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MINIREVIEWS

Three-dimensional imaging of the uterus: The value of the coronal plane

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Abstract

Advent in three-dimensional (3D) imaging technology has seen 3D ultrasound establish itself as a useful adjunct complementary to traditional two-dimensional imaging of the female pelvis. This advantage largely arises from its ability to reconstruct the coronal plane of the uterus, which allows further delineation of many gynecological disorders. 3D imaging of the uterus is now the preferred imaging modality for assessing congenital uterine anomalies and intrauterine device localization. Newer indications include the diagnosis of adenomyosis. It can also add invaluable information to delineate other endometrial and myometrial pathology such as fibroids and endometrial polyps.

Key words: Three-dimensional ultrasound; Coronal view; Pelvis; Uterus; Uterine anomalies

Core tip: Three-dimensional ultrasound imaging of the female pelvis is a useful adjunct to conventional two-dimensional imaging. By acquiring a set volume which is stored, volumetric acquisitions allow the offline review, manipulation and analysis of saved images to obtain the maximum information from a study. Recent literature has suggested this imaging approach is rapidly realizing widespread use in the assessment of a variety of gynecological disorders including uterine anomalies, intrauterine device localization, endometrial disorders and fibroids. Recent advances have also suggested it may be useful in diagnosing disorders of the endo-metrial-myometrial interface, such as adenomyosis.

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INTRODUCTION

Three-dimensional (3D) ultrasound imaging of the female pelvis is a useful adjunct to conventional two-dimensional (2D) imaging. By acquiring a set volume which is stored, volumetric acquisitions allow the offline review, manipulation and analysis of saved images to obtain the maximum information from a study. Recent literature has suggested this imaging approach is rapidly realizing widespread use in the assessment of a variety of gynecological disorders including uterine anomalies, intrauterine device (IUD) localization, endometrial disorders and fibroids[1]. Recent advances have also suggested it may be useful in diagnosing disorders of the endometrial-myometrial interface, such as adenomyosis[2].

While 2D imaging provides information through axial and sagittal planes, it is limited by accessibility to assess pathology in the coronal plane. One of the main advantages of 3D imaging of the uterus, on the other hand, is the capacity to reconstruct the coronal plane. Particularly when the 2D imaging is abnormal, it offers the ability to better define some uterine anomalies. Andreotti *et al*[3] reported that out of 49 patients with abnormal findings on 2D ultrasound, 3D ultrasound provided additional information in 26 (53%) of these patients. These included uterine anomalies, improved endometrium delineation, more accurate visualization of endometrial polyps, fibroids and location of IUD. In another study, Benacerraf *et al*[4] showed 3D ultrasound provided additional information in 16 out of 66 patients. When 2D imaging is normal, it is a less useful adjunct but still offers the ability to occasionally detect unsuspected anomalies in some circumstances, such as arcuate uteri. The improved visualization with 3D ultrasound is particularly evident when the endometrium thickness is greater than 5 mm, since there is greater contrast with the more hypoechoic myometrium[4].

This article aims to illustrate the applicability of 3D imaging of the uterus, particularly some of the newer advances of 3D imaging in the assessment of myometrial disorders.

OBTAINING A 3D CORONAL IMAGE OF THE UTERUS

Volume acquisition for 3D ultrasound requires specialized ultrasound systems and transducers. A transvaginal, compared to the transabdominal, approach is generally preferred, due to the higher frequency of the probe and the proximity to the pelvic organs, which improve image resolution[1]. An adequately enlarged mid-sagittal or transverse section of the uterine body is obtained, although a mid-sagittal plane is preferred since under optimal circumstances, this allows the visualization of the entire length of the endometrial cavity as well as the endocervical canal. Depending on the machine, an automatic or manual sweep is performed to obtain a volume of the region of interest. Upon acquisition of the 3D volume, examination of the volume is performed in the standardized multi-planar view by adjusting the slice through the three orthogonal planes separately (Figure 1). This standardized multi-planar view reduces inter-observer variation and may be achieved by the "Z-rotation" technique (Table 1)[5-7]. This information could be stored, which allows the user to manipulate and analyze the images offline. This may also facilitate the retrospective analysis of these images to give a second opinion by another examiner if required[1].

Table 1 Steps for the application of the "Z-rotation" technique

Step 1: Position the reference marker/dot et the level of the mid-cavity over the endometrial stripe in the sagittal plane (Figure 1A)
Step 2: Use the Z rotation to align the long axis of the endometrial stripe along the horizontal axis in the sagittal plane of the uterus
Step 3: Position the reference marker/dot et the level of the of the midcavity over the endometrial stripe in the transverse plane (Figure 1B)
Step 4: Use the Z rotation to align the endometrial stripe with the horizontal axis in the transverse plane of the uterus
Step 5: Following step 4, the coronal plane of the uterus will be displayed in plane C (Figure 1C); use the Z rotation on plane C to display the midcoronal plane in the conventional orientation (Figure 1D)

Data from "The Z Technique: an easy approach to the display of the midcoronal plane of the uterus in volume sonography". *J Ultrasound Med* 2006; 25: 607-612.

Multiple features for image optimization and post-processing functions are available, including surface rendering and volume contrast imaging (VCI) (Figure 2). VCI increases the contrast of images by refining the slices through the images. This improves depth perception and thus improves the visualization of finer detail. This is particularly useful for improving assessment of the junctional zone (JZ)[2,8]. Rendering is a technique that mimics the concept of placing a "drape" over the organ of interest. It is particularly applicable to visualizing the surface, such as over the external serosal contour of the uterus. However, the disadvantage of this method is that while the surface display is optimized, the sonographic information within the object is not displayed[9].

LIMITATIONS OF 3D ULTRASOUND OF THE UTERUS

Like 2D ultrasound, 3D ultrasound is subject to the same limitations of ultrasound physics. One of the main underlying prerequisites to a quality 3D image is a good 2D image. Volume acquisition in 3D imaging relies on reconstruction of a series of images processed during a sweep with a single elevation focus where the resolution of images beyond the focal zone is diminished[1]. Hence, it is quintessential that imaging settings are optimized to enhance 3D imaging. Artifacts in 3D reconstructions can be less readily recognizable and have the potential to distort an image enough to alter the diagnosis. In

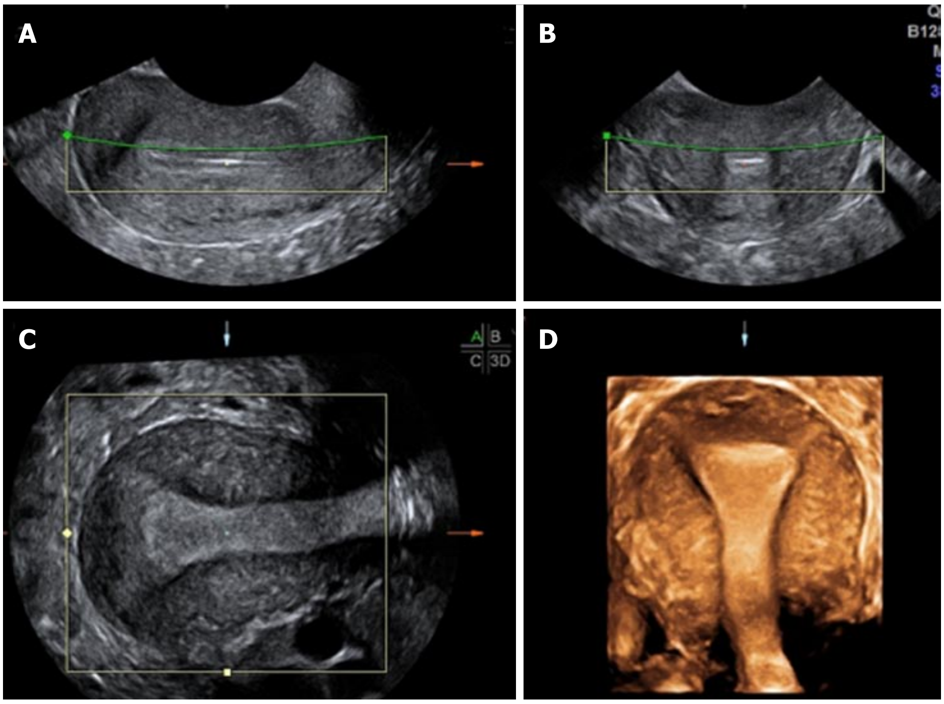

Figure 1 Multiplanar and rendering modes of the uterus. Multiplanar reconstructions from 3D ultrasound show a normal uterus in sagittal (A), transverse (B) and true coronal (C) planes. Surface rendering reconstructed image in a coronal plane of the uterus demonstrating a normal uterine fundal contour (D). 3D: Three-dimensional.

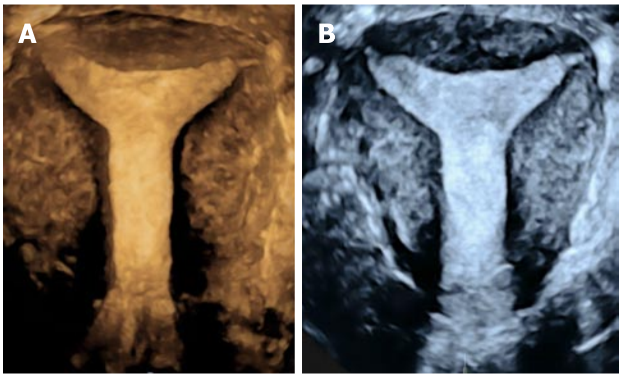

Figure 2 Examples of post-processing functions include surface render and volume contrast imaging. A: Three-dimensional (3D) ultrasound with surface rendering of a normal uterus in the coronal plane; B: 3D ultrasound with volume contrast imaging of the same uterus.

fact, artifacts can be compounded within a volume and not be immediately apparent. Thus, it is important to review the image in the acquisition plane to identify these artifacts[6]. Another potential disadvantage is the considerable "learning curve" associated with the manipulation of 3D ultrasound by the examiner. Various settings, which are machine-dependent, are available to the operator and optimizing the image through the manipulation of settings require training and time[1]. Machines and probes with 3D capability often come at an additional cost, which may limit its availability and accessibility although it is likely that with increasing popularity and acceptance, this will be less prohibitive since it also has proven cost effectiveness[10].

PRACTICAL APPLICATIONS

Mullerian duct anomalies

Congenital uterine anomalies are associated with an increased risk of infertility, recurrent miscarriages and other obstetric complications. It is estimated to have a prevalence of 17% in the population with recurrent miscarriages, compared to 6% in the general population[11]. Following a proposed classification by Buttram *et al*[12] of Mullerian duct anomalies in 1979, the American Society for Reproductive Medicine (formerly the American Fertility Society) subsequently adapted this classification for use in 1988, and this remains the most widely accepted over the last 25 years[12,13]. Traditionally, screening for uterine cavity anomalies has relied on hysterosalpingography, an image modality that is disadvantaged by potential contrast medium hypersensitivity and radiation exposure. If an anomaly was suspected, further investigations involving a hysteroscopy was considered the gold standard for diagnosing uterine cavity shape anomalies under direct vision, and laparoscopy could be used to assess the external fundal contour. The advances in magnetic resonance imaging (MRI), has increasingly gained popularity as an alternative modality for diagnosing congenital uterine anomalies since it has the potential to illustrate both the uterine cavity as well as external fundal contour. However, widespread uptake of MRI has been limited by its higher cost and lower patient acceptance. As 3D ultrasound gained validity, there has been shown to be a high degree of concordance between 3D ultrasound and MRI in defining uterine

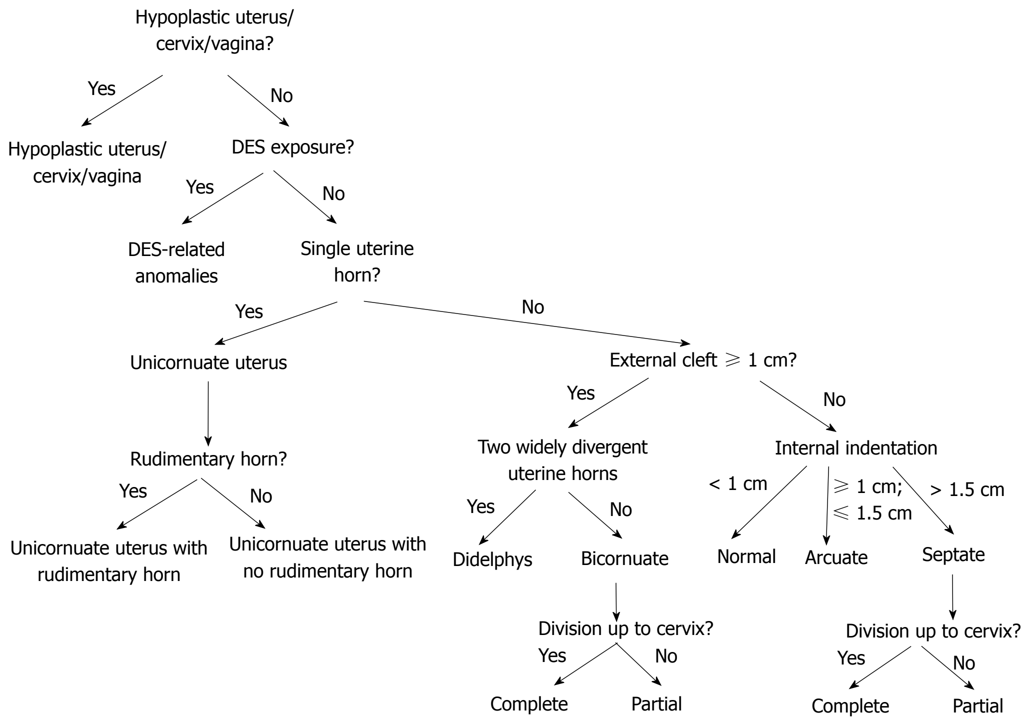

Figure 3 Algorithm for distinguishing between Mullerian duct anomalies. Modified to include morphology criteria by Ludwin *et al*[17], Bermejo *et al*[14] and Salim *et al*[17,18].

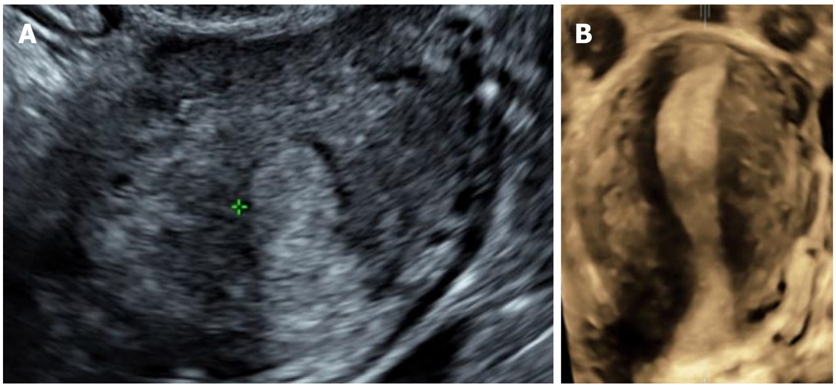

Figure 4 Unicornuate uterus with no rudimentary horn. A: Transverse 2D ultrasound image shows a single endometrial cavity; B: Coronal 3D (with VCI) ultrasound image of the unicornuate uterus showing a single uterine horn with no divergence of the endometrium towards both ostia and absence of a rudimentary horn. 3D: Three-dimensional; 2D: Two-dimensional; VCI: Volume contrast imaging.

anomalies[14]. While 2D transvaginal ultrasonography has an accurate diagnosis rate of 60%-82% for uterine malformation depending on different studies, 3D ultrasound was superior with a diagnostic accuracy of 88%-100%[15,16].

Uterine anomalies can be broadly classified into 3 broad categories: Fusion (didelphys and bicornuate uteri), septal resorption (arcuate and septate uteri) and hypoplasia/agenesis abnormalities. In 2D sonography, these abnormalities can present with a common feature: 2 endometrial cavities are seen. To distinguish between these various abnormalities, a coronal plane would be useful in demonstrating their distinguishing features. Although there no universally-accepted criteria for the classification of Mullerian duct anomalies, Ludwin *et al*[17], Bermejo *et al*[14] and Salim *et al*[18,19] described distinguishing features involving the external cleft of the fundal contour and internal cavity indentation, measured from a horizontal line drawn across the two uterine horns of the uterine cavity. Using this criterion, an algorithm for distinguishing between uterine anomalies is proposed (Figure 3). Hypoplastic uterus, cervix, vagina can be related to the Mayer-Rokitansky-Kuster-Hauser syndrome whereby the uterus, cervix and vagina are hypoplastic or absent. The classic anomaly associated with Diethylstilboestrol exposure is the T-shaped uterus which includes a widened lower uterine segment, a hypoplastic uterus, and a narrowed fundal endometrial cavity. A single uterine horn distinguishes a unicornuate uterus from the remaining ano-

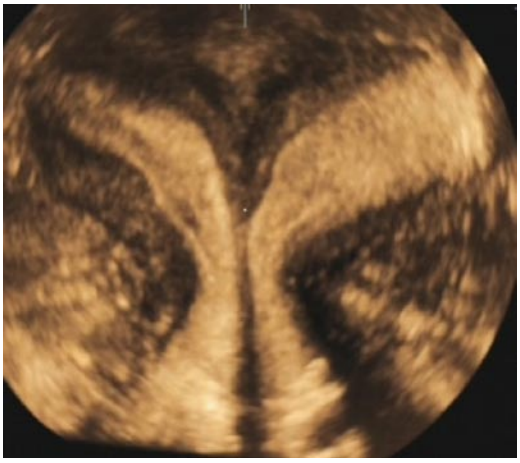

Figure 5 Uterine didelphys. Coronal 3D ultrasound image of a didelphys uterus show two widely divergent uterine horns separated by a deep external cleft ≥ 1 cm. 3D: Three-dimensional.

malies, although a rudimentary horn can sometimes be present (Figure 4). The distinguishing feature of fusion anomalies (didelphys or bicornuate uteri) from resorption anomalies is the external contour. Should the external cleft be greater than or equal to 1 cm, the degree of separation of the two horns will distinguish an uterine didelphys (Figure 5) from a bicornuate uterus (Figure 6). Uterine didelphys has 2 widely separated uterine horns, while a bicornuate uterus has a single uterine body with internal indentation greater than or equal to 1.5 cm. In the event that the external cleft is less than 1 cm, the depth of internal indentation will distinguish the septate (greater than 1.5 cm) (Figure 7) from the arcuate (between 1 and 1.5 cm) (Figure 8), and from normal uteri (less than 1 cm). Note that normal uteri can have either a straight or convex contour, or an external contour of less than 1 cm (Figure 3).

In several series, arcuate uteri was the commonest anomaly detected in 3D ultrasound when 2D ultrasound was normal[3,4]. While arcuate uteri is generally thought to be a normal variant with no reproductive consequences, there is some limited evidence that arcuate uteri can be associated with recurrent fetal loss[20]. It is particularly important to distinguish a septate uterus from fusion abnormalities since a septate uterus is amenable to hysteroscopic septoplasty to respect the residual septum while surgery is not an option for fusion abnormalities.

While septate and fusion anomalies are usually recognized on 2D ultrasound due to the presence of 2 uterine cavities, a unicornuate uterus (Figure 4) is more likely to be undetected given that the presence of a rudimentary horn can be very small and be masked by surrounding bowel. This anomaly has potentially severe consequences since besides the associations with miscarriage and premature delivery, the rudimentary horn can harbor a developing pregnancy and result in late uterine rupture and potentially life-threatening consequences[21].

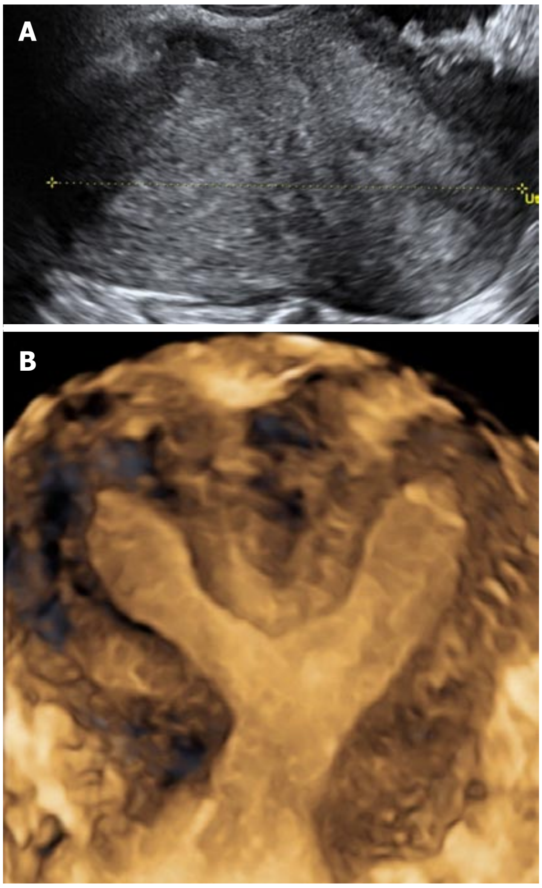

Figure 6 Bicornuate uterus. A: Transverse 2D ultrasound image of a bicornuate uterus showing the presence of 2 endometrial cavities; B: Coronal 3D ultrasound image of a bicornuate uterus showing external cleft ≥ 1 cm and internal indentation ≥ 1.5 cm. Note the presence of fundal soft tissue separating the 2 uterine cavities, which distinguishes it from uterine didelphys. 3D: Three-dimensional; 2D: Two-dimensional.

IUDs

While 2D transvaginal sonography has traditionally been used to assess the placement of IUDs, it is not able to demonstrate the entire IUD. 3D reconstructions in the coronal plane have the added advantage of demonstrating the complete IUD including shaft and arms. Lee *et al*[22] reported that by using the coronal plane, simultaneous visualization of the TCu380A IUD in its entirety was possible in 95% of 96 cases, while keeping examination time to a minimum. This can improve the detection rate of IUDs that have embedded in the myometrium since this can be a significant source of pelvic pain and abnormal bleeding for patients post IUD insertion (Figure 9)[23]. When assessing for IUD location, it should not extend past the endometrial cavity into the myometrium or cervix.

Fibroids and endometrial polyps

Fibroids are benign smooth muscle tumors of the uterus. While they are commonly asymptomatic, they can result in heavy menstrual bleeding, particularly when they are submucosal and distort the endometrial cavity (Figure 10)[24]. However, while fibroids can be

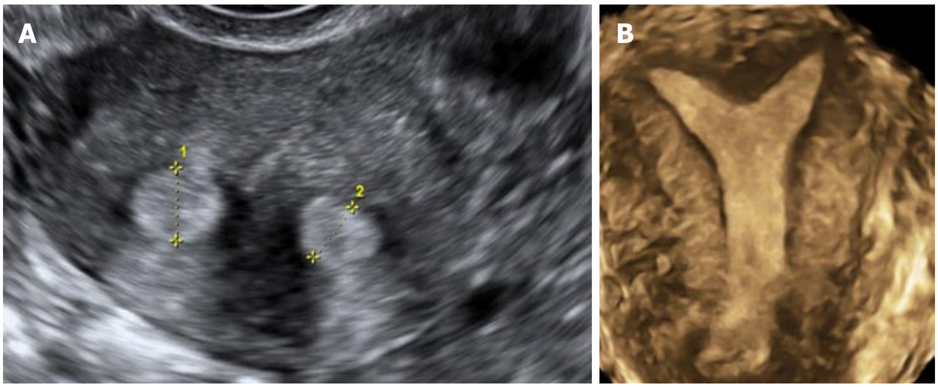

Figure 7 Septate uterus. A: Transverse 2D ultrasound image of a septate uterus showing the presence of 2 endometrial cavities; B: Coronal 3D ultrasound image of a partial septate uterus with the external cleft < 1 cm but internal indentation > 1.5 cm. 3D: Three-dimensional; 2D: Two-dimensional.

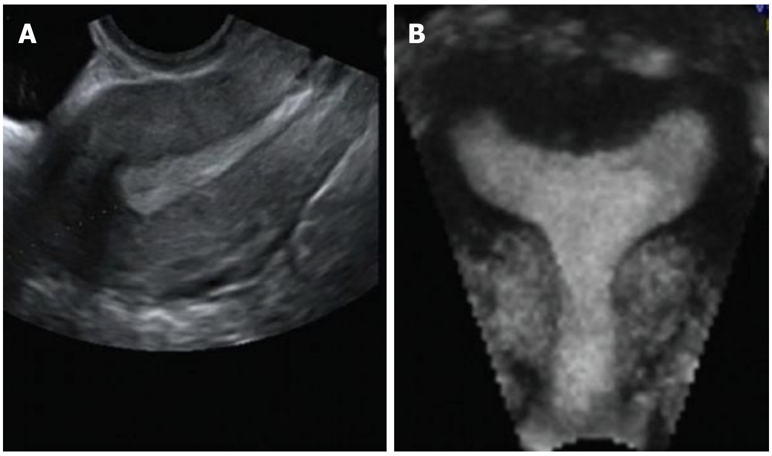

Figure 8 Arcuate uterus. A: Sagittal 2D ultrasound image of an arcuate uterus; B: Coronal 3D ultrasound image of an arcuate uterus with a smooth external contour and internal indentation ≥ 1 cm but ≤ 1.5 cm. 3D: Three-dimensional; 2D: Two-dimensional.

assessed on standard 2D imaging, their exact location in relation to the endometrial cavity and serosal contour can be difficult to determine due to shadowing artifacts. These difficulties can be overcome on a coronal plane since it allows the demonstration of the exact location of the fibroids, such as cavity distortion by submucosal fibroids and the planning of management options. Benacerraf *et al*[4] demonstrated that the 3D coronal view was useful in more accurately determining the specific location of fibroids (*i.e.*, submucous *vs* intramural) in 24% of patients using the coronal view.

Endometrial polyps are benign growths that are generally rounded, well-circumscribed echogenic masses seen within the endometrial cavity. Accurate imaging in 2D generally relies on the demonstration of a feeding vessel on color Doppler as demonstrated in Figure 11. As an adjunct, a coronal 3D imaging provides an opportunity to delineate the polyp more accurately since nearly the entire endometrial cavity can be seen in the same plane. However, the importance of the surrounding contrasting endometrium must not be overlooked. Indeed, Benacerraf *et al*[4] demonstrated that the width of the endometrium was an important predictor of whether the reconstructed coronal view would be helpful. Endometrium thickness of greater than 5 mm allowed a more confident diagnosis compared to patients whose endometrium was less than 5 mm[4].

Adenomyosis

Myometrial disorders are increasingly recognized as a cause for infertility and miscarriages, as well as subsequent obstetric complications[25,26]. The endometrium and the myometrial JZ, which is a highly-specialized inner third of the myometrium that together with its overlying endometrium, are key areas fundamental to the process of implantation and subsequently placentation. Consequently, any endometrial or myometrial disorders in the uterus that disrupt the transformation of these layers in early pregnancy can potentially interfere with the implantation and subsequent placentation, leading to various complications, such as miscarriage, pre-eclampsia and fetal growth restriction (Figure 12)[25]. Changes in the JZ have been thought to explain the pathogenesis behind why myometrial disorders such as adenomyosis can contribute to infertility[26].

Adenomyosis refers to the presence of ectopic endometrial glands and stroma within the myometrium, and

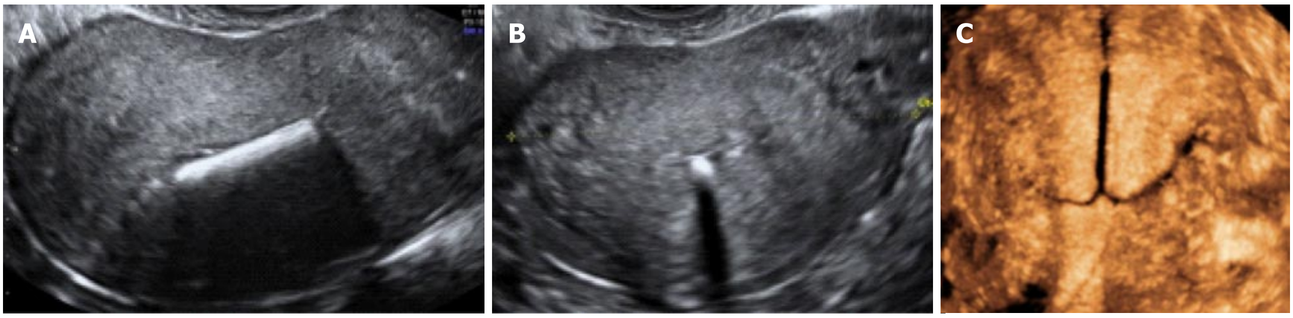

Figure 9 Malposition of an intrauterine device. Sagittal (A) and transverse (B) 2D ultrasound image showing the shaft within the endometrial cavity; C: Coronal 3D ultrasound image showing the IUD lying inverted with both arms embedded within the myometrium. 3D: Three-dimensional; 2D: Two-dimensional; IUD: Intrauterine device.

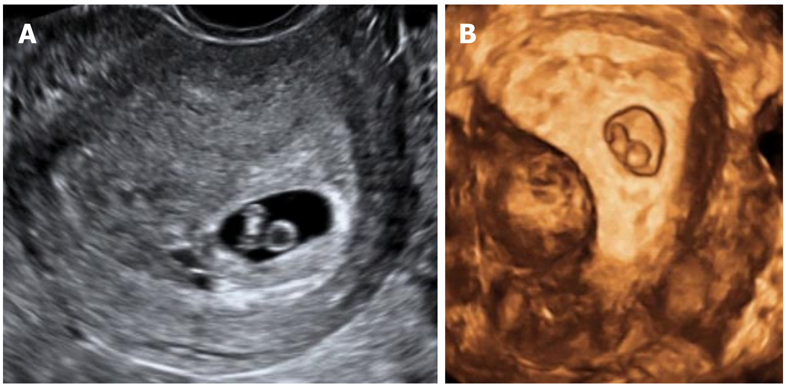

Figure 10 Intramural fibroid with an intrauterine pregnancy. A: Transverse 2D ultrasound image showing an intrauterine gestation sac positioned towards the left endometrial cavity; B: 3D coronal ultrasound image showing an intramural fibroid distorting the endometrial cavity, thus deviating the intrauterine pregnancy towards the left endometrial cavity. 3D: Three-dimensional; 2D: Two-dimensional.

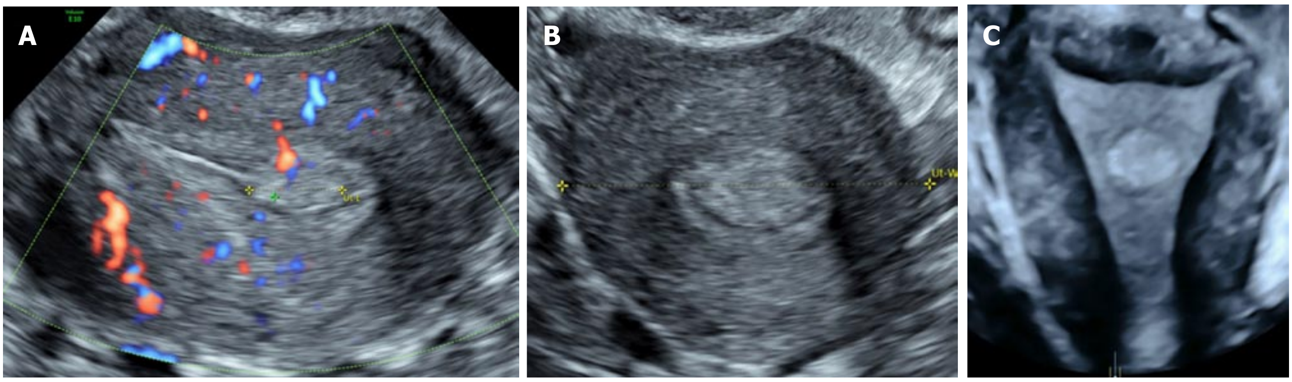

Figure 11 Endometrial polyp. A: Sagittal 2D ultrasound image of an endometrial polyp as identified by a vascular pedicle; B: Transverse 2D ultrasound image of the echogenic endometrial polyp; C: 3D coronal (VCI) ultrasound image showing the endometrial polyp better delineated as an echogenic mass. 3D: Three-dimensional; 2D: Two-dimensional; VCI: Volume contrast imaging.

is often classified as either diffuse or focal[27]. Rarely, it can present as a large adenomyotic cyst[28]. In assessing for changes due to adenomyosis, assessment of both the myometrium, as well as the JZ, are important features of diagnosing adenomyosis. In fact, in a recent consensus statement[28] describing ultrasound features of myometrial pathology, ultrasound features considered to be typical of adenomyosis include asymmetrical thickening, cysts, hyperechoic islands, fan shaped shadowing, echogenic subendometrial lines and buds, translesional vascularity, irregular JZ and interrupted JZ. While most of these features can be demonstrated on 2D ultrasound or colour Doppler, 3D ultrasound can be particularly useful for assessing the JZ in the coronal plane.

The JZ may be regular, irregular, interrupted, not visible, not assessable, or may manifest more than one feature, as classified by a recent consensus[28]. Although detailed morphological assessment and measurement of the JZ is currently predominantly for research pur-

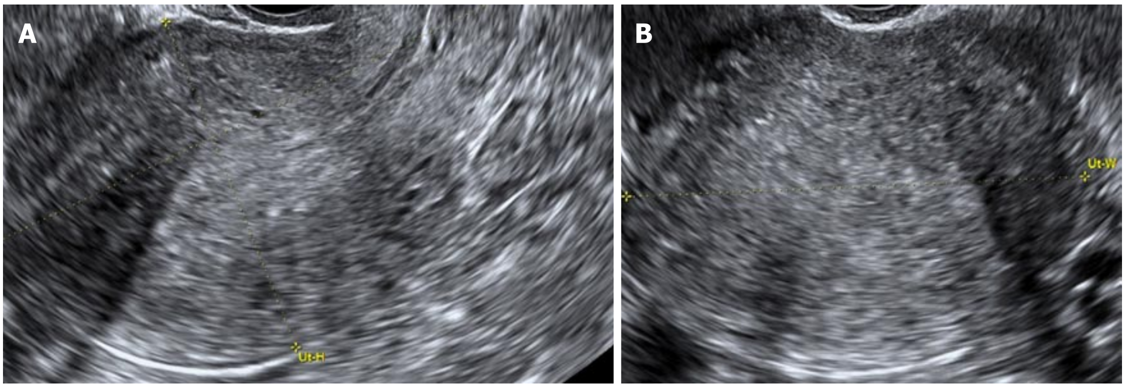

Figure 12 Adenomyosis with loss of the endometrial-myometrial junction. Sagittal (A) and transverse (B) 2D ultrasound images show the classic "venetian blind" shadowing of diffuse adenomyosis with loss of the endometrial-myometrial junction; B: 3D coronal ultrasound image (with VCI) showing the irregular endometrial-myometrial junction. Note the left lateral intramural fibroid. 3D: Three-dimensional; 2D: Two-dimensional; VCI: Volume contrast imaging.

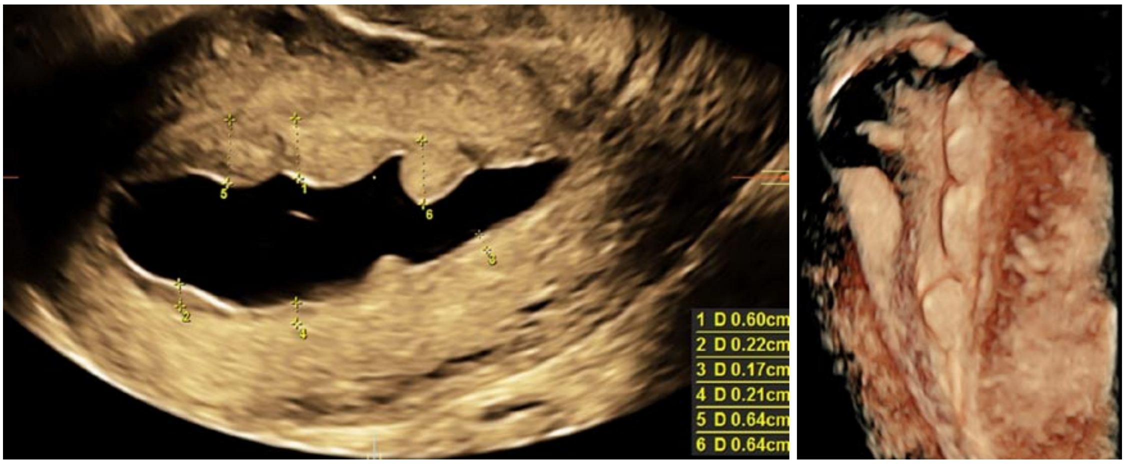

Figure 13 Saline infusion sonohysterography. A: 3D (VCI) A-plane image showing a thickened polypoid anterior endometrium upon distension with saline; B: 3D coronal image showing delineation of the polypoid endometrium on SIS. SIS: Saline infusion sonohysterography; 3D: Three-dimensional; VCI: Volume contrast imaging.

poses, broadly categorizing the JZ as either normal, or abnormal (irregular/interrupted), or not visible/not assessable will give an indication of the likelihood of JZ disorders[28].

Both MRI and 3D ultrasonography have been used to diagnose adenomyosis. In a systematic review by Champaneria *et al*[29] comparing the accuracy of the two imaging modalities, both TVUS and MRI were shown to have sufficiently high diagnostic accuracy although the study did not distinguish between 2D and 3D ultrasound. As on T2-weighted MR images, the JZ on 3D ultrasound appear as hypoechoic zone underlying the endometrium. 3D reconstruction of coronal sections of the uterine cavity has made it possible to assess minor changes in the lateral and fundal aspects of the JZ, which are impossible to delineate using standard 2D ultrasound. In additional, processing modalities such as VCI further enhance visualization of the hypoechoic JZ in comparison to that using 2D imaging[2,30,31]. Thus, 3D technology has made it possible to accurately assess and grade changes in the JZ architecture such as thickening, disruption and protrusion of the endometrium in to the inner myometrium. Exacoustos *et al*[2] correlated 2D and 3D transvaginal ultrasound imaging with histopathological features of adenomyosis in a total of 72 premenopausal patients. The most specific 2D-transvaginal ultrasound feature for the diagnosis of adenomyosis was presence of myometrial cysts (98% specificity; 78% accuracy), whereas a heterogeneous myometrium was most sensitive (88% sensitivity; 75% accuracy). On 3D-transvaginal ultrasound, the best markers were JZ difference ⩾ 4 mm and JZ infiltration and distortion (both 88% sensitivity; 85% and 82% accuracy, respectively)[2].

Uterine synechiae

Uterine synechiae or adhesions have a significant adverse effect on fertility. 2D ultrasound may present a diagnostic clue to adhesions within the endometrial cavity through the presence of bands seen within the endometrial echo, particularly with the aid of sonohysterography. However, the true narrowing or "bands" adherent across the cavity is usually well delineated on the coronal plane on 3D imaging. Knopman *et al*[32] demonstrated that the sensitivity of detection with 3D ultrasound was higher compared to hysterosalpingogram and that 3D ultrasound predicted adhesions and cavity damage with greater accuracy than hysterosalpingogram in patients with suspected Asherman's syndrome.

3D reconstructions with saline-instilled sonohysterography

Saline-instilled sonohysterography (SIS) involves injection of sterile saline into the endometrial cavity *via* a catheter (Figure 13). The main purpose is to allow for assessment of the endometrial cavity for possible distortion of the endometrial cavity due to submucosal fibroids or endometrial polyps, congenital uterine anomalies or synechiae after distension of the cavity. Besides 2D SIS, 3D SIS to assess this data in the coronal plane is also helpful. 3D SIS may have the advantages over 2D SIS because by injection of saline, it will enhance the contrast of the endometrial-myometrial junction. It will also allow the collection of volume data which can then be manipulated and analysed offline, hence potentially decreasing the time taken to perform the study[1].

CONCLUSION

Advent in 3D imaging technology has seen 3D ultrasound establish itself as a useful adjunct complementary to traditional 2D imaging of the female pelvis. This advantage largely arises from its ability to reconstruct the coronal plane of the uterus, which allows further delineation of many gynecological disorders. 3D imaging of the uterus is now the preferred imaging modality for assessing congenital uterine anomalies and IUD localization. Newer indications include the diagnosis of adenomyosis. It can also add invaluable information to delineate other endometrial and myometrial pathology such as fibroids and endometrial polyps.

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