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Polyacrylamide-based Tissue-Mimicking Phantoms for Performance Evaluation of Photoacoustic Systems

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1. Introduction

Tissue-mimicking material (TMM) phantoms have become one of the main points of research in the photoacoustic imaging (PAI) field. There is a need to create standards to test the performance of PAI systems to develop commercial systems that can be used in real settings. Phantoms that mimic the optical and acoustic properties of tissue are fundamental for the development of these standards. This paper focuses on the development of a polyacrylamide TMM phantom that mimics the optical and acoustic properties of dermis.

2. General Characteristics

Some criteria[1)] for TMM phantoms for PAI has been established: tissue-like properties, tunability, stability, architectural flexibility, reproducibility, simple maintenance, safety, and availability.

Polyacrylamide is one material that fulfills many of these requirements, many of which are analyzed in this paper. Some of these properties are somewhat subjective and based on qualitative analysis, such as architectural flexibility, reproducibility, and availability. In the case of polyacrylamide, it presents excellent architectural flexibility, since it can take the shape of any mold. The reproducibility can be somewhat difficult to keep consistent, since it requires precision measurements in the scale of microliters and milligrams, depending on the skill and technique of the author. As for its availability, most materials can be bought from specialized stores. Acrylamide is toxic so it requires special care and restrictions.

2.1 Composition

Two compositions, High and Low, of TMM have been developed in order to fulfill the range of values of optical and acoustic properties of dermis [2)]:

Total volume 10 mL	Low TMM	High TMM
Nigrosin	0.3 mg	0.5 mg
TiO2	0	12 mg
Tween 20	2 mL	3 mL
Acrylamide	2.5 mL	2.5 mL
APS	8 mg	8 mg
TEMED	10 uL	10 uL
DI Water	5.49 mL	4.49 mL

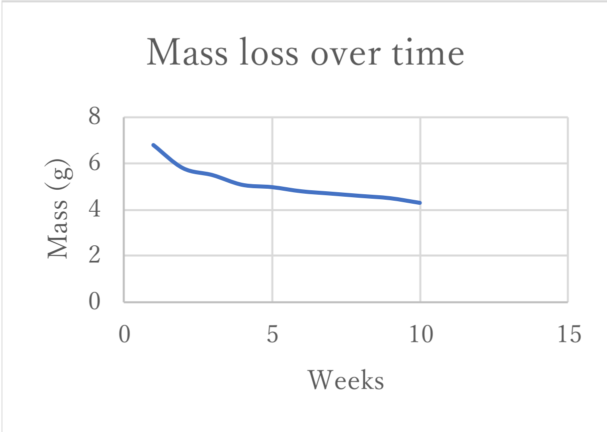

Fig. 1 Temporal stability of the TMM phantom over a period of 10 weeks.

2.2 Temporal Stability

The mass loss of the TMM was measured over a period of 10 weeks using a weight balance. As it can be seen on Fig 1., there is a sharp loss of mass the first few days (the TMM shrinks). Afterwards, it remains fairly stable, and the loss is around 2 mg. This shows that the polyacrylamide TMM can be useful for long periods of time. It is important to consider that the TMM must be kept in the fridge all time and contact with air should be avoided.

2.3 Optical properties

The IAD algorithm was used to measure the optical properties of the phantom, as shown in Fig 2 and Fig 3.

The measurements showed that the values of dermis were successfully reproduced with great accuracy at the wavelengths of interest (570 nm): for the LOW TMM μa= 0.0783 and μs= 1.0496, whereas for the HIGH TMM μa= 0.2876 and μs= 2.4519. This shows that the optical properties of the polyacrylamide TMM can be tunned according to the needs of the experiment, in this case dermis.

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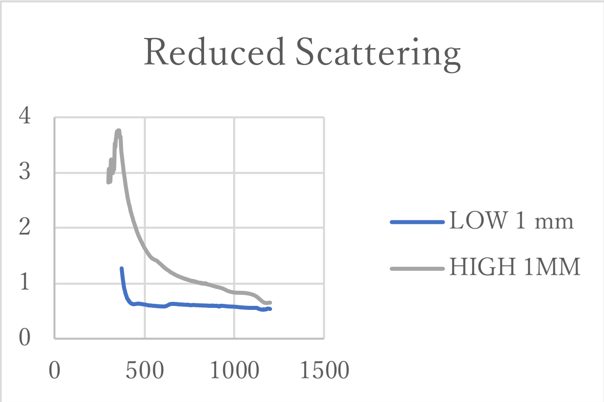

Fig. 2 Reduced scattering coefficient of TMM

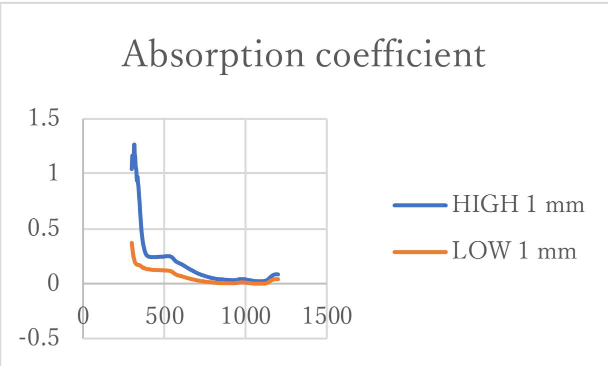

Fig. 3 Absorption coefficient of TMM

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2.4 Acoustic Properties

The acoustic properties of the TMM are also interest. Thus, the speed of sound of the TMM has been measured using the pulse-echo mode technique. The experiment shows that the TMM has a speed of sound of 2000m/s, very close to the real value of dermis, which varies from 1560 m/s to 1700 m/s. The acoustic attenuation must also be measured, and will be done in the future as soon as possible.

3. Discussion

The polyacrylamide TMM satisfies most of the points of the criteria established for PAI phantoms. The optical and acoustic properties are very close to the properties of real dermis, and also presents good tempoeral stability. Safety is one of the main concerns, as acrylamide is toxic. Correct equipment and technique should be used.

References

1) Lina Hacker, Heidrun Wabnitz. Nature. (2022).
2) Hsun-Chia Hsu, Keith A. Wear, William Vogt. J. Biomedical Express (2022).