Critical Review

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PROJECT

Ultrasound Imaging of Ventricular Brain Shunts

Our project is to develop a new ultrasound imaging technology that can explore the inner side of human brain with external probe through the skull.

PAPERS SELECTION

1) An Anthropomorphic Polyvinyl Alcohol Triple-Modality Brain Phantom based on Colin27

   Sean Jy-Shyang Chen, Pierre Hellier, Jean-Yves Gauvrit, Maud Marchal, Xavier Morandi and D. Louis Collins

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   MEDICAL IMAGE COMPUTING AND COMPUTER-ASSISTE INTERVENTION-MICCAI 2010 6362 (2010) 92-100

2) Three–Dimensional Printing (3DP) of neonatal head phantom for ultrasound: Thermocouple embedding and simulation of bone

   Matteo Gatto, Gianluca Memoli, Adam Shaw, Neelaksh Sadhoo, Pierre Gelat, Russell A. Harris.

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REASONS FOR SELECTING THE PAPERS

This project is to develop a new technology that can be used for the Ventricular Brain Shunts. A phantom, that can mimic the ultrasound properties of human brain, needs to be prepared for the investigation. For the purpose of minimizing the cost, our group decides to build our own phantom. These two papers provide us a practical way to build the phantom for the inner part and the skull, respectively.

Although, many materials can be used for the phantom inner part, polyvinyl alcohol cryogel (PVA-C) provides the best solution as it can be used permanently. This is also verified in ref. [1]. Paper-I did a good job on the material preparation and the shaping process. For the skull part, the correct infiltrant combination for the 3DP material has been addressed on paper-II. Also, it provides the data on how to control and change the acoustic properties by changing this combination.

Following these two papers, we can create the phantom inner part and outside part, respectively. After choosing appropriate dimensions, these two parts can be assembled and this would be used for mimicking the whole human brain.

Paper I: An Anthropomorphic Polyvinyl Alcohol Triple-Modality Brain Phantom based on Colin27

Background:

Polyvinyl alcohol cryogel (PVA-C) is a typical tissue-mimicking material for ultrasound imaging. It is formed from PVA solution undergoing some freeze-thaw (F/T) cycles. As the optical and mechanical properties change with the number of F/T cycle, certain requirements, like the scattering coefficient and absorption coefficient, for the phantom can be achieved. This kind of phantom can be used in a permanent way under humidity-controlled conditions.

Summary & Key Results

This paper develops a way to create a brain phantom with anatomically realistic structures and physically realistic texture by using PVA-C. The formulation of the phantom material to approximate live cerebral brain tissue makes it possible to improve the deep-brain stimulators and biopsy needle insertions. Also, different levels of $BaSO_4$ of the initial base solution are investigated to determine how to increase the phantom contrast.

The images, acquired from three ways of MR, CT and US, show good qualities, which can be verified from one modality to act as the ground truth of another. These multi-modal images can be used in very wide fields like segmentation, super-resolution, image reconstruction, linear or non-linear registration and denoising algorithms.

Construction Process:

1) 5% or 8% by weight PVA are dissolved in distilled water. And this solution is heated for about 7 hours at the temperature of 93 to 95 degree Celsius.
2) The PVA solution is cooled to -25 to -20 degree Celsius for about 12 hours. Then, the solution will warm back to room temperature in a continuous way for another 12 hours. If needed, this F/T cycle can be repeated for several times. Without the addition of dimethyl sufoxide (DMSO), the scattering coefficient will increase with each cycle and the phantom will be stiffer, too.
3) Brain Mold is prepared using Colin27 data set.
4) Approximating the live Brain Texture. (Useful data from paper: 6% PVA solution at 1 FTC is similar to palpating the surface of a live brain and 4% PVA at 3FTC as being similar to palpating a low-grade gliomas.)
5) Implants for registration and image guidance are included.

Future Work:

1) Develop better multimodal imaging spherical markers for higher contrast imaging.
2) Find better MR contrast agents to reduce diffuse.

Assessment:

The author did a good job on designing the experiment for materials formulation. A very detailed description of PVA solution preparation and PVA-C preparation is made, which makes it possible for the readers to reproduce the experiments. The author also provides a brief description what the mold looks like and how it is used.

However, the paper does not include any description on what it is based for the mold construction. Also, it is less instructed for the readers to generate the STL file without a specified CAD model creation description. Though this is, at some point, beyond the purpose of this paper, it is crucial for the readers to recreate the whole experiment, which can make it a more practical reference.

For approximating the live brain texture, the author gives the typical formulation of the solution, which narrows the range for the experiment in the future. The author also pointed out how to control the hardness of the phantom, which is also important for approximating the pathological tissue, like a tumor.

Aside from the experiments on creating the phantom, this paper also presents a novel idea to conquer the weakness of registration due to the small size of structures and insufficient contrast of the markers. By using images acquired from one modality to act as the ground truth of another, we can demonstrate the validation of certain imaging processes.

Conclusion:

The paper proposed a practical method to construct a realistic human brain phantom. This phantom has higher anatomical accuracy, more realistic texture than the conventional ones. And the phantom shows its validation in three imaging devices (MR, US and CT), which can have great significance in many applications.

Paper II: Three–Dimensional Printing (3DP) of neonatal head phantom for ultrasound: Thermocouple embedding and simulation of bone

Background:

Current phantoms applied in ultrasound are relatively simple, not only in the shapes (cylinder, spheres or disks), but also in the materials.

3DP provides a way to model complex structures that cannot be completed by conventional methods, such as molding, casting, milling, etc.

Another difficulty we face is the material, as most of the materials used in 3-D printer and thermal polymers that are relatively hard. This is a several problem for ultrasound imaging.

Summary & Key results:

A neonatal skull phantom for ultrasound testing is designed and created by using 3DP technology. Though the phantom is relatively simple in geometry in this paper, it still demonstrates its validation in shaping. This is because 3DP allows the manufacture of more geometrically complex ultrasound phantoms, which can be obtained with the help of reverse engineering of tomographic dataset of living patients. A novel 3DP material is found to be able to mimic the acoustic properties of the neonatal skull bone and has been used in producing this phantom. Also, post-processing (infiltration) plays a key role in reproducing good acoustic properties.

For the bone mimic, three different infiltrants were tested: epoxy resin, polyester resin and paraffin wax by using the attenuation coefficient as the target property. The resulting comparison with the target value identified that the ceramic infiltrated with epoxy resin is the best solution to mimic neonatal cranial bone (with an attenuation coefficient of 6.85 ± 0.7 dB cm^{-1}). And the polyester resin samples present acoustic properties in the range of adult skull bone (with an attenuation coefficient of 64.9 ± 6 dB cm^{-1}). These results show that we can create the phantom for both neonatal head and adult head. But polyester resin needs to deal with the problem of shrink.

Construction Process:

Typical modeling process for medical application is described here:

1) Use CT/MRI to get the medical image
2) 3D model reconstruction in the medical software
3) Computer Aided Design (CAD)
4) STL file generation
5) Prototyping (3DP)
6) Post-processing: cleaning, support removal, infiltration, etc.

Assessment:

3DP provides a way to manufacture complex structure. But the materials used in 3D printer are usually very hard, which is not proper for ultrasound imaging. The authors in this paper did a great job in finding a novel 3DP material combination. This provides the readers a good solution for modeling the human skull in using this technology. But what we should notice is that the results demonstrating its validation in US imaging is based on a very simple shape phantom, which we cannot guarantee it works well when the shape becomes complex. And the relatively smooth surface can also make the measurements inaccurate when we model a more realistic phantom. Thus, certain measurements are still needed when a more realistic phantom is needed.

Some further results in the later part still have the potential to improve as the brain mimic material used in this paper can be replaced by more suitable material discussed in paper-I.

The skin fabrication in this phantom also makes this phantom more realistic than simple skull as some other works did.

Conclusion:

The paper proposed a practical method to construct a realistic neonatal skull phantom. New material combination proposed in this paper makes it possible to print a realistic skull with acoustic properties. This phantom can be combined with a brain phantom to model a whole human head.

Reference

[1]. Fre´ de´ ric Bevilacqua, Dominique Piguet, Pierre Marquet, Jeffrey D. Gross, Bruce J. Tromberg, and Christian Depeursinge: In vivo local determination of tissue optical properties: applications to human brain. 1 August 1999/ Vol.38, No.22/ Applied Optics.