzo O, Cariello L, Salsi G, Morganelli G, Azzarone C, Pilu G, Rizzo N. Reliability of new three-dimensional ultrasound technique for pelvic hiatal area measurement. *Ultrasound Obstet Gynecol* 2016; **47**: 629–635.

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