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Ultrasound elastography: Advantages, limitations and artefacts of the different techniques from a study on a phantom

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Abstract Ultrasound elastography is a technique currently under development. Its use in clinical practice is complicated because of the wide range of techniques used by the different manufacturers and the parameters proposed to characterise tissues. A comparative analysis on five ultrasound diagnostic systems has been performed on a calibrated elasticity phantom and demonstrated that: (1) all systems tested are reliable for simple qualitative analysis: is a nodule present and is it harder or softer than neighbouring tissues? (2) the deformation or hardness ratios between two regions are usually, however, not proportional to the theoretical ratios and only a binary analysis greater than 1 (harder) and less than 1 (softer) is reliable and could be used as a negative predictive value (NPV) for malignant lesions, as has been suggested by some authors; (3) finally, quantitative analysis using shear wave techniques performed variably, reliable measurements being obtained with only one of the systems. Measurements produced by these different systems must not be compared in clinical practice to monitor a patient and the threshold values proposed in the literature must only be used in an analysis carried out with the same system and same probe.

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Tissue hardness can be altered by pathological processes, either focally as in a tumour or diffusely as in liver fibrosis.

The aim of elastography techniques is to assess the hardness of a tissue, either relatively compared to an adjacent tissue (e.g. breast, thyroid or prostate nodules) or by objective quantification (e.g. liver).

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Two basic concepts are currently used for ultrasound elastography: examination of the strain or deformation of a tissue due to a force (static elastography) and analysis of the propagation speed of a shear wave (shear wave elastography). Manufacturers have developed their elastography modules using one or other of these concepts and their own specific technologies (cf. article by J.L. Gennisson in the same edition).

Several parameters obtained from these elastography techniques have been studied in the literature in order to characterise a nodule or a tissue overall. In most cases each study was conducted using a single system. These parameters can be divided into three major groups: qualitative, semi-quantitative and quantitative:

- qualitative parameters are obtained from a visual analysis of parameter maps showing the distribution of deformities or elasticities, which are known as elastograms. These representations are available on most machines regardless of the technique used. They may be presented in grey scales or in colour and the representation scales vary between manufacturers: the hard structures may be coded, for example, in red or blue depending on the manufacturer (Fig. 1). The ratio between the diameter of nodules on B-mode and on elastography can be calculated;
- semi-quantitative parameters are calculations of deformation ratios or elasticity ratios between two regions of interest (ROI). These can be calculated with any of the techniques;
- quantitative parameters are only available from techniques which measure shear wave propagation speed, the values of which are given either in m/s or by calculating the Young module in kPa.

In clinical practice therefore, the user is faced with several co-existing data acquisition techniques and a large number of parameters available for the analysis. This then raises questions as to the significance and relevance of the different parameters depending on the system used and the question being asked, and the ability to extrapolate results obtained from one organ with one system to another system.

We felt it was therefore useful to compare the elastography systems on the same phantom in order to assess the precision of these parameters and the artefacts seen, in order to increase our understanding of the advantages and limitations of these different techniques and to improve our understanding of what we are measuring and how to take the measurements in order to optimise clinical applications. We describe here the practical implications of the results of a study which has also been submitted for publication.

Five manufacturers made their ultrasound elastography systems available to us. Measurements were taken using high frequency linear probes by a single operator on a dedicated ultrasound elastography phantom consisting of eight spherical inclusions of different hardesses enclosed in a homogeneous medium of known hardness (30 ± 5 kPa) (Elasticity QA Phantom model 049, CIRS Technology, Norfolk, VA USA). Measurements were taken of the four most superficial 10 mm diameter inclusions, the centre of which was located 15 mm from the surface of the phantom. Two inclusions were harder than the surrounding tissue (44 ± 6 kPa and 74 ± 10 kPa) and two were softer (12 ± 3 kPa and 18 ± 4 kPa). The study protocol is not described here.

We shall consider the current findings in the literature on the merits of qualitative, semi-quantitative and quantitative parameters from findings made from this phantom in succession.

**Qualitative analysis of elastograms (deformation or elasticity maps)**

The two main questions which arise in the elastography analysis of a nodule regardless, of its site are: "can it be detected even if it is invisible in B mode?" and "can its consistency be characterised compared to the neighbouring tissue (harder or softer)?".

The phantom analysis showed that the inclusions were detected by all of the elastometry systems, even if they were poorly visualised in B mode and that they were better detected if they were harder. In addition, they could be classified correctly as harder or softer than the neighbouring tissue by all of the systems.

Nodule characterisation studies in different organs showed that in general and regardless of organ, malignant nodules are harder than the adjacent tissue [1–20]. As some authors have suggested for the breast, elastogram analysis could be used as a screening technique for malignant nodules not visualised in B mode which are very much harder than the healthy structures [1,15]. It is essential, however, to take account of the fact that it may be difficult to visualise small nodules in some physiologically heterogeneous tissues (e.g. breast).

Calculation of the ratio of the nodule diameters in B mode and from the elastogram has been proposed in breast disease as a predictive indicator of malignancy if it is greater than 1 [2,3]. In clinical practice, this equates to a hard nodule which appears to be larger on the elastogram than in B mode. The phantom analysis showed that regardless of the technique used, the ratio is determined by the quality of visualisation of the inclusion in B mode and on the elastogram rather than by its hardness. This inconsistency between the diameter of breast nodules in B mode and on the elastogram which is seen in clinical practice, is therefore probably due to modifications in the tissues around the tumour which is invisible in B mode but change their hardness and suggest that the lesion is malignant [7].

 Artefacts have been seen on elastograms obtained from static elastography, often involving a band of overestimation of hardness on the surface of the phantom in contact with the probe due to direct pressure from the probe on this medium. This artefact is also seen in clinical practice and must be recognised by practitioners. The hardness of the tissue is also overestimated anteriorly and posteriorly to soft inclusions and tissue hardness is underestimated anteriorly and posteriorly to soft inclusions. This artefact is due to the fact that relative tissue deformation varies according to the hardness of the inclusion: if the inclusion is hard, the medium deforms more than the inclusion in response to pressure anteriorly and posteriorly, whereas with the soft inclusion, the inclusion deforms more under pressure than the medium. These artefacts illustrate the heterogeneous nature of the deformation applied to the medium during manual compression by the probe (Fig. 1).
Semi-quantitative analysis or evaluation of deformations or relative hardness

As described above, most malignant tissues are harder than the surrounding healthy tissues. The relative hardness of a lesion compared to the adjacent tissue has been studied in different organs, calculating the hardness or deformation ratio between the ROI in the nodule and the surrounding tissue [8, 11, 17, 18, 21]. The ratios were high for malignant lesions in all tissues although there were considerable overlaps with the ratios found for benign lesions, particularly in the liver and thyroid, which means that nodules cannot always be characterised.

The phantom analysis results show that the ratios obtained vary according to several parameters:

- the system used; in half of the cases, the values do not correspond to the theoretical ratios, systems based on shear waves giving more reliable measurements;
- the position of the ROI in the surrounding tissue compared to the nodule, with better results for measurements taken on each side of the inclusion at the same depth as the inclusion as recommended by the manufacturers;
- the hardness of the nodule, for which there is an error in the ratio which is greater than theoretical values for softer inclusions regardless of technique.

This variability in the ratios depending on the position of the region of interest in the surrounding tissue has also been found in clinical practice, in which threshold values to diagnose malignant lesions vary with the position of the reference ROI in the surrounding tissue [4].

It is important, therefore, to be very cautious in using these ratios and to bear in mind that the type of system used, position of the ROI and hardness of the nodule being examined change the result: in most cases, the ratio is not proportional to the true hardness ratios of the two structures being measured. Only a binary analysis greater than 1 (harder) or less than 1 (softer) is reliable. Furthermore, some authors have suggested that these ratios be used in breast disease for their negative predictive value (NPV): the likelihood of a malignant tumour is low if the ratio is low [1].

Quantitative parameters

Only shear wave elastography techniques can be used for quantitative analysis. The values are expressed in m/s or in kPa.

Only one of the three systems studied produced elasticity values which were consistent with the expected values...
except for the softest inclusion, the hardness of which was underestimated. Conversely, although measurements made with the other systems were outside of the expected values, they displayed low variability and measurement bias was constant.

The main current scope being studied is non-invasive assessment of liver fibrosis. Several points should be borne in mind for clinical practice:

- the measured values vary according to the system and the frequency of the probe used. As a result, the threshold values proposed to discriminate between the different stages of fibrosis and normal liver elasticity values can vary depending on the equipment used;
- the “hardness” of the liver is not only due to fibrosis but also to other factors such as inflammation and biliary or venous stasis. All of these clinical laboratory and imaging findings should therefore be considered when interpreting results;
- finally, because of the reproducibility of measurements, patients may be monitored over time although using the same system. It would be risky to compare values measured using two different systems.

In terms of characterising the nodule, elasticity measurements have been studied in the breast in which the specificity of the diagnosis has been increased without loss of sensitivity from the maximum hardness of a nodule combined with the BI-RADS score [1].

We must therefore remain cautious about using elasticity values or measured speeds which do not always represent the actual elasticity values of the tissue being examined. In clinical application, published results should be considered depending on the system and probe used by the author and following the measurement conditions described.

Conclusion

Ultrasound elastography is a useful and promising technique with various fields of application. The wide range of techniques used by the different manufacturers and the parameters proposed to characterise tissues make understanding and using it complicated in clinical practice. Our comparative analysis of the phantom shows that:

- all systems tested are reliable for simple qualitative analysis: is a nodule present and is it harder or softer than neighbouring tissues?
- the deformation or hardness ratios between two regions are usually, however, not proportional to the theoretical ratios and only a binary analysis greater than 1 (harder) and less than 1 (softer) is reliable and could be used as a NPV for malignant lesions as has been suggested by some authors. On the other hand, in contrast to some clinical publications, the ratio between the diameter of the nodule in B mode and its diameter measured on the elastogram does not clearly separate softer from harder targets, in contrast to some clinical publications;
- finally, quantitative analysis based on shear wave techniques performs variably, with reliable measurements being obtained from one of the systems and low variability measurements obtained from the other systems for which systematic measurement bias could be corrected.

Measurements produced by these different systems must not be compared in clinical practice to monitor a patient and the threshold values proposed in the literature must only be used in an analysis carried out with the same system and same frequency for the probe.

Disclosure of interest

Pr Correas is a speaker, expert and member of the scientific board of Toshiba MS and Philips US, and speaker and expert for the companies SuperSonic Imagine and General Electric.

References


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