The Practical Application and Clinical Use of Modern 3D Ultrasound Technology in Gynaecology

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Introduction

3D volumetric ultrasound is shown to be of tremendous value particularly in gynaecology and associated clinical areas. The combination of modern 3D technology and high resolution transvaginal scanning provides increased anatomical and clinical detail. Furthermore it offers considerable benefits from a practical point of view. Nevertheless, its role in gynaecological ultrasound has yet to be fully realised.

A single automated sweep of the ultrasound beam through a selected volume of tissue or specific organs produces a wealth of diagnostic information. Rapid acquisition and storage of ultrasound data, speedy retrieval of stored data and easy manipulation of retrieved images considerably reduces examination times. This has obvious positive implications both for the patient as well as the management of busy scan lists.

Advances both in transducer design and IT capability have generated high quality 3D imaging particularly when used with transvaginal scanning (TVS). As a result, 3D technology is now an integral part of gynaecological ultrasound in leading scan units. To date 4D (i.e. real-time 3D) scanning has had little to offer in terms of gynaecological ultrasound.

Volumetric facilities are now incorporated within most ultrasound systems. The principal operational controls and functions are similar from system to system, although terminology may obviously vary from one to another.
3D Image formats

The so-called sweep scan produces a volume of ultrasound data. This can be displayed in the following formats.

**Compound Imaging**

The Compound Image consists of standard x, y and z image components (i.e. parasagittal, transverse and coronal anatomical planes). An additional image is also displayed and is usually in surface rendered or block volume format (see fig. 1a and 2a).

The four displays within the Compound Image are quickly assessed and if satisfactory are instantly stored at the press of a button. The stored information is transferred to the system memory or hard disc. This data can be retrieved at any stage for further manipulation and evaluation of anatomical planes.

The retrieved ultrasound data can then be displayed and recorded in a number of ways or further image formats.

**Multi-Planar Imaging**

Multi-Planar Imaging (MPR) comprises of the x, y and z (parasagittal, transverse and coronal) components of a given Compound Image. This allows a specific structure or area within an organ to be viewed simultaneously in three orthogonal planes, i.e. 3D slices at right angles to one another. MPR provides increased anatomical information and greatly improved delineation of pelvic structures within a single image display.

**Multi View**

Multi View images (also known as Tomographic Ultrasound Imaging, TUI) consist of tomographic sections through any of the individual MPR image planes. Multi View provides very effective analysis of anatomical details and associated clinical information within any localised region of the pelvis or specific organ. It enhances clinical communication to a considerable extent and offers valuable information.

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**Fig. 1: 3D imaging formats of a multifollicular ovary containing an endometriotic cyst.**

**Fig. 1a:** Compound Image (x, y, z components + BVI) demonstrating antral follicle distribution, ovarian stroma, endometriotic cyst (E) and internal iliac vessel (V).

**Fig. 1b:** Multi View images from the x component of fig. 1a displaying the complete ovarian morphology and associated features. The extent of the endometriotic cyst (E) is completely demonstrated. The ovarian capsule is outlined and para-ovarian structures such as the pelvic vessel (V) are easily separated from ovarian features.

**Fig. 1c:** Block Volume clearly delineating the endometriotic cyst (E) and preservation of normal, healthy ovarian tissue.

**Fig. 1d:** Surface Rendered Image of endometriotic cyst content (E) and cavities of multiple follicles (f). Normal ovarian stroma (ov. strom) is very obvious.
support to ultrasound scan reporting (see fig. 1b, 3b and 6b).

**Block Volume Imaging**

Block Volume Imaging (BVI) displays internal, orthogonal anatomical planes within a given block volume. Its practical and diagnostic value is limited but it can be useful when displaying adjacent features which lie in a random manner in different anatomical planes (see fig. 1c).

**Surface Rendering**

Surface Rendered Images (SRI) display anatomical structures with a visual 3D effect. SRI provides greater delineation and increased visual impression of the physical nature of pelvic lesions. It can demonstrate the nature of cavities as well as give an impression of the external features of structures. In addition, it allows the separation of pelvic organs to be visualised with greater clarity (see fig. 1d and 9d).

**4D Ultrasound**

4D ultrasound utilises advanced IT capability to produce real-time 3D SRI ultrasound imaging. Its role in obstetric scanning and creating image recordings of the baby is well established but its clinical impact to date appears to be relatively limited. This is currently reflected in general pelvic scanning with little application in terms of gynaecological ultrasound to date.

**3D Colour Doppler Imaging**

Advanced 3D technology incorporates colour Doppler (Power Doppler) imaging. 3D reconstruction of imaging planes and volumetric studies demonstrate blood flow within tissues down to the capillary level and the vascular nature of pelvic lesions. The ability to show tissue vascularity is important in the assessment of diffuse disease and detection of high risk pathological changes in particular. Blood flow indices can provide quantitative measurement of tissue vascularity within a selected volume.

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**Fig. 2: 3D imaging formats of a normal uterus and uterine cavity.**

**Fig. 2a:** Compound Image (x, y, z components + SRI) demonstrating a normal endometrial cavity (Endom). Note the interstitial portion of the uterine tube (I) visualised on the rendered image.

**Fig. 2b:** A surface rendered image in Cavity Mode clearly highlights the interstitial tube (I).
Principles of 3D Volumetric Imaging

A conventional 2D (TVS) ultrasound image or sector is usually generated by electronically steering a narrow ultrasound beam through the body tissues. The size of the 2D image, or anatomical slice, depends upon the 2D sector angle and depth of field selected.

A 3D volume is created by generating a rapid series of 2D scan sweeps, each very slightly displaced perpendicular to the direction of the scan sweep. A large number of sequential 2D anatomical slices are built up to produce in effect a 3D volume. The size of the volume will be determined by the distance between first and final 2D anatomical slice creating the volume, i.e. 3D sector angle, as well as the 2D sector angle utilised and depth of field selected.

The volume information acquired is displayed straight away usually in the form of a stored Compound Image for direct viewing. The ultrasound data stored can then be transferred to the system memory or a server for future interrogation or simply deleted if not required.

Practical aspects

Technical Considerations

3D (TVS) ultrasound scanning is both convenient and straight-forward from a practical point of view. The basic technical requirements of a modern 3D system include the following:

- Uncomplicated, user-friendly controls for acquisition and storage, retrieval, post-scan manipulation and image recording of ultrasound information.
- Simple initiation of a single, automated 2D scanning (“survey”) sweep of the area of interest. A stable, high quality grey-scale...
image maintained throughout the survey sweep.

- Rapid acquisition and viewing of stored scan information. Instantaneous transfer of acquired ultrasound data to the system memory or a server or deletion of stored data if not required.
- Uniform spatial and contrast resolution in the grey-scale image in all anatomical planes within the ultrasound volume.
- Accurate geometric registration of echo point sources within the 3D volume.
- Rapid, easy retrieval of stored ultrasound data.

It is important to notice that the quality of 3D imaging reflects that of the fundamental 2D grey-scale performance levels of the ultrasound system. Correct utilisation of 2D system controls and grey-scale pre-sets is essential in order to maximise the diagnostic information provided by 3D ultrasound technology.

Utilisation of 3D volumetric technology presents considerable benefits from a practical point of view:

- Reduces scanning time and length of the ultrasound examination.
- Reduced examination time for the patient and exposure to ultrasound energy.

- Promotes the concept of post-scan evaluation.
- Reduces probe movement as part of TVS in order to acquire ultrasound information and therefore causes less discomfort particularly with patients presenting with pelvic pain.
- More efficient and cost effective storage and archiving of image material compared to conventional 2D image recording.

Scanning Issues

3D ultrasound scanning involves in practice holding the TVS transducer stationary and initiating the single 3D survey sweep. The survey sweep produces the 3D volumetric data which can then be stored once the Compound Image has been assessed.

Fig. 4: 3D – TVS SIS or “fluid ultrasound” demonstrating a normal uterine cavity.

Fig. 4a and 4b: Composite parasagittal 2D and surface rendered 3D images of the uterine cavity. The SRI reference plane (SR) has been shifted and slightly curved in fig. 4b to accommodate both the uterine cavity and cervical canal. As a result the rendered image clearly demonstrates the complete cavity from the internal os to fundus compared to only the cavity of the uterine body in fig. 4a.

Fig. 4c: Multi View coronal sections fully demonstrate the extent and nature of the uterine cavity in a single image.
It is important to ensure the correct use of 2D controls in order to maintain optimal 3D detail. These include selection and utilisation of transducer frequency, focal length and zone, 2D sector angle, frame rate/PRF, image size etc. as well as sensitivity controls and greyscale preset functions.

The survey sweep allows (2D) visualisation of the area of interest as the system collects the 3D data. This in itself can be of considerable diagnostic and practical value. It is therefore important that a constant level of greyscale imaging is maintained throughout the duration of the 3D sweep.

 Acquisition and Storage of 3D Volumes

The 3D sampling box or sector is superimposed upon the realtime 2D image. The survey or 3D sweep should be adjusted to cover the area of interest only. This involves appropriate selection of both 3D sector angle and the depth of the 3D sample sector or box. The detail obtained from ultrasound images derived from the stored 3D data largely depends upon the following factors:

- Correct use of 2D greyscale controls
- 3D sector angle
- 3D sweep speed
- Depth of 3D sample sector

The selection of 3D sector angle, sweep speed and sampling box size greatly influences frame rates and hence line density within the 3D image volume. These are important considerations in the ability to maximise 3D image quality. The absence of tissue movement problems in general pelvic scanning, certainly compared with ultrasound of the fetus, allows slower sweep speed and improved 3D image definition. 3D sweep scans can typically take 4–8 seconds in gynaecological ultrasound. The acquired ultrasound data is usually immediately displayed in the form of a stored Compound Image. This can be manipulated and/or converted into other forms of 3D imaging if required. Otherwise the volume data can be very quickly trans-
ferred to the system memory, hard disc or server, or otherwise instantaneously deleted.

Retrieval and Manipulation of 3D Volumes

Stored volumetric data is usually retrieved in the Composite Image format. All components can be manipulated simultaneously or independent of one another.

MPR images can be rotated in any geometric plane. It is also possible to scroll through the volume thickness in any one of the anatomical planes. Alternatively, Multi View will generate a series of tomographic images within that plane. The number of image slices as well as the distance between slices making up the Multi View format can be varied.

The greyscale characteristics of the retrieved MPR and/or Multi View can be varied by means of a number of post-processing options. This allows particular features or tissue changes to be visually enhanced in order to highlight diagnostic findings.

Similarly, the surface rendered image (SRI) can be geometrically manipulated. There are also post-processing options specific to SRI again serving to visually outline structures with greater clarity. These include:

- Cavity Mode: This essentially reverses the grey-scale or selected colour mapping, i.e. making cystic regions lighter and solid regions darker (inversion, see fig. 6).
- Threshold Control: This is basically a control which determines the level to which ultrasound information is suppressed for surface rendering (mainly low level clutter and noise).

A combination of algorithms, typically available in most systems, enables adjustment to be made regarding colour, surface textured appearances, transparency of structures etc. within the rendered volume.

Fig. 6: ART stimulated multifollicular ovary.

Fig. 6a: Compound Imaging (x, y, z components + BVI) provides immediate visualisation of the number, distribution and relative sizes of stimulated follicles.

Fig. 6b: Multi View delineates multiple follicles – the facility to scroll through the retrieved tomographic sections enables rapid evaluation and speedy measurements of developing ovarian follicles. This proves to be a considerable asset in terms of the monitoring and measurement of ovarian follicle response to ART stimulation.

Fig. 6c: Surface rendered images of the ovary highlighting individual follicles with considerable clarity.

Fig. 6d: Cavity Mode further enhances visualisation and provides precise delineation of the multiple follicles.
The SRI reference plane (SR) determines the thickness or at what depth the rendered image is visualised. The level can be adjusted under visual control and the shape of the SR can be curved in order to demonstrate non-linear anatomical sections (see fig. 4 and fig. 5c).

**Clinical Aspects**

**Uterus**

3D reconstruction of the uterus and uterine cavity in coronal section is a considerable asset particularly with access to Multi View formats. The anatomy of the uterus and presence of uterine lesions prove to be much more recognisable even to the untrained eye in this image plane.

The shape and size of the uterine cavity is clearly demonstrated and anatomical malformation readily identified in the coronal plane. The combination of MPR and Multi View formats provide precise location of IUD/IUS devices in-utero and confirms the presence, size, position and nature of intracavitary lesions such as polyps, fibroids, adhesions etc. (see fig. 2 and 3).

The utilisation of 3D TVS technology as part of Saline Infusion Sonohysterography (SIS), or “fluid ultrasound”, procedures increases the diagnostic effectiveness of ultrasound examination of the endometrium and uterine cavity. MPR, Multi View and manipulation of SR (coronal) displays present very detailed studies of the distended cavity and any associated pathologies. In a number of clinical units, 3D TVS SIS has proven to be an appropriate alternative to diagnostic hysteroscopy with obvious advantages to both the clinic and patient (see fig. 4 and 5).

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**Fig. 7: Perimenopausal ovary with an intact follicular cyst (C¹) and remnants of a collapsing, clot-filled cyst (C²).**

**Fig. 7a and 7b: Compound Imaging (x, y, z components + BVI) and Multi View sections provides complete details of ovarian morphology and associated lesions. The functional cysts are seen quite separately from one another. The nature of the ovarian stroma can be easily evaluated. The absence of antral follicles remains consistent with patient age.**
3D TVS provides more elaborate evaluation of endometrial changes. The introduction of 3D colour Doppler is shown to be extremely useful in terms of identifying high risk changes as well as gauging the extent of endometrial malignancy. Volumetric assessment of blood flow changes within the myometrium also demonstrates diffuse benign disease. This has increased our ability to confirm the likelihood of adenomyosis in particular and has been an important element in the early detection of endometriosis.

3D volumetric ultrasound has had a major clinical impact in other areas of gynaecology. More comprehensive examination of the myometrium, uterine cavity and endometrium greatly assists investigation of fertility issues and possible causes of recurrent miscarriage.

**Ovaries**

3D volumetric ultrasound presents the ideal imaging modality for examining ovarian morphology. MPR, Multi View and a choice of surface rendered displays offer very precise imaging of follicle patterns and stromal distribution within the ovary. This has proved invaluable both in the assessment of gynaecological disease as well as the investigation of fertility and ovulatory issues (see fig. 6 and 7).

Improved delineation and interrogation of ovarian lesions provides a more reliable diagnostic impression of their nature. 3D imaging formats accurately gauge the preservation of normal, functional ovarian tissue in the presence of large lesions. This remains crucial in terms of clinical management and choice of surgical techniques if indicated. The introduction of 3D colour Doppler differentiates between high and low risk lesions with far greater diagnostic confidence.

The additional use of SRI facilities not only outlines pelvic structures with greater clarity but can distinguish between ovarian and adjacent para-ovarian features with more certainty. This is particularly useful in examination of the adnexal regions and associated pathologies involving the Fallopian tube.

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**Fig. 8: Adherent ovary with extensive adnexal/pelvic adhesions and loculated fluid collections.**

![Fig. 8a: Localised 2D image of the adnexal region shows a complex mass.](image)

![Fig. 8b: Multi View sections through the area outlined in fig. 8a clearly demonstrate the ovary (Ov) adherent to the pelvic sidewall with numerous, extensive bands of adhesions. Associated loculated fluid contains clot which has probably resulted from spill from the collapsed corpus luteum (CL) just visible within the ovary.](image)

![Fig. 8c: Composite image of 2D and SRI 3D images. The rendered image highlights remnants of the corpus luteum (CL) and visualises the fluid cavities (c) resulting from the multiple bands of adhesions clearly evident.](image)
**Pelvis (General)**

Complex, diffuse gynaecological disease affecting adjacent organs or structures within the pelvic cavity are very often difficult to evaluate by conventional 2D TVS ultrasound scanning. This might include for example chronic PID, extensive pelvic endometriosis or the spread of malignancy.

The facility to retrieve 3D ultrasound data and carefully examine different anatomical planes using a choice of 3D imaging formats is a tremendous benefit in these cases. Individual, neighbouring structures involved with the spread of disease can be recognised more easily and the extent of the disease estimated with greater diagnostic accuracy (see fig. 8 and 9).

3D volumetric ultrasound is a particular asset for those patients presenting with moderate to severe endometriosis. These patients experience considerable discomfort during a conventional TVS ultrasound examination. The ability to restrict probe movement to a minimum is a major consideration especially in these cases and also for any patient experiencing significant pelvic discomfort. The TVS probe is held still in order to carry out 3D scan sweeps and gently repositioned in only a selected number of locations in order to interrogate all areas of interest.

**Post scan evaluation**

**Scan Reporting**

Modern 3D volumetric ultrasound promotes the possibility of post-scan evaluation. The speed of system operation and quality of stored images makes it convenient and reliable to consider reporting of ultrasound examinations at a later time after the scan has been completed.

The survey sweep itself should be adequate to serve as an initial evaluation of relevant structures or areas of interest in a large number of cases. Minimal scanning only is sometimes required to view the pelvic structures and select relevant

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**Fig. 9: Early tubal ectopic pregnancy (5+ weeks gestation) and associated haematosalpinx.**

**Fig. 9a:** Multi View coronal sections confirm an obvious decidual response but no intra-uterine pregnancy sac was identified.

**Fig. 9b:** Compound Imaging \((x, y, z + SRI)\) identifies the ovary \((Ov)\), a para-ovarian mass \((T)\), a fimbrial cyst \((F)\) with an early extra-uterine pregnancy sac \((G)\) outlined on the rendered image. Manipulation of the anatomical planes allows more effective examination and recognition of relevant structures.
areas for speedy acquisition and storage of scan details. As a result, scanning times are considerably reduced certainly in more straightforward, non-complex cases.

The facility to connect the ultrasound system to a suitable IT workstation means reporting of scans can be easily carried out remotely and at anytime following completion of the scan or scan list. This has practical advantage certainly in the management of busy scan lists and regarding efficiency of patient throughput. In addition, it has been shown that post-scan evaluation of 3D images in more complex clinical cases, especially those involving extensive, diffuse pelvic change, is extremely useful in terms of accuracy of diagnosis.

**Clinical Communication**

Ultrasound images remain an essential part of ultrasound scan reporting. Standard 2D greyscale images can be difficult to interpret both in terms of the anatomy and clinical features shown, particularly to the untrained eye.

3D reconstruction, especially the use of MPR, Multi View and volume rendering, can make the content of the ultrasound image much more apparent. Multi View coronal sections of the uterus or SRI of the adnexal region for example result in much more obvious detail as part of the images used to support written texts.

Volumetric imaging formats produced from the retrieved data can be of value to referring clinicians in terms of pre-surgical planning. 3D volumetric ultrasound reconstruction in modern systems can be utilised in a similar manner to MRI regarding image interpretation and clinical communication.

![Fig. 9c: Localised Multi View sections show the distended, blood-filled uterine tube (UT) immediately adjacent and probably adherent to the ovary (Ov). The fimbrial cyst (F) is again well seen and free fluid (clot) present within the pelvic/adnexal region.](image1)

![Fig. 9d: Composite image of an individual MPR section showing the tubal mass (T), fimbrial cyst (F) and ovary (Ov) and surface rendering of the adnexal structures. The rendered image shows the convoluted nature of the tube (UT) and its attachment to the ovary (Ov).](image2)