Research Article

# An indigenously fabricated Doppler ultrasound blood flow phantom

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## Abstract

The objective of fabrication of Doppler Ultrasound Blood Flow Phantom is to develop an indigenous Doppler ultrasound compatible model with simulated pulsatile blood flow. The criteria for the phantom fabrication are that it should be simple, effective, economical and user-friendly. The phantom consists of a pumping mechanism to induce pulsatile flow. The blood vessels of interest are two peripheral arteries (the brachial and femoral) of normal subjects. The diameter measurements from the normal subjects are incorporated in the fabrication of a new ultrasound compatible blood vessel equivalent tube. Also tube models with various degrees and lengths of stenosis are fabricated. An affordable ultrasound compatible blood mimicking fluid having same viscosity as that of normal human blood is prepared and made to run through the system. This model acts as a phantom to educate or train a person handling ultrasound equipment on operation of the Doppler ultrasound machine controls and the effects of each control on the image. A patient or a volunteer need not be troubled for this purpose. Moreover, this phantom acts as a Quality Assurance tool to assess some of the performance of the Doppler ultrasound machine and also acts as an aid for research purpose.

**Keywords:** Blood mimicking fluid, Blood vessel equivalent tubes, Doppler ultrasound compatible blood flow phantom, Peristaltic pump, Tissue mimic.

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## INTRODUCTION

Even though, ultrasonography is considered as a safer diagnostic modality, recent research work on Bio-effects (thermal and cavitational effects) of ultrasound states that ultrasound should be used judiciously on patients[1,2,3]. Color Doppler mode ultrasonography utilizes comparatively high ultrasound power for imaging which makes it necessary for us to use it wisely on patients. Generally it has been a normal practice to utilize the body of any patient or volunteer to provide operator training or for trial / experiment / practical examination on Doppler ultrasound machine controls to sonography students or trainees which gives unnecessary ultrasound exposure to patients / volunteers. This has initiated the need for using phantoms in the place of patients. In the field of Medical Physics, phantom means a model of the body which simulates in-vivo effects. A Doppler ultrasound compatible blood flow phantom shall be used instead of patients / volunteers to get familiarized with the Doppler ultrasound machine controls and to ponder the effect of each control on the image. The Doppler ultrasound scan compatible blood flow phantom should simulate the flow of certain arteries of the human body. For this, a pulsatile flow of a blood mimicking fluid should be induced in blood vessel equivalent tubes embedded in a tissue mimic. Most importantly, the materials used for fabricating such phantom should be ultrasound compatible. In developing countries, such phantoms are not readily / commercially available. In

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developed countries like United States of America and some European countries, such phantoms are commercially available, but the cost is not-at-all affordable for hospitals and scan centres in developing countries as the phantom costs nearly the price of a lower end ultrasound scanner itself. This situation has paved the way for an idea of fabricating a simple but effective and an affordable phantom which could be fabricated easily by anyone with commonly and easily available products.

## MATERIALS AND METHODS

**Ultrasound scanning system** (Fig.II.1.a) The ultrasound scanner used for the study is GE's Logiq P5. It is a simple, user-friendly and yet efficient ultrasound scanner. Modes of imaging available in the scanner are B-scan, TM mode, Pulsed Doppler, Color Doppler, Power Doppler, Harmonic Imaging and 3D imaging. Ultrasound Transducer probe: The linear array ultrasound probe is used for the study as the blood vessels of interest are superficial peripheral arteries – Brachial and Femoral arteries.

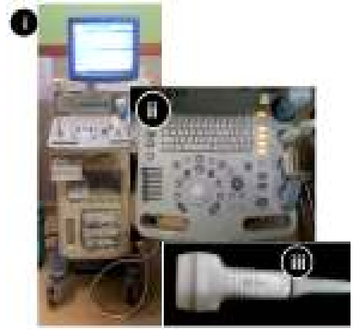

**Figure II.1.a.:** Ultrasound scanning system i) GE Logiq P5 scanner ii) Control panel iii)Linear array (12 MHz) probe

### Pulsatile flow inducing pump

For inducing pulsatile flow, a peristaltic pump with variable speed (bought from DBK Instruments, Mumbai through Science house, Chennai and customization done at Science house, Chennai) is used (Fig.II.2.a. and Table: II.2.a.). Peristaltic type pumps find its application in regulated drug delivery systems, heart-lung machines to circulate blood during by-pass surgery and also in dialysis machines.

**Figure II.2.a:** Pulsatile flow inducing pump i) Oblique view of Peristaltic pump ii) Front panel of the pump

**Table II.2.a:** Technical specifications of the peristaltic pump

| **DBK Digital Peristaltic Pump (Variable speed)** | |
|---|---|
| Designed to control the flow rate of liquid with precise volume | |
| No. of rollers | 4 |
| Motor | Step controlled |
| Compatible tube size | 1mm to 8mm ID |
| Compatible tube wall thickness | 1mm to 1.5mm |
| Speed | Adjustable from 5 RPM to 120 RPM |
| Display | 4 digit, 12 mm Red LED |
| Flow direction | Selectable Forward or Reverse |
| Flow rate | Up to 100ml/250ml per minute (depending on tube size) |
| Electical supply | 230V, 50Hz AC |

### Data Collection

For the fabrication of the blood vessel equivalent tubes, blood vessel data are collected from normal subjects. Institutional ETHICS committee clearance (Ref.no.: IEC/07/JUN/58/29 dated 26.06.2007) was obtained for collecting data from normal subjects for the fabrication of the blood vessel equivalent tube.

- Participants: Normal young adults of age group 18 to 26 years
- Blood vessels of interest: Bilateral Brachial and Femoral arteries
- Measurements taken: The blood vessel diameter and the Doppler spectrum after obtaining informed consent.
- Number of participants: 50 for brachial artery and 50 for femoral artery.

- Number of measurements: 100 readings for each artery (as measurements are taken bilaterally)

### Ultrasound Scan Procedure

The ultrasound scanner is switched on. After getting the informed consent form filled, the demographic details of the person are entered into the system. Ample acoustic coupling gel is taken on the linear probe. The linear probe setting is selected on the scanner. B-scan mode is selected. The probe is kept on the location of the brachial artery - centre of the probe at 2 inches above the level of antecubital fossa. The cross-sectional image of the brachial artery is obtained and from which the diameter is measured. The image is saved (Fig.II.3.a.). Then the probe is pivoted at that location to $90^0$ to get a longitudinal image of the brachial artery. The mode is switched over to Pulsed Wave Doppler (PW). The sample volume is selected as 1mm, placed at the centre of the vessel and Doppler spectrum is obtained. The image is saved (Fig.II.3.c.). Same is repeated for the other side brachial artery also (Fig.II.3.b. and Fig.II.3.d.). Similarly the diameter and Doppler spectrum data are obtained for bilateral Common Femoral arteries at 1 inch above the bifurcation of the vessel (Figures II.3.e., II.3.f., II.3.g. and II.3.h.).

**Figures:** Data collected from young and normal adults (18 to 26 years old)


**Figure II.3.a:** Right Brachial artery diameter measurement, showing as 0.40cm


**Figure II.3.b:** Left Brachial artery diameter measurement, showing as 0.41cm

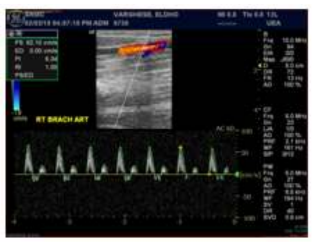


**Figure II.3.c:** Right Brachial artery Doppler spectral display


**Figure II.3.d:** Left Brachial artery Doppler spectral display


**Figure II.3.e:** Right Common Femoral artery diameter measurement, showing as 0.78cm


**Figure II.3.f:** Left Common Femoral artery diameter measurement, showing as 0.86cm

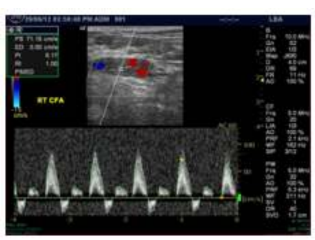


**Figure II.3.g:** Right Common Femoral artery Doppler spectral display

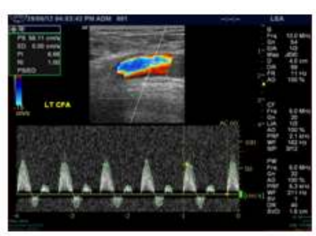


**Figure II.3.h:** Left Common Femoral artery Doppler spectral display

### Ultrasound compatible blood vessel equivalent tube

The blood vessel equivalent tube is made up of Ethylene Vinyl Acetate (EVA). This material is translucent and has very good acoustic impedance [Z] (Fig. II.4.b.) and speed of sound matching with the tissue. Z value for Human tissue and EVA is 1.63 x $10^6$ rayls and 1.60 x $10^6$ rayls respectively. The average speed of ultrasound in Soft tissue and in EVA is 1540 m/s and 1600 m/s respectively[4,5]. But EVA is comparatively more rigid than the conventionally used blood vessel mimics - silicon or latex tubes. Silicon or latex tubes are usually preferred in pumping systems as they have less rigidity and good tensile strength[6], but are of less ultrasound compatible nature when compared with EVA. To sort out this issue, Silicon tube is chosen to be the tubing in the peristaltic pump to withstand the wear and tear caused by the pumping mechanism and EVA tube is chosen as the tubing inside the tissue phantom for its good impedance and velocity matching with soft tissue and blood. These tubes are connected to each other using leak-proof tube connectors (Fig. II.4.a.).


**Figure II.4.a:** Blood vessel simulating tubes and connectors

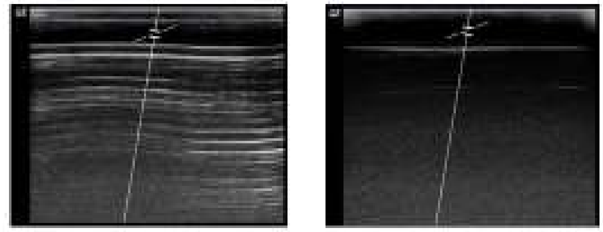

**Figure II.4.b:** Acoustic Impedance matching of blood vessel equivalent tube i) Improper impedance matching of silicon tube producing reverberation ii) Good impedance matching of EVA tube showing good transmission

### Ultrasound compatible flow restrictors

Flow restrictors are used within the blood vessel equivalent tubes to simulate various lengths and degrees of stenotic conditions (Fig. II.5.a.). Acrylic is the material chosen for simulating stenosis as there was no problem in transmitting ultrasound through it. Acrylic sheets are cut and shaped into short cylinders of various diameters and lengths (Fig. II.5.b.) and drilled at the centre using a drill tool to form various inner diameters (Fig. II.5.c.) using lathe machine and then are coaxially placed inside the EVA tubes to simulate various degrees and lengths of stenosis. Thus various brachial artery and femoral artery models are created (Fig. II.5.d.).

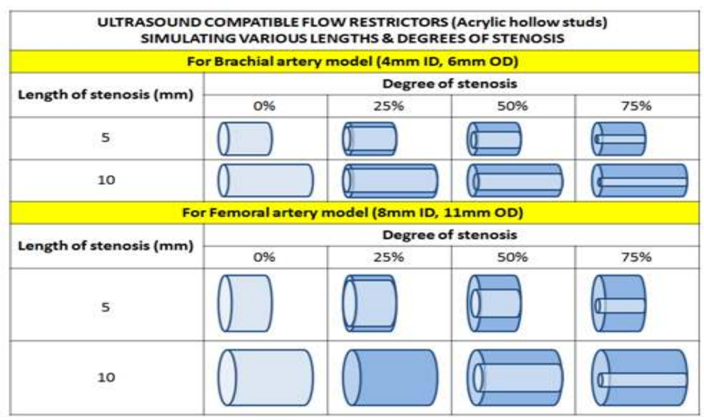


**Figure II.5.a.:** Flow restrictors

**Figure II.5.b.:** Cut acrylic stub shaped into a cylinder using a lathe machine

**Figure II.5.c.:** The acrylic cylinder drilled coaxially using lathe machine

| | |
|---|---|
|  | **Brachial & Femoral artery model** 0% stenosis is represented by the EVA tube itself |
|  | **Brachial artery model** 25%, 50% & 75% stenosis with 5mm length |
|  | **Brachial artery model** 25%, 50% & 75% stenosis with 10mm length |
|  | **Femoral artery model** 25%, 50% & 75% stenosis with 5mm length |
|  | **Femoral artery model** 25%, 50% & 75% stenosis with 10mm length |

**Figure II.5.d:** EVA tubes of various lengths and degrees of stenosis

### Ultrasound compatible tissue equivalent material

The classical Agar-Gelatin mixture itself is used as the tissue mimic. The ultrasound compatible tissue equivalent material is Agar-Gelatin mixture as the speed of ultrasound in it closely matches with the average speed of ultrasound in Soft-tissue (1540 m/s) and also produces a texture in the image similar to soft-tissue (Fig.II.6.b.i.). The speed of ultrasound check in the tissue mimic is done indirectly by verifying that the size of the image equals the size of the object (Fig.II.6.b.ii.).

### Procedure for preparation of tissue mimic

Take 3 g of Agar and 5 g of Gelatin powder for every 100ml of distilled water. As 1500ml of distilled water was needed for the tissue set-up, 45g of Agar and 75g of Gelatin were used. Stir mix the contents and heat it for about 5 minutes. Cool it down to 40$^{o}$C and pour into the phantom container having blood vessel equivalent tubes (Fig.II.6.c.i.). Then gelatin-soaked cotton gauze is laid on its surface to mimic skin (Fig.II.6.c.ii.). This tissue mimic can be refrigerated and used for up to one month.

**Figure II.6.a.:** Agar powder and Gelatin powder

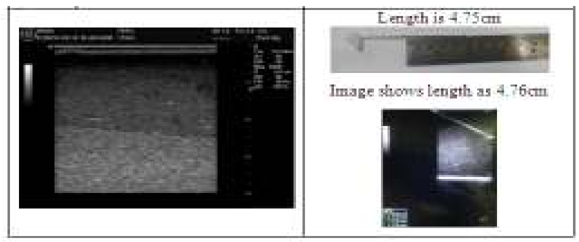


**Figure II.6.b.:** Ultrasound images of Tissue mimic i) Scatter produced similar to soft-tissue ii) Speed of sound check in the mimic

**Figure II.6.c.:** Tissue and Tube phantom container i) EVA tubes inserted through the drilled holes of the Plastic container ii) Agar-Gelatin mixture filled into the container and layered with gelatin to mimic skin

### Ultrasound compatible blood mimicking fluid

Conventionally, Blood Mimic is made up of Water-Glycerin mixture. But this mixture does not contain any scattering medium (as the RBCs in blood) to yield good signal. In some of the studies, to produce scatter, 5 micron size nylon powder[7] or 50 micron size Sephadex particles[8] have been added to the Water-Glycerin mixture. But these are not very affordable and not commonly available (imported). In these solutions, to rule-out bubbles, a food colour also is added. In order to have a commonly available and at the same time less expensive ultrasound scatterer to serve the purpose of producing enough signal, lot of materials were tried as a substitute for micron sized nylon powder / sephadex and lastly ended up in replacing water with Waterbury's compound syrup (a syrup used for cough, cold, bronchitis and respiratory infections - marketed by Pfizer Limited). The Waterbury's compound syrup which contains 3mg of elemental Iron per 15ml produced better signal than water (Fig.II.7.b.). Moreover, the syrup is already colourful (caramel and erythrosine) and hence no need for adding any food colour. To determine the viscosity of liquids, Ostwald's viscometry was carried out (tests done in Department of Pharmacy or could be done in any Physics laboratory). The viscosity of Waterbury's compound syrup is found to be 2 cP. To get the viscosity of whole blood (which is 3centipoise)[9], 1 part of Glycerine was added to 4 parts of Waterbury's compound syrup (Table II.7.a.). If Waterbury's compound syrup is not available any other syrup containing elemental iron shall be used. But the viscosity check needs to be done.

**Figure II.7.a.:** Waterbury's Compound syrup and Glycerin

**Table II.7.a:** Viscosity values by Ostwalds Viscometry

| Sr. No. | Sample | Viscosity (centipoise) |
|---|---|---|
| 1 | Distilled water (reference medium) | 1.008 |
| 2 | Waterbury's compound (Syrup) | 2.062 |
| 3 | 80% Syrup + 20% Glycerin | 3.057 |

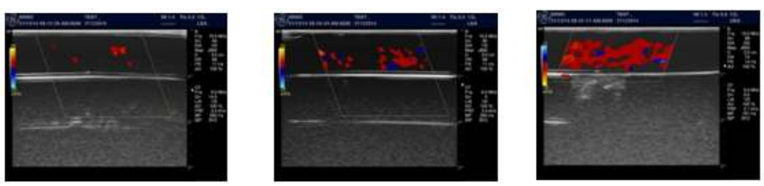

**Figure II.7.b.:** Color Doppler signals from the liquid flowing within the blood equivalent EVA tube i) Water ii) Water + Glycerol iii) Waterbury's compound + Glycerol

## Procedure

The work started with the identification and availability of the suitable materials for the fabrication of Doppler Ultrasound compatible blood flow phantom. Simultaneously, the diameter and Doppler flow pattern data of bilateral brachial and femoral arteries are collected from the normal young adults of age group 18 to 26 years old. After which, the materials are procured and fabrication work started.

## Fabrication work

The diameter of brachial artery is around 4mm and femoral artery is around 8mm. So tubes of these diameters are fabricated. Silicon tubes of 4mm inner diameter (ID) and 6mm outer diameter (OD) for brachial artery model and 8mm ID and 10mm OD for femoral artery model are available readymade. But EVA tubes of these dimensions are not readily available and so are specially fabricated at Sona plastics, New Delhi. Then acrylic flow restrictors to simulate various degrees (25%, 50% and 75%) and lengths (5mm and10mm) of stenotic conditions are fabricated and coaxially inserted into the EVA tubes. The silicon tube is let into the roller system of the pump. The inlet of the silicon tube is dipped into the blood mimicking fluid reservoir and the outlet side is connected to same dimension EVA tube fitted inside the tissue mimic container and the outlet of which is let into the reservoir. This forms a loop and the peristaltic pump helps to set up a pulsatile circulatory flow of the blood mimicking fluid in the phantom (Fig.III.8.a.). The ultrasound scanner is turned on. The linear array ultrasound transducer is used. Linear array display setting is selected in the machine. Initially B-scan is activated. The probe is kept on the tissue phantom and B-scan image is performed. The image of the longitudinal section of the vessel mimic is brought on to the monitor. Then the mode is switched over to Pulsed Doppler mode. The sample volume of 1mm is set at the middle of the vessel lumen. Auto Doppler setting is selected which has Doppler angle as $60^o$. A Doppler spectrum of the signal within the sample volume is generated by the machine. The rollers of the pump are made to rotate at a speed of 80RPM and adjusted to impart adequate pressure to the silicon tube so as to produce an identical brachial or Femoral Doppler spectral waveform.

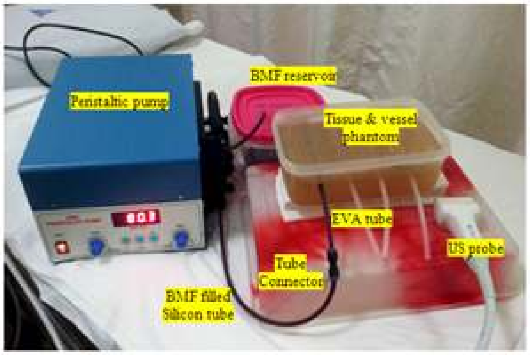


**Figure III.8.a.:** Phantom set-up

**Figure III.8.b.:** Experimental set-up

## OBSERVATIONS AND RESULTS

### The result of the data collection from normal subjects

i) The diameter of the Brachial artery is nearly **4mm** and the Doppler spectral waveform is triphasic.
ii) The diameter of the femoral artery is nearly **8mm** and the Doppler spectral waveform is triphasic.

Graphical representation of the diameter values of Brachial and Femoral arteries of normal subjects are shown in Fig. IV.a.i.and IV.a.ii. respectively.

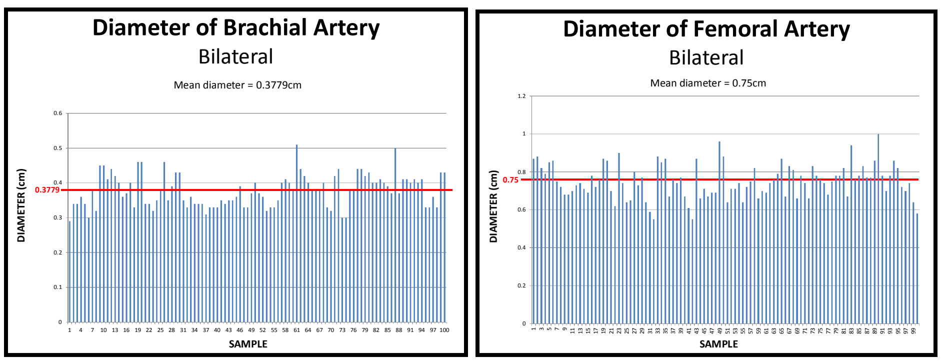


**Figure IV.a:** Bar diagram showing Diameter values i) Mean value of brachial artery = 0.3779cm ii) Mean value of Femoral artery = 0.75cm

### The result of the Doppler blood flow Phantom fabrication work

i) The materials required for the fabrication work are identified.
   They are
   - Pulsatile flow inducing pump is Peristaltic pump
   - Ultrasound compatible
   - tissue equivalent material is the classical Agar and Gelatin mixture
   - blood vessel equivalent tube is the newly tried EVA tube
   - the stenotic condition mimicking material is the newly tried Acrylic
   - blood mimicking fluid is the newly tried concoction of 80% Waterbury's compound syrup and 20% Glycerin

ii) The availability of each was checked with the concerned company and products were purchased.
iii) The acrylic flow restrictors to simulate various stenotic conditions were fabricated at Department of Engineering design in Indian Institute of Technology, Madras (IITM, Chennai) and the parts were assembled at Sri Ramachandra University (SRU).
iv) The Phantom's performance was checked in due course at Department of Radiology and Imaging Sciences, SRU. Required customization in the pump was done at Science House, Chennai.
v) The Doppler spectral waveforms generated by the phantom during brachial artery and femoral artery set-up are as shown below (Fig. IV.b.i. and Fig. IV.b.ii.)

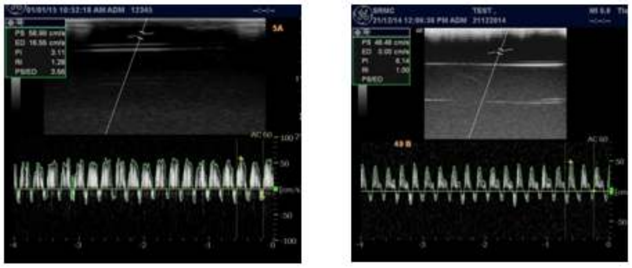

**Figure IV.b.:** Doppler spectrum waveform i) Brachial artery model ii) Femoral artery model

## DISCUSSION

The novelties shown in the fabrication work are the use of

i) EVA material for the fabrication of blood vessel equivalent tubes as EVA has very good impedance matching with soft tissue than the conventionally used silicon or latex tubings.
ii) Acrylic material for the fabrication of flow resistors to simulate various stenotic conditions and the deployment technique of it into the EVA tubes.
iii) very affordable elemental iron containing Waterbury's compound syrup as a replacement to very costly micro sized plastic particles for the preparation of Blood Mimicking Fluid to produce scatter like that of RBC in blood.

With reference to the result, the waveform obtained from the Doppler flow phantom is almost replicating the waveform from the human subjects. The waveform can be even improvised if the pump is controlled by computer software. This may demand for some more investment and might make the phantom costlier and complex. The fabrication work is complete with this simple set-up itself in order to stick back to the objective of fabricating an easy, effective and affordable flow phantom.

## CONCLUSION

The fabrication work of the Doppler blood flow phantom is completed and the functioning of the same is satisfactory as the objective of the work is reached in the sense that this phantom is effective, simple, user-friendly and can be in constant use in the department as an educational / training tool. The design can be replicated without much investment and effort. Fabrication and usage of such phantoms as an educational / QA tool will encourage and develop the safety and quality culture among the ultrasonogram users.

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## REFERENCES

1. Susan Katz Miller, Exposure Criteria for Medical Diagnostic Ultrasound: II. Criteria Based on all Known Mechanisms on Diagnostic Ultrasound Safety - A summary of the technical report: National Council on Radiation Protection and Measurements (NCRP) Report No. 140, 2002.
2. Guidelines for the Safe Use of Diagnostic Ultrasound, published by Minister of Public Works and Government Services Canada, 2001.
3. Gail ter Haar: The Safe Use of Ultrasound in Medical Diagnosis, 3rd Edition: Published by the British Institute of Radiology, 2012.
4. George D. Ludwig: The velocity of sound through tissues and the acoustic impedance of tissues: The journal of the acoustical society of America, Volume 22, Number 6 November, 1950, Pages 862-866.
5. Alan R.Selfridge: IEEE Transactions On Sonics and Ultrasonics, Vol. SU-32, No.3, May 1985. Pages 381-394.
6. Von Boetticher H, Delebinski R, Risch U, Luska G: A versatile phantom for hemodynamic measurements with ultrasound Doppler equipment: Ultraschall Med, 1994Oct;15(5): 264-8 mentions that "blood vessels are simulated using latex or silicone tubes or heat-shrink sleeving; in the artificial blood, sephadex particles or silicone emulsion were used as scatterers".
7. H. Samavat, J.A. Evans: An ideal blood mimicking fluid for Doppler ultrasound phantoms: Journal of Medical Physics, Volume 31, No.4, 2006.
8. Hoskins PR, Loupas T, McDicken WN: A comparison between the Doppler signals from human blood and artificial blood used in a flow phantom: Ultrasound in Medicine and Biology,1990; 16 (2): 141-7 mentions that "the artificial blood used was a suspension of Sephadex particles in a glycerol solution".
9. K. Rammnarine, et. al.: Validation of a New Blood-Mimicking Fluid for Use in Doppler Flow Test Objects: Ultrasound in Medicine and Biology, Vol. 24. No. 3,

pp.454. states “the Properties of Human Blood (at 37°C) - Viscosity = 3 mPa and Velocity = 1583 m/s”

10. Jia Wei Li, Manoj K. Karmakar, Xiang Li, Wing Hong Kwok, and Warwick Dean Ngan Kee: Gelatin-Agar Lumbosacral Spine Phantom - A Simple Model for Learning the Basic Skills Required to Perform Real-time Sonographically Guided Central Neuraxial Blocks: JUM February 1, 2011 vol. 30 no. 2 263-272
11. William Tsai • O¨ mer Savas: Flow pumping system for physiological waveforms: Med Biol Eng Comput (2010) 48:197–201
12. Ronald O. Bude, Jonathan M. Rubin: Relationship between the Resistive Index and Vascular Compliance and Resistance: Radiology 1999, 211:411-417
13. Hoskins PR, Anderson T, McDicken WN: A computer controlled flow phantom for generation of physiological Doppler waveforms: Phys Med Biol. 1989 Nov;34(11):1709-17
14. H. Samavat, J.A.Evans: An ideal blood mimicking fluid for Doppler ultrasound phantoms: Journal of Medical Physics, Vol.31, No.4, 2006 while mentioning about BMF states that “ However the ideal BMF has not yet been produced, differences in parameter values and physical behaviour still exist between the BMF and real blood in in-vitro studies”.

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