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Review of Ultrasound Elastography Quality Control and Training Test Phantoms

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Abstract

While the rapid development of ultrasound elastography techniques in recent decades has sparked its prompt implementation in the clinical setting adding new diagnostic information to conventional imaging techniques, questions still remain as to its full potential and efficacy in the hospital environment. A limited number of technical studies have objectively assessed the full capabilities of the different elastography approaches, perhaps due, in part, to the scarcity of suitable tissue-mimicking materials and appropriately designed phantoms available. Few commercially-available elastography phantoms possess the necessary test target characteristics or mechanical properties observed clinically, or indeed reflect the lesion-to-background elasticity ratio encountered during clinical scanning. Thus, while some phantoms may prove useful, they may not fully challenge the capabilities of the different elastography technniques, proving limited when it comes to quality control (QC) and/or training purposes. Although a variety of elastography tissue-mimicking materials, such as agar and gelatine dispersions, co-polymer in oil and poly(vinyl) alcohol cryogel, have been developed for specific research purposes, such work has yet to produce appropriately designed phantoms to adequately challenge the variety of current commercially-available elastography applications. Accordingly, there is a clear need for the further development of elastography TMMs and phantoms to keep pace with the rapid developments in elastography technology, to ensure the performance of these new diagnostic approaches are validated, and for clinical training purposes.

1. Introduction

For more than two decades, ultrasound elastographic techniques for both measuring and imaging the mechanical properties of soft tissues have been of great interest, with the aim of these techniques being the presentation of mechanical information of the tissue.[1-4] Changes in the mechanical properties of tissues are known to correlate closely with various pathological conditions and hence ultrasound elastography should provide a method for differentiating between various abnormalities and pathological states which may not be apparent using traditional ultrasound imaging techniques.[5-7] The technology has now reached the stage where numerous incarnations have left the research laboratory and are appearing in the clinical environment.

Elastographic techniques typically investigate the elastic nature of compliant tissue tracking the longitudinal strain of tissue elements by ultrasonically assessing the one-dimensional local displacements in the medium.[1] Depending on the specific technology and/or clinical application, the mechanical information can then be either presented as an average measurement across an assumed homogeneous organ (for example, the liver) or, for more heterogeneous tissue sections, presented in the form of a parametric map of relative tissue property (typically either strain or Young's modulus [1-4]), where a knowledge of normal and pathological values can thus provide additional diagnostic possibilities beyond that of conventional imaging techniques.[5-7]

Test objects are widely used in ultrasound imaging. These reproduce the essential geometric features of tissue and are acoustically equivalent so that images are comparable with those produced clinically. Often, simulated lesions of different sizes are embedded within a tissue-mimic to enable studies to be performed which are concerned with the detection of minimal lesion size. Test objects generally have 3 functions, providing a source of realistic and reproducible datasets in the development of new ultrasound techniques, for the objective evaluation of the accuracy of particular measurements (eg. lesion size, stenosis diameter), and for use in QA/QC programmes.

A concern relating to the clinical implementation of this new technology may be the lack of adequate end-user training, which could be significant when one considers that in some cases the patient probe can incorporate both a conventional imaging transducer and a device for introducing a shear wave into the patient, coupled with the need to obtain accurate and sensitive quantitative measurements. Here again, test phantoms have a role to play, ranging from simple phantoms designed to allow the user familiarise themselves with the probe and how to make a measurement, to more complex phantoms containing various targets designed to train users in the identification of tissue pathology in a realistic model using the elastographic information content alone or perhaps also in conjunction with B-mode imaging.

The aim of this article is thus to review both the research-based and commercially-available test objects which have been developed for both quality control and training purposes, covering both their design and composition and their appropriateness for use in various clinical situations. The review will begin with a brief description of the technology underpinning the main clinically-available ultrasound elastography systems (for a more in-depth treatise, the reader is referred to the article by Dr. Peter Hoskins in this issue) together with a description of the main tissue mimicking materials (TMMs) which have been developed for use in the various test phantoms.

2. Elastography techniques

Four main elastographic approaches have been developed: static elastography, dynamic elastography, transient elastography and remote elastography.[6,8] Of these four, static, remote and transient elastography have been successfully implemented in the clinical environment and thus are briefly discussed here.

2.1 Static Elastography

Static elastography examines the tissue's response to compression by comparing ultrasonic signals of tissue before and after compression.[2,9] Static elastography techniques have been implemented by a number of manufacturers such as General Electric (USA), Hitachi (Japan), Philips (The Netherlands), Siemens (Germany) and Toshiba (Japan), and have become commercially available on ultrasound scanners in the clinical areas of breast, prostate and thyroid imaging. In most cases, compression to the area of interest is manually applied, with some scanners relying on internal patient movement such as respiratory or cardiac motion.[10-13] The commercially-available intravascular ultrasound (IVUS) system (EndoSonics, USA) investigates the morphology of the coronary wall and plaque by observing the induced strain in the vascular tissue via different levels of the intraluminal pressure.[14] While static elastography is beneficial for IVUS, the technique is regarded as being limited when applied to deep organs such as the liver where predictable and controlled compression is not easily attainable due to the organ's depth.[2] Consequently, its use has been limited to the clinical areas highlighted above, and test objects should be designed with this in mind. The static elastography technique is thus restricted to investigating relative elasticity in small parts applications and as such a suitable test object for this technique should contain inserts of varying stiffness and sizes relative to the background material, with a range of mechanical properties similar to those found in the tissue of interest; see Table 2 for details.

2.2 Remote Elastography

Acoustic radiation force elastography, also known as remote elastography, utilises an acoustic radiation force to generate localised displacements within the tissue by the transfer of momentum from the acoustic wave to the propagation medium. This transfer of momentum can be used for different elastography approaches, either for strain imaging or for the generation of shear-waves for making a quantitative stiffness measure.

For strain imaging, the mechanical strain within the tissue can be evaluated by measuring local tissue displacements, using ultrasonic correlation-based methods.[4] This technique, effectively a form of static elastography with the compression effected using focussed ultrasound, has been implemented clinically by Siemens (Germany) in the form of "Virtual Touch[TM] Tissue Imaging". Acoustic radiation force impulse imaging (ARFI) of this type has been demonstrated to show clinical promise for use with radiofrequency ablation procedures of liver lesions.[15] An appropriate test phantom for performance assessment of ARFI strain imaging, similar to that of static elastography, would contain inserts of varying stiffness and sizes embedded in relatively lower background TMM.

ARFI can also be used to quantity tissue stiffness in a selected region of interest through ultrasonically measuring the velocity of shear waves produced by the acoustic radiation impulse. This technique has been implemented in the form of Siemen's "Virtual Touch Tissue Quantification" and has been used for the diagnosis of chronic liver disease by correlating shear wave velocity with liver fibrosis.[16] For ARFI, where the shear wave velocity is measured, test phantoms should contain homogenous regions with a range of shear wave velocities for assessment of the systems accuracy. The range of mechanical properties for ARFI phantoms should be similar to those found in the tissue of interest, see Table 2 for details.

Further applications of ARFI elastography come in the form of supersonic shear imaging (SSI) produced by Supersonic Imagine (France), which also relies on an acoustic radiation force to excite the shear wave. The resultant tissue elasticity information is provided in the form of an elasticity map which is overlaid on the B-mode image, rather than a numerical estimation of the shear wave velocity averaged across an interrogated area of interest. The SSI technique derives its elasticity map by relating tissue stiffness to the shear wave velocity, and, in the case of liver assessment, has also been shown to offer a quantitative assessment of liver parenchyma stiffness, where the global elasticity can be calculated from the measured image.[17] The clinical application areas for the SSI technique also extend beyond the liver to encompass breast, prostate and thyroid imaging. SSI can be used to investigate relative elasticity in tissue and, thus, in these instances a suitable test object for this technique should contain lesion-like inserts of varying stiffness relative to the background TMM, with a range of mechanical properties similar to those found in the tissue of interest (see Table 2). Where SSI offers a quantitative estimation of a homogenous region of tissue, such as in the liver, a suitable phantom would be one which contained a set of homogenous regions of increasing stiffness for calibration of the systems' ability to accurately determine the relevant tissue's Young's modulus.

2.3 Transient Elastography
Transient elastography utilises a low frequency short-pulsed excitation to excite the tissue of interest.[6,9] The resultant mechanical stimulation causes the propagation of a low-frequency shear wave in the tissue with a velocity related to the tissue stiffness and which can be measured using an ultrasound pulse-echo mode.[6,9] A current commercially-available implementation of transient elastography is the Fibroscan® system produced by Echosens (France). The Fibroscan® is designed for use in the assessment of liver fibrosis by quantifying liver stiffness, which has been shown to correlate with fibrosis, through the use of a shear elasticity probe. A shear wave, excited by a low-frequency vibrator with an ultrasonic single-element transducer, is tracked and its velocity derived. The system assumes that the liver is a uniform medium and consequently averages its single measurement over a specific region within the patient, and hence an appropriate phantom for assessment of this system's accuracy would need to be homogenous rather than containing small targets as would typically be the case for a spatially-resolved technique.

3. Relevant Standards and Design Criteria

Ultrasound phantoms play an important role in the quality control (QC) and performance testing of ultrasound equipment, and are also very useful tools for providing an initial safe means for clinical training in instances where the phantom has clinically-relevant targets. In order to ensure that the measurements taken on such QC test phantoms are consistent with clinical performance, test objects should be tissue-mimicking, exhibiting similar acoustic properties to tissue across the range of frequencies used diagnostically.[18] The "International Electrotechnical Commission (IEC) 1390"[19] and the "American Institute of Ultrasound in Medicine (AIUM) Standard 1990"[20] standards for conventional B-mode ultrasound tissue mimicking material recommend an acoustic velocity of 1540 m/s, attenuation coefficients of between $0.5 - 0.7$ dBcm^{-1}MHz^{-1} for the frequency range of $2 - 15$ MHz, with a linear response of attenuation to frequency, f^1, as detailed in Table 1.

Table 1. Summary of the IEC 1390 and AIUM Standard 1990 standards for conventional B-mode ultrasound tissue mimicking materials.[19,20]

Acoustic Velocity (m/s)	Attenuation Coefficient (dBcm^{-1}MHz^{-1})	Frequency Range (MHz)	Response of Attenuation Coefficient to frequency
1540	$0.5 - 0.7$	$2 - 15$	f^1 (linear)

However, for ultrasound elastography TMMs, no mechanical standards have been recommended. Nevertheless, it is reasonable to state that the IEC and AIUM standards should be applied for ultrasound elastography phantoms, with the additional integration into the design of the range of mechanical characteristics mimicking both healthy and pathological tissue. Indeed, the relevant commercial and scientific literature reveals that both manufacturers and researchers alike have designed ultrasound elastography TMMs to match the acoustic properties of soft tissue with some integration of the mechanical properties of soft tissue.[21-37] Questions still remain, however, as to the efficacy and suitability of such TMMs for their intended purposes. Table 2 presents a list of suggested tissue mimicking properties matched to specific clinical applications, based on measured mechanical properties reported in a number of clinical studies.[11,38-48] The background properties are usually representative of the approximate stiffness values of the healthy tissue in the respective clinical application, while the range of the target stiffness usually represents the typical values of malignant lesions. The minimum target dimensions seem to reflect the minimum lesion dimensions detected in the studies, while the elastic contrast is the ratio of the stiffness of the target to that of the background material. In the case of fibrosis of the liver, the liver parenchyma range represents those stiffness values encountered for the various stages of fibrosis of the liver, where the disease is regarded as affecting the whole liver rather than simply manifesting in the form of lesions.

Table 2. Proposed mechanical properties for tissue mimicking materials, including background and target stiffness values and elastic contrast, in addition to the typical target dimensions for each of the respective clinical applications.

Clinical Applications	Mechanical Properties			Typical Range of Target Dimensions (mm)
	Background (kPa)	Target (kPa)	Elastic Contrast	
Breast [11,38,39]	25	$30 - 200$	$1.2 - 8$	$1 - 20$

Prostate [40-43]	15	10 – 40	0.7 – 2.7	5 – 40
Thyroid [44,45]	10	15 – 180	1.5 – 18	10 – 40
Liver [46,47]	3	3 – 16	1 – 5.3	10 – 80
Liver parenchyma [48]	3 – 30	–	–	–

In Section 4, the current commercially-available ultrasound elastography test phantoms are described, with a distinction made between those aimed at QC testing and those developed primarily for training purposes. The properties of the phantoms are examined in the context of their tissue-mimicking characteristics and their suitability for their intended applications. An overview is then provided in Section 5 of the broad range of research phantoms which have been described in the literature, together with a description of the novel TMMs used in their construction. These TMMs, which were developed to optimally replicate both the acoustic and mechanical properties of the soft tissue of interest in the respective studies, will also be discussed in terms of the suitability of their application to the different ultrasound elastography techniques.

4. Commercially-available elastography phantoms

Only one company (Computerized Imaging Reference Systems CIRS) Inc., USA) has produced phantoms specifically designed for quality control testing and/or performance assessment of clinical ultrasound elastography systems. These phantoms (specifically models 049 and 049a) contain targets of varying Young's modulus values (quoted as being 8, 14, 45, 80 kPa) embedded in a uniform background material with a stated Young's modulus of 25 kPa.[23] The former contains spherical targets of diameter 10 and 20 mm while the latter contains a set of cylindrical target masses with varying diameters in the range 1.58 – 6.49 mm. CIRS also produce a multi-purpose multi-tissue phantom (model 040GSE) with two sets of elastography targets (quoted as being 10, 40 and 60kPa) given below.[24] All elastography phantoms produced by CIRS are manufactured with the tissue-mimicking material Zerdine®, which has an acoustic velocity of approximately 1540 ± 10 m/s and an attenuation coefficient of 0.5 dB/cm/MHz,[18] although the material's response to frequency has been found to be non-linear varying as $0.48f^{1.3}$.[18] The embedded spherical and cylindrical targets are at clinically-relevant depths for small parts applications, ranging from 15 – 60 mm in both the 049 and 049a phantoms and 15 and 50 mm in the CIRS 040GSE.[23,24] The Young's modulus values, however, are of a limited range for determining the elastographic accuracy and across the full range encountered during clinical scanning of the prostate, breast and liver, and further do not adequately reflect the lesion-to-background elasticity ratio observed clinically. Furthermore, while the background material has a suitable Young's modulus for mimicking breast tissue, the value is not appropriate in the case of the prostate, thyroid or liver. In addition, these phantoms are not suitable for the performance testing of devices such as the Fibroscan®, the operation of which dictates the use of a range of homogenous phantoms of varying Young's modulus values rather than those containing embedded targets for the measurement of the stiffness of targets relative to the background tissue. Nevertheless, the designs of the CIRS phantoms are quite well suited to QC testing of small parts applications for static, ARFI and SSI elastography techniques.

Clinical training phantoms, which are important for providing an initial safe tissue mimicking medium for clinical training purposes, are generally anthropomorphic in design, and commercially available from two manufacturers, namely CIRS Inc and Blue Phantom (USA).[21,22,25] CIRS have produced two training phantoms, one for prostate scanning (model 066) and one for breast scanning (model 059). The CIRS model 066 phantom simulates the prostate area and adjoining structures and includes three randomly embedded 10mm diameter isoechoic lesions which are three times the stiffness of the simulated prostate tissue, thereby

making the lesions detectable only when using elastographic techniques.[22] There is, however, limited detail in both the commercial and scientific literature as to the stiffness values of both the background and target material of this phantom and whether they are representative of those seen clinically in the prostate. In addition, both the lesion diameter and elastic contrast are at the upper range of those reported clinically and thus may not be challenging enough to provide adequate training to the clinician or to adequately challenge the elastography technique under evaluation. The CIRS model 059 phantom mimics the anatomical and ultrasonic properties of breast tissue and similarly contains lesion-mimicking masses (2 – 10 mm in diameter) of an isoechoic nature with a Young's modulus, again, three times that of the background material.[21] However, as with the model 066 phantom, there is limited information regarding the reported stiffness values of this phantom and furthermore, the target-to-background ratio may not be challenging enough to provide adequate training to the clinician or to adequately challenge the evaluated elastography technique. The elastography phantom manufactured by Blue Phantom[TM] is designed for breast applications and caters not only for elastography clinical training, having embedded lesions of varying stiffness and size, but also contains masses of varying echogenicity and varying diameter (6 – 11 mm) which can be used for conventional B-mode ultrasound training.[25] However, once again, limited details of the stiffness values of both the target and background material, or indeed of the elastic contrast, have been reported in either the commercial and scientific literature and thus, it is difficult to ascertain the capabilities of this phantom in terms of its ability to fully mimic the properties of breast tissue.

The clinical training phantoms described above have been developed specifically for imaging and biopsy training purposes in the clinical applications of breast and prostate imaging. Nevertheless, it is clear that considerable further scope exists for the development of more clinically-relevant phantoms for both QC/performance testing and training purposes, from the point of view of replicating a broader range of pathologies in the areas currently mimicked but also for extending the application to other anatomical sites of interest.

5. Research elastography phantoms

A wide variety of phantoms developed by elastography research laboratories have been reported in the literature, where the motivation has typically been to evaluate the performance of the ever-increasing range of research and commercial ultrasound elastography techniques. Many of these groups have focused on the use of novel TMMs in the construction of these phantoms, with a view to extending the range of pathologies and/or anatomical sites to which they can be applied, extending their reach beyond that of the commercially-available phantoms. Thus, these phantoms will be reviewed in the following sub-sections by categorising them according to the TMM used in their construction. Table 3 lists details of both the research and commercial phantoms including their acoustic and mechanical properties and their limitations.

5.1 Agar and gelatine dispersions

The combination of agar and gelatin in TMMs has revealed interesting characteristics, with the ultimate stiffness properties of the material controllable with the addition of macroscopic safflower oil droplets, and the acoustic velocity and attenuation controlled by the addition of propylene glycol and glass beads, respectively. TMMs based on these constituent materials have been used to produce relatively simple heterogeneous phantoms containing inserts of varying elastic contrast, with the geometry and elastic properties of the material proving to be relatively stable with time.[26] Further development of the material as an elastography tissue-mimic has seen it utilised in the manufacture of an anthropomorphic breast phantom, mimicking the properties of both subcutaneous fat and glandular tissue. In addition, embedded lesion-like inserts with a variety of geometries and mechanical properties have been constructed, representing a range of pathologies.[27,28] The Young's modulus values produced by these agar and gelatin dispersions have ranged between 5 – 135 kPa, a range representative of soft tissue, while the acoustic velocity and attenuation values achieved have

ranged between 1492 – 1575 m/s and 0.1 – 0.52 dB/cm/MHz, respectively, again representative of soft tissue.[26-28] Agar and gelatin based materials have proved successful in validating and testing transient elastography using acoustic radiation force impulse ,[30] where the produced phantom has contained targets of high stiffness embedded in a lower Young's modulus background material. Another clinical application of this TMM has been the carotid artery, where the mechanical properties of the carotid artery were successfully mimicked for validation of noninvasive strain imaging using gelatin dispersions.[29] It is clear that the agar and gelatine dispersions can demonstrate great versatility across clinical applications and can be used in phantoms for any of the elastography techniques; however, the full potential of this TMM has yet to be explored. Furthermore, the proposed function of agar and gelatin dispersion phantoms has been to serve as intermediaries between simple phantoms and actual patients in order to assess elastography systems and techniques in the research stage,[27] and thus, little emphasis has been placed on producing phantoms suitable for QC of commercially-available systems. In addition, the manufacture process of such dispersions involves the use of formaldehyde, a highly toxic chemical, which may discourage production of the TMM in a hospital environment where the necessary fume hood and production equipment may not be available.

5.2 Copolymer-in-oil

A relatively novel approach to the manufacture of phantoms for transient elastography systems has seen the emergence of compounds based on the principal ingredient styrene-ethylene/butylene-tyrene (SEBS)–type copolymers. These copolymers are mixed with mineral oil and acoustic scatterers, and processed to form a soft elastic translucent media of controllable mechanical properties. With an increase in the SEBS copolymer concentration in the mixture, an exponential increase in the Young's modulus of the material is produced. The material has been shown to be stable over time and to exhibit the mechanical properties of a number of different types of soft tissue.[31] A Young's modulus range from 2.2 – 150 kPa has been achieved while the attenuation coefficient has been shown to range from 0.4 – 4.0 dB/cm. Although such results have proved encouraging, the acoustic velocity range of 1420 – 1464 m/s is much lower than that prescribed by the IEC and AIUM standards.[19,20] Similarly, the density of the material has been found to be 0.90 ± 0.04 g/cm^3, a figure that is significantly less than that expected of soft tissue.[31] While the achievable acoustic velocities are much less than that of soft tissue, the attainable Young's moduli of this material may prove to be useful for assessing transient elastographic techniques where a homogenous test object is needed, indicating its potential for evaluating the performance of elastography systems. This TMM, however, has not been used to construct phantoms which contain targets of varying stiffness relative to background material, and hence it may not be suitable for static elastography or ARFI where this design of phantom is necessary for QC testing.

5.3 Poly(vinyl) Alcohol Cryogel (PVA-C)

Poly(vinyl) alcohol-cryogel, a relatively novel TMM, is manufactured through repeated 24 hr freeze-thaw cycling (-20°C and +20°C) of aqueous high-grade PVA solution, which produces a gelation effect. Cross-linking occurs when crystal nuclei are generated in the freezing stage, and, on thawing, these nuclei grow into crystallites that act as cross-linking sites for the polymer.[7,32-34] Variation of the initial PVA-C concentration, the thawing rates and the number of freeze/thaw cycles have been identified as a means of manipulating the material's Young's modulus, making it possible to produce samples with a range of 2 – 600 kPa, which covers both healthy and pathological tissue.[32,35] In addition, the acoustic velocity and attenuation coefficient of PVA-C can be altered by varying the glycerol content and the scatterer content respectively, producing tissue-mimicking ranges of 1505 – 1570 m/s and 0.2 – 0.6 dB/cm/MHz, respectively.[35] A further advantageous feature of this material is its compatibility to both magnetic resonance and ultrasound imaging, and thus, it has been used

Phantom/ Material	Commercial /Research	Purpose/ Application	Acoustic Properties		Mechanical Properties			Range of Target Dimensions (mm)	Limitations/ Disadvantages
			Acoustic Velocity (m/s)	Attenuation Coefficient (dBcm^{-1}MHz^{-1})	Targets (kPa)	Background (kPa)	Elastic Contrast		
CIRS 059[21]	Commercial	Anatomical training phantom for breast elastography and biopsy	1540 ± 10	0.5	n/a	n/a	3	2 – 10	Elastic contrast very high. Limited detail of mechanical properties.
CIRS 066[22]	Commercial	Anatomical training phantom for prostate elastography and biopsy	1540 ± 10	0.5	n/a	n/a	3	10	Elastic contrast very high. Limited detail of mechanical properties. Target dimensions large
Blue Phantom[25]	Commercial	Anatomical training phantom for breast elastography and biopsy	n/a	n/a	n/a	n/a	n/a	6 – 11	Limited detail of mechanical and acoustic properties. Target dimensions large for breast.
CIRS 049 & 049a[23]	Commercial	Elasticity phantoms for QA	1540 ± 10	0.5	8, 14, 45, 80	25	0.3 – 3	1.58 – 6.49	Background mechanical properties suitable for breast only.
CIRS 040GSE[24]	Commercial	Multi-purpose multi-tissue phantoms for QA	1540 ± 10	0.5 & 0.7	10, 40, 60	n/a	n/a	6 – 8	Limited detail of background mechanical properties. Limited number of targets.
Agar and gelatine[26-30]	Research	Anthropomorphic breast, carotid phantoms for testing transient and ARFI elastography	1492 – 1575	0.1 – 0.52	15 – 92	5 – 135	0.5 – 4.6	0.5 – 14	Manufacture process involves toxic chemicals.
Copolymer-in-oil[31]	Research	Transient elastography accuracy measurement	1420 – 1464	0.4 – 4.0	n/a	2.2 – 150	n/a	n/a	Has not been used to construct embedded targets thus not applicable to ARFI and Static elastography. Acoustic velocity low
Poly(vinyl alcohol) cryogel[32-37]	Research	Transient elastography accuracy measurement, multi-modality studies	1505 – 1570	0.2 – 0.6	n/a	4 – 615	n/a	n/a	Has not been used to construct embedded targets thus not applicable to ARFI and static elastography.

to construct a range of tissue mimicking phantoms for QC testing and research for both ultrasound and MR imaging.[33,34,36] The accuracy of a commercially-available reflective-mode transient elastography system has been assessed using PVA-C as a test object to mimic the shear elastic, acoustic velocity and attenuation coefficient characteristics of the progressive states of liver fibrosis.[35] Furthermore,intravascular studies have employed PVA-C to simulate the local elastic properties of plaque and of the surrounding carotid arterial wall and similarly the material has been used in the construction of aortic vessel phantoms, proving the material to be durable and replicative of the vessel wall stiffness.[7,33] Anatomically-realistic renal artery vessels has also been mimicked in terms of both their acoustic and mechanical properties.[37] Anthropomorphic brain phantoms, multi-volume stenosed vessel phantoms and breast biopsy phantoms have also been successfully developed using PVA-C as the base TMM for multi-modality studies.[34] Although PVA-C has been useful not only for research purposes but also in the assessment of commercial clinical elastography systems, the material must be processed under very specific conditions in order to achieve specific stiffness values, and thus the TMM can be laborious to manufacture. Similarly, as is the case for copolymer-in-oil TMM, PVA-C has not been used to construct targets of elevated stiffness relative to the background phantom material, and thus has not yet been proven appropriate for QC testing of static elastography and ARFI.

6. Conclusion

There is a continued strong interest in the growing clinical utilisation of elastographic techniques for both qualitatively visualising and quantitatively measuring the mechanical properties of soft tissues, presenting new clinical information relating to the pathological state of tissue as an adjunct to conventional ultrasound imaging techniques.[49] It is vitally important that these new techniques are fully evaluated technically as well as clinically before they are introduced into routine clinical practice. Furthermore, as with all ultrasound techniques, there is a requirement for clinicians and sonographers to be adequately trained to enable them to acquire high quality images, free from artefacts and, further, for them to understand the role of instrument controls on the resultant image quality. Accordingly, TMM phantoms have a valuable role to play and there is thus an equal requirement for commercial availability of suitable tissue mimicking anthropomorphic phantoms. Despite the relatively large number of phantoms reviewed here which are either commercially-available or under development in various research laboratories, few of these phantoms adequately meet the requirements of the different ultrasound elastography techniques or the range of clinical applications in terms of their mechanical properties and the characteristics of their test targets. There thus exists a clear need for the continued development of suitable tissue mimicking phantoms with more specialised designs, moving away from the current general purpose phantom approach used by some manufacturers to more anatomically-specific phantom designs. The rapid pace of developments of elastographic systems will likely continue over the coming years, which will further challenge our ability to adequately assess the performance of these diagnostic systems and train staff in their use.

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