Learning objectives

- To describe the most common artefacts in prostate US elastography.
- To suggest how to interpret them, for improving the operator's diagnostic confidence.

Ultrasound (US) elastography is a novel imaging technique which was purposed as to be able to map tissue stiffness in various organs [1-5]. Elastography measures tissue stiffness looking at modifications of the US image after applying mechanical stress [6].

Two real-time elastography methods have been proposed for the prostate tissue elasticity analysis: strain elastography (SE) [7] and shear wave elastography (SWE) [8]. Color-coded maps provide a visual representation of the results. No quantitative elasticity analysis is available with SE; on the other hand, when using SWE a lesion stiffness quantification is given (in kPa or m/s). Both methods have been demonstrated to provide high sensitivity for detecting prostate cancer; moreover, they show high negative predictive values, ensuring that few cancers will be missed [9, 10]. A detailed explanation of prostate elastography can be found in the WFUMB guidelines [11].

However, both SE and SWE have some limitations, mainly related to inherent limits and operator dependency. Moreover, they are affected by artefacts which should be recognised to avoid pitfalls.
Background

Image artefacts are common in US imaging. In prostate ultrasound elastography most of them are generated by the physical limitations and cannot be avoided; some others, related to the organ and transducer geometry or the examination technique can be overcome by a proper technique. Some artefacts are strictly related to the algorithms used by the different systems. These artefacts will be described to accurately distinguish them, leading the operators to improve their diagnostic level.
Findings and procedure details

MATERIALS

Our collection of artefacts in prostatic elastography was carried out using various systems equipped with different elastography algorithms for SE (Resona 7, Mindray, China; MyLab Twice HD and MyLab 8, Esaote, Italy; Hi-Vision EUB 8500 and Preirus, Hitachi Medical System, Japan; Logiq E9, GE Healthcare, USA). For SWE only one system was available on the market until recently (Aixplorer, SuperSonic Imagine, France).

TRANSDUCER CHOICE

Although bi-convex and linear transducers are available, the end-fire convex transducer is generally preferred for SE; prostatic SWE is currently supported by end-fire curved transducer only.

EXAMINATION TECHNIQUE

The examination technique varies between SE or SWE methods.

In SE, a series of minimal compressions and decompressions induced with the transducer are necessary to obtain the right displacement of the prostatic tissue, while the probe is maintained in a fixed position or moved along the prostate surface in transverse scan [12]. SE estimates the relative tissue stiffness of the prostate by visualising the differences in strain among adjacent regions. To obtain a correct estimation, the elastography region of interest (ROI) should be wide and cover the prostate and the surrounding fatty tissue but, when possible, avoid the bladder which is a no strain zone [12, 13] (Fig. 1). The SE-ROI size wideness is not limited in itself; however, the tissue displacement far from the probe may be insufficient to be measured, resulting in incorrect coding on the map. The regular SE pattern varies with age and the inner gland volume (Fig. 2).

In SWE, data are acquired by examining the prostate in transverse scans, slowly moving the transducer from base to apex, while avoiding manual transducer pressure to minimise pre-compression artefacts. SWE distinguishes the prostatic zones that are characterised by different stiffness values (Fig. 3). The regular SWE pattern varies with age and the inner gland volume (Fig. 4). The SWE-ROI size is limited by physics of shear wave propagation and allows simultaneous visualisation of the two lobes only in small and medium volume prostates (Fig 5); to overcome this limitation, in large prostate the peripheral zone of each lobe must be studied separately (Fig. 6). With SWE the ROI size doesn't affect the map representation of the absolute tissue stiffness.
TYPES OF ARTEFACTS

Both techniques are affected by multiple artefacts which should be known in detail.

In SE, the map varies according to the type of tissue present within the ROI, the ROI size and the distance from the probe. However, the manual compression and decompression are relatively uncontrolled elements, with wide variability. Thus, images affected by artefacts have been found in up to 32% of cases [14]. Moreover, some artefacts are related to the algorithm used by specific systems.

In SWE, the map reflects the shear wave propagation, which may be affected by different factors such as beam penetration, tissue uniformity and tissue pre-compression. With SWE, it is critical to avoid any pressure on the prostate gland applied by the transducer [15].

- **Geometric Artefact**

The prostate is studied for the characterisation of abnormal lesions and detection of stiff suspected areas.

Because of its geometric characteristics and a reduced contact surface, the convex transducer produces a non-uniform distribution of the pressure during the SE acquisition (Fig. 7), thus generating lateral artefacts [3]. Their presence becomes more evident in large prostates. In some systems, the algorithm assigns the stiff code to every not-displaced target, independent from their real stiffness. As a consequence of the reduced tissue displacement due to the transducer geometry, the lateral sides of large glands are displayed as stiff (Fig. 8A). This common artefact can be overcome by tilting the probe laterally (Fig 8B).

The same artefact can be observed in the fatty tissue neighbouring to the lateral sides of the prostate, which might be not-displaced in some condition (Fig 9A). In some systems, the algorithm assigns the soft code to the fatty tissue, even when it is not adequately displaced by manual compressions (Fig. 9B).

Concerning the limited width of the SWE-ROI and in particular to the different physical principle on which the SWE technique is based, the correspondent SWE map is not affected by geometric artefacts.

- **Color Noise Artefacts**
With SE, the frequency of the micro-compression should remain constant, allowing the scanner to assign the correct displacement average value for every pixel of the image. It reduces background signals ("colored noise artefacts") brief, non-reproducible flashes of apparent stiff pixels that affect the image quality [12].

- **Soft Rim Artefact**

At SE a thin periprostatic border, known as the "soft rim artefact," can be seen and suggests that the prostate is freely movable within the periprostatic tissues. These areas will be depicted as soft, meaning that large displacements are seen from one frame to the next [16]. Its presence also reflects the difference in relative elasticity between the prostate and the adjacent tissue, which contains the periprostatic venous plexus [12]. The "soft rim" visualisation and its thickness may depend on the axial resolution and sensitivity of the scanner or the dynamic range setting (Fig. 10). Some authors have proposed this as a marker of capsule integrity in prostate cancer [17]. However, this artefact is not always visualised even in normal prostate: in a study it was observed in only 73% of cases and its complete visualisation was possible on only 12% [12].

- **Cyst Artefacts**

In cyst, when SE measures the tissue displacement between subsequent frames, random noise is detected. The noise may be displayed in different ways depending on the algorithm used by the system. The two most commonly described artefacts are the "3-layer pattern" [18] (Fig 11A) and "bull's eye artefact" (Fig 11B) [19]. These artefacts are considered useful since they highlight the cystic nature of the target, even when internal echoes are present. Frequently some small cysts may be coded as a target of an intermediate or absent displacement (Fig 12A and 12B), thus creating problems of interpretation; in this condition, the B-mode image represents the key to understanding.

SWE imaging usually shows the cyst as a blanked cavity because shear waves don't propagate into the fluid. However, sometimes SWE shows the cyst in the map coded as tissue without any significant stiffness, which represents an artefact.

- **Mismatch Color Code Assignment**

In some systems, during the SE processing, an area of fluid collection (such as the bladder or a vessel) in which the transducer detects any radiofrequency variation of the signal is displayed as blanked in the color-coded map (Fig 13A), thus clearly showing the absence of scattering inside the cited area. In other systems a soft code (Fig 13B) or a hard code (Fig 12A) are assigned to these targets, thus generating a mismatch in the color-code assignment.
Sometimes a mismatch in the code assignment may also happen in areas of solid tissue where extremely low amplitude echoes, related to the US beam attenuation, are displayed in the B-mode image. In this condition, some systems may assign a soft code to anatomical structures by themselves stiff, since they are misinterpreted as anechoic areas. These artefacts can be observed for example in the peri-urethral tissue, at the bladder neck, which frequently appears hypoechoic (Fig. 14) or along the acoustic shadow of a calcification (Fig. 15).

With SWE, a mismatch in the color-code assignment may happen when the system cannot measure the shear waves propagation. This phenomenon becomes evident in areas of highly stiff tissue such as cancer with significant shadowing or in case of marked shadowing behind calcifications [20]. It can also be seen at the level of the bladder neck; in these cases, the stiff tissue is coded as a lack of shear wave signal (Fig. 16).

• **Black Hole Artefacts**

Another example of this lack with SWE can be seen in small prostatic cancers. This artefact, which was not explicitly described before in prostate elastography, can be named "black hole sign". Usually, only cysts are displayed as a blanked round cavity. However, signals also absent in small hypoechoic lesions may be suspicious. This is because cancer stiffness is related to the amount of stromal matrix, but also depends on the lesion shape and the tensile pressure inside the tumor, which is dependent on the increased vascularization.

Consequently, a small rounded lesion behaves with a shell that can refract the shear waves heating the rounded surface at the lesion boundary. In these conditions, the propagation velocity of the shear waves inside the lesion cannot be measured. Thus, the lesion is displayed as a "black hole". In contrast, stiff signals, a consequence of the lesion "shell", are shown in the surrounding (Fig. 17 and Fig. 18).

• **Pre-compression Artefacts**

Pre-compression of the prostatic tissue can affect the displayed map for both the SE and the SWE maps. These artefacts can be generated by the external pressure exerted on the prostate with the endorectal probe, or by the internal compression on the peripheral zone.

At SE, the pre-compression of the peripheral zone affects the regular tissue displacement, thus mimicking chronic disease or cancer lesions (Fig. 19).

At SWE, it also influences the quantitative measurement of the tissue stiffness, thus inducing a wrong finding (Fig. 20).
Another condition that may affect the SWE map is the decubitus which may generate an asymmetric pre-compression on the prostate. In detail, the patient usually is lying in the left lateral position, and this might alter the compressibility of the right side of the prostate; the same artefact becomes evident on the left side of the prostate when the patient is lying in the right lateral position (Fig 21). This artefact may result in a potential cause of misdiagnosis.
Fig. 1: The SE map allows the different zones of the prostate to be distinguished. TZ=Transitional zone; CZ=Central zone; PZ=Peripheral zone; U=Urethra/Verumontanum; SR=Pericapsular soft rim artefact. The normal PZ is usually displayed of intermediate stiffness, whereas TZ is typically stiffer than the PZ.

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Fig. 2: The SE normal pattern of the prostate varies with age and the growing of the inner gland (arrows). (A) 20 years of age; (B) 30 years of age; (C) 40 years of age; (D) 50 years of age; (E) 60 years of age; (F) 70 years of age.

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Fig. 3: The SWE map allows the different prostatic zones to be distinguished. TZ= Transitional zone; CZ= Central zone; PZ= Peripheral zone. SWE is a quantitative method and can also measure the stiffness value of the different anatomical zones. The stiffness value range of the TZ and PZ varies between young and old subjects.

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**Fig. 4:** The SWE normal pattern of the prostate varies based on the age and the growing of the inner gland (arrows). (A) 20 years of age; (B) 30 years of age; (C) 40 years of age; (D) 50 years of age; (E) 60 years of age; (F) 70 years of age.

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**Fig. 5**: Comparison between SWE (A) and SE (B) in an hypertrophic prostate. Due to the shear waves attenuation, the SWE-ROI can usually cover the entire volume only in prostate below 40 ml.

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**Fig. 6:** SWE only allows to study a limited ROI, which cannot cover the entire width of large prostates, thus limiting the visualisation of the lateral peripheral zone of both lobes (*). In this case, the two lobes must be studied separately.

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**Fig. 7:** The end-fire convex transducers, due to their geometric characteristics, produce a nonuniform distribution of the pressure (arrows) during the SE acquisition, resulting in a non-uniform displacement of the prostatic tissue.

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**Fig. 8:** At SE, the reduced tissue displacement of the lateral lobes of large prostates results in the display of a stiff aspect of the gland at those levels (A). This geometric artefact can be overcome by tilting the probe laterally and aligning each side separately (B and C) with the transducer axis.

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Fig. 9: Geometric artefact and code assignment at the two edges of the SE-ROI. (A) Some systems assign the stiff code to the not-displaced periprostatic fatty tissue (*), independent from their real stiffness. (B) Other systems assign the soft code to the not-displaced fatty tissue (*).

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**Fig. 10:** Soft rim artefact (*) at the right lobe boundary shown by different systems at SE. The "soft rim" visualisation and its thickness may depend on the axial resolution and sensitivity of the scanner or the dynamic range setting.

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Fig. 11: Cyst Artefacts at SE. (A) A typical "BGR sign (blue/green/red layers)" or "3-layers" pattern (arrow) and (B) a "bull's eye artefact" (arrowhead) at the level of intraglandular cysts.

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**Fig. 12:** Cyst Artefacts at SE. Small cysts may be coded as a target of an intermediate level of displacement (A), here depicted in green, or an absent level of displacement (B), here displayed in blue. In (B) the bladder is displayed as stiff (*) in the color-coded map.

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**Fig. 13:** Mismatch color code assignment at SE. Based on the proprietary algorithm of the different systems, an area of fluid collection such as the bladder is displayed as (A) blanked (*), as (B) soft (**) or as stiff (* in Fig 11B) in the color-coded map.

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Fig. 14: Mismatch color code assignment at SE. The peri-urethral tissue, at the level of the bladder neck (arrowheads), frequently appears hypoechoic at the B-Mode imaging, due to the US beam attenuation and their specific histological pattern. Based on the low tissue displacement exerted by the probe movements in the anterior side of the prostate, the bladder neck should be correctly displayed as stiff (* in A). However, some systems may assign a soft code to the bladder neck (** in B), since it is misinterpreted as anechoic area because of the extremely low amplitude echoes.

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Fig. 15: Mismatch color code assignment at SE. (A and B) In the case of marked shadowing behind calcifications (arrows), some systems may assign a soft code along the acoustic shadow (*).

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Fig. 16: Mismatch color code assignment at SWE. When the system cannot measure the shear waves propagation, the stiff tissue is coded as a lack of shear wave signal. An example of this artefact can be seen at the bladder neck (*).

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**Fig. 17:** Examples of the "black hole" artefacts at SWE in three different patients with prostatic well-defined cancer in the peripheral zone, biopsy proved with Gleason score (GLS) 4+3 (A), GLS 4+4 (B) and GLS 3+4 (C), respectively. A rounded lesion refracts shear waves heating the surface at the lesion boundary. Thus, shear waves in the lesion cannot be measured, resulting in a "black hole" displayed at the SWE map. In contrast, a stiff high signal is shown and can be measured in the surrounding area.

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**Fig. 18:** "Black hole" artefact at SWE. Multimodality and multiparametric evaluation of a small rounded cancer (arrow) biopsy proved (GLS 3+4). (A) B-mode imaging: a 5 mm hypoechoic lesion in the peripheral zone (PZ) of the right lobe. (B) Color Doppler imaging: hypervascularity of the lesion. (C) SE map: a small "hard" area in the nucleus of the lesion; SWE map: a "black hole" area at the lesion level. (D) CE-MR: a dynamic contrast-enhanced small lesion. (E) T2W-MR: missed lesion in the PZ. (F) DWI-MR: a diffusion-weighted sequence shows a high-intensity signal (PIRADS 5) at the tumor site.

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Fig. 19: Pre-compression artefact at SE. (A) The peripheral zone compression affects the normal tissue displacement and assigns the hard code signal (arrows) to the prostatic tissue, thus mimicking chronic disease or cancer lesions. (B) A slight pressure exerted on the peripheral zone allows the correct tissue coding (arrows), here as intermediate stiffness level, thus displayed in green.

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Fig. 20: Pre-compression artefact at SWE. (A) A slight pressure of the transducer on the prostate avoids pre-compression artefacts displayed on the map (yellow arrow) and allows a correct quantitative evaluation of the tissue stiffness (red arrow). (B) Pre-compression of the prostatic tissue affects the displayed map (yellow arrow) and strongly influences the quantitative measurement of the tissue stiffness (red arrow), thus inducing a wrong grading. The elastic modulus is increased from 30 to 60 kPa in this case.

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**Fig. 21:** Pre-compression artefact at SWE in the different decubitus position. (A) The patient is lying in the left lateral position. (B) The patient is lying in the right lateral position. The lateral decubitus may change the compressibility of one side of the prostate (arrows) compared with the opposite side, thus affecting the map display and resulting in a potential cause of misdiagnosis.

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Conclusion

Elastography is a low-cost and non-invasive technique, easy to use after proper training and without any additional discomfort to the patient, compared to standard TRUS. It is essential for any operator to be aware of, and able to recognise US elastography artefacts, thus improving the diagnostic accuracy.
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