TOSHIBA

Leading Innovation

Advances in transvaginal scanning modalities and their clinical application

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Introduction

Transvaginal ultrasound scanning (TVS) is now established as the principle technique for imaging of the female pelvic organs and early pregnancy. It is regarded as safe and well tolerated by patients. Its technical benefits are considerable and its clinical impact has been well documented.

The ability to utilise much higher transmission frequencies and the continuing developments in terms of transducer design and performance have resulted in vastly improved image quality compared with transabdominal scanning. Increased spatial and contrast resolution produces high definition 2D grey scale imaging of the pelvic structures and associated gynaecological issues.

Advances in scanning technology have resulted in the combined use of TVS with more recently developed imaging modalities. These include colour Doppler, 3D (volumetric), 3D ("virtual reality") and real-time elastography ultrasound techniques. Top of the range ultrasound systems incorporate these facilities thereby creating the concept of a comprehensive approach to modern TVS studies. Collectively, they offer an increase in both diagnostic capability, as well as confidence, as part of the investigation of gynaecological disease, fertility issues and early pregnancy development. [FIGS. 1A–1G]

FIGS. 1 demonstrate the value of a comprehensive approach to TVS ultrasound and utilization of the various imaging modalities available in a case of severe endometriosis.

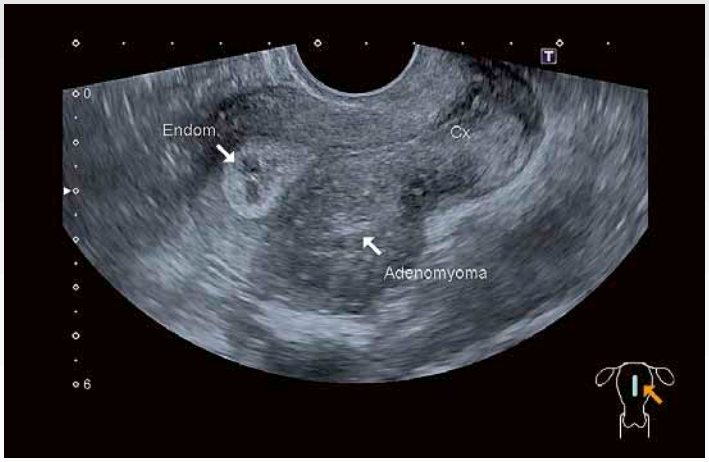

FIG. 1A shows subtle diffuse grey scale changes and asymmetrical thickening of the uterine wall consistent with uterine endometriosis and formation of an adenomyoma.

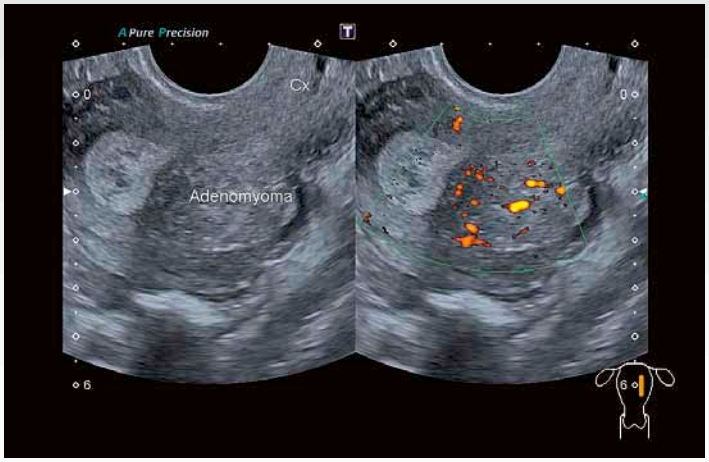

FIG. 1B highlights increased myometrial vascularity associated with adenomyosis using colour Doppler (PD) imaging.

TVS 2D Grey Scale Imaging

It needs to be stressed that the diagnostic effectiveness of the ultrasound imaging modalities outlined below largely reflect the performance levels of a system's 2D grey scale functions. There is no doubt that modern TVS systems are capable of generating what are accepted as very high quality grey scale images. Nevertheless considerable thought and care needs to be given to setting up basic pre-sets within the ultrasound system and ensuring correct utilisation of sensitivity controls is employed in order to maximise anatomical and diagnostic information gained from the 2D grey scale image.

Numerous examples illustrating the level of detail expected from current grey scale systems are found throughout this paper. However, it remains

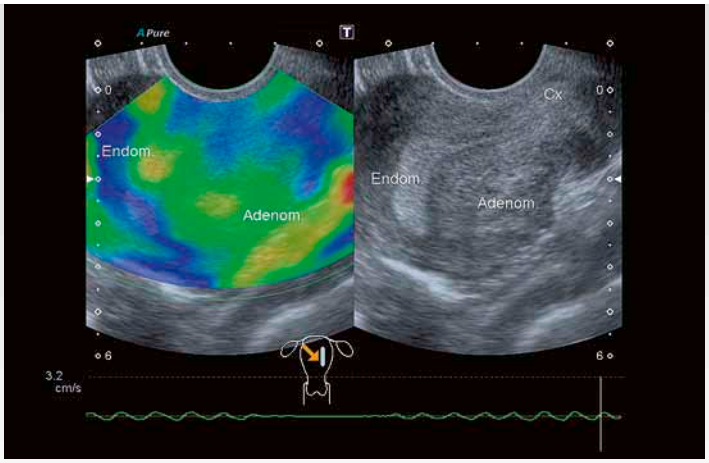

FIG. 1C confirms changes in the elastic properties of the myometrium caused by uterine endometriosis. Note – the similar compression colour coding between the affected area and adjacent endometrial tissue.

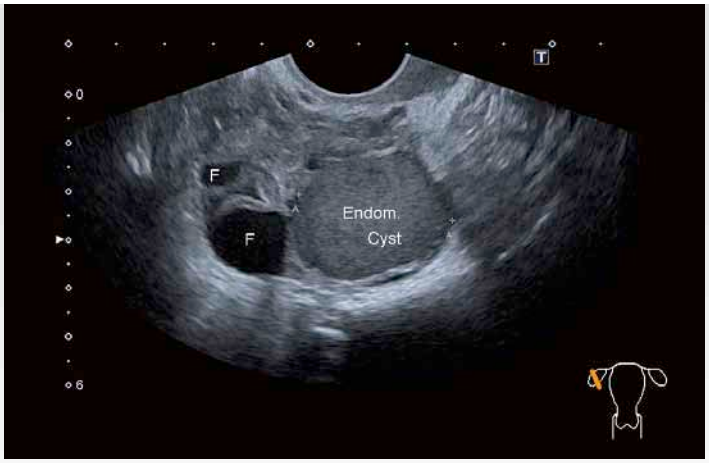

FIG. 1D demonstrates the characteristic grey scale appearances of an endometriotic cyst and ovarian follicles ("F") and stroma within the rt. ovary. Poor delineation of the ovarian capsule particularly within its upper, outer margins was consistent with para-ovarian adhesions.

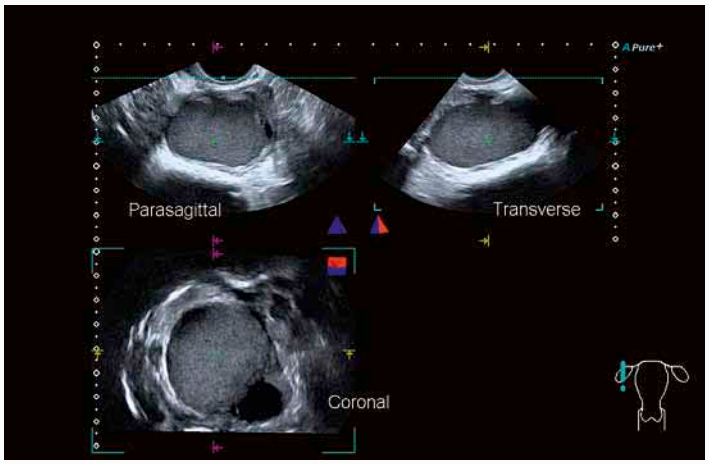

FIG. 1E

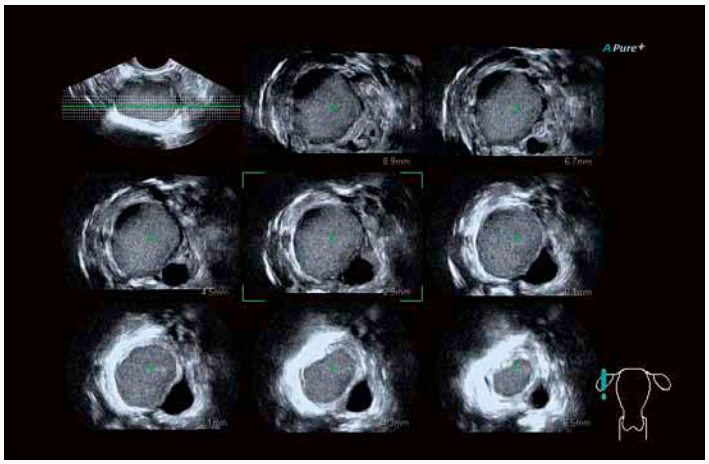

FIG. 1F

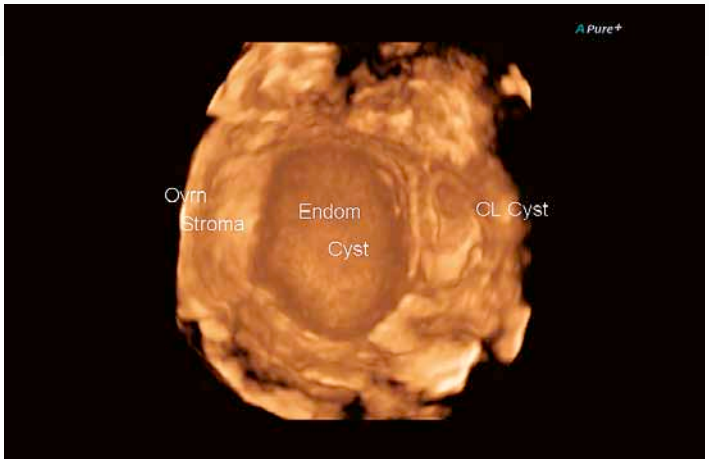

FIG. 1G

FIGS. 1E + 1F demonstrate the value of multiplanar and multiview 3D reconstruction of the rt. ovary, clearly illustrating ovarian morphology and indicating both the extent of the endometriotic lesion as well as preservation of normal, functional ovarian tissue. These features are very clearly demonstrated within the high resolution surface rendered image [FIG. 1G].

difficult to quantify what is acceptable or how to gauge the grey scale capability of a modern TVS 2D grey scale system. Manufacturers can install presets and signal processing functions which will generate smooth, cosmetically appealing grey scale images but not necessarily adequate for demonstrating fine tissue information. Gynaecological scanning demands images which provide a wide range of grey scales with an emphasis on low-level echoes in order to visualise subtle tissue changes. Cystic areas need to remain anechoic. Clear edge enhancement between large and small structures need to be maintained. Optimal image quality should be achieved in at least 80–90 % of patients encountered within a general gynaecological clinic. The adnexal region and associated structures provide an ideal source for testing the grey scale capability of a TVS system. [FIGS. 2A + 2B]

FIGS. 2 Demonstration of typical examples of grey scale quality demanded of 2D and 3D systems.

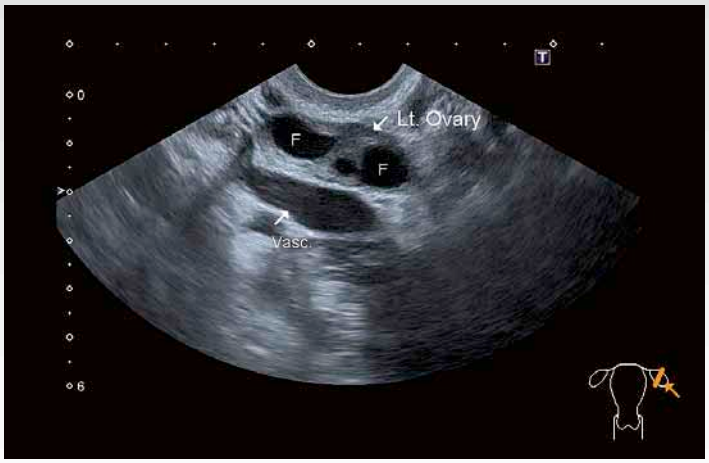

FIG. 2A shows good grey scale sensitivity demonstrating flow through the internal iliac vein ("Vasc") without the use of contrast agents, but still maintaining anechoic appearances of the ovarian follicles ("F"). Characteristic grey scale appearances of normal ovarian stroma are very evident.

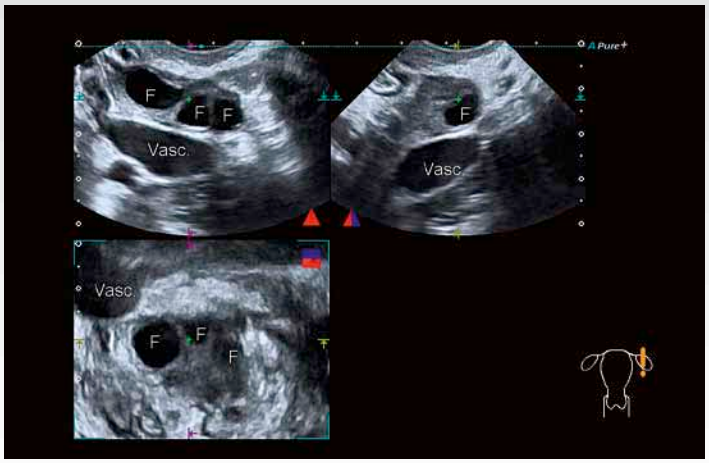

FIG. 2B shows multiplanar reconstruction of the same ovary with similar degree of grey scale quality and image resolution preserved within all x, y and z components.

FIGS. 3 demonstrate the value of CDI (PD) in terms of differentiating between low and high risk ovarian lesions.

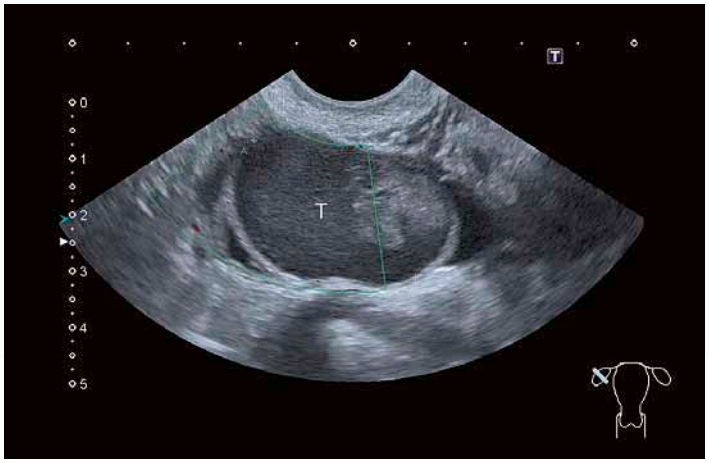

FIG. 3A shows an endometriotic cyst ("T") containing different stages of clotting of internal blood, thereby creating a complex appearance. PD confirms a relatively avascular lesion with no evidence of internal capillary bloodflow.

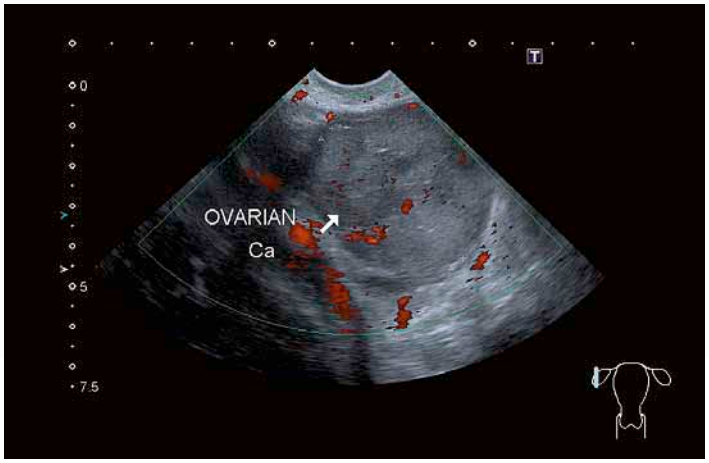

FIG. 3B shows a solid, malignant lesion of the ovary with characteristic internal vascularity confirming high risk changes.

Colour Doppler Imaging (CDI)

Spectral Doppler remains very limited in the assessment of gynaecological issues. The nature of the waveform itself and quantitative measurements obtained from it vary tremendously whether examining normal bloodflow within the pelvis or the vascular features of gynaecological masses. The development of high definition colour flow mapping (CFM) and "Power Doppler" (PD) in combination with TVS has had considerable impact in terms of diagnosis and its effects on clinical managements.

The ability to identify fine capillary bloodflow as part of natural angiogenesis associated with placentation, peri-ovulatory endometrial development and, in particular, ovarian follicle maturation allows more elaborate assessment of physiological as well as anatomical changes within the body.

Visualisation of tissue vascularity allows assessment of diffuse disease as well as providing crucial information relating to the nature of pelvic tumors. High definition CFM has been shown to identify angiogenesis associated with "high risk" changes at a very early stage of malignancy.

CFM demonstrates the peripheral angiogenesis associated with developing ovarian follicles approximately 4–5 days prior to ovulation. This allows accurate timing of the ovulatory window as part of cycle monitoring and provides a reliable indicator to the quality of ovulation. Extensive studies prove the value of CFM/PD in the investigation of the luteal phase. They confirm a very close correlation between CDI appearances of the corpus luteum and circulating serum progesterone levels. Evaluation of corpus luteum vascularity has been shown to be of considerable clinical value not only in terms of ovulatory assessment and monitoring of ART cycles but also the early management of high risk pregnancies and recurrent miscarriage. Advanced CFM systems provide a reliable alternative to biochemical testing in a significant number of cases. [FIGS. 4A + 4C]

Hyperaemic changes associated with diffuse diseases such as adenomyosis and pelvic inflammatory changes can be demonstrated from relatively early onset. Serial CDI scanning can accurately gauge reduced vascularity in response to clinical management in theses cases. CFM interrogation of retained products of conception, presenting either as a result of miscarriage or post-partum complication, is an essential component of TVS examination. It is the vascular nature and not quantity of retained tissues that should influence clinical management. Again, extensive

FIGS. 4: Composite images show normal peri-ovulatory endometrial thickening in response to pre-ovulatory ovarian follicular activity.

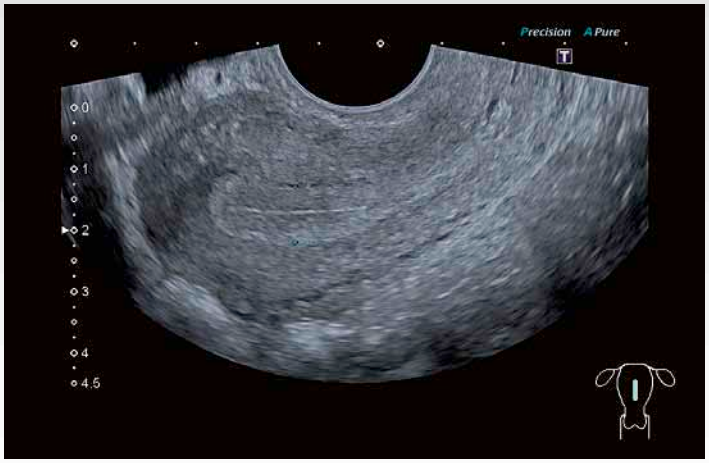

FIG. 4A shows typical grey scale appearances of the endometrium indicative of good ovulation.

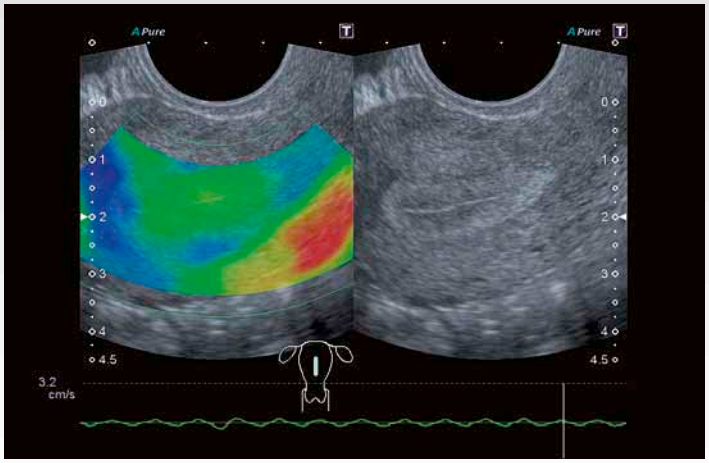

FIG. 4B demonstrates characteristic appearances and colour coding of normal endometrial development as illustrated by TVS RTE.

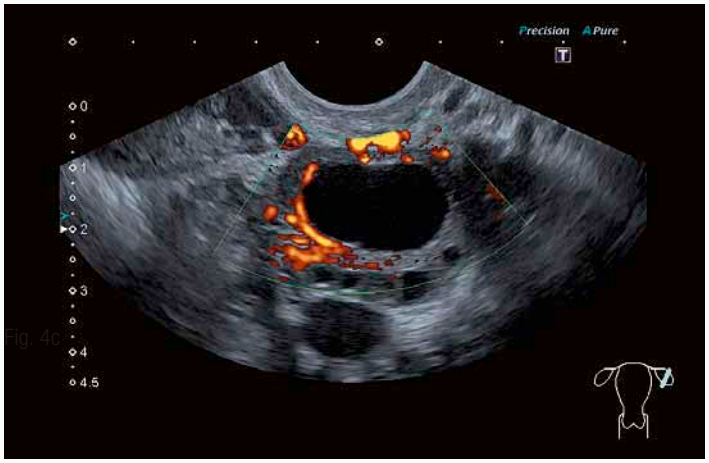

FIG. 4C: CDI (PD) confirms good pre-ovulatory activity and reflects favourable peri-ovulatory hormonal (oestrogen + progesterone) levels.

studies have shown the accuracy of TVS-CFM in identifying the presence of RPOC as well as its value in determining whether conservative management or surgical intervention is appropriate. [FIG. 1B] [FIGS. 6A + 6B]

CFM evaluation of uterine lesions is a crucial element in identifying the presence of benign or malignant disease. Increasing or decreasing levels of vascularity within fibroids reflect their growth patterns. Assessment of vascular appearances is extremely useful in differentiating between fibroid or adenomyoma formation. The vascular supply to endometrial polyps is again a determining factor in terms of conservative or surgical management choice. The vascular appearance of polyps, particularly in the post-menopausal patient, reflects the likelihood of high risk changes. [FIG. 1B] [FIG. 7B]

It is increasing tissue vascularity not the thickness of endometrial tissues which is the major ultrasound component that alerts us to the possibility of malignant changes. Increased CFM sensitivity can demonstrate very early vascular changes associated with both benign and malignant disease processes. TVS-CFM does not indicate with total certainty the aetiology of endometrial disorders but nevertheless confirms those cases where surgical intervention needs to be considered. [FIG. 5B]

It follows that colour Doppler TVS examination has a major role to play in the detection of ovarian cancer. Experience has shown that the likelihood of ovarian malignancy can be demonstrated by detailed TVS-CFM assessment at an extremely early stage ie within relatively small lesions and even before there is any significant enlargement of the ovary itself, particularly in post-menopausal patients. A totally benign, normal functional (luteal) cyst can seem quite complex and often sinister in its TVS grey scale appearances. However, it is the ability to visualise fine, capillary (internal) blood-flow that strongly suggests ovarian cancer. Therefore, the confidence to exclude suspicious tissue vascularity associated with ovarian lesions using modern TVS-CFM techniques significantly reduces the unacceptable high numbers of "false-positives" currently presenting to gynecology-oncologists treating ovarian cancer! Survival rates in ovarian cancer have not improved in several decades, principally because of the failure to identify the disease at an early stage. High resolution, sensitive CFM systems have the capability of identifying vascular changes associated with ovarian malignancy at an extremely early stage of the disease process. [FIGS. 3A + 3B]

FIGS. 5 demonstrate the ability of CDI (PD) and RTE to reveal abnormal tissue changes within a case of endometrial malignancy.

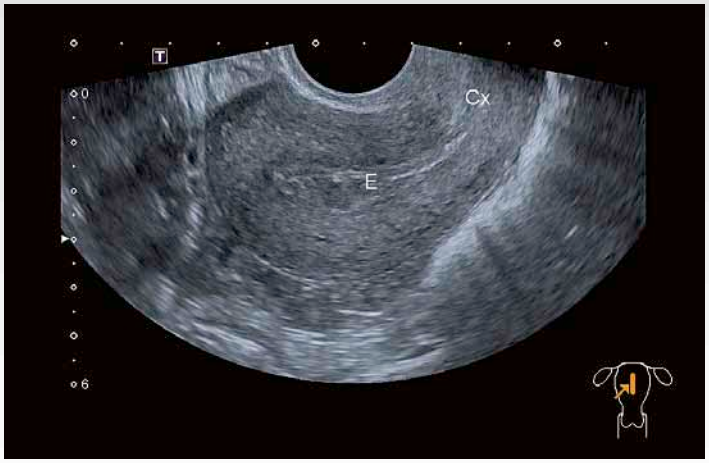

FIG. 5A demonstrates subtle grey scale changes indicating a localized area of abnormal appearances within the endometrium ("E").

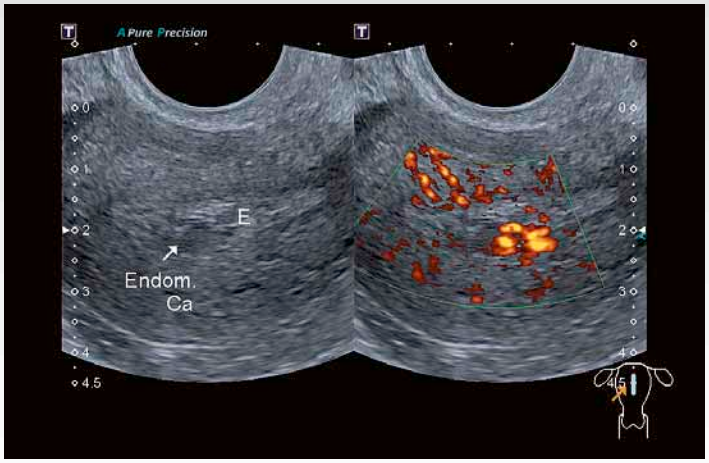

FIG. 5B: Corresponding, localized vascularity identified by CDI confirms high risk changes.

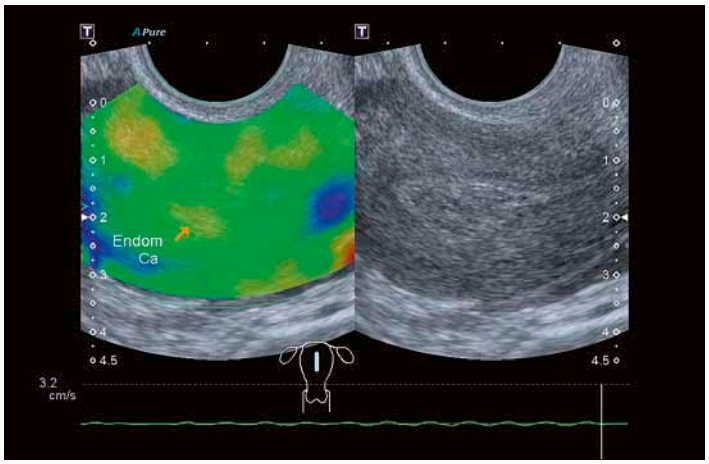

FIG. 5C: Abnormal changes are confirmed by increased compressibility of the affected tissues as shown by RTE.

3D (Volumetric) Imaging

State of the art 3D ultrasound systems are capable of producing high quality images in a number of different formats. A single sweep of the ultrasound beam generates a wealth of anatomical and clinical information within a selected volume. The ultrasound data stored can be easily retrieved and manipulated to create 2D images in any anatomical plane or offer a choice of image formats. The performance of the 3D imaging system can be reliably gauged from the multi-planar reconstruction (MPR) of the acquired data. Inspection of the "x" and "z" components should demonstrate identical levels of image quality in terms of both spatial (definition) and contrast (grey scale) resolution.

The value of 3D-TVS assessment of the uterus in particular and the ability to display the uterine cavity in coronal section has been well described. The presence and nature of congenital malformations are easily recognised. Distortion of the cavity wall by intramural lesions is well shown. Intracavital lesions are clearly delineated. The correct positioning of IUD's/IUS can be confirmed with total confidence.

3D-TVS volumetric ultrasound offers the ideal means for examining ovarian morphology, particularly the distribution of antral follicles. Improved delineation and examination of ovarian lesions provide more reliable diagnostic impression of their nature and extent. 3D imaging formats accurately gauge the preservation of healthy, functional stromal tissue in the presence of large ovarian lesions. This proves to be a crucial factor influencing the choice of surgical management.

The ability to manipulate stored ultrasound data and select different anatomical planes at will, facilitates careful evaluation of complex gynaecological disease. This might include extensive chronic or acute inflammatory changes, grade IV endometriosis or spread of pelvic malignancy ie all examples of diffuse pelvic processes which might involve adjacent pelvic tissues or structures.

In addition, manipulation of stored image information is of considerable use in terms of separating para-ovarian structures and pathologies from those which are ovarian in origin. Conventional 2D TVS can often have difficulty in this respect especially in cases where extensive adnexal/pelvic adhesions are present. [FIGS. 1D–1G] [FIGS. 12F–12L]

FIGS. 6 demonstrate the value of CDI and RTE modalities in the TVS assessment of retained products of conception.

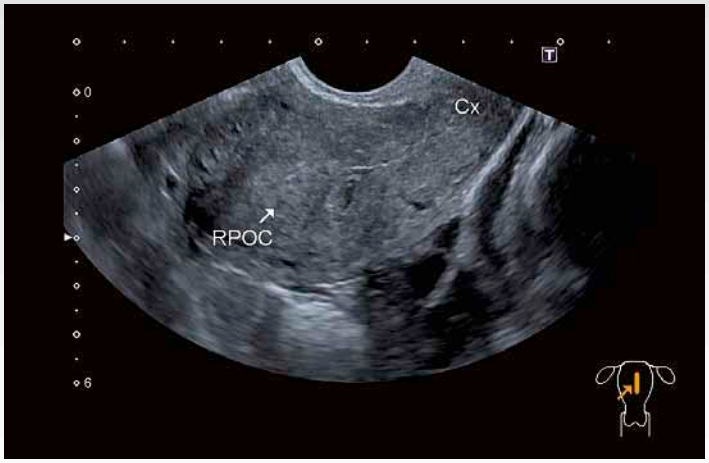

FIG. 6A: The retained tissue ("RPOC") is not clearly delineated by TVS grey scale imaging.

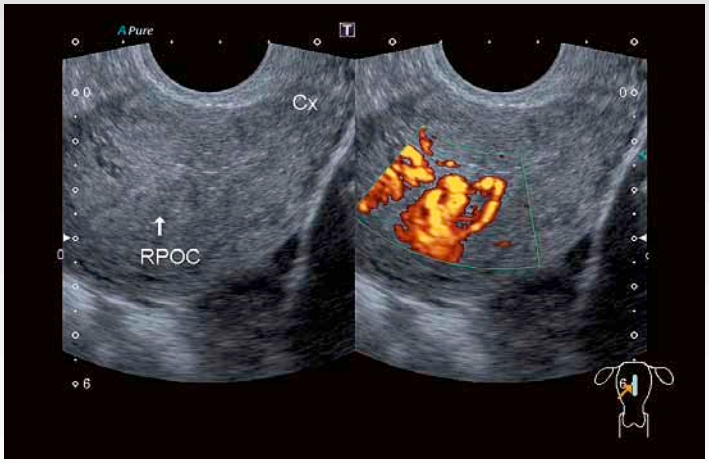

FIG. 6B: However the vascular tissue is clearly shown by PD imaging.

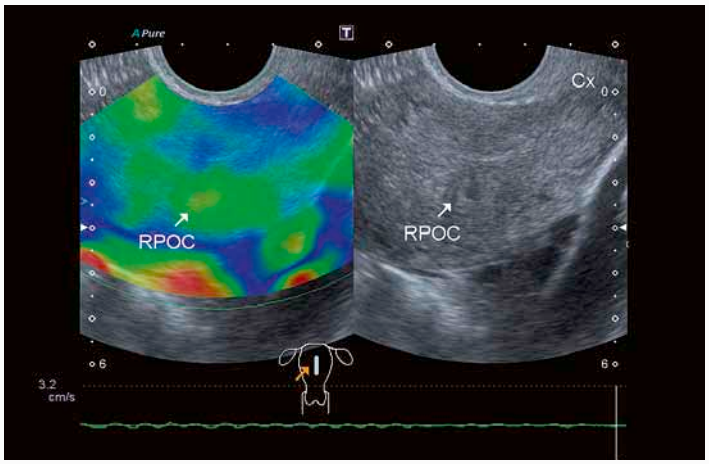

FIG. 6C: RTE colour coding further outlines the tissue separate from surrounding, less compressible myometrium.

FIGS. 7

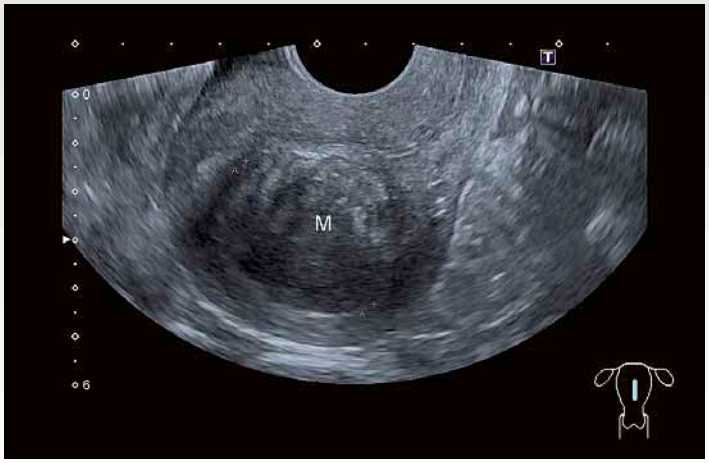

FIG. 7A

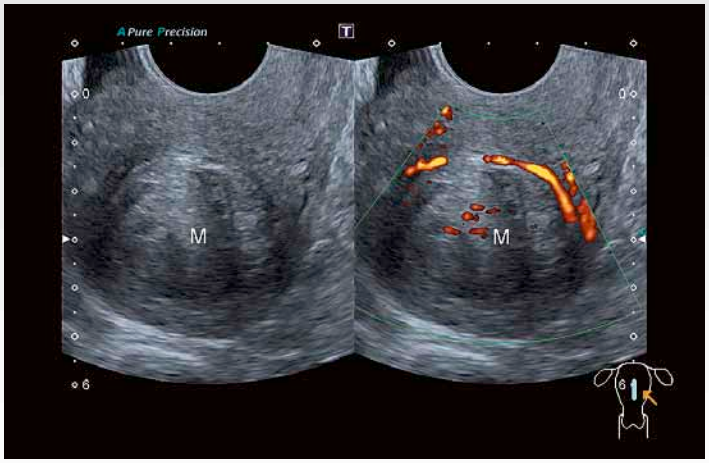

FIG. 7B

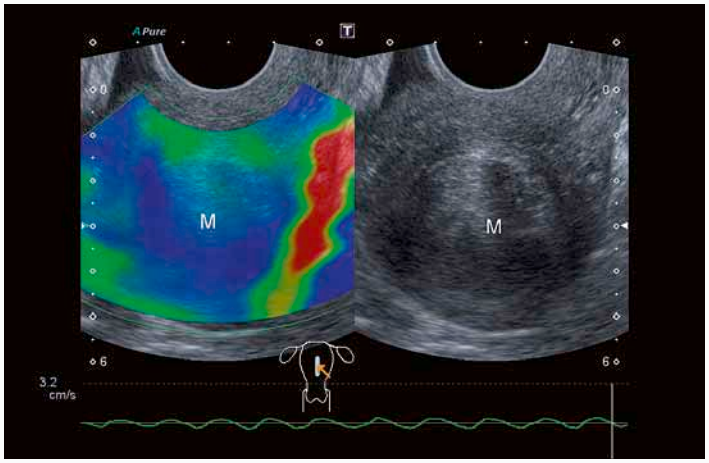

FIG. 7C

FIGS. 7A–7C show the characteristic appearances of a uterine fibroid ("M") as demonstrated by 2D grey scale [FIG. 7A]. Its solid, relatively non-compressible nature is obvious as shown by RTE [FIG. 7C]. Typical peripheral bloodflow is shown by CDI (PD) which provides a reliable means of differentiating between fibroids and other myometrial tumours [FIG. 7B].

FIG. 8

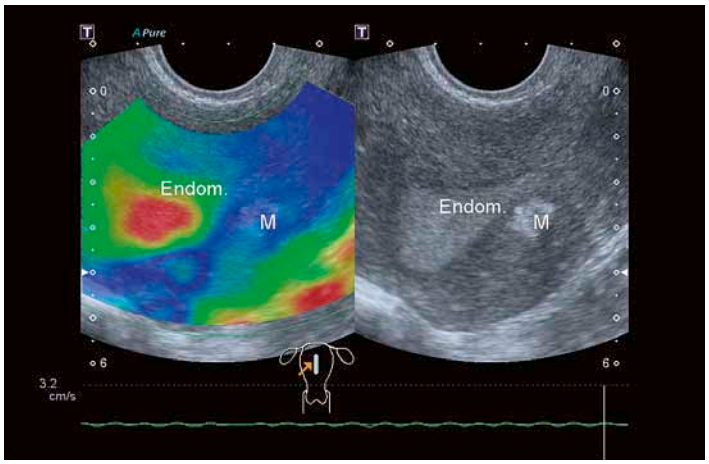

FIG. 8 shows the value of RTE in differentiating between fibroids and other myometrial lesions such as adenomyosis. The myometrial mass ("M") appears to be of a similar echogenicity compared to the endometrium on the TVS grey scale image. However, RTE confirms the lesion is much less compressible than the endometrial tissue but similar to surrounding myometrial tissue in this respect i.e. confirming the presence of a small fibroid.

Saline Infusion Sonohysterography (SIS)

SIS is now established as a routine ultrasound procedure in leading units. The uterine cavity is gently distended by saline solution. 3D-TVS assessment of the fluid-filled cavity offers extremely detailed studies. The size and shape of the cavity are very clearly seen and any distortion of the cavity wall contour, caused by myometrial lesions or congenital anatomical variation, is well demonstrated. Intracavital lesions such as endometrial polyps, submucosal fibroids and adhesions are clearly outlined. SIS promotes detailed ultrasound evaluation of the endometrium and peri-ovulatory changes as well as associated pathological disease.

Indications for SIS include the presence of suspicious intracavital features identified on conventional TVS examination and / or cases of irregular pv bleeding. In addition, it is now common practice to carry out the procedure as a pre-requisite to IVF and also as a standard test as part of investigation into recurrent miscarriage. The effectiveness of the technique, in both technical and clinical terms, has led SIS to be utilised as an alternative to diagnostic hysteroscopy in many leading units. Benefit to the patient and positive cost implications are very relevant. [FIG. 9] [FIGS. 10A + 10B] [FIGS. 11A + 11B]

FIG. 9

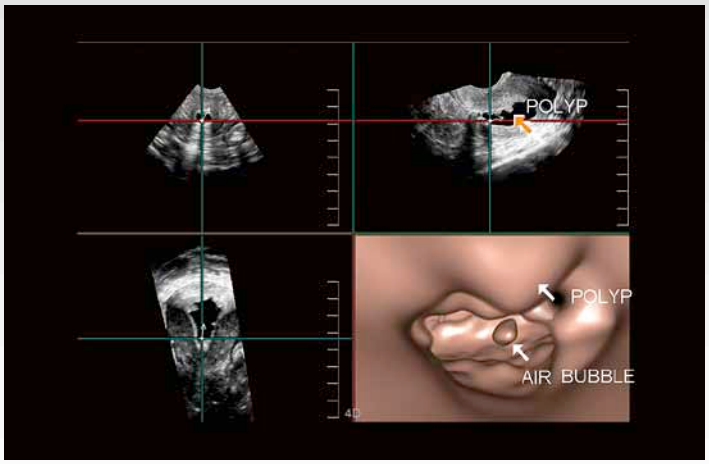

FIG. 9 illustrates the very fine detail obtained by "Fly Thru" technology. Multiplanar sections, as part of 3D – TVS SIS procedure, demonstrate the uterine cavity distended by saline solution with several polyps of only a few mms. in size clearly identified. The "Fly Thru" image clearly shows the polyp(s). A small air bubble (< 1mm size) within the distended uterine cavity is very obvious.

FIGS. 10

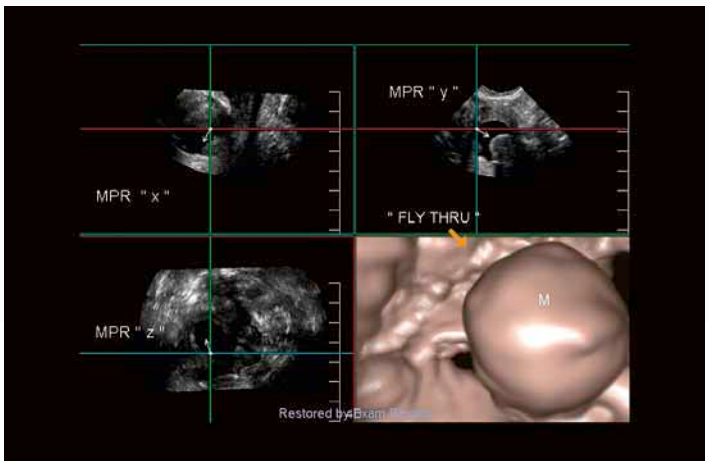

FIG. 10A

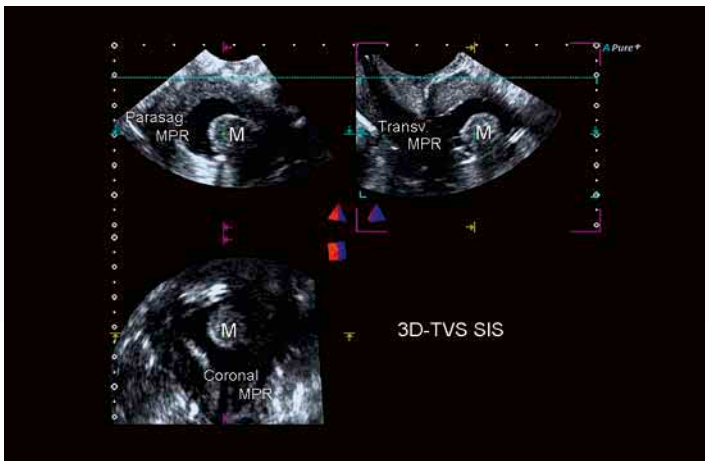

FIG. 10B

FIGS. 10A + 10B demonstrate the precise clarity 3D – TVS SIS offers in outlining the intracavital lesion ("M") which was confirmed by hysteroscopic surgery as being a fibroid [FIG. 10A]. Application of "Fly Thru" [FIG. 10B] provides obvious visual recognition of the presence and nature of the fibroid ("M").

"Fly Thru" Imaging

Advances in Toshiba 3D (Volumetric) ultrasound technology have culminated in the development of "Fly Thru" imaging. It uses the raw TVS 3D data obtained by SIS and stored within the ultrasound system to create a visual display comparable to virtual reality endoscopy. Perspective projection capability created a true 3D visual effect. Structures can be studied from any direction, unlike with endoscopic techniques, and movement through the area of interest can be automatic or controlled manually.

The high quality images produced confirm the normality of the uterine cavity and healthiness of the endometrial lining with much more confidence. It has a crucial role in excluding intracavital uterine pathology particularly in post-menopausal cases presenting with irregular pv bleeding.

The visual impact and diagnostic capability it offers gives considerable credence to the concept of "ultrasound hysteroscopy". This advanced form of 3D-TVS SIS imaging has significantly reduced the number of referrals for diagnostic hysteroscopy. Again, advanced 3D-TVS SIS utilising "Fly Thru" technology offers considerable benefits from both patient care as well as a financial point of view. [FIG. 9] [FIG. 10B] [FIGS. 11A + 11B]

FIGS. 11 again demonstrate the diagnostic value of 3D – TVS SIS combined with "Fly Thru" technology.

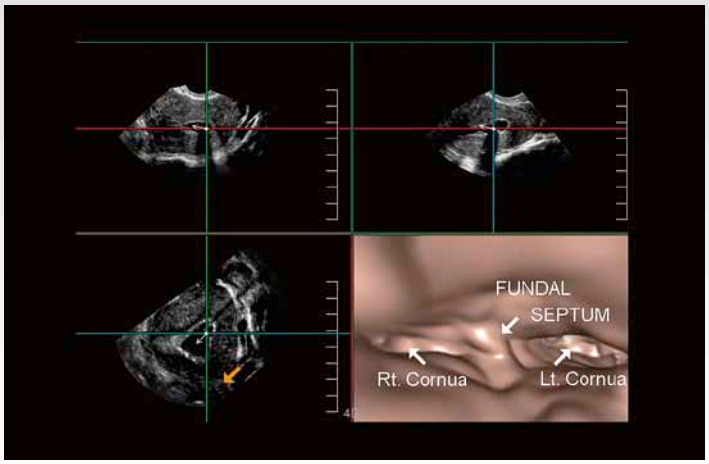

FIG. 11A: A small fundal septum is delineated on "Fly Thru" visualization of the upper uterine cavity.

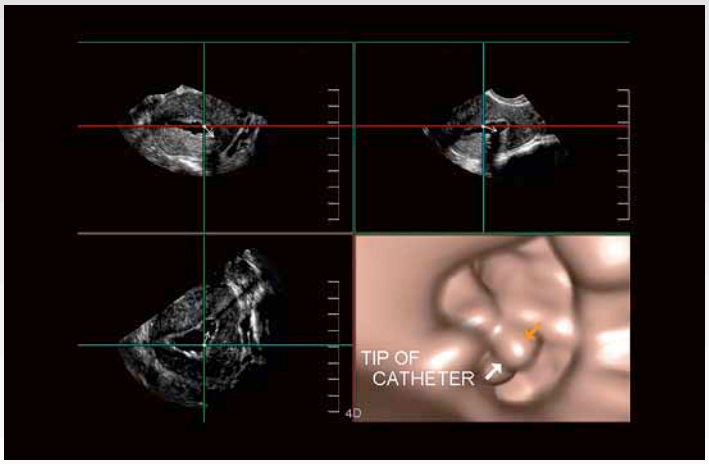

FIG. 11B: The fine detail obtained by "Fly Thru" imaging is shown – the tip of the SIS cannula can be recognised protruding through the internal os into the main uterine cavity.

FIGS. 12: A case of extensive pelvic and uterine endometriosis illustrates the value of utilizing a range of TVS imaging modalities applied to evaluating complex, diffuse pelvic disease.

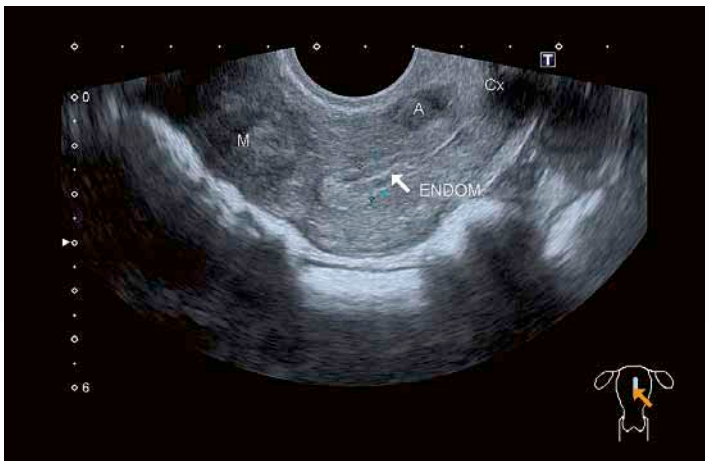

FIG. 12A

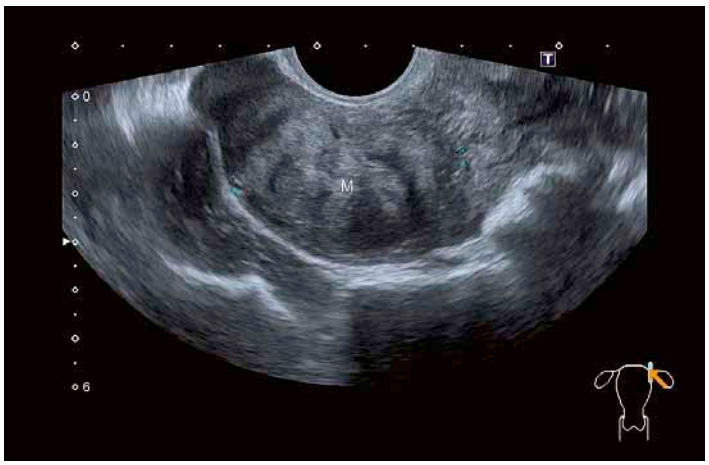

FIG. 12B

FIGS. 12A + 12B: 2D grey scale TVS identifies a large Lt fundal uterine fibroid ("M") and lower anterior uterine wall adenomyoma ("A").

Real Time Elastography (RTE)

RTE is an integral part of breast imaging in many leading units. Its clinical value has been well documented in this area of medical ultrasound. The principle of the technique is based on the concept of manual compression of tissues producing a colour mapping image superimposed onto the 2D grey scale display. The colour coding system reflects the relative compressibility of adjacent tissues. The technique compares the relative "hardness" or "softness" of structures with that of surrounding tissues.

RTE has been particularly useful in the diagnosis of suspected adenomyosis. Increased compressibility of the uterus appears to correlate well with the concept of a softer, more vascular myometrium certainly in cases where ultrasound (grey scale + colour Doppler) grading suggests extensive adenomyosis. The ability to depict myometrial changes resulting from uterine endometriosis has proven to be of particular value in terms of differentiating between uterine fibroids and adenomyomas. Increased vascularity associated with pelvic infection unsurprisingly alters the elasticity of myometrial tissue which again can be shown by RTE. Follow-up RTE assessment can demonstrate changes in response to medical treatments in cases of diffuse myometrial disease such as adenomyosis and PID. [FIG. 1C] [FIG. 8] [FIG. 12C]

The sensitivity of RTE is of a level to show characteristic changes within the peri-ovulatory endometrium at a different stage of the cycle to include those present in early pregnancy. It follows that abnormal changes within the endometrium can be demonstrated, particularly increased proliferation of tissue associated with both benign and malignant disease. RTE is also shown to increase accuracy in confirming the presence of retained, active decidual or placental tissue in cases of RPOC. [FIG. 4B] [FIGS. 5A–5C] [FIGS. 6A–6C]

RTE at present offers little in addition to conventional TVS grey scale and CDI in the evaluation of ovarian lesions. However, it remains very useful in confirming the presence of pedunculated pelvic fibroids and excluding other forms of adnexal pathology. Recognition of typical RTE appearances of the ovary often reduces difficulty in differentiating between para-ovarian and ovarian lesions as well as providing clearer delineation of ovaries in post-menopausal patients.

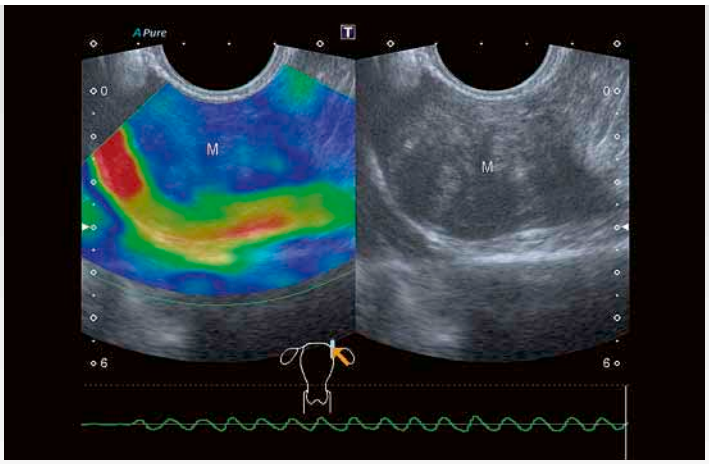

FIG. 12C

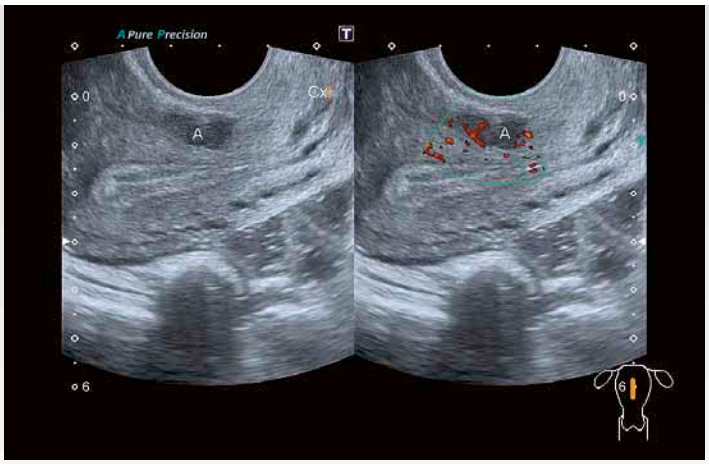

FIG. 12D

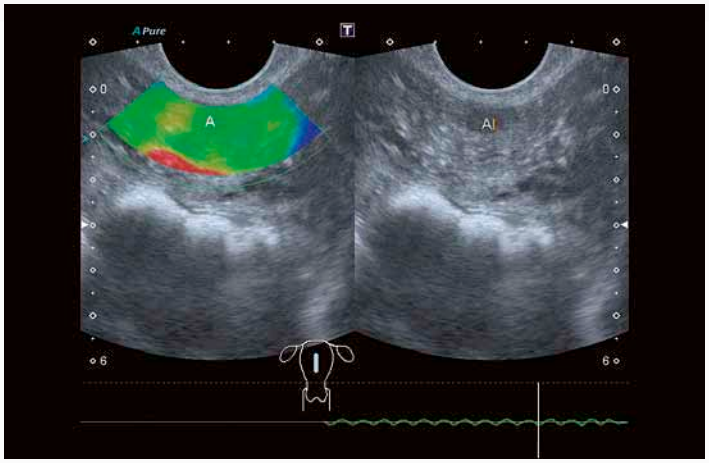

FIG. 12E

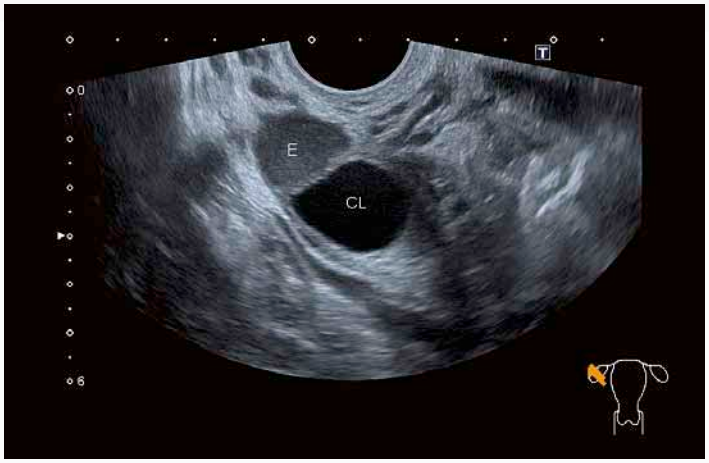

FIG. 12F

FIGS. 12C–12F: Colour Doppler (PD) [FIG. 12D] show the vascular nature and increased elasticity respectively associated with an adenomyoma ("A").

Conclusion

Modern ultrasound systems can now offer a range of TVS ultrasound imaging modalities. There is no doubt that each of these add to the diagnostic capability of the ultrasound system and appear to offer particular clinical and technical benefits in most aspects of gynaecology to include reproductive medicine and early pregnancy assessment. The Toshiba "Leading Innovation" programme is committed to establishing a comprehensive approach to TVS involving further development and improvements in all the above elements of scanning in order to maximise the clinical effectiveness of ultrasound as part of gynecological investigation and patient management. [FIGS. 12A–12L].

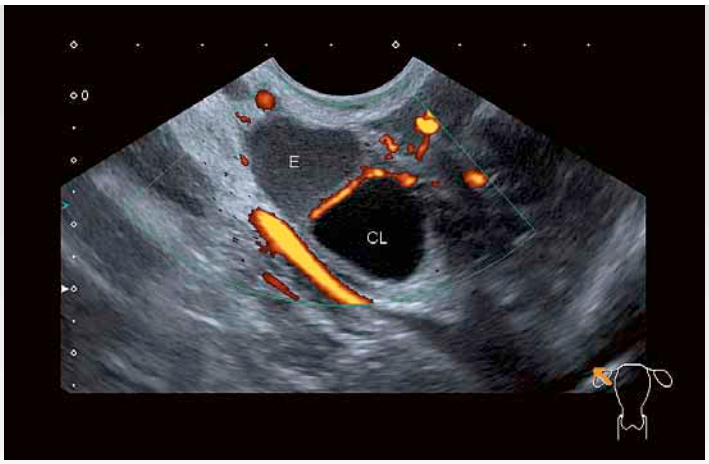

FIG. 12G

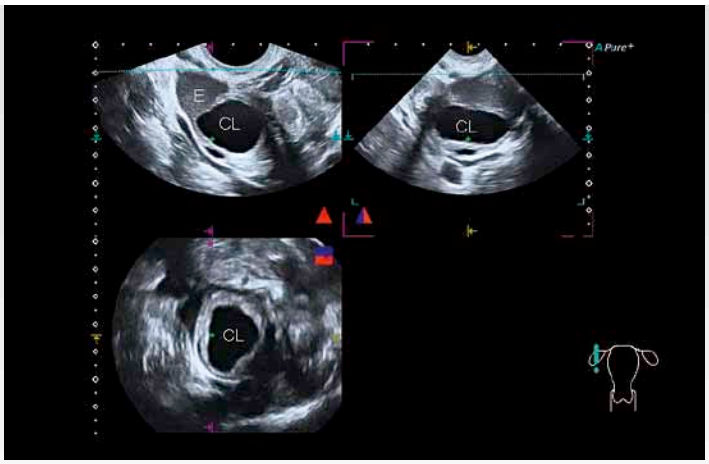

FIG. 12H

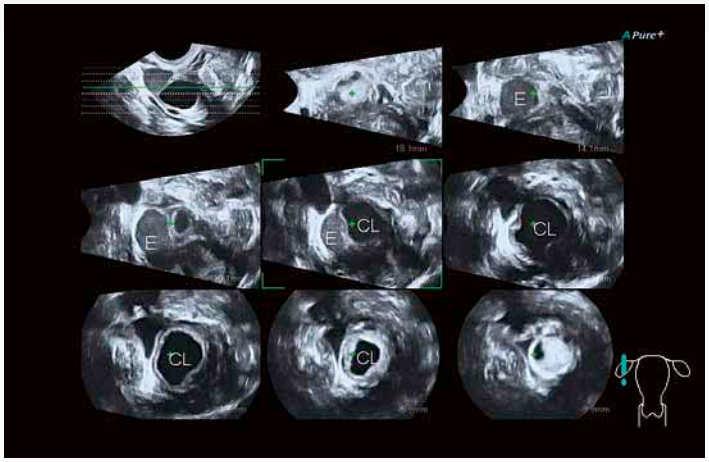

FIG. 12I

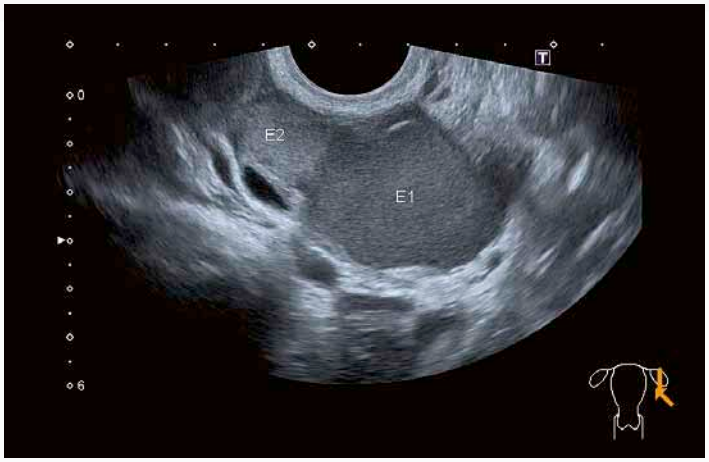

FIG. 12J

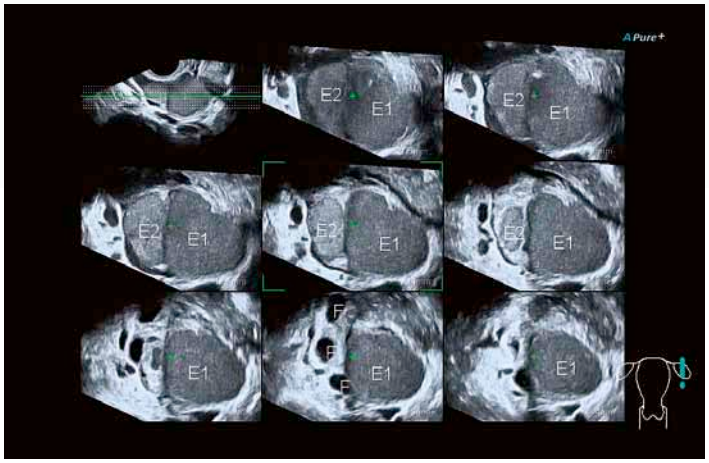

FIG. 12K

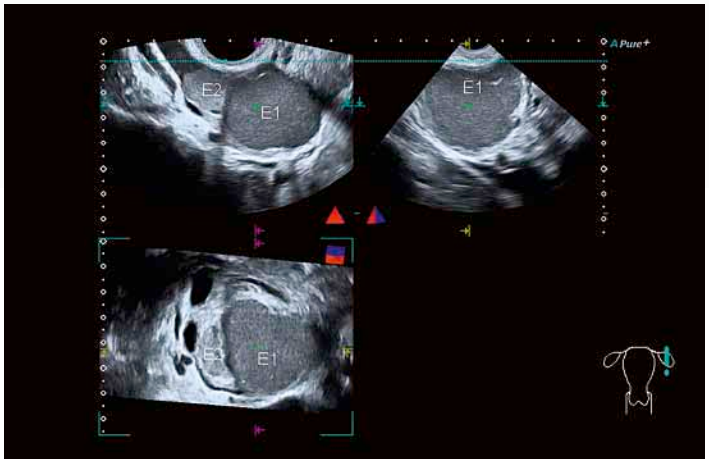

FIG. 12L

FIGS. 12G–12L: Characteristic peripheral vascularity around the CL cyst confirms its nature and activity [FIG. 12G] resulting in the thickened peri-ovulatory endometrium [FIG. 12A]. Multiplanar and multiview 3D reconstruction of the Rt ovary provides detailed anatomical studies of ovarian morphology [FIGS. 12H + 12I]. 2D grey scale imaging delineates large endometriotic cysts ("E1" + "E2") within the Lt ovary [FIG. 12J]. Again, multiplanar and multiview 3D volumetric reconstructions confirm the extent of the lesions ("E1" + "E2") as well as demonstrating preservation of normal functional stroma and antral follicles within the Lt ovary [FIGS. 12K + 12L].

Further Reading

Toshiba Leading Innovation:
"The Practical Application and Clinical Use of
Modern 3D Ultrasound Technology in Gynaecology".
TWPUS0012EC.EU

Toshiba Leading Innovation:
"Advanced Transvaginal 3D/4D Imaging of the
Uterine Cavity Paves the Way for Ultrasound
Hysteroscopy".
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