Acoustic Characterisation of the International Electrotechnical Commission (IEC) Agar-based Tissue Mimicking Material Under Freeze-Thaw Cycles for Ultrasound Test Objects

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Background/Aims. Ultrasound is the second most utilised medical imaging modality in England(NHS England, 2023), thanks to its non-invasive and non-ionising nature, affordability, and portability(Carovac et al., 2011). Quality assurance (QA) of ultrasound systems relies on test objects, often composed of tissue-mimicking materials (TMM)(Dudley et al., 2014). The Edinburgh Pipe Phantom (EPP)(Pye & Ellis, 2002) is a test-object made from the IEC agar-based TMM (IEC, 2001), for assessing imaging performance. Innovations in its design, such as incorporating polyvinyl alcohol (PVA) cryogel pipes, require further exploration to easily vary the acoustic properties within the pipes. Although the effects of freezing on agar's structural properties are well documented(Dalvi-Isfahan et al., 2017), the impact on its acoustic properties remain uncharacterised, limiting the integration of freeze-thaw cycles into multi-material phantoms.
This study aimed to acoustically characterise the IEC agar-based TMM subjected to up to three freeze-thaw cycles, assessing its suitability for constructing EPPs with PVA cryogel pipes.
Methods. IEC agar-based TMM samples were fabricated using a standardised recipe and preserved in a water-glycerol-benzalkonium chloride solution. Samples underwent 0-3 freeze-thaw cycles, each comprising 12 hours at -18°C followed by controlled thawing. Acoustic properties, including speed of sound, and acoustic attenuation were measured using through-transmission substitution methods over the 3.5-50MHz frequency range, whilst the relative backscatter power was measured using the substitution method(International Electrotechnical Commission, 2019). Microscopic analysis was conducted to observe structural changes.
Results. No significant variations in speed of sound, acoustic attenuation, or relative backscatter power were observed across freeze-thaw cycles, over the 3.5-50MHz frequency range. Acoustic attenuation averaged 0.57 ± 0.13 $dB.cm^{-1}.MHz^{-1}$ and the speed of sound was found to be 1536.72 ± 43.14 $m.s^{-1}$, both remaining consistent regardless of freeze-thaw treatment. Microscopic analysis revealed structural changes, such as micro-cracks, but these did not impact acoustic properties – however their impact on imaging remains to be assessed.
Discussion/Conclusion. The findings demonstrate that IEC agar-based TMM maintains stable acoustic properties despite freeze-thaw-induced structural changes. These results support its use in developing advanced phantoms, such as the EPP with PVA cryogel pipes, broadening the scope of QA and training applications in ultrasound imaging. Further work is required to optimise the incorporation of PVA cryogel within EPPs.

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Key words. *Pipe Phantom, Quality Assurance, IEC agar-based material, Acoustic characterisation*

Title of Study: Characterisation of a novel tissue mimicking material for fabrication of ultrasound flow phantoms of pre-clinical dimensions

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***Key words:** Acoustic characterisation, DLP printing, Hydrogel, Flow phantom, Microfluidics*

Background. Flow phantoms with comparable acoustic and elastic properties to soft tissues are important tools to develop and validate imaging techniques. The development of pre-clinical sized vessel mimics (diameter: 150 to 810 μm. Müller *et al* 2008) have been restrained by the difficulties in casting such small vessels. Bisphenol-A-ethoxylate dimethacrylate (BEMA) is a non-cytotoxic, photo-responsive dental restorative hydrogel. Three-dimensional microchannels with diameters between 250 and 370 μm using BEMA based hydrogels have previously been manufactured by Domingo-Roca *et al* (2023). However, the speed of sound of BEMA has only been characterised at low ultrasound frequencies at 2.25 MHz, at 1387.4 ~ 1566.5 m·s^{-1}. This study aims to extend the characterisation of BEMA hydrogel up to 50 MHz, and compare its properties with other tissue- and vessel-mimicking materials (IEC TMM and C-flex®).

Methods. BEMA hydrogels were printed using the digital light processing technique (ASIGA MAXX27) as described previously by Domingo-Roca *et al* 2023, IEC agar was prepared in-house (Browne *et al*., 2003) according to IEC 2019, and C-flex® tubing samples were purchased (Cole-Parmer 06424-64). Speed-of-sound (SoS) and attenuation measurements were undertaken using a broadband substitution technique (Browne *et al*., 2003 and Sun *et al*., 2012). The properties were measured over a frequency range from 2.25-50 MHz using 7 broadband transducers.

Results. The results showed that BEMA has similar acoustic properties to IEC TMM up to 10 MHz. At frequencies greater than 10MHz, the attenuation of BEMA begins to increase more rapidly compared to the IEC TMM. In contrast, C-flex® has similar SoS to IEC TMM and human tissue, however with much higher attenuation. The attenuation results of C-flex® are consistent with previous literature (Hoskins 2008) measured at 8 MHz.

Table 1. Comparison of SoS and attenuation properties among IEC TMM, BEMA, C-flex®, and blood vessels

Material	Speed of sound (m·s^{-1})	Attenuation (dB·cm^{-1})	Frequency range (MHz)
IEC TMM	1513.5± 8.3	$\alpha_{TMM} = 0.002418f^2 + 0.4327f$	1 ~ 50
BEMA	1570.5 ± 3.5	$\alpha_{BEMA} = 0.0063f^2 + 0.466f$	2.25 ~ 50
c-flex®	1549.6 ± 11.2	$\alpha_{C-flex} = 0.3742f^2 + 4.697f$	2.25 ~ 15
Blood vessels	1560 ~ 1573 (at 20°C, Duck, *et al* 2012)	$\alpha_{Human\ tissue} = 0.4 \sim 0.77f$ (Szabo, *et al* 2004 and Duck *et al*., 2012)	3.3 ~10 (Szabo, *et al* 2004)

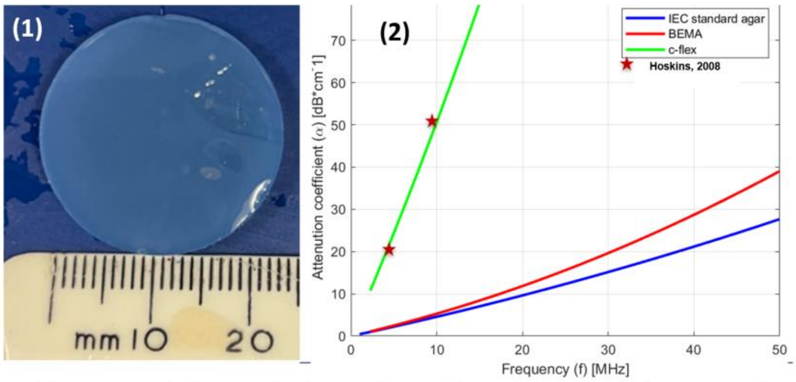

Figure (1) BEMA sample for acoustic characterisation (diameter: 20 mm, thickness: 3 mm); (2) Comparison of different attenuation coefficients among IEC standard agar, BEMA, and c-flex®

Discussion. In future work, we aim to print hollow channels inside a BEMA block, and embed these into a customised holder to enable fluid to flow through the channel. The performance of the pre-clinical phantom will be quantitatively assessed using a pre-clinical ultrasound scanner.

Conclusion. This study demonstrated the potential use of BEMA to fabricate ultrasound flow phantoms of pre-clinical relevant dimensions.

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Synthetic Spheres: Modeling Anechoic Lesion Detectability with a Uniformity Phantom

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Background. There is growing interest in assessing ultrasound system performance using anechoic targets embedded within a homogenous, tissue-mimicking material, either in the form of randomly distributed spherical voids (the "RSV phantom") [Madsen, Holland, IEC, Yu] or angled pipes ("Edinburgh Pipe Phantom") [Moran].

An alternative method for assessing system performance is presented that combines correlation length measurements from a uniform tissue mimicking phantom with noise measurements obtained using an in-air scan. From this data, it is possible to construct "synthetic spheres" at arbitrary locations within the image frame. These synthetic spheres can be used to obtain quality metrics such as the depth-dependant lesion signal-to-noise ratio (LSNR).

Methods. A Philips C5-1 probe was used to obtain two single-frame images, one of a uniform phantom and one of air. A MATLAB script (MathWorks, Natick, MA, USA) combined data from these images to map depth-dependent LSNR of the "synthetic spheres" formed using this image data. These LSNR plots were compared to similar maps of depth-dependent LSNR obtained using cine-loop images of an RSV phantom with a 15% volume concentration of 6-mm spheres. Another MATLAB script was used to create the corresponding map of LSNR versus depth for the images acquired from the RSV phantom. To compare performance of the two methods, images were acquired of a range of dynamic range, focal length, and harmonic imaging settings.

Results. Figure 1 compares results for the two methods at one setting (DR = 86 dB, harmonic imaging on and focus at 7 cm) while figure 2 compares the maximum LSNR obtained for the C5-1 probe at six different settings (DR = 86, 50 & 30 dB; harmonic imaging on and off).

Discussion. Both methods capture similar trends in imaging performance, with LSNR decreasing as dynamic range is reduced and as harmonic imaging is turned off. The synthetic spheres method shows a smoother profile in LSNR versus depth, as this method is not subject to the same variances in LSNR associated with cine loop acquisition speed, partial volume effects, and image segmentation of lesions.

Conclusion. The synthetic spheres method shows promise as an alternative to the RSV phantom for testing ultrasound imaging performance. More work is still needed to determine how well the method captures 3-D spatial resolution and other factors critical to ultrasound imaging performance.

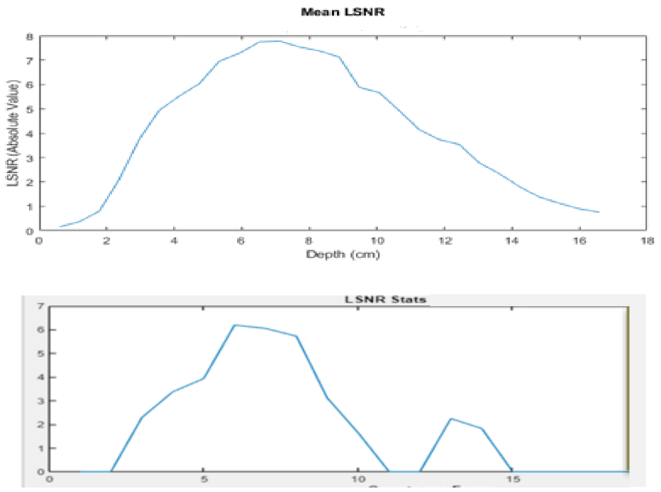

Figure 1: LSNR vs depth for the synthetic spheres method (top) and for the RSV phantom (bottom)

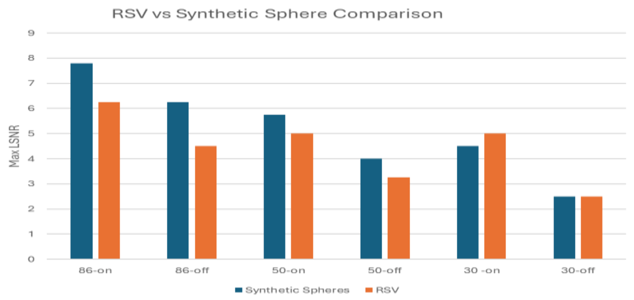

Figure 2: The max LSNR obtained with the two methods at six different settings

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NHSBSP guidelines for the procurement and testing of ultrasound scanners used in the breast screening programme.

Prashant Verma, Dept of Medical Physics, Sheffield Teaching Hospital NHS Trust

The updated guidance outlines the clinical and technical imaging specifications for ultrasound equipment. It provides a framework for the quality assurance process and guidance on User and Physics tests, to assess and monitor the imaging performance of scanners. Baseline testing, including tolerance limits, changes to the in-air reverberation test and spatial resolution tests are recommended. Suggestions for acceptable limits to spatial resolution and imaging penetration depth are provided. All tests are accompanied by acceptable levels of performance (Standard) and suggested remedial actions when the Standard is not met.

Comparison of Point Shear-Wave Elastography and 2D Shear-Wave Elastography: a phantom study

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Aims

Point Shear-Wave Elastography (pSWE) and 2D shear wave elastography (2D-SWE) techniques are both used clinically to assess tissue stiffness. Despite increasing clinical use, the relative merits of both techniques remains unclear. This study aimed to compare pSWE and the 2D-SWE measurements in test phantoms of known stiffness.

Methods

Four homogeneous phantoms (CIRS, model 039) with stiffness values ranging from 1.83–40 kPa were scanned using a Philips Epiq Elite equipped with 2D-SWE and pSWE. Measurements were performed at two depths (2.5 cm and 5 cm) using two probes: a curvilinear (C5-1) and a linear (eL18-5) transducer. Two acquisition techniques were used: (1) fixed with the probe clamped to the phantom, and (2) with free-hand imaging. This was carried out for both pSWE and 2D-SWE with 20 measurements recorded per configuration.

Results

C5-1 Probe (2D-SWE and pSWE):

- pSWE demonstrated the highest overall accuracy of 13.4%. However, it exhibited significantly greater coefficient of variation (CV) (0–55%) compared to 2D-SWE, which had a lower CV range (0–15%) and comparable accuracy of 15.7%.
- The interquartile range-to-median ratio (IQR/MED), reflecting the reliability of measurements, was notably higher for pSWE (0–75%) than for 2D-SWE (0–15%)
- Fixed SWE demonstrated the lowest CV (typically <5%), though its average bias was comparable to the free method (15-17% vs. 12-16%).

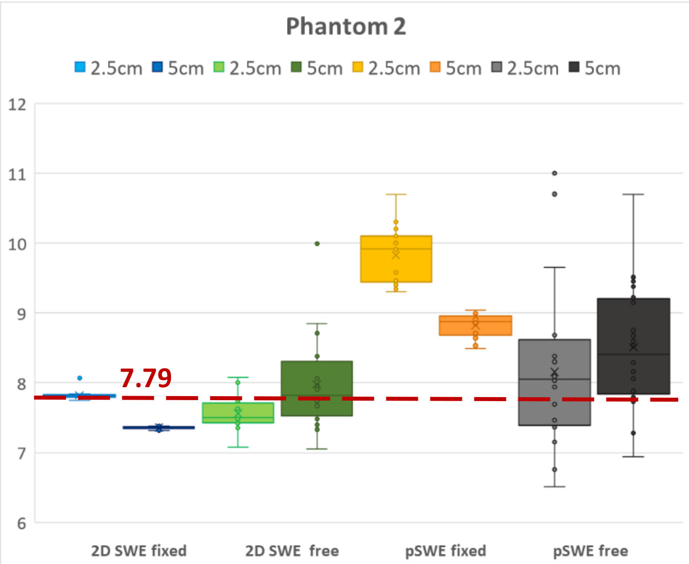

Fig. 1: Box and whisker plots for C5-1 probe; 7.8 kPa phantom

eL18-5 Probe (2D-SWE):

- Accuracy was significantly reduced compared to the C5 probe, with biases ranging from 5–2400%.
- Higher stiffness phantoms produced more accurate measurements (bias 5–16% at 39.98 kPa) compared to lower stiffness phantoms (bias 160–850% at 1.83 kPa).
- Measurements at 2.5 cm depth were more accurate (% bias 5–170%) and consistent (CV 0.5–7%) compared to those at 5 cm depth (% bias 9–2400%, CV 5–145%).

Conclusions

2D-SWE offers improved reliability over pSWE, with comparable accuracy and significantly lower IQR/MED and coefficients of variation. The comparison between fixed and random SWE methods showed that 2D-SWE maintains accuracy in freehand operation, with IQR/MED consistently below 10%. Probe selection and measurement depth strongly influence stiffness measurement accuracy, with the C5 probe outperforming the eL18. These findings underscore the need for optimized protocols to minimize bias and variability in clinical SWE applications.

Key words: Shear-Wave Elastography, point SWE, ultrasound, stiffness quantification

Progress Report: Non Ionising Scope of Practice for Clinical Technologists

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Registration is an important tool to assure patients and the public, as well as employers that Clinical Technologists are appropriately qualified and work to a defined set of professional standards. Having a dedicated Non-Ionising scope of practice allows the profession to set a benchmark defining minimum standards to ensure that non ionising technologists are knowledgeable and competent to carry out their role. It will improve visibility of the specialism and should provide stimulus for the development of training pathways and career frameworks, helping with potential recruitment issues and support the retention of expertise and experience.

In 2020, an IPEM task and finish group was formed to develop a proposal for a Non-Ionising Radiation and Ultrasound Technologist Scope of Practice. The task and finish group comprised members of the IPEM Ultrasound and Non Ionising Radiation Special Interest Group (IPEM UNIR-SIG), Clinical Technologists and Clinical Scientists representing Optical Radiation and Ultrasound specialities from across the UK. The IPEM Magnetic Resonance Special Interest Group (IPEM MR-SIG) then approached us about working on a combined proposal and we have been working together to take this forward. At critical stages advice has also been sought from members of the registration committee in terms of direction and applicability of content.

The key documents produced by the working party include:

1. Scope of Practice
2. Work-based Training Syllabus
3. Equivalence Standards
4. Equivalence Route Portfolio Guidance
5. Equivalence Route Evidence Matrix

First drafts of the documents listed above have put forward to the professional standards committee of IPEM for comments and feedback. The expectation is that this approval process should be completed by June 2025. At this point the working group will be looking for potential volunteers as means of testing the workability of the new registration route.

References

[1] RCT Guidance notes for proposing a new scope of practice to the RCT management board 03-21-42-0492-01.00-Guidance-notes-for-proposing-a-new-scope-of-practice-to-the-RCT-Mgt-Board.pdf (therct.org.uk)

Ultrasound & Optical Radiation Symposium

‘Qualitative review of an ultrasound QA feedback survey sent to imaging departments within our service. ’

Eloise O’Sullivan & Vincent Pelling

- ***Aims and/or Background***: Within our medical physics department, we routinely provide a formal annual ultrasound QA report to imaging department leads. This report comes without any follow up, there is no formally documented feedback of how the QA report has been received. *Do staff find the report clinically relevant? Is there anything in our report that staff would like to see?*
  We have created a QA survey for all imaging departments that we currently service. Our goal is to use the QA survey feedback to make informed changes to our reporting methods. The overall goal is to provide a QA service that better meets the needs of the end user, as it fundamental to us, that clinical staff have maximum engagement with our QA reports. We have also asked for information from departments about the level of user QA performed internally.

- ***Methods***: Qualitative survey created for clinical ultrasound department leads to complete, one per department. Microsoft forms used, survey was emailed to contact. Example of survey question below.

4. Please rate your satisfaction with our reporting when it comes to each of the following.

	Extremely dissatisfied	Dissatisfied	Neutral	Satisifed	Extreme
Ease to interpret					
Conciseness					
Evidence driven					
Depth of infomation					
Format consistency					
Clarity of advisory steps if given					

- ***Results:*** We are currently receiving completed surveys for analysis, deadline for completion is 30th Dec. Results to be finalised by January 31st.
- ***Discussion around results*** (if applicable)
- ***Conclusion:*** TBC
- ***Key Words:*** For example: *ultrasound, survey, QA, report writing, feedback*

Early experiences using a prototype random low echo sphere (voids) tissue mimicking test object.

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Background.

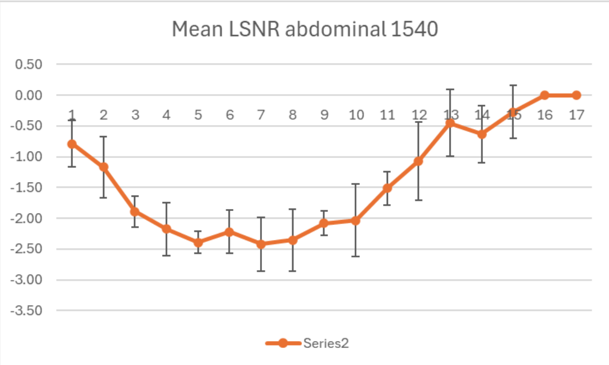
Extended imaging performance evaluation using tissue mimicking test objects (TMTO) is recommended for Radiology systems and prescribed for BSP systems. Current commercial TMTOS employ cylindrical targets to assess imaging performance however these exclude elevational information for performance assessment. A TMTO with a random distribution of spherical voids may be used to acquire translated frames from a cine loop and the number of voids (lesions) detected along with their signal to noise ratio. In this work a loaned prototype random spherical void TMTO, (Sun Nuclear, USA) was made available for first user trials and feedback.

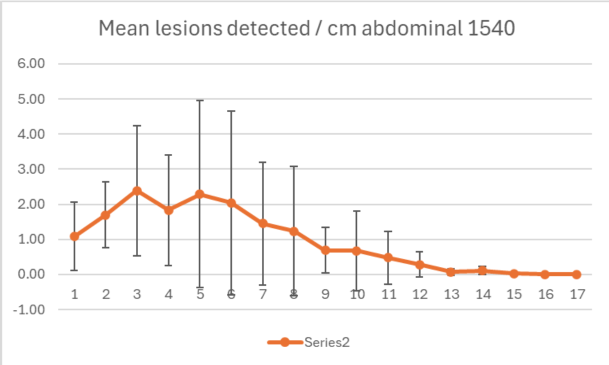
Methods.

A range of broadband abdominal ultrasound transducers currently in clinical use at Sheffield Teaching Hospitals were imaged for a minimum of 3 acquisitions and the resulting cine loop data processed using the manufacturer's supplied MATLAB script. Scores for lesion signal to noise ratio (LSNR) and number of lesions detected were compared using comparable settings. Mean data were compared for performance trends in raw LSNR and number of lesions detected. In addition to the above basic work a comparison was made between a known faulty transducer and a comparable acceptable transducer. All data was constrained to a maximum of 50 frames for processing.

Results.

The results for a Siemens S2000 (6C1), Samsung Hera W10 (CA1-7A), GE Voluson (C1-5-D), GE Logiq E9 (C1-6), GE Logiq E10 (C1-6), Mindray TE9 (C5-1 and V11-3WS) are shown below (error bars show +/- 1 s.d. over 3 sets of data):





Discussion.

Variability in ROI selection, acquisition sweep speed and alignment have potentially all contributed to a high variability in the number of lesions detected; consequently, LSNR was considered the more useful performance measure at this stage. Discussions with the manufacturer suggest re-analysis including the standard deviation derived from the individual cine loop frames, effectively enriching the elevational aspect performance measurement.

Conclusion.

Comparable trends in transducer performance can be described by LSNR vs depth but further planned work is necessary to establish the sensitivity with respect to known performance issues and other test object metrics.

Key references.

(1) IPEM, 2010, Report 102

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Meeting Note.
Next steps will be to reanalyse the data including the slice s.d. for comparison and reporting. A further period with access to the test object is planned for early 2025 and should allow more complete evaluation statistics to be completed ahead of the proposed meeting in March.

"Development and Application of a Flow Phantom for Verifying the Accuracy of Transcranial Doppler (TCD) Ultrasound Systems"

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Background.

The accuracy of ultrasound transcranial Doppler (TCD) blood flow measurements plays an important role in the assessment of cerebral blood flow in many conditions, including the management of patients with sickle cell disease[1-3]. TCD systems from some manufacturers have been reported to give slightly higher readings than other TCD systems when measuring velocities near the stroke prevention threshold in sickle cell disease. Therefore, the aim of this study was to develop a flow phantom to assess the accuracy of velocity estimates obtained with various TCD machines. We also aimed to quantify the differences between time-averaged mean velocity (TAMV) and time-averaged mean maximum velocity (TAMMV) estimates based on imaging transcranial colour Doppler (TCCD) and non-imaging TCD systems.

Methods.

A middle cerebral artery (MCA) flow phantom connected to a programmable gear pump was developed to evaluate velocity estimates from different devices under controlled conditions. Two TCD systems, DWL and Spencer, were used to obtain TAMMV measurements. Their accuracy was assessed by comparison with TAMV velocities obtained with the Zonare scanner (TCCD) and the timed fluid collection method. Bland-Altman analysis was used to estimate the bias between devices. Paired t-tests were used for group comparisons, with significance accepted a p-value of <0.05.

Results.

Angle-corrected estimates of TCCD TAMVs were not statistically different from actual mean flow velocities determined by the timed fluid collection method (p=0.5) for velocities in the normal range.

(1) For velocities in the low to normal range, differences between the two TCD systems were not significant (p >0.9). However, the velocities measured with the DWL system were +4.1 cm/s higher than those measured with the Spencer system at a TAMMV of 110 cm/s (p <0.05). At a measured velocity of 210 cm/s, the DWL system gave a reading that was +12 cm/s higher that the Spencer (p<0.05).
(2) Comparison of the TAMMV measurements displayed by the TCD systems with the TAMV estimates based on timed collection showed that the values were consistent with a multiplication factor of 1.74, assuming a 30° Doppler angle and laminar flow. However, at higher velocities, TAMMV and TAMV started to diverge, and the values no longer agreed when the scaling factor was used.

Discussion.

The DWL TCD measurements were significantly different from the Spencer TCD values at high velocities, close to the diagnostic threshold for stroke intervention. Furthermore, because TCD and TCCD calculate and display different measures of velocity (TAMMV and TAMV), the diagnostic thresholds for these two techniques are not directly transferable.

Conclusion.

We found the MCA phantom to be a valuable tool for quantifying differences in velocity estimates between different TCD devices. For centres using a range of TCD scanners, significant differences in measurements obtained by different TCD systems at high velocities may have clinical implications. Therefore, additional care may be needed to correct for bias when making treatment decisions for patients with sickle cell anaemia at velocities close to the diagnostic threshold.

Key references.

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IPEM abstract

Title

Verification and integrity checks on a commercial Doppler flow phantom

Introduction

Doppler flow phantoms are the most clinically relevant devices for checking the Doppler performance of an ultrasound system. One difficulty is ensuring that a commercial phantom has not degraded to a point where it is no longer reliable. Furthermore, users of such devices have to rely on the calibration of the device that is performed at the time of manufacture and to get them re-calibrated regularly can be prohibitively expensive. Also this often involves retuning the device to the factory which means it would be out of service for a considerable time period. A method for independently verifying the flow velocities within a flow phantom is described.

Methods

A visual inspection and a B-Mode scan was made to check the casing integrity and phantom membrane and to check for anomalies within the tissue mimicking material. An assessment of the caliper grid targets in the phantom was performed to ascertain if the phantom had deteriorated or had suffered a significant change in sound speed.

The Doppler accuracy of a Siemens S3000 ultrasound scanner was assessed using a string phantom fitted with a rubber O-ring (as recommended by Brown et. Al.2012[1]) and vibrating test object (VTO)[2], both built in-house. The VTO was driven using a function generator app on a smartphone that had been verified using a calibrated oscilloscope.

The same scanner and probes were also used with the same settings to make velocity measurement of a Sun Nuclear (Gammex) Doppler 403 flow phantom in 3 different scanning situations using a CH6-2 convex and a VFX9-4 (1.5D) linear array with flow settings between 2 and 10 ml/s.

Analysis

The VTO results were used to calibrate the Doppler system on the S3000 using the Doppler equation, transmit frequency displayed by the scanner, the speed of sound in blood and the driving frequency delivered to the VTO. The string phantom was used to calculate the expected error due to intrinsic spectral broadening (ISB)[3] for each situation at nominal velocities of 20, 40 and 60cm/s. The data from these tests was then used to calculate the expected velocity and variability likely to be measured by a commercial scanner (VTO correction only) and to estimate the true velocity in the pipe (VTO and ISB correction).

Results

Flow velocities adjusted for the scanner calibration errors yielded results that were very close to the manufacturer declared values[4] with an uncertainty due to variability of ±6.8%. Flow velocities adjusted for the ISB errors suggest the true flow velocity in the phantom is lower than the declared value by 10.4% and 16.9% on average for the ranges 20-50cm/s and 61-100cml/s respectively and with an uncertainty of ±3.7%. Also some minor anomies were observed from the B-mode images and it was found that emboli were introduced into the fluid at high flow rates. These did not prevent effective Doppler testing.

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[1] Browne J, Cournane S, Fagan A. *Evaluation of CIRS string Doppler phantom as a test tool for use in a Doppler Ultrasound Quality Assurance program*, Phys. Med. 2012, Volume 28, Issue 4p334

[2] Rowland D, *A Low Cost Doppler Test Object*, BMUS 2014 ultrasound conference proffered paper.

[3] IPEM Report 102 - *Quality Assurance of Ultrasound Imaging Systems*, IPEM York, 2010

[4] Sun Nuclear, *Ultrasound Production Report 009828-00-00*, Sun Nuclear Corporation Midleton WI, USA, 2022