

Advances in transvaginal ultrasound scanning and their clinical application

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Introduction

Transvaginal ultrasound scanning (TVS) is universally accepted as the principal technique for imaging of the female pelvic organs and early pregnancy. It is regarded as safe and well tolerated by patients. The practical and technical benefits of TVS are fully recognised. The diagnostic value of TVS is well documented and its considerable impact in key clinical areas of gynaecology and reproductive medicine is acknowledged worldwide.

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. Increased spatial and contrast resolution produces high-definition 2D grey-scale imaging of the pelvic structures and associated gynaecological issues. Advances in multi-element array technology have resulted in the combined utilisation of TVS with more recently developed imaging modalities. These include SMI (Superb Microvascular Imaging), 3D (volumetric), 3D ("virtual imaging") 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. They offer an increase in both diagnostic capability and confidence, particularly in the investigation of gynaecological disease, fertility issues and early pregnancy development when fully utilised together.

The scan images presented cover a wide range of clinical cases which collectively emphasise the role of modern TVS in both clinical and technical terms. They especially demonstrate the increased

diagnostic effectiveness achieved by the combination of high-quality grey-scale and increased colour Doppler sensitivity provided by SMI.

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 very high-quality grey-scale images. Nevertheless considerable thought and care need to be given to establishing basic presets within the ultrasound system and to ensuring correct utilisation of sensitivity controls 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, quantification of acceptable quality levels and gauging grey-scale capability of a modern TVS 2D grey-scale system remain difficult. Manufacturers can install presets and signal processing functions which will generate smooth, cosmetically appealing grey-scale images but which are 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. TVS is not possible

or is contra-indicated in a number of cases mainly due to technical problems or age factors. Nevertheless, high-quality grey-scale imaging also needs to be maintained for all pelvic scan techniques (Fig. 1).

Colour Flow Mapping (CFM)

Spectral Doppler remains very limited in the assessment of gynaecological issues. However, the development of high-definition colour Doppler Imaging (CDI) and power Doppler (PD) in combination with TVS appears to have considerable impact in terms of diagnosis and its effects on clinical management. This particularly applies to the more recent introduction of SMI (Superb Microvascular Imaging) by Canon Medical Systems. SMI provides increased sensitivity, improved resolution, high frame rate and less motion artifacts in the interrogation of tissue vascularity.

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 pelvis. Visualisation of tissue blood flow allows assessment of diffuse disease and provides crucial information regarding the nature of pelvic tumors. CDI has been shown to identify angiogenesis associated with "high-risk" changes at a very early stage of malignancy.

SMI 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 show the value of CFM in the investigation of the luteal phase. They confirm good correlation between vascular appearances of preovulatory follicles and corpus luteum with corresponding serum oestrogen and progesterone levels respectively. 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 in terms of early management of high-risk pregnancies and recurrent miscarriage. Hyperaemic changes associated with diffuse diseases such as adenomyosis (Fig. 2 A), pelvic inflammatory changes or hormonal factors (Fig. 2 B) can be demonstrated from relatively early onset. Increased ovarian activity is shown to be associated with endometriosis often resulting in increased

endometrial proliferation and menstrual issues (Fig. 3). Excessive tissue vascularity invariably causes pain and is often associated with increased (multifollicular) ovarian activity. Invariably this involves the presence of haemorrhagic (functional) cysts – a common feature associated with gynaecological symptoms (Fig. 4). CFM interrogation of retained products of conception, presenting either as a result of miscarriage or post-partum

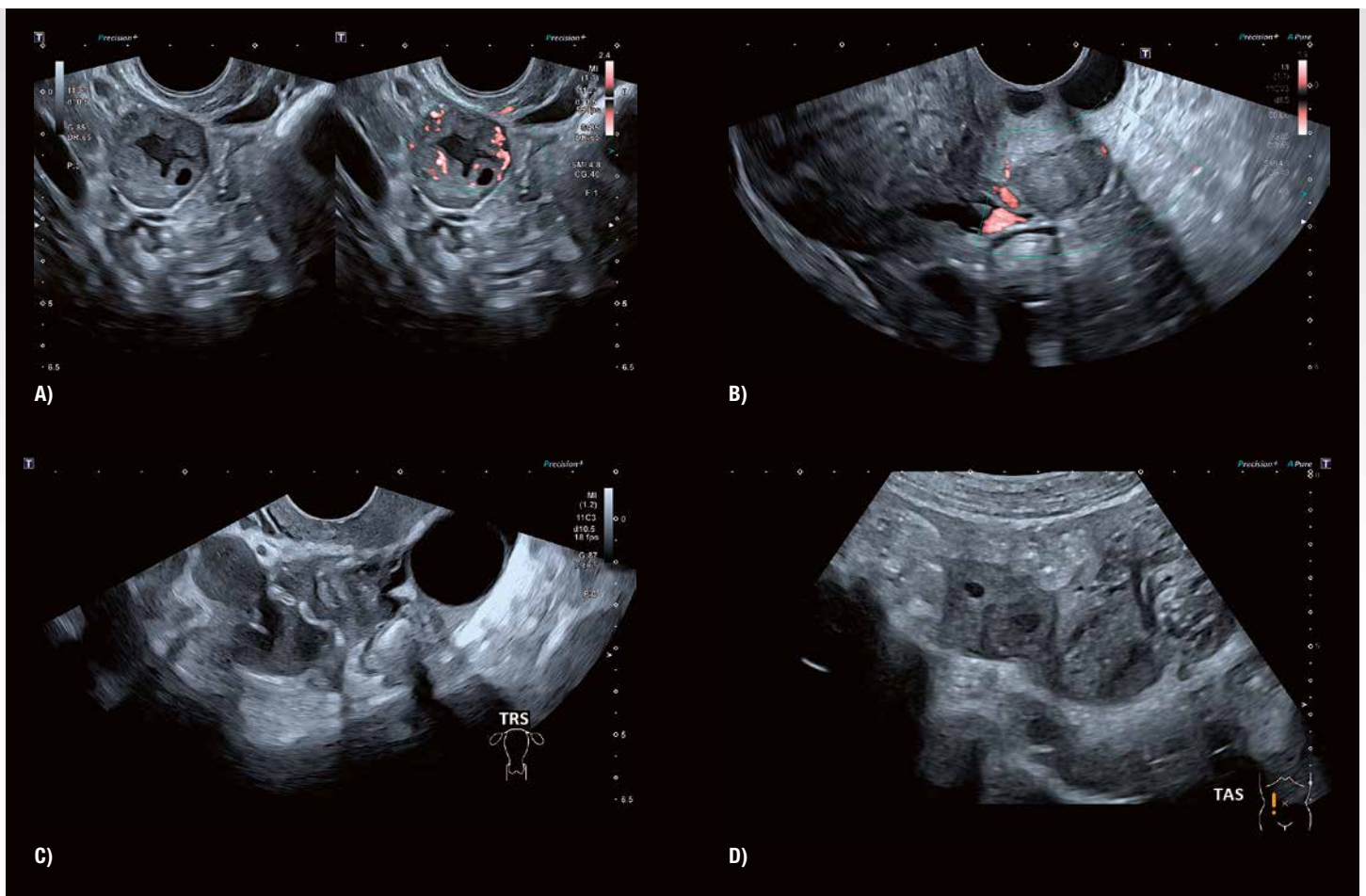


Fig. 1 (A–D): Examples of cases presenting with acute / chronic pelvic pain. (A) shows a haemorrhagic, active corpus luteum, (B) an endometrial nodule on the posterior lateral wall of the cervix – Note: transrectal scan. (C) shows a rupture of a large endometriotic cyst on the Rt ovary and a persistent functional cyst on the Lt side – Note: transrectal scan. (D) shows a chronic Rt tubulo-ovarian inflammatory mass – Note: transabdominal scan. The cases demonstrate a need for a flexible approach to ultrasound scanning of the pelvic organs. TVS examination could not be adequately carried out in cases (B), (C) and (D) mainly due to patient discomfort.

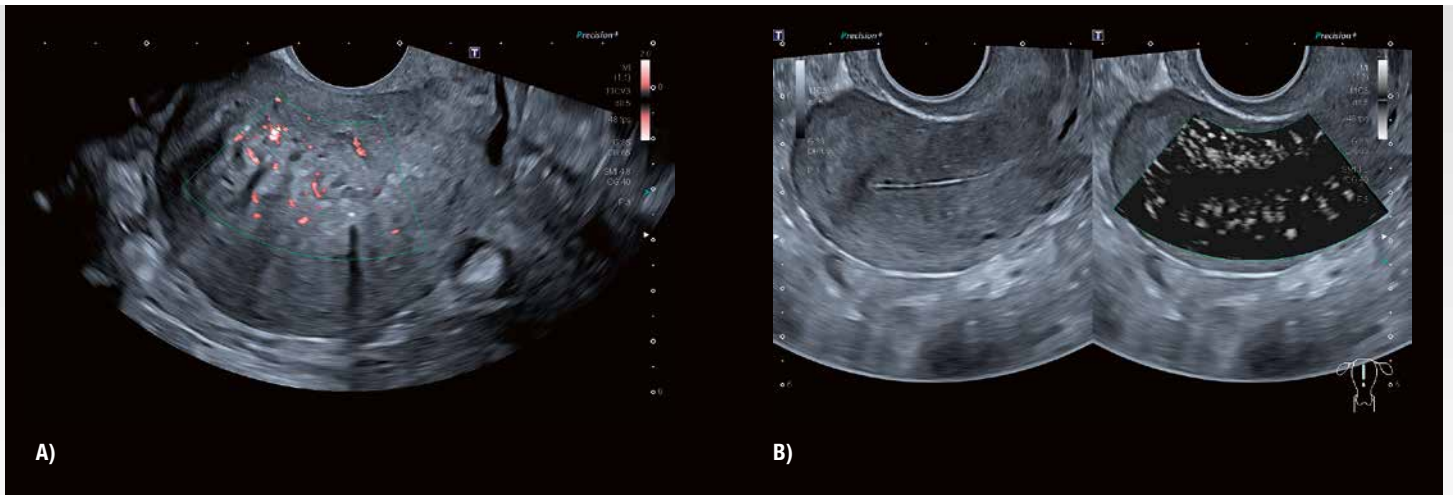


Fig. 2 (A): TVS + SMI demonstrate the extent of a large, poorly-defined adenomyoma. Fig. 2 (B): Increased myometrial vascularity demonstrated by SMI and associated with "oestrogen dominance". Hyperaemic changes associated with the uterus remain a common cause of pelvic pain and menstrual issues particularly in peri-menopausal cases.

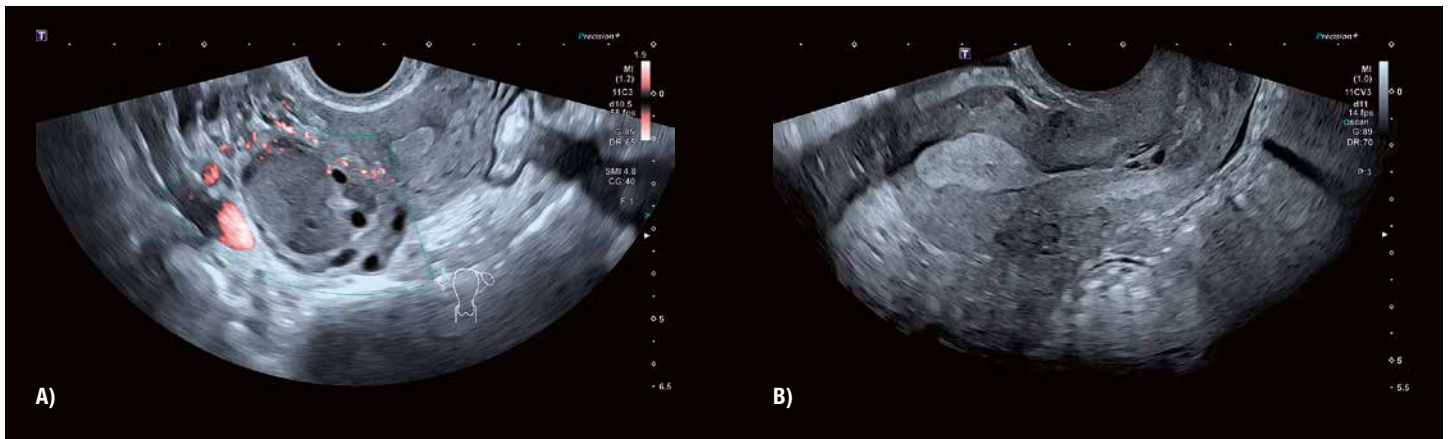


Fig. 3 (A–B): TVS-SMI assessment of an endometriotic cyst in (A) confirms the relatively avascular nature of endometriotic cysts which tend to differentiate them from other forms of pathological or functional lesions. The ovaries very often appear multifollicular (A) with increased (hormonal) activity associated with endometriosis. As a result the peri-ovulatory endometrium appears very thickened (B) and patients often present with menstrual issues.

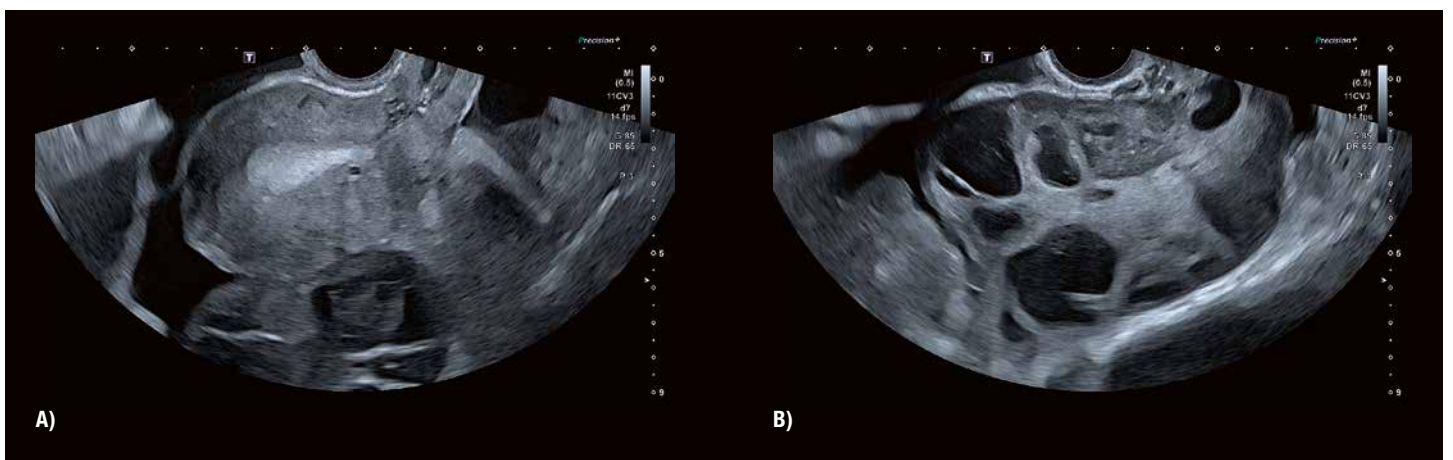


Fig. 4 (A–B): TVS examination of the uterus (A) and ovary (B) in a case of acute pelvic pain. Multiple collapsing functional cysts are identified within the enlarged ovary. The scan of the uterus demonstrates excessive pelvic fluid, i.e. spill/bleeding from the ovarian lesions. Functional issues, rather than the presence of pelvic pathology, remain the most common cause of acute gynaecological symptoms.

complication, is a crucial diagnostic factor in this respect. It is the vascular nature and not quantity of retained tissues which influences clinical management. Studies have shown the accuracy of TVS-CFM in identifying the presence of RPOC as well as its reliability in determining whether conservative management or surgical intervention is to be applied.

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. Increasing tissue vascularity not the thickness of the endometrium presents as the major ultrasound feature that alerts us to the possibility of malignant changes. Increased CFM sensitivity

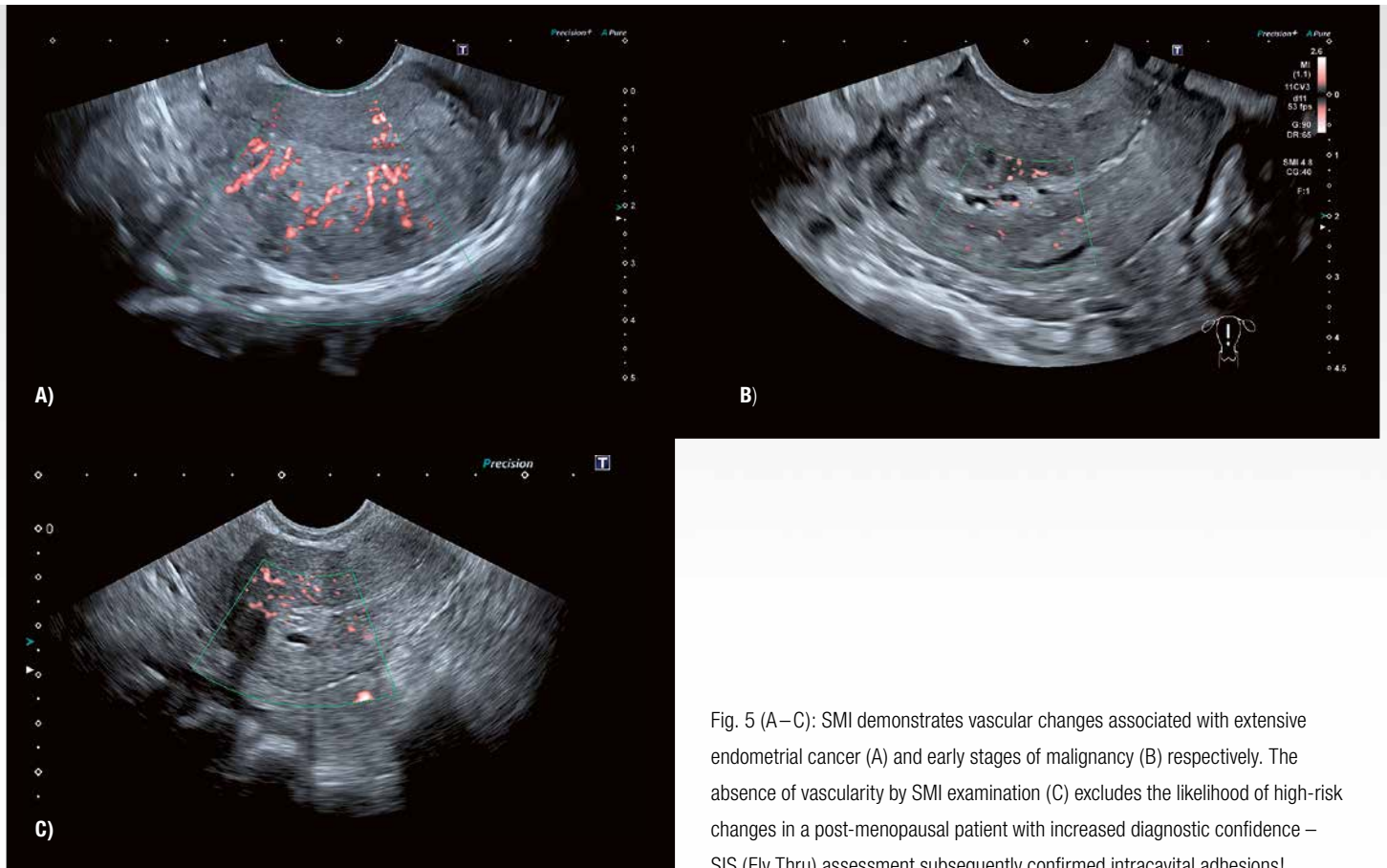


Fig. 5 (A–C): SMI demonstrates vascular changes associated with extensive endometrial cancer (A) and early stages of malignancy (B) respectively. The absence of vascularity by SMI examination (C) excludes the likelihood of high-risk changes in a post-menopausal patient with increased diagnostic confidence – SIS (Fly Thru) assessment subsequently confirmed intracavitary adhesions!

can demonstrate very early vascular changes within the uterus associated with both benign and malignant disease processes (Fig. 5).

Colour Doppler TVS examination has a major role to play in the detection of ovarian cancer. The likelihood of ovarian malignancy can be demonstrated by good-quality CFM assessment at an extremely

early stage even before there is any significant enlargement of the ovary itself, particularly in post-menopausal patients. It is the ability to visualise fine, capillary (internal) bloodflow that suggests high-risk changes in ovarian neoplasms. Conversely the confidence to exclude suspicious tissue vascularity associated with ovarian lesions using modern TVS-CFM techniques significantly

reduces “false positive” rates in defining associated pathology in terms of being clinically “high” or “low” risk in nature (Fig. 6).

Experience has shown SMI to be of particular value as part of assessing post-menopausal issues – it identifies abnormal vascular changes within the ovaries and uterus at an early stage of

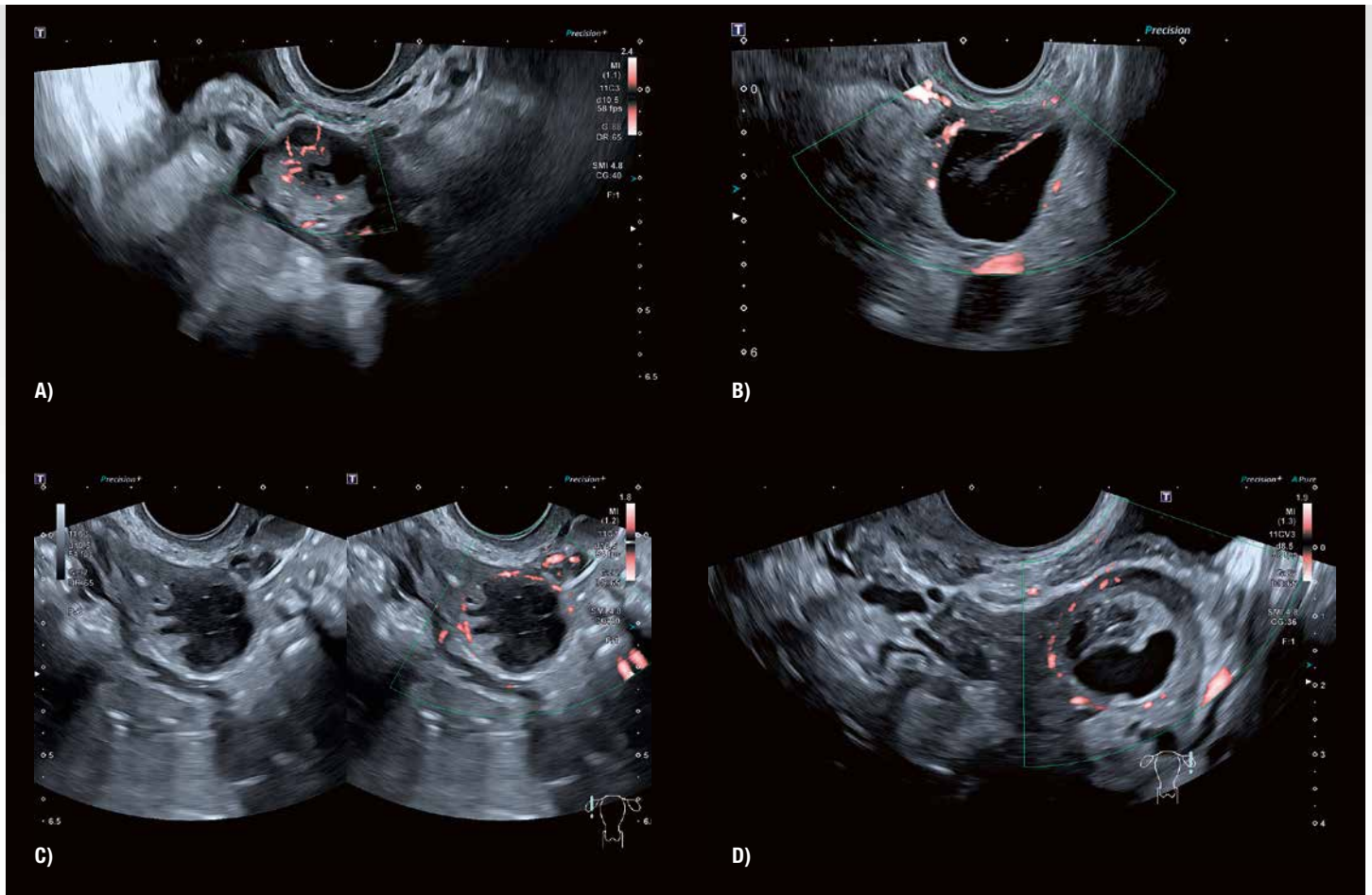


Fig. 6 (A–D): SMI imaging of ovarian lesions. (A) shows an early ovarian cancer (tumour size 1.5 cm) – high-risk changes are indicated by the internal vascularity demonstrated. (B) and (C) presented histologically with “borderline” changes. Again, a combination of increased vascularity with suspicious internal features indicated clinical concern. (D) is the typical appearances of a clot-filled, active corpus luteum. Peripheral vascularity demonstrated by SMI with total absence of internal vascularity were suggestive of a functional rather than pathological lesion.

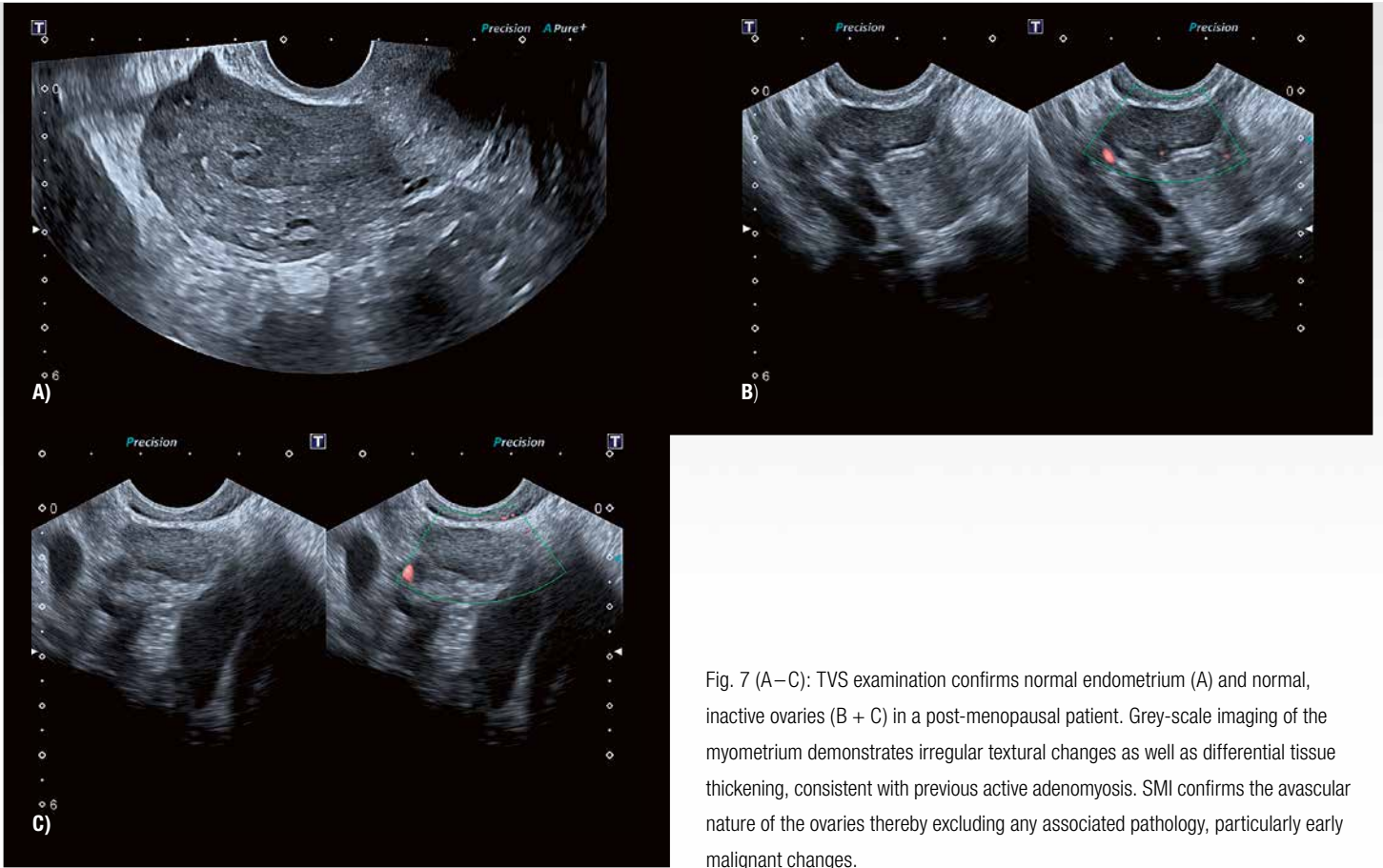


Fig. 7 (A–C): TVS examination confirms normal endometrium (A) and normal, inactive ovaries (B + C) in a post-menopausal patient. Grey-scale imaging of the myometrium demonstrates irregular textural changes as well as differential tissue thickening, consistent with previous active adenomyosis. SMI confirms the avascular nature of the ovaries thereby excluding any associated pathology, particularly early malignant changes.

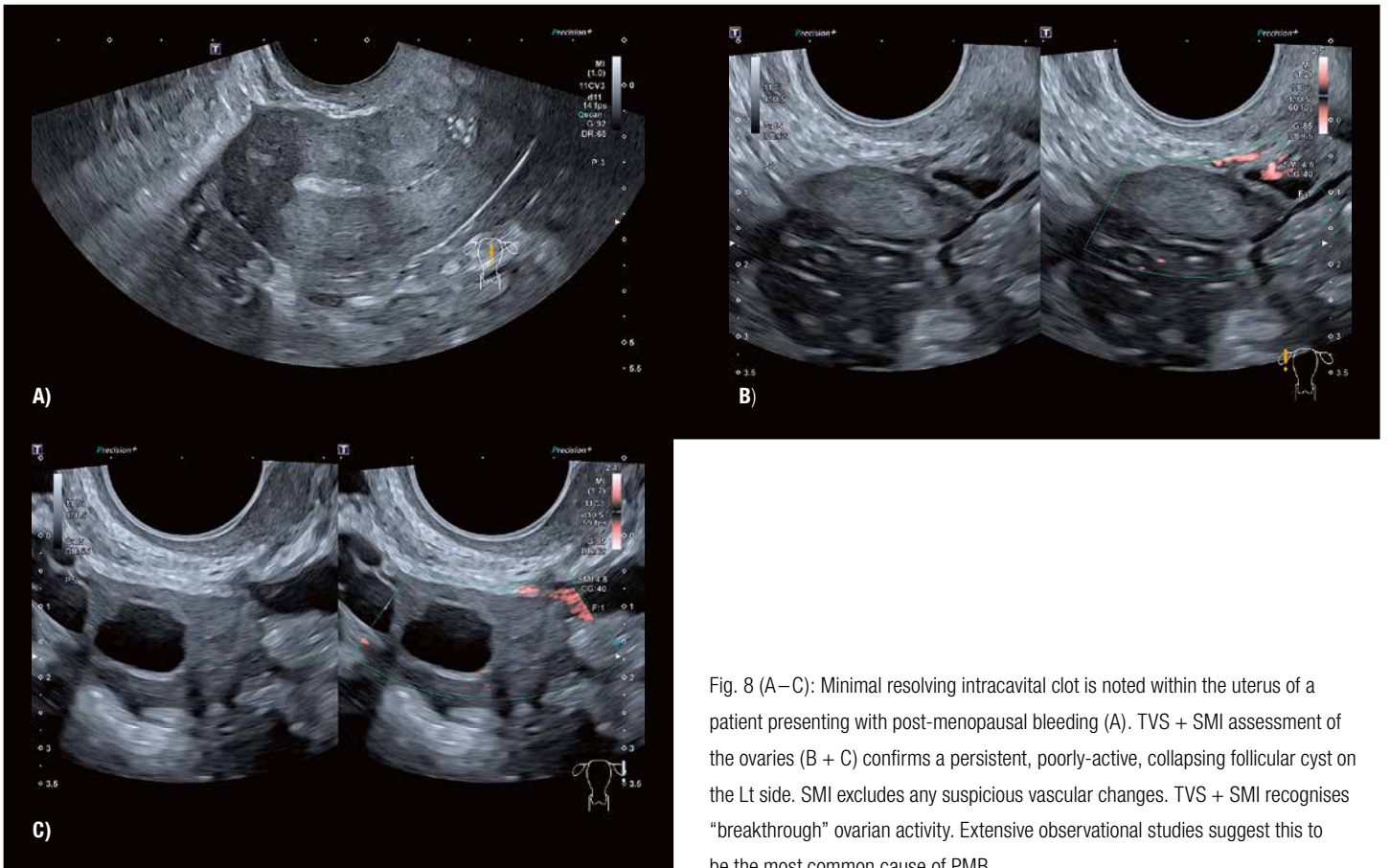


Fig. 8 (A–C): Minimal resolving intracavitary clot is noted within the uterus of a patient presenting with post-menopausal bleeding (A). TVS + SMI assessment of the ovaries (B + C) confirms a persistent, poorly-active, collapsing follicular cyst on the Lt side. SMI excludes any suspicious vascular changes. TVS + SMI recognises “breakthrough” ovarian activity. Extensive observational studies suggest this to be the most common cause of PMB.

development. It also demonstrates breakthrough ovarian activity as a principal cause of post-menopausal bleeding (Figs. 7 + 8).

The impact of SMI and other forms of CFM remain somewhat restricted because of the subjective nature of the imaging process. Nevertheless, the ability to demonstrate very fine neovascularity within tissues remains an important factor in the ultrasound evaluation of gynaecological lesions and pathological disease generally.

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 recon-

struction (MPR) of the acquired data. Inspection of the “x” and “z” components should demonstrate similar levels of image quality in terms of both spatial (definition) and contrast (grey-scale) resolution (Fig. 9 A).

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. (Fig. 10). The presence and nature of congenital malformations are easily recognised (Fig. 12).

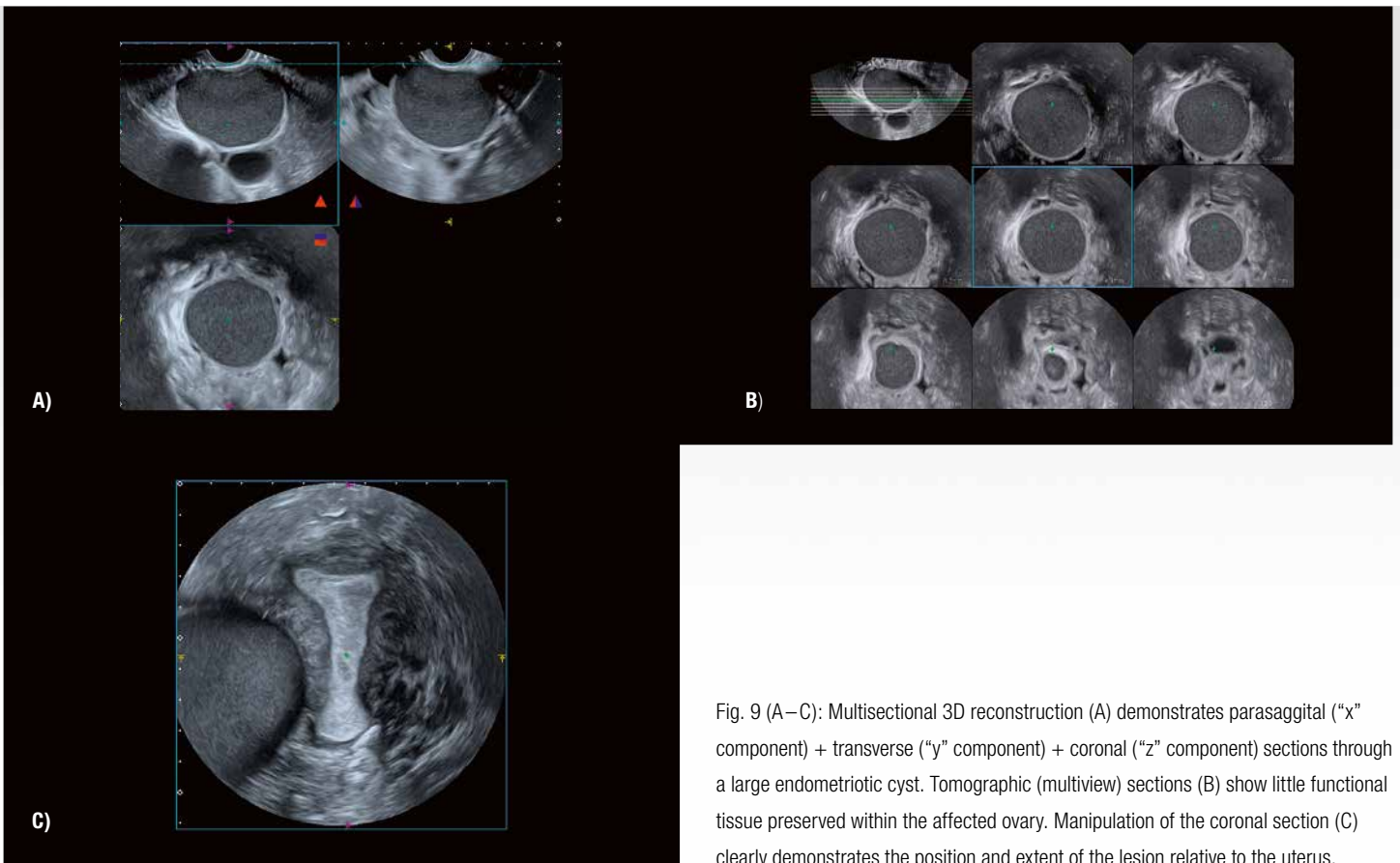


Fig. 9 (A–C): Multisectional 3D reconstruction (A) demonstrates parasagittal (“x” component) + transverse (“y” component) + coronal (“z” component) sections through a large endometriotic cyst. Tomographic (multiview) sections (B) show little functional tissue preserved within the affected ovary. Manipulation of the coronal section (C) clearly demonstrates the position and extent of the lesion relative to the uterus.

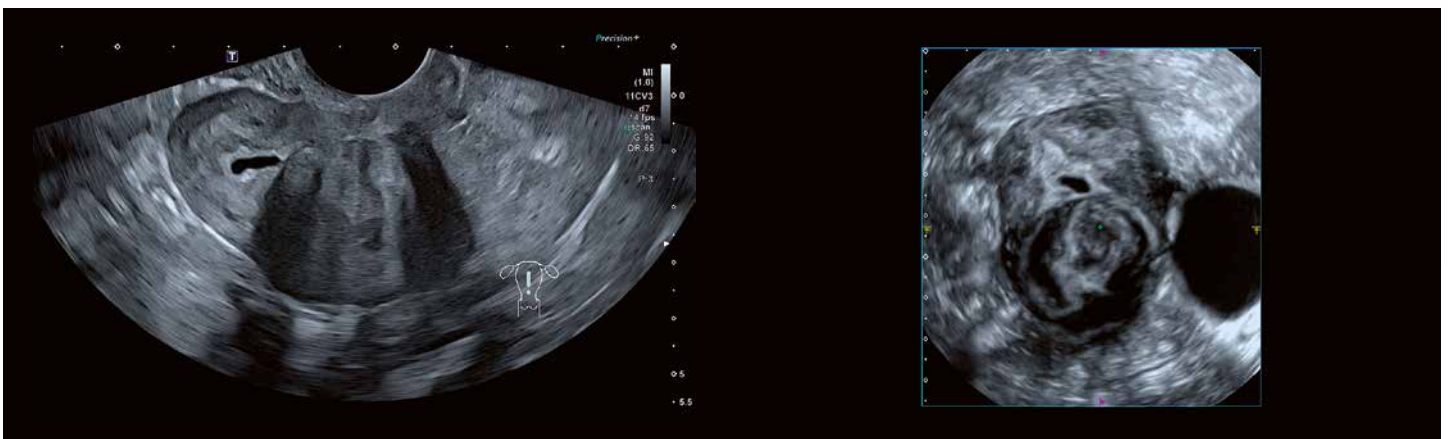


Fig. 10 (A–B): Conventional 2D (parasagittal) TVS imaging (A) confirms a posterior wall fibroid compressing the mid-lower cavity. Reconstructed 3D coronal section (B) confirms distortion of the uterine cavity with (menstrual) clot retained within the rotationally displaced fundal cavity. A simple large left ovarian cyst is noted.



Fig. 11 (A–C): Asherman's syndrome. SIS procedure has opened previously adherent walls of the cavity to a degree sufficient to identify localised adhesions as demonstrated by multisectional (A) and coronal 3D (B) images. The Shadow Glass (C) image clearly indicates poor distention and separation of the cavity walls with multiple localised adhesions very evident. The cavity size is reduced by the extensive adenomyosis – compare with Fig. 16 (B).

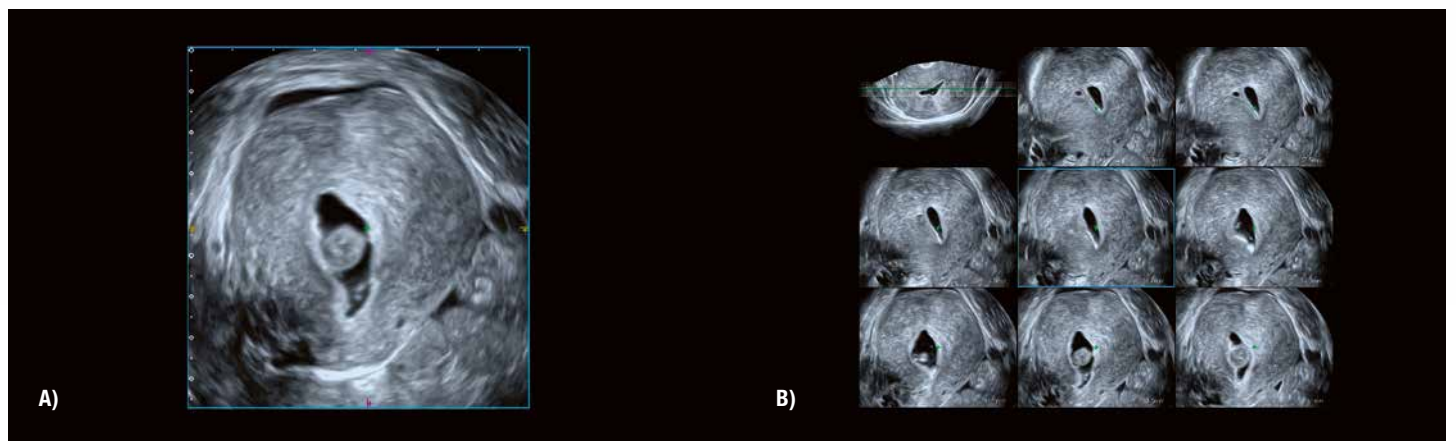


Fig. 12 (A–B): 3D SIS procedure showing a unicornuate uterus with a fibroid polyp within the mid-cavity in coronal section (A). Tomographic coronal sections (B) confirm the anatomical malformation and identify a small rudimentary horn within the right upper uterus.

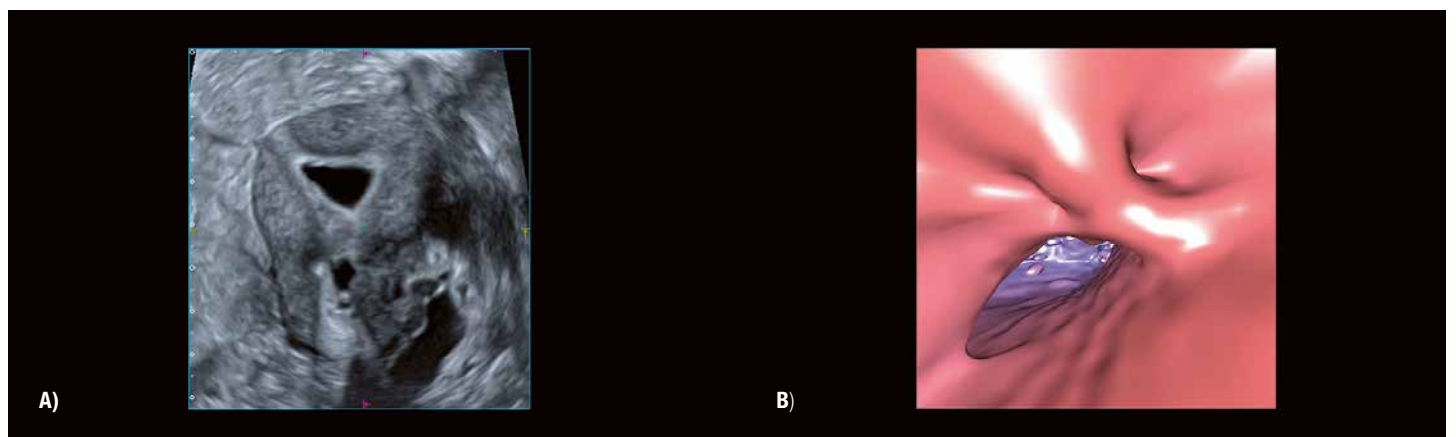


Fig. 13 (A–B): 3D SIS procedure (A) demonstrates the presence of adhesions within the mid-cavity. Findings are confirmed by advanced Fly Thru virtual imaging (B).

Distortion of the cavity wall by intramural masses is well shown (Fig. 14) and intracavitary lesions clearly delineated (Figs. 11, 12, 13). The correct positioning of IUD/IUS can be confirmed with confidence.

3D-TVS 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 (Fig. 15). 3D image manipulation accurately gauges the preservation of healthy, functional stromal

tissue in the presence of large ovarian lesions, a crucial factor influencing the choice of surgical management.

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

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.

3D post-processing options

Manipulation of 3D anatomical planes is of considerable value both in terms of post-scan assessment of complex pelvic disease as well as clinical communication and pre-surgical planning.

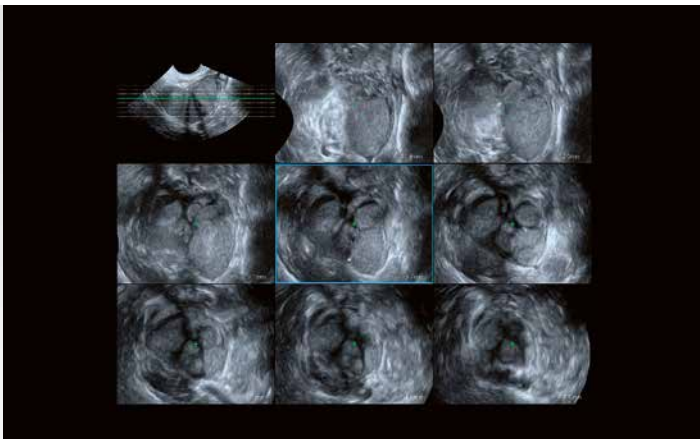


Fig. 14: Multiview 3D coronal sections clearly delineate the presence of multiple fibroids.

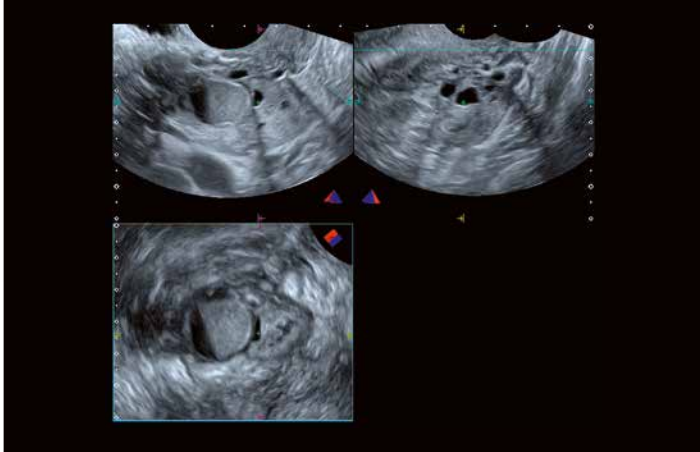
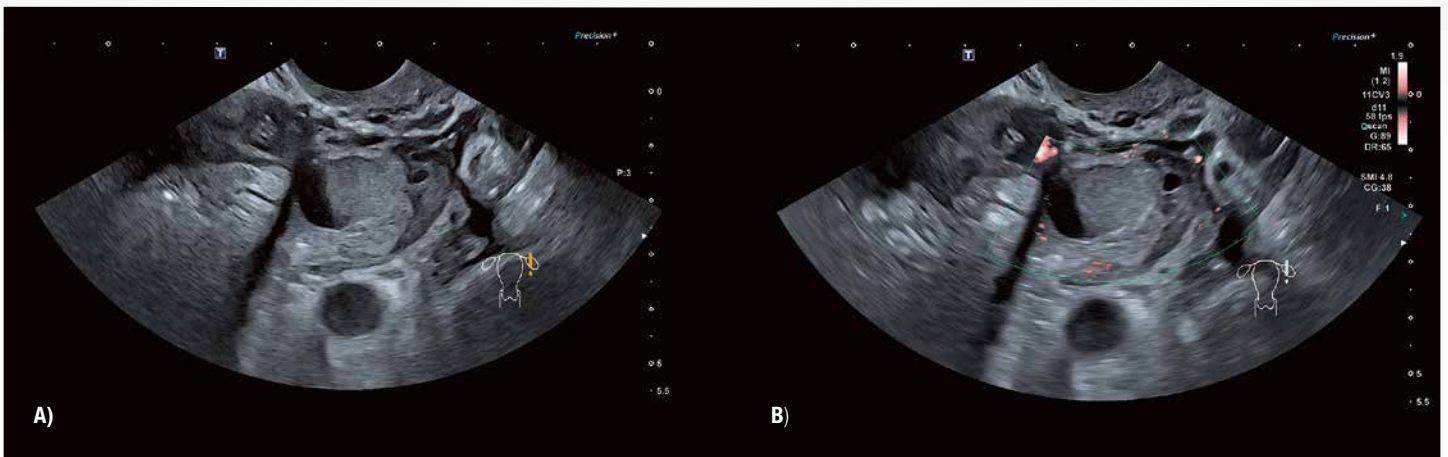


Fig. 15 (A–C): The ultrasound appearances of endometriotic cysts change within the first few days of the menstrual cycle. This is due to internal bleeding within the lesion concurrent with shedding of the endometrium. (A–C) show areas of recent bleeding into an endometriotic cyst. The lesion usually resumes its characteristic uniform, “grey-scale” appearances within the first week of the cycle.

Advances in post-processing options involving the rendered image include Fly Thru capability as well as Luminance and Shadow Glass formats. Fly Thru has had a significant impact particularly as part of saline infusion procedures in the examination of the uterine cavity. Extensive observational studies have confirmed its diagnostic value in key areas of reproductive medicine. Visual aspects of the ultrasound information can be considerably enhanced by utilising Luminance and Shadow Glass imaging technology (Figs. 11 + 16). As a result the 3D rendered image can be significantly improved to provide increased definition and outline of individual structures or tissues. This is shown to be particularly useful when conveying ultrasound findings as part of more efficient clinical communication.

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 clearly delineated and any distortion of the cavity wall contour, caused by myometrial

lesions or congenital anatomical variation, is well demonstrated. Intracavitary lesions such as endometrial polyps, submucosal fibroids and adhesions are clearly outlined. SIS promotes detailed ultrasound evaluation of the endometrium and periovulatory changes as well as associated pathological disease (Figs. 11, 12, 13, 16).

Indications for SIS include the presence of suspicious intracavitary 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 involving investigation of 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 a significant number of cases. Benefit to the patient and positive cost implications are very relevant.

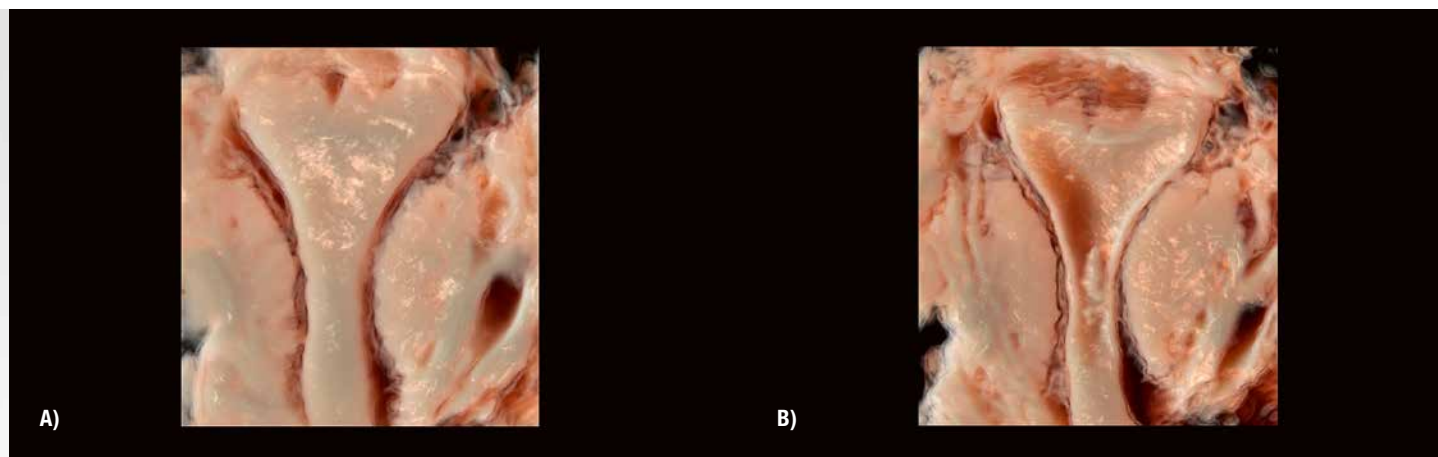
Fly Thru imaging

Advances in Canon Medical Systems 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 (Fig. 13). Perspective projection capability creates a true 3D visual effect. Structures can be studied from any direction, unlike with surgical endoscopic techniques, and movement through the area of interest can be controlled automatically or manually.

The high-quality images produced confirm the normality of the uterine cavity and healthiness of the endometrial lining with much more confidence. Fly Thru imaging has an important role in excluding intracavitary 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 and diagnostic points of view.



Figs. 16 (A–B): Shadow Glass manipulation of the rendered 3D image clearly delineates the outline and external aspect of the uterine cavity in (A). It provides very precise evaluation of the myometrial – endometrial interface, particularly important in the diagnosis of the presence and extent of adenomyosis. A small, very localised septum can be seen within the fundal cavity. Further processing adjustment (B) demonstrates internal features of the uterus. Normal cavity size and shape with a small polyp noted within the mid-lower cavity was demonstrated.

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 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 compressibility of individual tissues or organs. The technique compares the hardness or softness of structures with that of the surrounding tissues. The clinical role of RTE in combination with TVS continues to be evaluated.

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 (Fig. 17). 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.

RTE is sensitive enough to show characteristic changes within the peri-ovulatory endometrium at different stages 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 has also been shown to increase accuracy in confirming the presence of retained, active decidual or placental tissue in cases of RPOC.

RTE at present offers relatively little in addition to conventional TVS grey-scale and CDI in the evaluation of ovarian lesions. However, it is often useful in differentiating between pelvic fibroids and ovarian/adnexal lesions.

Shear wave technology as an alternative to manual compression RTE has more recently become available with TVS transducers. Evaluation of

its diagnostic value is still in the early stages but current experience remains encouraging in terms of the growing impact of RTE as part of pelvic ultrasound.

Conclusions

Modern ultrasound systems offer a choice of imaging modalities and scanning techniques as part of routine TVS. Their combined use within a given TVS examination is shown to enhance the diagnostic effectiveness of pelvic ultrasound. Canon Medical Systems continues to provide technology that facilitates comprehensive pelvic scanning. Advanced ultrasound imaging technology is shown to influence clinical management and enhance patient care in major areas of gynaecology and reproductive healthcare.

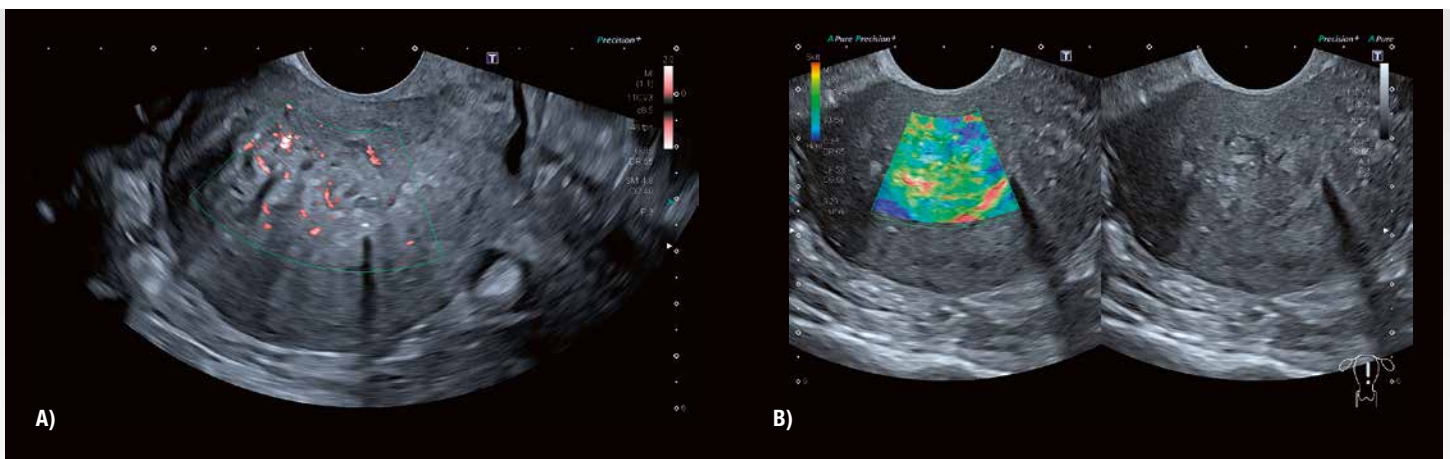


Fig. 17 (A–B): TVS + SMI (A) demonstrate the extent of a large poorly-defined adenomyoma. RTE imaging (B) demonstrates associated changes within the compressibility of the affected myometrial tissue – RTE proves to be useful in terms of differentiating between adenomyosis and fibroid change within the uterus.

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