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Diagnostic ultrasound for assessment of pelvic floor muscle contraction: frequently asked questions

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Abstract
Diagnostic ultrasound is being employed by physiotherapists as an assessment tool to provide biofeedback to both the patient and the clinician. Physiotherapists who use the modality often have many questions about the technique, and seek advice on how to produce an effective image and how to interpret it. This paper explores the evidence produced in response to questions posed by women's health physiotherapists working with patients with pelvic floor muscle (PFM) dysfunction and familiar with diagnostic ultrasound who attended focus groups at the University of Newcastle, Callaghan, NSW, Australia. These physiotherapists highlighted the difficulties that they face when trying to find simple answers to their enquiries. In order to answer these questions, researcher experience and the literature are explored in relation to the physics of diagnostic ultrasound, ultrasound transducers, image production and interpretation, and the use of diagnostic ultrasound for the assessment of PFM contraction. The literature was searched using the following databases: Medical Literature Analysis and Retrieval System Online (MEDLINE); Cumulative Index to Nursing and Allied Health Literature (CINAHL); and Embase.

Keywords: biofeedback, pelvic floor contraction, ultrasound.

Introduction
Diagnostic ultrasound has been reported to be one of the commonest methods of medical imaging employed world-wide (Corr 1999). The primary application of the technique continues to be in the radiology department, where it is utilized as part of the assessment of the morphological characteristics and structural integrity of organs and tissues (Whittaker *et al.* 2007a). Over the past 10–15 years, the use of diagnostic ultrasound has expanded beyond these traditional areas into other health disciplines, such as physiotherapy (Abu-Zidan *et al.* 1999; ASUM 2013). Siegel (2001) attributed the widespread use and acceptance of ultrasound as an imaging technique to the limited biological effects of the modality.

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Focus groups involving women's health physiotherapists working with patients with pelvic floor muscle (PFM) dysfunction and familiar with diagnostic ultrasound were run at the University of Newcastle, Callaghan, NSW, Australia (McKiernan *et al.* 2013). During these sessions, it became evident that the participants had many questions about the modality, and that they were frustrated by the difficulties they faced when trying to find simple and understandable answers to their enquiries. The physiotherapists commented that the available relevant textbooks were costly and too onerous, and that they simply did not have the time to read these. Training courses in diagnostic ultrasound are limited, costly, and involve time and travel. Internet searches are time-consuming and not discipline-specific, and sometimes it proves difficult to satisfy particular learning needs. The present paper explores the evidence in order to answer the questions that the focus group participants raised.

Diagnostic ultrasound

How is diagnostic ultrasound different to therapeutic ultrasound?

Physiotherapists are very familiar with how therapeutic ultrasound works since it has been used in their clinical environment for over 60 years. In comparison, diagnostic ultrasound uses short pulses of sound, and involves the reflection of waves to produce images that provide information without any biological effects to the tissue (Baker *et al.* 2001; ter Haar 2007).

How is the sound produced and received?

Sound is produced by the piezoelectric effect. This is a property of some naturally occurring and artificial crystalline materials, such as tourmaline and quartz. When pressure or tension (such as a sound wave) is applied to the crystal, it expands or contracts, but these changes in thickness are very small. The molecular alignment within the crystal is slightly altered because the electrically charged particles (i.e. dipoles) within it move. Because of this, the crystal exhibits an electrical potential difference between its surfaces (i.e. voltage); in other words, one side of the crystal will be positive and the other negative. When the pressure or tension is removed, the crystal returns to normal. This production of a voltage from changes in thickness is known as the piezoelectric effect, and it is responsible for image production. The reverse of this is also true, meaning that, if a voltage is applied to the crystal, it will expand or contract, and pressure or tension will be produced, sending out a pulse of sound. This process is known as the converse piezoelectric effect, and is responsible for the production of ultrasound (Gent 1997).

As such, the crystal provides a means of inducing the electromechanical conversion of energy, i.e. electrical energy is converted to sound and *vice versa.* If an alternating voltage is applied to the crystal, it will expand and then contract, causing a pressure wave to be transmitted. If this occurs more than 20 000 times per second, an ultrasound wave is generated. If only a short voltage is applied, a pulse of sound will be produced. Conversely, if the returning echo is applied to the crystal, it will expand and contract, producing an alternating voltage across its surface that can be electronically processed (Gent 1997; Sanders & Winter 2007).

How is an image produced?

A typical ultrasound transducer consists of a series of piezoelectric crystals, and works by employing a pulse–echo technique in which the device both transmits the pulse of sound and then receives the returning echo. A pulse of sound is sent out, and then after a very short delay, listening time occurs, during which echoes are received. This is then repeated many times per second, and therefore, the ultrasound image is also updated at this rate (Ziskin 1993; Gent 1997).

How does sound reflection occur?

In diagnostic ultrasound, the reflected sound wave is referred to as the echo, and it is from this signal that an image is produced (Ziskin 1993). Reflection occurs when a sound wave hits a boundary between two tissues. The greater the difference in the properties of the tissues on either side of the boundary, the greater the reflection (Ziskin 1993; Gent 1997; Whittaker *et al.* 2007a).

Choice of transducers

How do we select the right transducer frequency?

The sound wave is attenuated as it travels through the tissue. Attenuation is defined as the decrease in acoustic energy per unit of distance travelled (Ziskin 1993). This phenomenon limits the depth of imaging because it limits the penetration of sound. The higher the frequency of the ultrasound, the greater the attenuation and the lower the sound penetration within the body. Thus, higher frequencies are used to image more superficial structures within the body (Gent 1997; Whittaker *et al.* 2007a). When scanning, it is important that the user is aware of this relationship, and selects the appropriate transducer and the correct frequency to image structures at different depths; for example, a 12-MHz transducer may be used to image the shoulder, while a 3-MHz transducer may be used to image the urinary bladder, which lies deeper within the body.

What is a linear transducer?

A linear transducer (Fig. 1a) has up to 300 piezoelectric crystals arranged side by side, producing a rectangular image (Fig. 1c) with a width that is the same as the transducer length (Gent 1997; Backhaus *et al.* 2001; Sanders & Winter 2007; Whittaker *et al.* 2007a). Linear transducers usually come in frequencies of around 7 and 12 MHz, and are used to image superficial

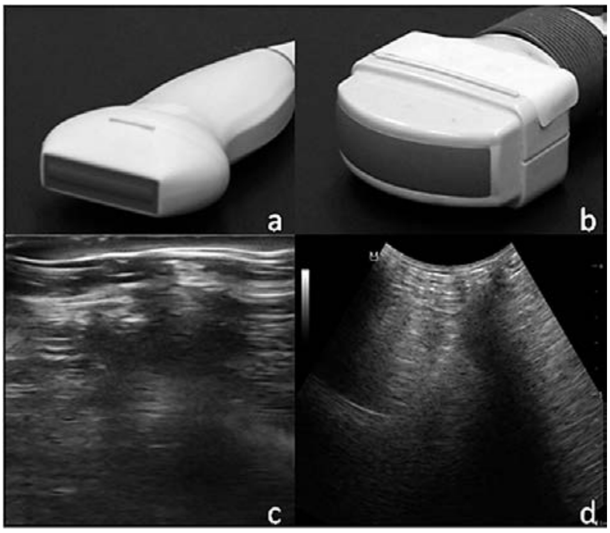

Figure 1. Two types of ultrasound transducers and the respective resultant images: (a) linear transducer; (b) curved transducer; (c) resultant linear rectangular image; and (d) resultant curved image with wide far field.

structures such as the shoulder, knee and ankle (Gent 1997; Sanders & Winter 2007; Whittaker *et al.* 2007a).

What is a curved transducer?

In a curved transducer (Fig. 1b), the piezoelectric crystals are arranged in an arc, producing a diverging image (Fig. 1d). This gives a wide far field, which is good for imaging structures deeper within the body (Gent 1997; Backhaus *et al.* 2001; Sanders & Winter 2007; Whittaker *et al.* 2007a). Curved transducers usually come in frequencies of around 3- and 5-MHz, and are used to image deeper structures such as the urinary bladder, as well as PFM contractions, abdomen and pregnancies (Gent 1997; Sanders & Winter 2007; Whittaker *et al.* 2007a).

Modes of imaging

What is B-mode?

B- or brightness mode is the method commonly used to display the ultrasound image. In B-mode, a grey-scale image appears on the monitor, as in Figure 2. The image consists of dots that vary in brightness depending on the strength of the echo; a bright dot represents a strong echo. The location of the dot on the monitor is related to the depth of the tissue or organ reflector within the body. The deeper the tissue or organ reflector, the longer the echo has taken to return to the transducer, and the closer to the bottom of the image or monitor the dot is placed (Gent 1997; Sanders & Winter 2007).

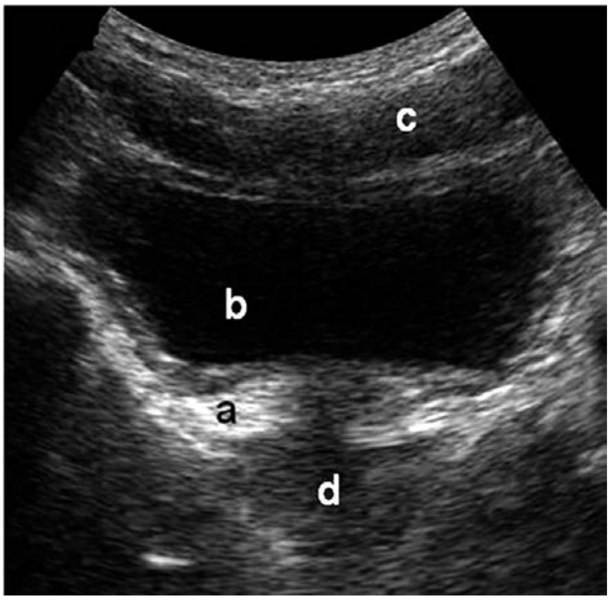

Figure 2. B-mode image of the urinary bladder of a male: structure "a" has a stronger echo than structure "b" (the bladder), and therefore, "a" is brighter on the image; structure "d" (the prostate) is deeper in the body than structure "c", and therefore, "d" is located closer to the bottom of the image.

Is Doppler ultrasound required?

Doppler ultrasound is largely used for assessing blood flow in vessels, and therefore, it is not required for the measurement of a PFM contraction. When a high-frequency sound wave meets a moving structure, the echo returns at a different frequency. This is referred to as a frequency shift or Doppler shift, and the speed at which the structure is moving can be calculated (Gent 1997; Sanders & Winter 2007).

Colour Doppler ultrasound allows the detection of blood flow over a large area of the image. Colour is assigned to areas of a B-mode image in which flow, or a Doppler shift, is detected. Different colours are chosen to represent forward and reverse flow (Gent 1997; Sanders & Winter 2007).

Using the equipment

How should the ultrasound image be orientated?

All transducers have a dominant side that will be marked in some way such as an arrow, a light or a dot (Fig. 3a). It is important to always orient the body anatomy with this transducer indicator so that the right and left sides of the body are known. When scanning transabdominally in the transverse plane, the indicated dominant side of the transducer should be aligned with the

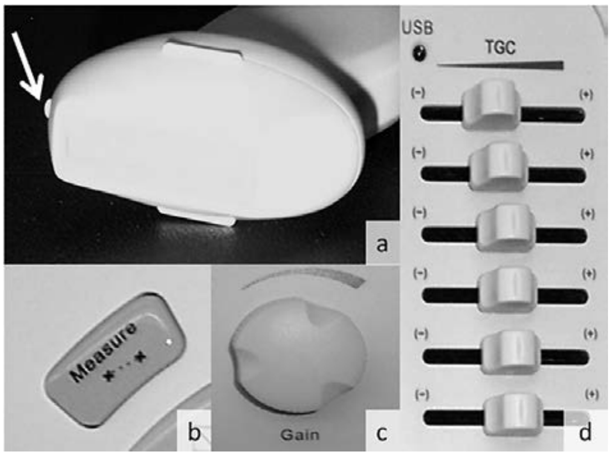

Figure 3. Important machine controls: (a) the arrow indicates the dot on one side of the transducer marking the dominant side of the device; (b) the "Measure" button; (c) the overall gain turn button; and (d) the time gain compensation ("TGC") controls.

patient's right-hand side; in the longitudinal plane, place this indicated dominant side of the transducer cephalad, i.e. towards the patient's head. When undertaking a transperineal scan in order to assess PFM contraction, the indicated dominant side of the transducer should point toward the ceiling. The image orientation will then be as shown in Figure 4.

How is image brightness controlled?

All diagnostic ultrasound machines have two brightness controls: overall gain and time gain compensation (TGC) (Gent 1997; Sanders & Winter 2007). The overall gain is a single button (Fig. 3c), which makes the whole image brighter or darker when turned. The TGC consists of a series of controls (Fig. 3d), each regulating the brightness of different levels of the image. These buttons allow the operator to compensate for attenuation with depth so as to enable a uniform image to be obtained (Gent 1997; Sanders & Winter 2007). The uppermost button corresponds to the superficial structures seen at the top of the image, and the bottom one to the deepest structures seen at the bottom of the image. The image at each corresponding level can be made brighter or darker by sliding the button along. This means that a structure such as the bladder can be displayed with the same level of brightness instead of being brighter at the top of the image and darker at the bottom.

Can bladder volume be measured?

Capture two images of the bladder at its largest, one in the transverse plane and the other in the longitudinal one. Press the "Measure" button on the machine (Fig. 3b), select the volume measurement and callipers will appear on the images. Place these callipers in the desired location, as seen in Figure 5, and a result will be displayed on the image. The formula used to calculate volume is: length × width × height × 0.53 (Baxter *et al.* 1999); however, most ultrasound machines automatically perform this calculation when in volume mode.

What does the arrow on the screen at the side of the image indicate?

This arrow indicates the focus and is the area on the image where resolution is highest (Sanders & Winter 2007). It should be placed at the level of the structure of interest in order to display the target most clearly (Gent 1997). This is also called the focal zone and is indicated by the asterisk in Figure 6.

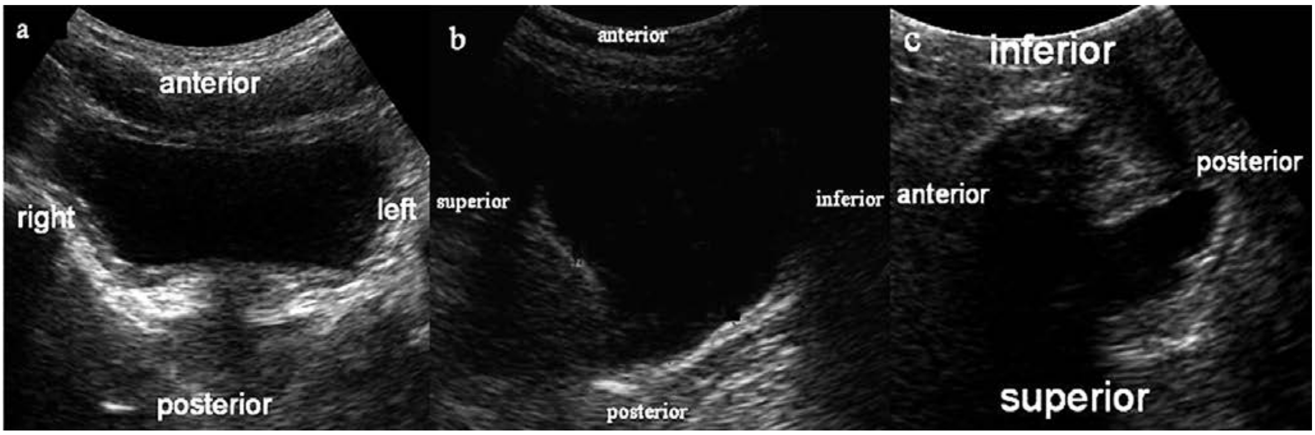

Figure 4. Image orientation: (a) B-mode transabdominal image of the urinary bladder of a male in the transverse plane; (b) B-mode transabdominal image of the urinary bladder of a female in the longitudinal plane; and (c) B-mode transperineal image of the urinary bladder of a female.

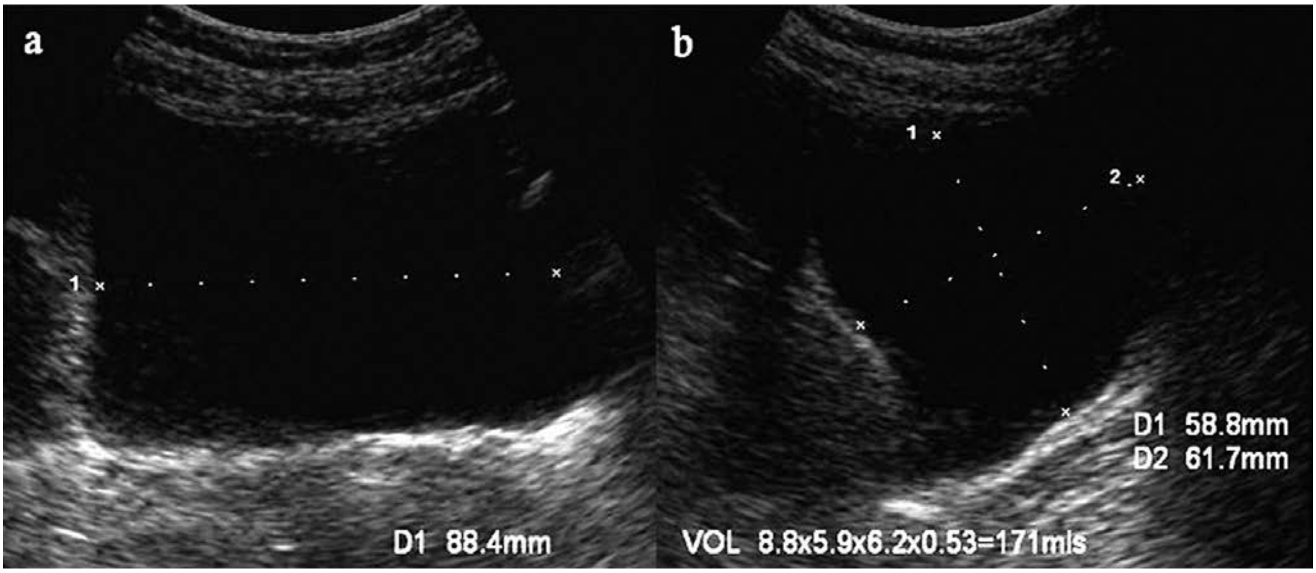

Figure 5. An example of a volume measurement of the bladder: (a) transverse image; and (b) longitudinal image.

Scanning the pelvic floor

What might be seen when scanning the pelvic floor?

Patients who present with PFM dysfunction can be specifically trained to perform a contraction that elevates the bladder base and neck. This movement can be seen and assessed with transabdominal imaging, and measured using transperineal imaging by visualizing movement of the base of the urinary bladder (Thompson *et al.* 2005; Whittaker *et al.* 2007b). Information about the supporting function of the PFMs during manoeuvres such as sneezing, coughing and Valsalva can also be assessed by imaging the bladder. Studies have found transabdominal ultrasound to be reliable and comparable to transperineal ultrasound except in the case of the Valsalva manoeuvre, where the transperineal technique has been found to be more reliable (Thompson *et al.* 2005; Whittaker *et al.* 2007b).

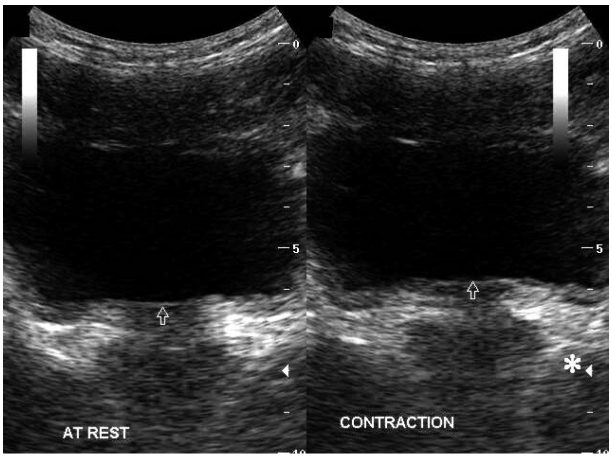

Figure 6. Transabdominal images of a male bladder in the transverse plane. The arrows indicate the change in the shape of the bladder base from flat at rest to convex on muscle contraction, indicating a pelvic floor muscle (PFM) contraction. The asterisk (*) indicates the focal zone, which is placed at the level of the base of the bladder for imaging a PFM contraction.

In transabdominal diagnostic ultrasound, a 3-MHz curved transducer is placed on the anterior abdomen just above the symphysis pubis. It is important to angle the transducer down to image the base of the bladder so that a PFM contraction can be seen. In the transverse plane, as shown in Figure 6, both the right and left sides of the bladder base can be viewed at the same time so that the symmetry of a contraction can be observed. The bladder base should be seen to elevate, as shown in Figure 6. Since the bladder base is supported directly by the PFMs, the observed movement of the bladder base is a reflection of a PFM contraction. The movement being viewed is the reaction that a PFM contraction causes on the base of the bladder. The bladder needs to have a moderate amount of fluid within it for this technique to work (Whittaker 2004; Whittaker *et al.* 2007b).

In transperineal scanning, the 3-MHz curved transducer is placed in contact with the perineum in the sagittal plane. Gel should be placed on the transducer, then the device should be covered with a protective sheath such as a glove and gel should be placed on top of the glove. In this view, the bladder should be seen to move anteriorly and superiorly, as shown in Figure 7. Note that the urethra will also elongate and move anteriorly. The symphysis pubis can be used as a static reference point and landmark for

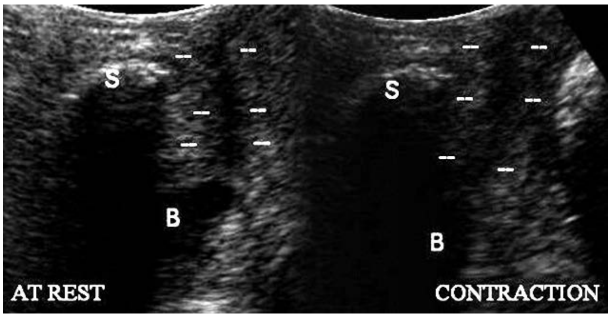

Figure 7. Transperineal images of a female bladder (a) at rest and (b) on contraction. The arrows indicate the urethra, which is black, and can be seen to elongate and move anteriorly towards the symphysis pubis (S) on contraction. The urinary bladder (B) has also moved anteriorly and superiorly on contraction, and therefore, it is now mostly hiding under the symphysis pubis.

measurements. When using the transperineal technique, it is better that the bladder is empty, which is actually beneficial because the bladder neck and proximal urethra will be more mobile (Whittaker *et al.* 2007b).

Why does diagnostic ultrasound of the pelvic floor not work on every patient?

Users of diagnostic ultrasound for the assessment of PFM contraction should be aware of the pitfalls inherent to the technique. Since it is open to misinterpretation, it should be used in conjunction with other methods of assessment of PFM contraction in order for a complete picture to be obtained.

Misinterpretation might be underpinned by a number of contributing factors. Descent of the pelvic floor can occur if intra-abdominal pressure increases, even if the PFMs are activated. When scanning transabdominally, the transducer can be moved and give the visual appearance of pelvic floor descent if the abdominal wall is pushed out (Hodges 2005; Whittaker *et al.* 2007b). The starting position of the bladder base depends on things such as pre-existing muscle activity and the laxity of the myofascial support structures. The bladder base may be elevated from the beginning of the assessment, and therefore, no further elevation may be observed on PFM contraction. Furthermore, overfilling of the bladder can induce PFM resting activity to increase. Other considerations include the skill of the operator, task standardization and patient position (Whittaker *et al.* 2007b).

Diagnostic ultrasound does not give information about things such as tension in the endopelvic fascia, the timing of a contraction or the influence of a PFM contraction on other structures (Whittaker *et al.* 2007b). Accuracy of image production and interpretation comes with extensive experience, which is gained from undertaking many examinations and a full realization of the complexity of the modality (Mateer *et al.* 1994).

Conclusion

Diagnostic ultrasound is being utilized by the physiotherapy profession. However, many physiotherapists are struggling to find answers to their questions. It is hoped that the present paper provides some. Heightened awareness of the positive impact of this modality on clinical practice is likely to increase its use and acceptance within the discipline. Users who are not trained as sonographers but wish to use diagnostic ultrasound should be encouraged to seek education about the modality, particularly with respect to its limitations since it does have pitfalls. The skill required to practise the technique and the interpretation of ultrasound images can both prove to be very difficult.

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