Principles and Technical Aspects of Integrated Pelvic Floor Ultrasound

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Learning Objectives

- To learn basic principles of physics of ultrasonography and their influence on obtained images.
- To familiarize with types of pelvic floor ultrasound including 2D/3D transperineal ultrasound (TPUS), 2D/3D endovaginal ultrasound (EVUS), and 2D/3D endoanal ultrasound (EAUS) and their advantages and limitations.
- To identify various types of transducers and anatomical approaches which can be applied for pelvic floor ultrasound and distinguish different imaging possibilities with each type of transducer.
- To learn about existing more advanced ultrasound options such as Doppler ultrasound, elastography, three- and four-dimensional US, and tomographic ultrasound imaging (TUI) and recognize their possibilities.

5.1 Introduction

Female pelvic floor is one of the most complex regions in the human body. Pelvic organs with different functionality are supported by numerous muscular fibers (levator musculature and perineal musculature) and connective tissue forming ligaments and fascia (endopelvic fascia, pubocervical fascia, rectovaginal septum, perineal membrane, perineal body, uterosacral ligaments, cardinal ligaments) and interconnected to somatic and autonomic nerves and vascular structures. The simplistic division in three compartments should be replaced by the current concept of considering the pelvic floor as a mechanical three-dimensional apparatus that acts as unit, influencing urinary and anal continence, sexual satisfaction, and vaginal delivery [1, 2]. Viewing the pelvic floor as a horizontal model rather than as a set of vertical compartments helps to understand why disorders observed in one compartment may have their origin in dysfunction of another compartment or why most females present multicompartmental damages. As a consequence, there is a need of an integrated approach to the management of the pelvic floor disorders involving a multidisciplinary team of clinicians that address these problems (urologists, gynecologists, colorectal surgeons, gastroenterologists, radiologists, physiotherapists) [1, 2].

The aim of pelvic floor evaluation is to explain the symptoms, identify the causative mechanism and its risk factors, and finally propose treatment. A thorough history and physical examination will often provide ample evidence to make a diagnosis and develop an effective treatment plan. Patients unresponsive to the initial therapy or with recurrence of symptoms or candidate to surgery should however further be investigated using sophisticated tests. Imaging techniques play a fundamental role in the diagnosis of pelvic floor disorders and are included in the pathways of urinary and anal incontinence, obstructed defecation, voiding dysfunction, and pelvic organ prolapse proposed by various scientific societies (ICS, International Continence Society; IUGA, International Urogynecological Association; ICI, International Consultation on Incontinence) [3–5]. Ultrasound, X-ray (evacuation proctography, cystography, videourodynamics, barium enema, transit time) and MRI techniques can help to identify the anatomical or functional abnormalities of the pelvic floor. Radiological findings can confirm clinical findings or discriminate damages that were misled or underestimated by physical examination alone. Due to costs, access and availability, and patient compliance, most guidelines recommend

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to perform pelvic floor ultrasound as the first-line or screening tool modality [3–5].

"Pelvic floor ultrasound" is a synonymous of a large variety of techniques (translabial, transperineal, endovaginal, endoanal, 3D/4D acquisitions, dynamic US, assessment of vascularity patterns, and tissue stiffness—elastography), having different advantages and limitations [6, 7]. Understanding the physics of ultrasound, the mechanism of interactions of ultrasound beam with tissues, the process of image formation, the choice of imaging parameters, the optimization of quality of image (gain, focus, resolution), the identification of artifacts, the characteristics of transducers (mechanical and electronic frequencies, field of view, convex, end-fire, linear) and scanners, and the different anatomical approaches that can be used is therefore of utmost importance [8–11]. Despite ultrasound is considered operator-dependent, an adequate training and use of standardized methodology have demonstrated a very good intra- and interobserver reproducibility of this modality [12–14]. Great advance has been made in developing a very sophisticated ultrasound technology; however the vertical model for care of disease has limited a clinician's understanding to the vertical unit in which the clinician (urologist, gynecologist, and colorectal surgeon) has an expertise. The emerging concept of horizontal integration of pelvic floor dysfunction evaluation and management is expanding to ultrasound approach that must be integrated and multicompartmental [6, 15]. Global or total ultrasound addresses all pelvic floor anatomy and functionality in one setting, allowing identification of coexisting dysfunctions of the three compartments [6].

5.2 Principles of Pelvic Floor Ultrasound

Ultrasound imaging is a technique of generating images using a very high-frequency sound. Sound is a mechanical, vibration form of energy. Ultrasound for medical imaging is generated in special crystalline materials which, when electrically excited, are capable of vibrating at frequencies of millions of vibrations per second [8]. Operating frequencies for medical ultrasound are in the 1–40 MHz range, with external imaging machines typically using frequencies of 1–20 MHz. Higher frequencies are in principle more desirable, since they provide higher resolution, but tissue attenuation limits how high the frequency can be for a given penetration distance. However, one cannot arbitrarily increase the ultrasound frequency to get finer resolution, since the signal experiences an attenuation of about 1 dB/cm/MHz [9].

The velocity of propagation of ultrasonic longitudinal waves in soft tissues varies depending on the type of tissue, in single collagen fibers (tendons) equals c = 1700 m/s, in lung tissue 650 m/s, in bone tissue from 1500 to 4300 m/s [3]. The speed of ultrasound wave c is determined by the formula:

$$c = \sqrt{\frac{C}{p}}$$

c—speed of sound, C—coefficient of stiffness, p—density.

Different materials respond differently to interrogation by ultrasound, depending on the extent to which their medium particles will resist change due to mechanical disturbance. This medium property is referred to as the characteristic *acoustic impedance* of a medium. It is a measure of the resistance of the particles of the medium to mechanical vibrations. This resistance increases in proportion to the density of the medium and the velocity of ultrasound in the medium. Acoustic impedance, Z, may be defined as the product of medium density and ultrasound velocity in the medium [8]:

$$Z = \text{density} \times \text{velocity}$$

Ultrasound waves are generated by *piezoelectric crystals* in the transducers. The number of piezoelectric crystals in the transducers and the range of frequencies they can operate in are very important features. In case of 2D technology, the number usually exceeds 190 elements; in 3D and 4D technologies, the transducer may be designed as a matrix array, where the number of piezoelectric elements may be multiplied to more than a 1000 elements. The signals generated in the transducer are subsequently sent to the tissue and received back by *transmit channels*. The number of physical active channels can reach a few hundred (over 500), whereas transmit channels used in post-processing may reach even a few millions. Ultrasound imaging is based on the signals generated by the returning echoes at the transducer that are electronically processed to increase their sizes and organized in computer memory before being displayed to the user. The echoes returning from different tissue depths must be subjected to compensation for attenuation differences. *Time gain compensation (TGC)* is a process of applying differential amplification to signals received from different tissue depths, with echoes originating from longer distances being amplified to a greater extent than those from shorter distances in such a way that similar tissue boundaries give equal-sized signals regardless of their depth in tissue. The latest generations of scanners have automatic adjustment of TGC independent from the operator.

The difference between the maximum and minimum values of the displayed signal is defined as *dynamic range*, and it is one of the most essential parameters that determine its image quality [11]. Nowadays dynamic range may vary from 70 Db to over 300 Db. Because the dynamic range of signal sizes may be very wide, the range of signal sizes is compressed by using logarithmic amplifiers. Pulses with identical waveforms are repeated each time the crystal is excited, at a rate known as the *pulse repetition frequency (PRF)*. The PRF represents the number of pulses or bursts of ultrasonic energy, released by the transducer in one second, and is different from the vibration frequency of the transducer [8].

The most basic but at the same time a crucial mode in pelvic floor ultrasound is the *brightness mode (B-mode)*. In B-mode the signals from returning echoes are displayed as dots of varying intensities *(gain)*. The intensity of a dot (the brightness) is a relative measure of echo size, with large echoes appearing as very bright dots, while at the other extreme non-reflectors, they appear totally dark.

It is important to notice that an ultrasound pulse consists of a range of frequencies, not a single frequency. For example, a pulse from a 5 MHz transducer could be composed of a range of frequencies from 4 MHz to 6 MHz. This range of frequencies is called the *bandwidth* [5]. Another important feature is use of *harmonics imaging*. The ultrasound pulse starts out with a sinusoidal waveform. As the wave passes through tissue, the wave speeds up very slightly during the compression phase, and during the refraction phase, the wave slows slightly. This causes a distortion of the wave and creates the harmonic frequencies. Harmonics are frequencies at multiples above the fundamental frequency—the frequency that was emitted from the transducer. The fundamental frequency is also known as the first harmonic [5]. The main advantage of the harmonic imaging is increasing the resolution of the image obtained.

More advanced techniques in pelvic floor ultrasound include the use of multidimensional imaging—*three-dimensional (3D) and four-dimensional (4D)*. The main prerequisite for construction of three-dimensional (3D) ultrasound images is very fast data acquisition. Transducers for real-time imaging may be classified broadly into two categories: mechanical transducers and electronic transducers. In mechanical transducers, the beam sweep is achieved through physical movement of some part of the transducer, usually the crystal element(s), whereas in electronic transducers the beam is swept by electronic activation of crystal elements, without causing the transducer to move physically. The collected data are processed at high speed, so that real-time presentation on the screen is possible. This is called the four-dimensional (4D) technique (4D = 3D + real time) [8]. The 3D image can be displayed in various ways, such as transparent views of the entire volume of interest (*render mode*), images of surfaces (*surface mode*), images in three perpendicular sections (axial, sagittal, coronal) called *multiplanar reconstruction (MPR)*, or as a *volume 3D box* accessible from every side and section. Post-processing options of 3D and 4D images enable numerous manipulations of the image such as zooming, rotating, contrasting, sharpening, changing the transparency, removing artifacts in order to present the volumetric image in the most diagnostic manner.

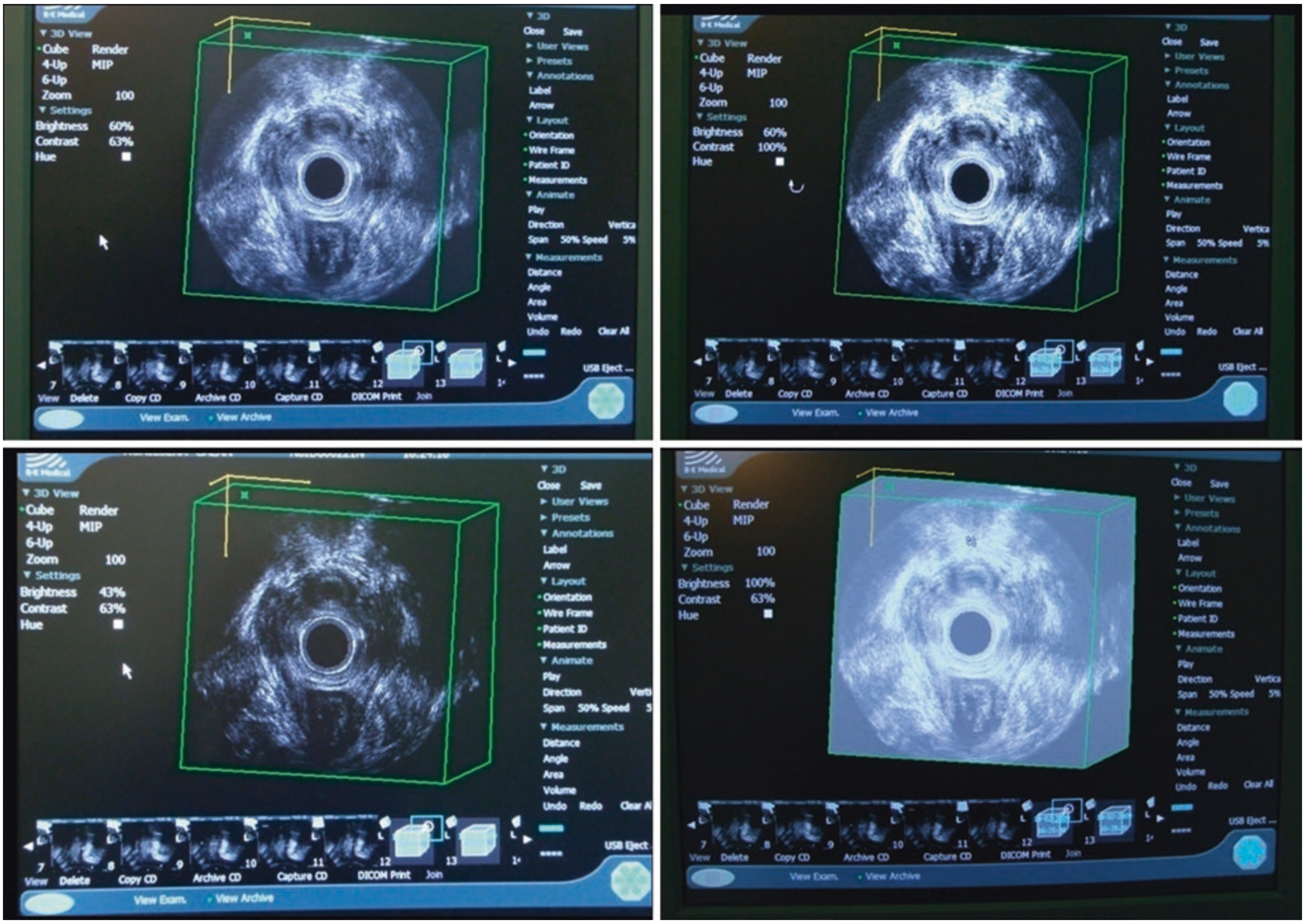
In order to produce high-quality images, it is crucial to understand the nature of artifacts in pelvic floor imaging. The major causes of artifacts include multiple reflections across acoustic boundaries, acoustic shadowing due to strong reflectors or absorbers of ultrasound, and poor physical condition of the transducer. Other artifacts may be caused by refraction of ultrasound, scattering, wave interference phenomena, or less than perfect mechanical and electrical isolation of crystal elements.

Lastly important features influencing the diagnostic value of pelvic floor ultrasound are the environmental conditions such as proper room lightning, proper monitor settings (Fig. 5.1), and the ability of the user to operate the scanner accordingly.

Summarizing, a variety of factors contributes to the overall quality of the ultrasound image. These include the design of equipment components, especially the transducer; the choice of imaging parameters, particularly the beam frequency; and the skilled use of the equipment by the operator. A good-quality image should contain information that is associated with high spatial resolution (ability to distinguish between objects in space), high contrast resolution (ability to distinguish between signals of different size), and high temporal resolution (ability to separate between events in time). In addition, the image should be free of any avoidable artifacts [8].

5.3 Two-Dimensional Transperineal Ultrasound (2D TPUS)

2D TPUS is performed with the patient placed in the dorsal lithotomy position, with hips flexed and abducted and a convex transducer positioned on the perineum between the mons pubis and the anal margin (perineal approach). The dimension of the transducer should be large enough to cover in the midsagittal plane all anatomical structures between posterior margin of the symphysis pubis and anterior margin of the coccyx/posterior part of the levator ani, e.g., bladder, urethra, vaginal walls, anal canal, and rectum. TPUS is a term that should be regarded as being synonymous with “translabial ultrasound” (transducer placed on one of the labia majora) or “perineal ultrasound” (transducer placed between the posterior vaginal wall and anal canal), while “introital ultrasound” is usually assumed to imply placement of transducers with smaller footprints (such as end-fire transvaginal probes or hokey-stick intraoperative transducers) within the introitus. The general term of “TPUS” is often adopted for all these techniques. Imaging is usually performed



Zoom 100
Brightness 60%
Contrast 63%

Zoom 100
Brightness 60%
Contrast 100%

Zoom 100
Brightness 43%
Contrast 63%

Zoom 100
Brightness 100%
Contrast 63%

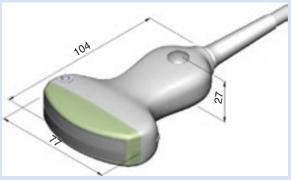
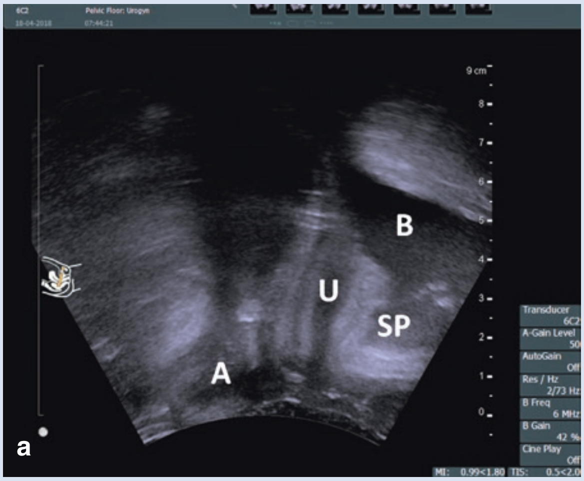
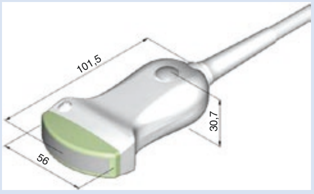
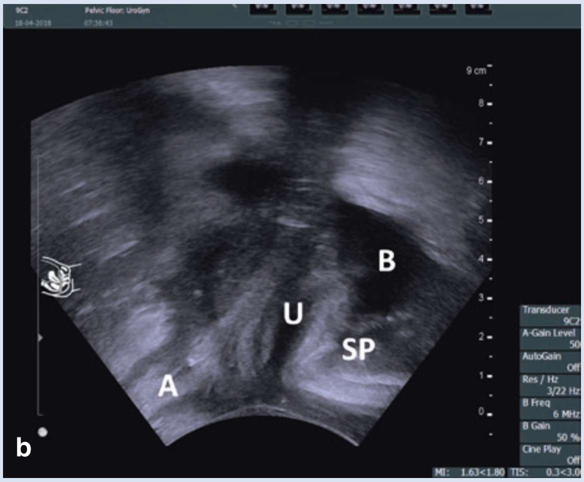
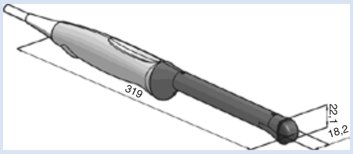
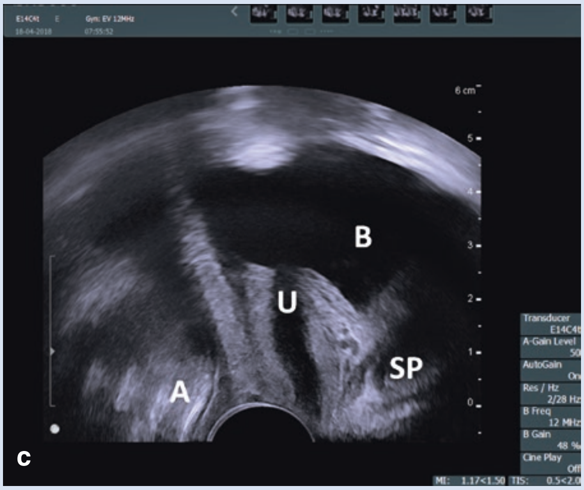
Fig. 5.1 Influence of monitor setting for the quality image

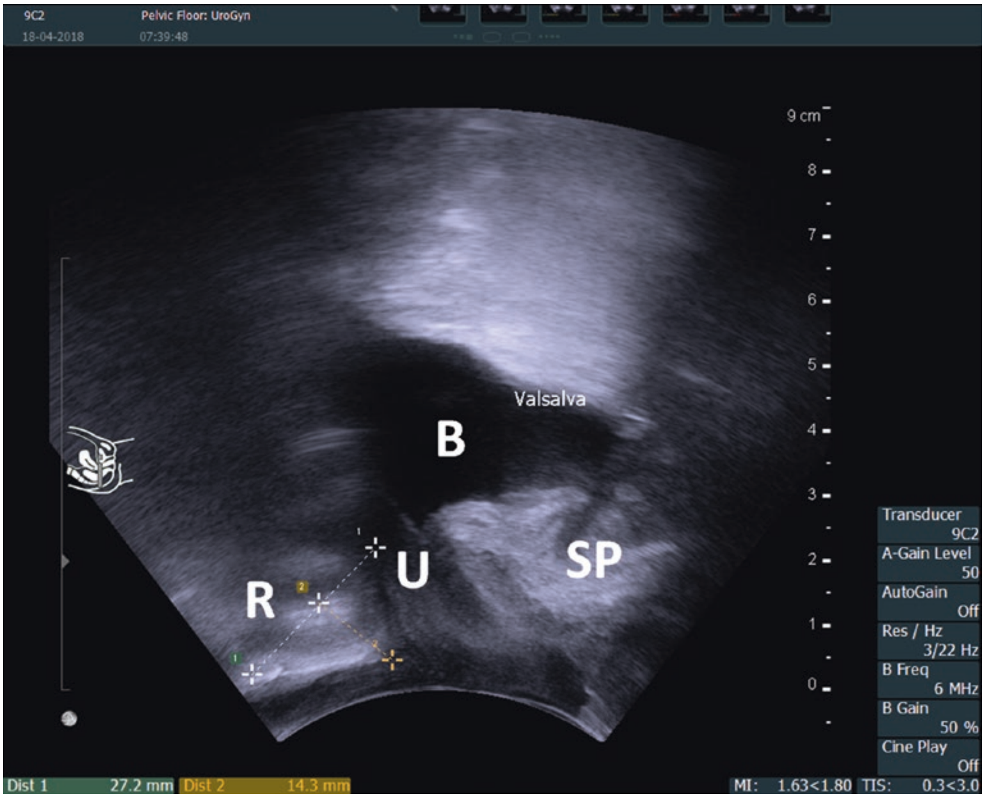
with the patient at rest, during maximal Valsalva maneuver and during pelvic floor muscle contraction (squeeze test) to dynamically define the position and anatomical relationship between urethra and bladder, vaginal walls, and the anorectal region anal canal. In order to avoid false-negative results, transducer pressure on the perineum must be as small as possible, while still maintaining good tissue contact, in order to allow full pelvic organ descent [16, 17].

5.3.1 Convex Transducers

Two-dimensional transperineal ultrasound (2D TPUS) in B-mode represents the most frequently used modality providing 2D imaging of the pelvic floor in the midsagittal section [6, 16, 17]. It is performed with convex transducers that may differ depending on frequency and surface of contact (Table 5.1). The higher is the frequency, the smaller is the shape of convex surface. The conventional "large" convex transducers usually used for abdominal and obstetrical scanning have low resolution due to low frequencies, because they must have high penetration to image deep organs in the patient's body. They work at frequencies ranging from 2 to 6–8 MHz, with a field of view at least 70° (Fig. 5.2a). The number of crystals/piezoelectric elements in large convex transducers may differ depending on manufacturers; however it is around 192 elements placed on a surface of approx. 50–62 mm length and 8–13 mm width (acoustic aperture). Another type of transducer also used for 2D TPUS scanning is a "small" convex transducer designed primarily for pediatric or early pregnancy examinations. It is characterized by higher frequency (from 5 to 9–10 MHz) in comparison to "large" convex transducers and smaller sizes of acoustic aperture (Table 5.1, Fig. 5.2b). A third type of transducer also suitable for 2D TPUS scanning is an endocavitary end-fire microconvex probe used for gynecological/urological purposes. It is characterized by frequency ranging from 5–6 to 8–9 MHz and smallest acoustic aperture (Table 5.1, Fig. 5.2c). Some scanners have dedicated protocol for urogynecology; however the operator can adjust the setting to get good-quality images. The focal zone should be concentrated at the level of the bladder neck, which is approx. 30–40 mm deep, whereas the field of view and the ultrasound angle can be regulated to focus on a certain anatomical structure to obtain better image. A limitation of the 2D TPUS technique is its sensitivity in

Table 5.1 Types and characteristic of convex transducers used in 2D TPUS examinations

Type of probe	Example transducer		Example ultrasound 2D TPUS image
"Large" convex	6C2 BK-Medical		**Fig. 5.2** Two-dimensional transperineal ultrasound performed with different types of transducer. Pelvic floor structures are visualized in the midsagittal section. Differentiation of the external and internal sphincters and the lumen of anal canal are visible better with higher-frequency (small convex and end-fire) transducer than with lower-frequency (large convex) transducer. (**a**) Large convex 
	Primary purpose	Abdominal Obstetrical	
	Range of frequencies	2–6 MHz	
	Number of elements	192	
	Image field	62°/71°	
	Acoustic aperture	62.5 × 13 mm	
"Small" convex	9C2 BK-Medical	 *Fig.2* Technical drawing and dimensions (mm)	(**b**) Small convex 
	Primary purpose	Pediatric Early pregnancy	
	Range of frequencies	2–9 MHz	
	Number of elements	192	
	Image field	74°/104°	
	Acoustic aperture	52 × 8 mm	
End-fire	8819 BK-Medical		(**c**) End-fire. *A* anal canal, *B* bladder, *SP* symphysis pubis, *U* urethra 
	Primary purpose	Gynecology Urology	
	Range of frequencies	6–9 MHz	
	Number of elements	128	
	Image field	150°	
	Acoustic aperture	26 × 5 mm	



Transducer 9C2
A-Gain Level 50
AutoGain Off
Res / Hz 3/22 Hz
B Freq 6 MHz
B Gain 50 %
Cine Play Off
Dist 1 27.2 mm
Dist 2 14.3 mm
MI: 1.63<1.80
TIS: 0.3<3.0

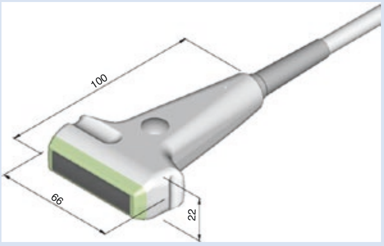
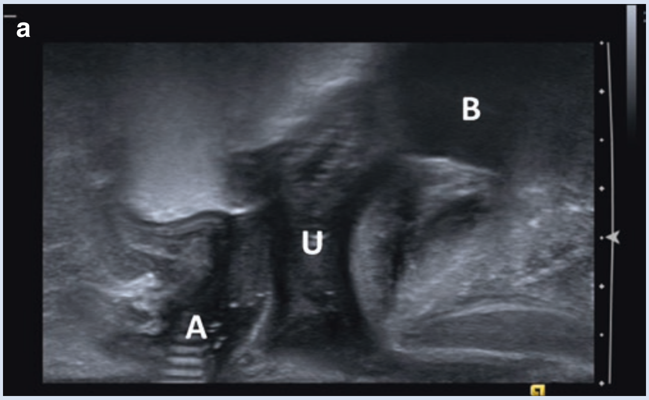
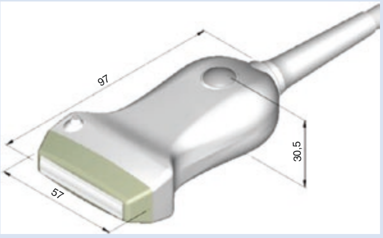
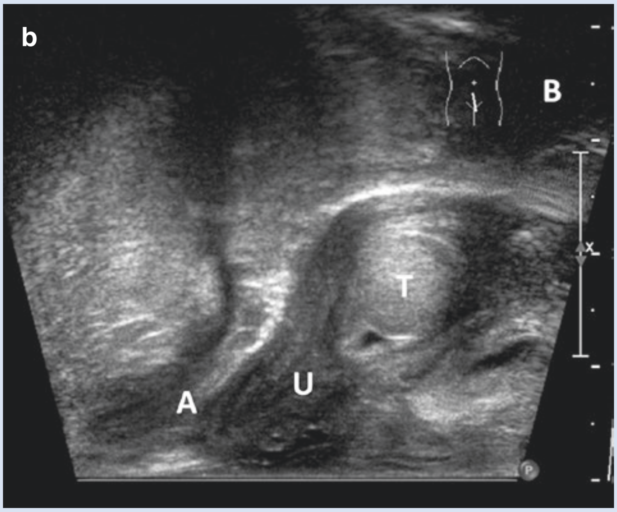
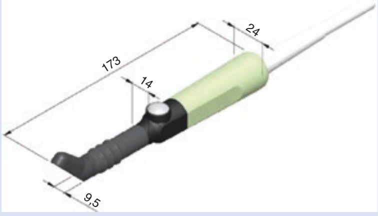
Fig. 5.3 Sagittal section of pelvic floor structures by two-dimensional transperineal ultrasound. During Valsalva maneuver, air trapped into rectocele (R) produces typical reverberation artifact. *B* bladder, *SP* symphysis pubis, *U* urethra

dynamic studies when the image may be distorted by artifacts caused by the reflections from gases in the anal canal in patients with rectocele/enterocele (Fig. 5.3).

5.3.2 Linear/Microconvex Transducers

For introintal use in adult patients and in case of children and newborns to find out the anatomical disorder in pelvic floor, higher-frequency transducers (linear, microconvex, or end-fire gynecological/obstetrical or urological) can be used (Table 5.2, Fig. 5.4). Linear transducers provide visualization of superficial pelvic anatomical structures or subcutaneous fluid collections/fistulas and anorectal malformations that can be missed by low-frequency transducers. Frequency of linear transducers is higher than large convex transducers and may range from 5–7 MHz even up to 20–22 MHz. The most common range of frequency varies from 8 to 10–12 MHZ for the transducers dedicated to small part imaging, breast imaging, and musculoskeletal scanning. “Hokey-stick” intraoperative linear transducers are also appropriate for this purpose due to small size, angulated shape, and high frequency, delivering high-resolution image. These transducers can be introduced endovaginally/endoanally with a finger guidance to the suspected area. Microconvex and end-fire gynecological/obstetrical or urological transducers have higher frequencies starting from 5 up to 9–12 MHz, with better resolution than large convex transducers, but are limited by a small surface of contact (Table 5.2, Fig. 5.4).

Table 5.2 Types and characteristic of linear transducers used in 2D TPUS examinations

Type of probe	Example transducer		Example ultrasound 2D TPUS image
"Lower-frequency" linear	13 L5 BK-Medical		**Fig. 5.4** Pelvic floor structures by transperineal ultrasound visualized with different types of transducers. (**a**) "Lower-frequency" linear transducer— sagittal section (*A* anal canal, *B* bladder, *U* urethra) 
	Primary purpose	Small parts MSK (large joints)	
	Range of frequencies	5–13 MHz	
	Number of elements	192	
	Image field	49.9 + 2 × 15°	
	Acoustic aperture	50 × 4 mm	
"Higher-frequency" linear	18L5 BK-Medical		(**b**) "Higher-frequency" linear transducer—sagittal section showing intraurethral tumor (T) 
	Primary purpose	Pediatric small parts MSK (small joints)	
	Range of frequencies	5–18 MHz	
	Number of elements	192	
	Image field	38.4 + 2 × 15°	
	Acoustic aperture	38.4 × 3.5 mm	
Foot-print/ hokey-stick	X18 L5s BK-Medical		(**c**) Foot-print/hokey-stick transducer—the lumen of an ectopic ureter (EU) having the orifice in the urethra 
	Primary purpose	Intraoperative MSK (finger/toe joints)	
	Range of frequencies	5–18 MHz	
	Number of elements	150	
	Image field	Trapezoidal: 24.0 mm wide + expansion angle 2 × 15°	
	Acoustic aperture	3.5 × 24 mm	

5.4 Three-Dimensional/Four-Dimensional Transperineal Ultrasound (3D/4D TPUS)

5.4.1 Volumetric Transducers

Volumetric transabdominal probes developed for obstetric imaging (RAB 8–4, GE Healthcare Ultrasound, Milwaukee, WI, USA; AVV 531, Hitachi Medical Systems, Tokyo, Japan; V 8–4, Philips Ultrasound, Bothell, WA, USA; 3D 4–7 EK, Medison, Seoul, South Korea) and other may be used for 3D/4DTPUS. These transducers combine an electronic curved array of 4–8 MHz with mechanical sector technology, allowing fast motorized sweeps through the field of view, a technology that was pioneered in the Voluson systems manufactured by Kretztechnik, now GE Healthcare Ultrasound [18]. For the "pelvic floor" assessment, the suggested set is maximum aperture and acquisition angles (70° and 85°, respectively), depth of 8 cm, two focal zones at 1.5 cm and 4.5 cm, low or medium harmonics, speckle reduction 5, and crossbeam 2 [18] (Table 5.3, Fig. 5.5).

An advantage of 3D TPUS compared with 2D mode is the opportunity to obtain tomographic or multislice imaging (TUI), for example, in the axial plane, in order to assess the entire puborectalis muscle and its attachment to the pubic rami, as described by Dietz et al. [19, 20]. It is also possible to measure the diameter and area of the levator hiatus and to determine the degree of hiatal distension on Valsalva maneuver. 4D TPUS imaging involves real-time acquisition of volume ultrasound data, which can then be visualized instantly in orthogonal planes or rendered volumes. This simplifies the assessment of functional anatomy since 3D data can be archived as a cine loop, encompassing maneuvers such as squeeze test or Valsalva maneuver [6]. Similar to DICOM viewer software used in radiology, offline analysis is possible on the actual system or on a personal computer (PC) with the help of dedicated software.

Similarly as in 2D TPUS, particularly on prolapse assessment, pressure on the perineum must be kept to a minimum to allow full development of the prolapse [18]. The limitation of 3D/4D TPUS is a small region of interest (acquisition angle) not able to cover all pelvic floor organs in patients with high-grade prolapse and in patients with high BMI.

5.5 Two-Dimensional Endovaginal Ultrasound (2D EVUS)

EVUS is performed with the patient placed in the same position as that adopted for TPUS. It may be performed with electronic linear transducer, frequency 4–14 MHz (type 8838, X14L4 BK-Medical, Herlev, Denmark); with electronic biplane transducer (linear and transverse perpendicular arrays), frequency 5–12 MHz (type 8848, BK-Medical) [21]; with high-multifrequency (9–16 MHz), 360° rotational mechanical transducer (type 2052, 20R3 BK-Medical) [21]; or with radial electronic probe (type AR 54 AW, 5–10 MHz, Hitachi Medical Systems) (Table 5.4, Fig. 5.6 and 5.7).

It is important to keep the transducer inserted into the vagina in a neutral position and to avoid excessive pressure on surrounding structures, which might distort the anatomy [6, 21]. The biplane electronic probe provides 2D sagittal (linear array) and axial (transverse array) sectional imaging of the anterior and posterior compartments. Imaging is usually performed with the patient at rest, during maximal Valsalva maneuver and during squeeze test. The vascular pattern of the pelvic floor structures may also be assessed using color Doppler mode [21, 22].

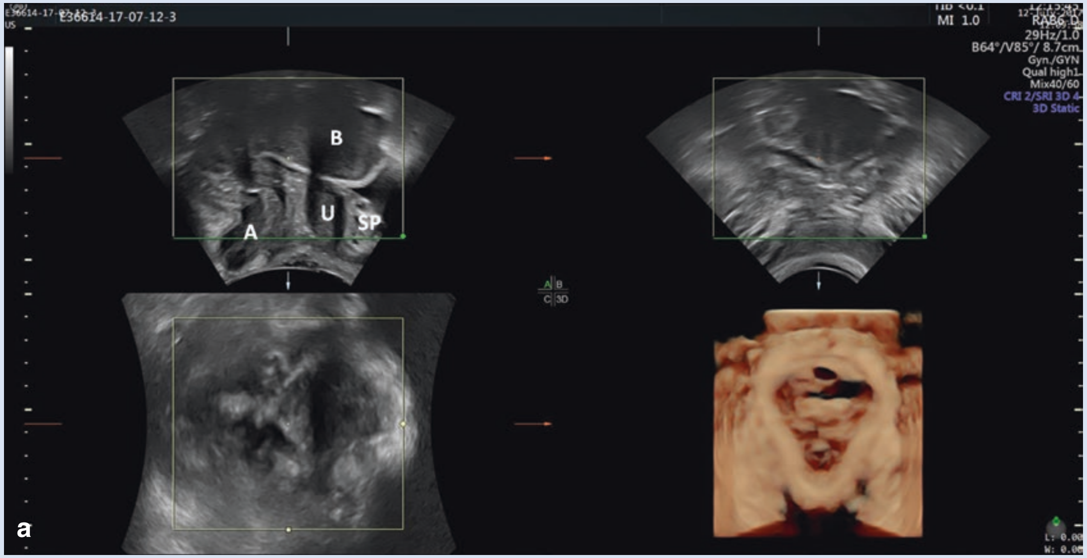
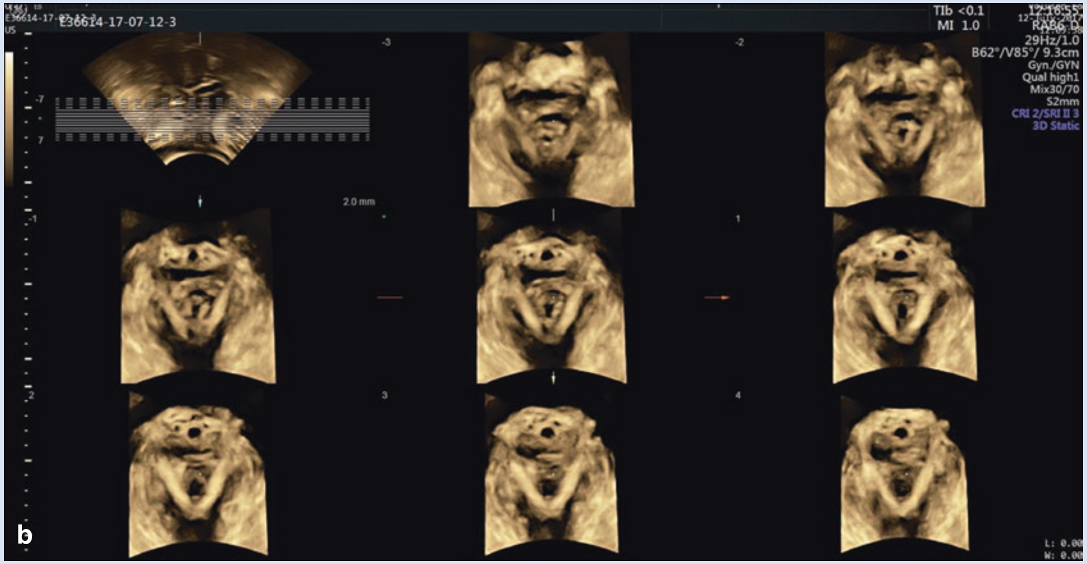
Dressler et al. [13] reported from good to excellent repeatability and reproducibility of the measurements of the suburethral tape location obtained by pelvic ultrasound performed with transvaginal end-fire probe. This demonstrates that for experienced operators which have no access to dedicated pelvic floor equipment, conventional gynecological transducers provide adequate results.

5.6 Three-Dimensional Endovaginal Ultrasound (3D EVUS)

Radial electronic transducer, electronic linear transducer, and rotational mechanical transducer provide a 360° view of the pelvic floor [6, 21]. However with the radial electronic transducer, the 3D acquisition is freehand, whereas with the linear electronic transducer and the mechanical transducer, the 3D acquisition is automatic. The mechanical probe has an internal motorized system that allows an acquisition of 300 aligned transaxial 2D images over a distance of 60 mm in 60 s, without any movement of the probe within the tissue. The set of 2D images is reconstructed instantaneously into a high-resolution 3D image for real-time manipulation and volume rendering. However the operator may individually adjust the distance of acquisition, slice thickness, and time of acquisition which is subsequently reflected in the image quality obtained (shorter time and thicker slice thickness are related to lower quality of the image). An advantage of 3D compared with 2D mode is the opportunity to obtain sagittal, axial, coronal, and any desired oblique sectional image. The 3D volume can also be archived and further post-processed for offline analysis on the ultrasonographic system or on a PC with the help of dedicated software.

The methodology of 2D and 3D EVUS was described by Santoro and Wieczorek [6, 7, 14, 21]. Detailed ultrasound morphology of the urethra and its vasculature was described by Wieczorek et al. [7, 12, 22–24] and Lone et al. [25, 26]. Shobeiri et al. [27] described the ultrasonographic anatomy of levator ani subdivisions, whereas Santoro et al. [28] described the perineal body anatomy.

Table 5.3 Types and characteristic of volumetric transducers used in 3D/4D TPUS examinations

Type of probe	Example transducer		Example ultrasound 2D TPUS image
“Large” volumetric	RAB 4–8 GE Medical		**Fig. 5.5** Three-dimensional image of pelvic floor structures by 3D TPUS visualized with different types of transducers. (**a**) Volumetric “abdominal/obstetrical” transducer—multiplanar reconstruction and surface mode (*A* anal canal, *B* bladder, *SP* symphysis pubis, *U* urethra)  (**b**) Volumetric “abdominal/obstetrical” transducer—tomographic imaging 
	Primary purpose	Abdomen, Pediatric, obstetric, and gynecology	
	Range of frequencies	2–8 MHz	
	Number of elements	192	
	Image field	70° × 85°	
	Acoustic aperture	63.6 × 37.8 mm	
“Small” volumetric	RAB6-D GE Medical		
	Primary purpose	Abdominal Obstetrics, urology, and pediatrics	
	Range of frequencies	2–8 MHz	
	Number of elements	192	
	Image field	90° × 85°	
	Acoustic aperture	62.2 × 34.0 mm	

(continued)

Table 5.3 (continued)

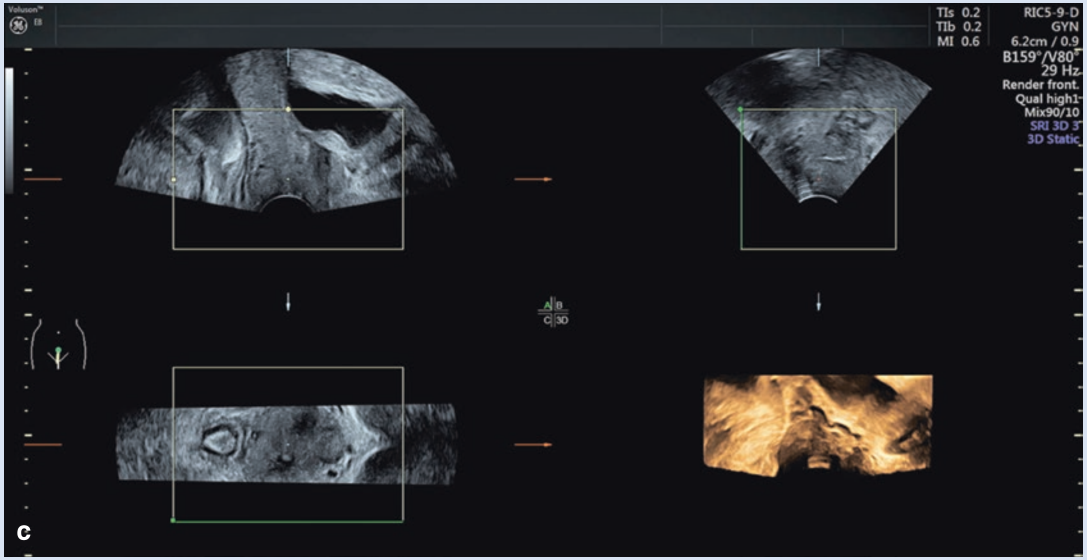
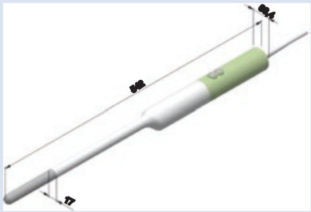
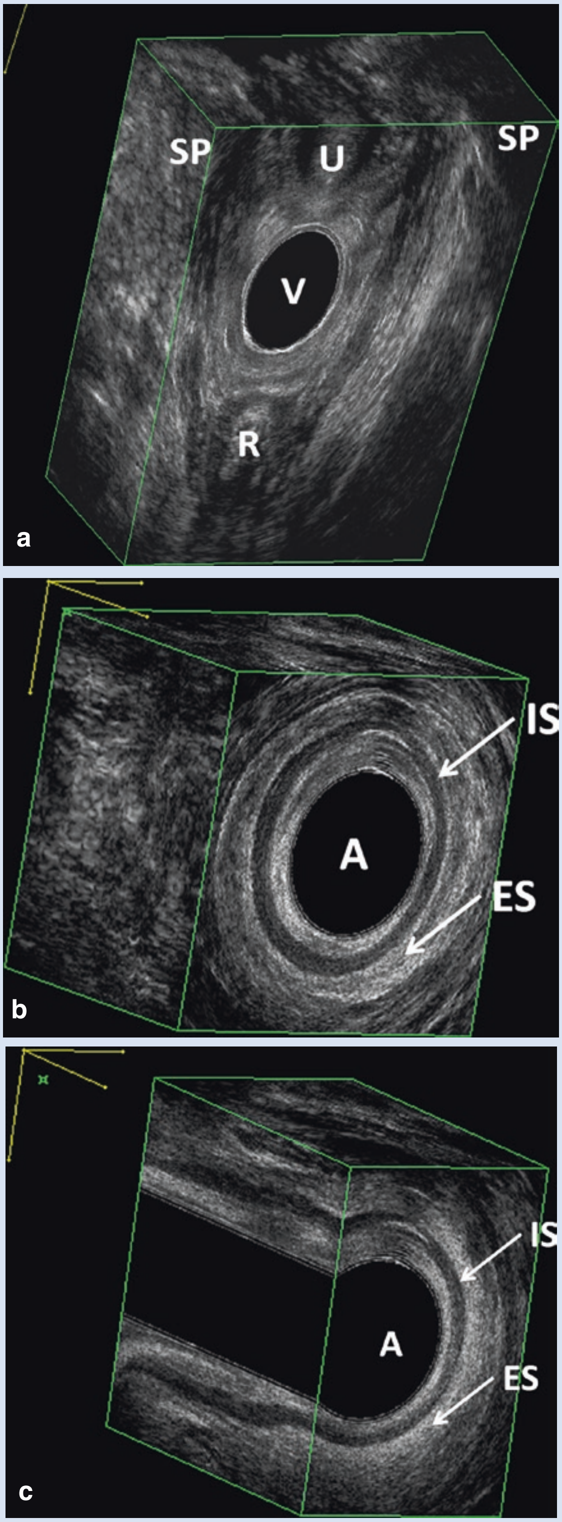
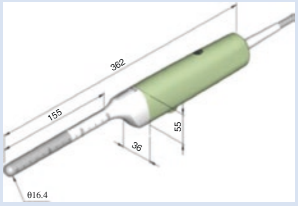
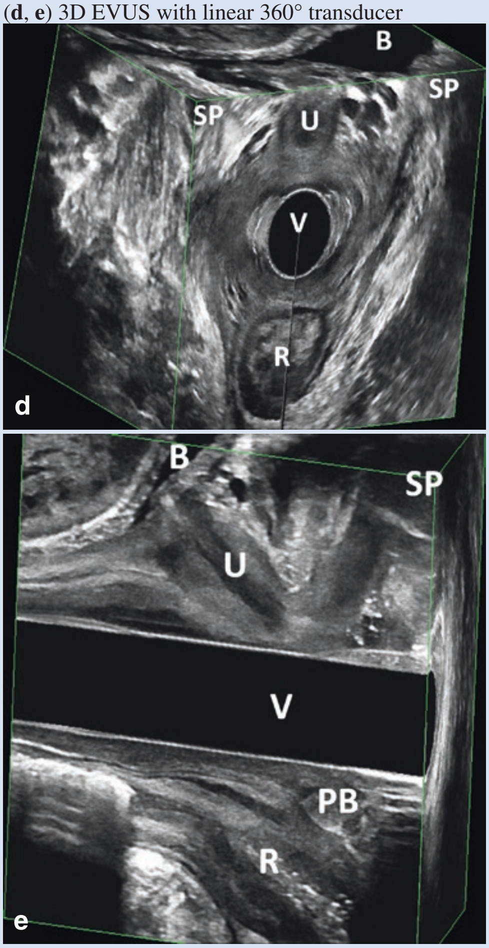
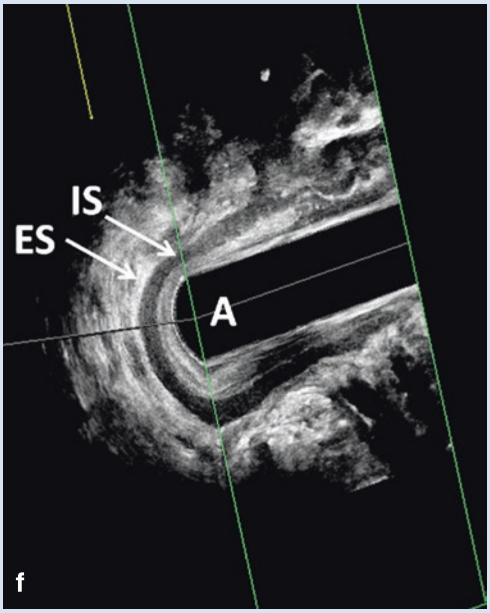
Endovaginal volumetric	RIC5-9-D GE Medical		(**c**) Volumetric endovaginal transducer—multiplanar reconstruction and surface mode 
	Primary purpose	Obstetrics, gynecology, and urology	
	Range of frequencies	4–9 MHz	
	Number of elements	192	
	Image field	179° × 120°	
	Acoustic aperture	22.4 × 22.6 mm	
Matrix	RSM 5-14 GE Medical		
	Primary purpose	Gynecology and urology Small parts, pediatrics, MSK Peripheral vascular	
	Range of frequencies	5–13 MHz	
	Number of elements	960	
	Image field	37.5 mm (B) × 30° (Volume scan)	
	Acoustic aperture	54.3 mm × 50.5 mm	

Table 5.4 Types and characteristic of transducers used in 2D/3D EVUS and 2D/3D EAUS examinations

Type of probe	Example transducer		Example ultrasound 3D EVUS/EAUS image
High-resolution 360°	20R3 BK-Medical		**Fig. 5.6** Three-dimensional image of pelvic floor structures by endovaginal (3D EVUS) and endoanal (3D EAUS) approaches visualized with different types of transducers. High-resolution 360° transducer: (**a**) 3D EVUS, (**b**, **c**) 3D EAUS. *A* anus, *ES* external sphincter, *IS* internal sphincter, *R* rectum, *SP* symphysis pubis, *U* urethra, *V* vagina 
	Primary purpose	EVUS EAUS	
	Range of frequencies	9–16 MHz	
	Number of elements	1	
	Image field	360°	
	Acoustic aperture	NA	

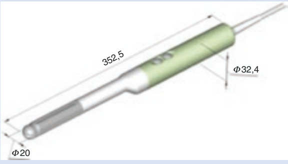
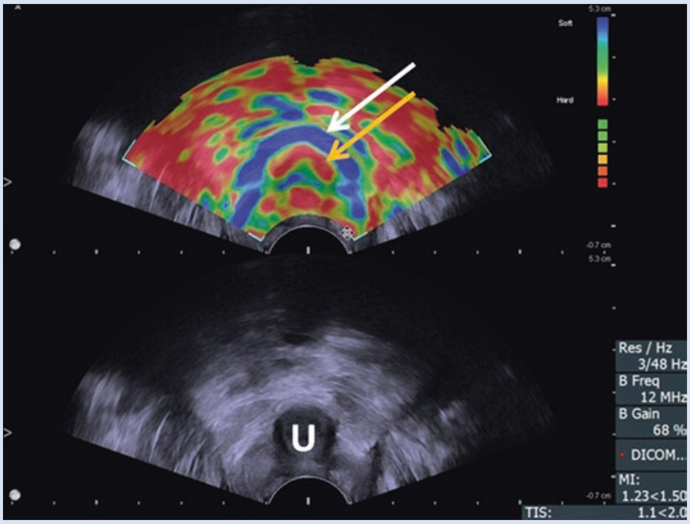
(continued)

Table 5.4 (continued)

Type of probe	Example transducer		Example ultrasound 3D EVUS/EAUS image
Linear 360°	X14L4 BK-Medical		(**d**, **e**) 3D EVUS with linear 360° transducer  (**f**) 3D EAUS with linear 360° transducer. *A* anal canal, *B* bladder, *ES* external sphincter, *IS* internal sphincter, *PB* perineal body, *R* rectum, *SP* symphysis pubis, *U* urethra, *V* transducer into vagina 
	Primary purpose	EVUS EAUS	
	Range of frequencies	4–14 MHz	
	Number of elements	192	
	Image field	360°	
	Acoustic aperture	65 × 5.5 mm	

(continued)

Table 5.4 (continued)

Type of probe	Example transducer		Example ultrasound 3D EVUS/EAUS image
Linear biplane	E14CL4b BK-Medical		**Fig. 5.7** Axial section of the urethra visualized with linear biplane transducer. (**a**) Elastographic image of the urethra during Valsalva maneuver; (**b**) compare B-mode gray scale of the urethra image shown simultaneously to the elastographic image. *U* urethra; white arrow, rhabdosphincter muscle at rest (blue, soft); yellow arrow, longitudinal smooth muscle during contraction/bladder neck opening (red, hard) 
	Primary purpose	Urology/prostate Prostate elastography	
	Range of frequencies	4–14 MHz	
	Number of elements	128 transverse 192 sagittal	
	Image field	138°/178° transverse 65 mm + 2 × 15° sagittal	
	Acoustic aperture	23 × 5.5 mm transverse 65 × 5.5 sagittal	

5.7 Two-Dimensional Endoanal Ultrasound (2D EAUS)

Endoanal ultrasound (EAUS) includes examination of the anal canal (endoanal ultrasound—EAUS) and of rectal region (endorectal ultrasound—ERUS). EAUS is performed with high-multifrequency, 360° rotational mechanical transducer, linear electronic transducer, or a radial electronic transducer, as described above for EVUS (2052, 20R3, 8838; E14CL4b BK-Medical). During examination, the patient may be placed in a dorsal lithotomy, left lateral or prone position. However, irrespective of patient position, the transducer should be rotated so that the anterior aspect of the anal canal is superior (12 o'clock position) on the screen: the right lateral aspect is to the left (9 o'clock), the left lateral aspect is to the right (3 o'clock), and the posterior aspect is inferior (6 o'clock) [6]. The recording of data should extend from the upper aspect of the puborectalis muscle to the anal verge [6, 29] (Table 5.4, Fig. 5.6). The high-resolution 360° transducers provide minimal slice thickness of 1 mm. The rotating crystal moves mechanically, and the operator can decide individually and adjust the distance scanned up from a minimum of 0 mm to a maximum of 60 mm using two buttons on the probe. The number and the depth of the focal zone/zones can be also manually adjusted by the user. The location of the buttons directly on the probe enables manipulation of the image without the need of changing the position of the transducer introduced endoanally, which is mostly important in rectal examination performed with a distension of rectal ampulla by a water-filled balloon. For such type of examination, a special ring is applied to the probe handle, sealing the probe cover. The cover is filled with a variable amount of degassed water (approx. 60–100 ml) depending on the compliance of the examined section of the bowel. Using a dedicated rectoscope (slightly wider than the standard one), the probe can be inserted to a depth of 20 cm enabling examination of the deeply located lesions and precise assessment of the depth/extend of the infiltration of tumors (Fig. 5.8) as well as precise

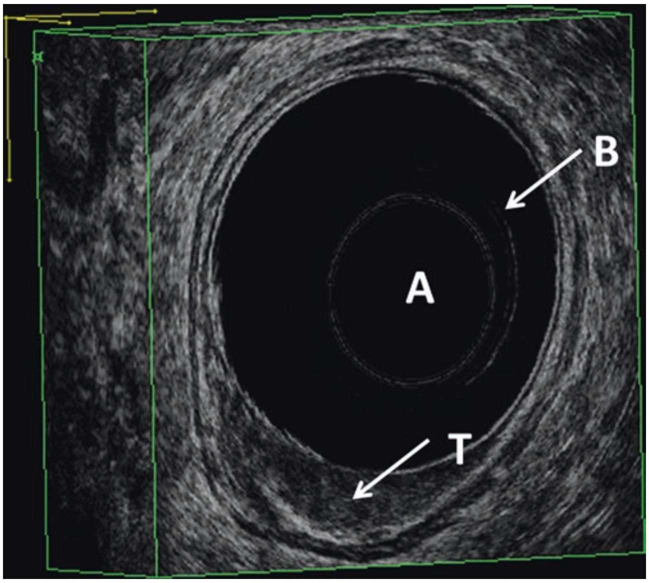


Fig. 5.8 3D ERUS. High-resolution 360° transducer. Examination performed with degassed water-filled balloon. *A* ampulla recti, *B* water balloon, *T* tumor

assessment of very high fistulas. In the evaluations of fistulas, it is helpful to use hydrogen peroxide (approx. 2–5 ml) as a contrast medium that is injected through the external opening. Hydrogen peroxide allows precise visualization of the anatomy of the fistulas and helps to differentiate active tract from scar tissue. Similar technical solution with the opportunity of examining the anorectal region is offered with the transrectum composite probe type UST-678 (Hitachi, Japan). This probe enables scanning with the field of view of 120° (convex array), on the length of 60 mm (linear array). The frequency of the transducer can be adjusted from 3 to 9 MHz (convex array) and from 4 to 10 MHz (linear array). A balloon cover filled with water and fixed by the dedicated rubber band to the transducer allows examination of the rectal ampulla. Compared to the transducers previously described, the new linear electronic probe (type 8838, BK-Medical), frequency of 4–4 MHz, or its recent version X14L4 offers similar imaging opportunities (only in sagittal section) (360°, length of scanning from 0 to 60 mm length, 1 mm minimal slice thickness, manual adjustment of focal zones) with full measurement capabilities as the probes above but with higher resolution. The limitation of this probe is lack of a system for the distension of rectal ampulla by a water-filled balloon.

5.8 Three-Dimensional Endoanal Ultrasound (3D EAUS)

The methodology of 2D and 3D EAUS was described by Santoro et al. [6, 29]. The mechanical rotational transducer or the electronic linear transducer allows automatic 3D acquisition without movement of the probe relative to the tissue under investigation. After the dataset has been recorded, it is possible to interrogate the dataset in 3D, with multiplanar imaging [6]. The 3D image may be rotated, tilted, and sliced to allow the operator to vary infinitely the different section parameters and to visualize and measure distance, area, angle, and volume in any plane [29]. There are also tools to change the transparency of the dataset (volume rendering) [29].

5.9 Conclusions

Ultrasound technology provides a variety of transducers with high range of frequencies, different acoustic aperture, shape, size, and philosophy of beam formation. Pelvic floor ultrasound can be performed both with relatively simple ultrasound equipment used for abdominal or obstetrical purposes and with high-end scanners dedicated for urology or proctology. Technical achievements together with Doppler modes, elastography, as well as the opportunity of ultrasound/MR fusion allow for assessment of female pelvic floor structures of all three compartments in 2D, 3D, and 4D techniques. Different anatomical approaches such as TPUS, EVUS, EAUS, and abilities of post-processing give the clinicians diagnostic power to understand the anatomy and anatomical abnormalities. Ultrasound can be used as an extension for clinically obtained dose of information and its better understanding but can be also employed for qualification for certain surgical procedures. Another advantage of using ultrasound is the opportunity of detailed diagnosis of post-surgical complications and explanation of the causes of surgical failure. All these factors make ultrasound the modality which should be considered as the first choice imaging technique in diagnostics of female pelvic floor disorders.

Take-Home Messages

- Pelvic floor ultrasound can be performed with a variety of transducers and anatomical approaches.
- The knowledge of capabilities and limitations of each type of transducer, anatomical access, and post-processing options is crucial for performing pelvic floor ultrasound in a proper way and making reliable diagnosis.
- Modern ultrasound technologies such as Doppler ultrasound, elastography, three- and four-dimensional ultrasound, and tomographic ultrasound imaging (TUI) can enhance significantly the quality of information obtained; however good knowledge of the technical aspects of the techniques and their pros and cons is essential.

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