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Polyvinyl chloride-plastisol: a soft tissue-mimicking phantom dedicated to multi-modality elastography

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Over the past three decades, different methods have been developed for tissue elasticity measurement using medical imaging. All elastography approaches rely on the encoding of tissue displacement as a result of a force field that can be either external or internal, static or dynamic [1]. Displacements can be encoded by using medical imaging, such as Magnetic Resonance Imaging (MRI), ultrasound imaging or optical imaging. Tissue-mimicking phantoms are of primary importance during the development, validation and calibration processes in elasticity imaging [2,3]. Phantoms are typically used not only for the development and validation of elasticity reconstruction algorithms in a controlled medium, but also for operator training. Research-based and commercially available phantoms are today proposed for elastography, mostly dedicated to one specific elastography modality [4].

Ideally, elastography-dedicated phantoms are expected to offer the following features: (1) Their mechanical properties must be well controlled and must lie within typical values of soft tissues they are supposed to mimic (such as elasticity, viscosity, hyperelasticity, anisotropy or porosity); (2) They must possess specific constitutive properties, such as storage conditions, duration and conservation requirements; (3) They must be compatible and optimal for the medical imaging modality they have been developed for. Important features that need to be accounted for are the preservation process, the stability over time and the toxicity. Depending on the imaging method, the elastography phantoms are mainly composed of a matrix, solvents, scatterers and other additives [3]. Attempts to propose multi-modality elastography comparisons are related in the literature [5,6], showing the necessity of investigating multi-modality elastography phantoms. Soft PolyVinyl Chloride (PVC) suspensions in a liquid plasticizer (plastisol) have been proposed as tissue-mimicking candidates for MRI-Elastography (MRE), ultrasound-based and optical elasticity imaging [7-10]. In addition to their inexpensiveness, PVC phantoms are simple to prepare, stable over time at room temperature and resistant to handling.

The objective of the current study is to characterize the mechanical and imaging properties of plastisol gels. We aim at fully characterizing the ability of soft plastisol to mimic biological soft tissues for multi-modality elasticity imaging. Mechanical properties, MRI relaxation times, acoustic and optical properties are successively quantified. The following properties are investigated with 40% to 80% PVC-concentrated gel phantoms (*Plastileurre Soft and Softener, Bricoleurre, Mont-Saint-Aignan, France*):

(1) The mechanical properties: the dynamic linear (elasticity) and non-linear mechanical properties (hyperelasticity). These properties are investigated using both rheometry (*Thermo Scientific HAAKE MARS III, Rheology Solutions, Bacchus Marsh, Australia*) and indentation, as well as their sensitivity to temperature of use and stability over time (samples tested over two months). The mechanical properties in terms of stiffness and hyperelasticity are compared and shown as similar to typical values for the biological soft tissues. After two weeks, the gel is shown as stable for months.

(2) The MRI properties: the T1 and T2 relaxation times. These properties are acquired in a 1.5T MRI scanner (*MAGNETOM Aera, Siemens AG, Erlangen, Germany*) essential for the use of the phantom in MRE and are systematically compared to typical values found in the literature for biological tissues.

(3) The acoustic properties: the absorption properties. These properties are essential for the use of the gel phantom in ultrasound-based elastography. They are measured using an acoustic test bench with a 1 MHz mono-element transducer and a 0.2 mm needle hydrophone (*SN2319, Precision*

Acoustics Ltd, Dorchester, UK). The values are compared and shown as similar to typical values found in the literature for biological soft tissues.

(4) The optical properties: Plastisol refractive index is measured (at 589 nm) using a refractometer (*Universal Refractometer, OPL, France*), depending on PVC concentration (Fig (A)). The absorption coefficient μ_a (Fig (B)) and reduced scattering coefficient μ'_s (Fig (C)) are shown as independent on the PVC concentration and depends on the Nigrosin volume concentration (at 665 nm) and TiO_2 volume concentration (at 665 nm), respectively. The comparison between this table and Fig. 5 gives an indication about how to prepare a phantom using plastisol in order to mimic as closely as possible the optical properties of any biological soft tissue.

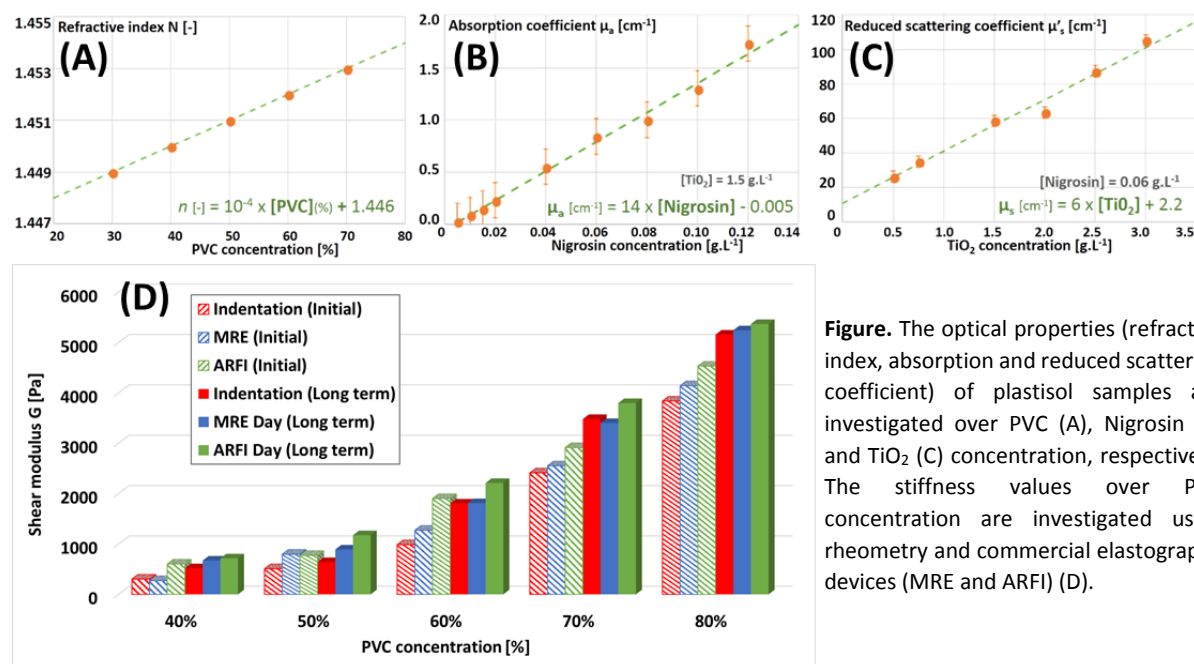


Figure. The optical properties (refractive index, absorption and reduced scattering coefficient) of plastisol samples are investigated over PVC (A), Nigrosin (B) and TiO_2 (C) concentration, respectively. The stiffness values over PVC concentration are investigated using rheometry and commercial elastography devices (MRE and ARFI) (D).

The comparison (Fig (D)) of the stiffness (initial and after 2-weeks stabilization) values is also performed, depending on the PVC concentration, between rheometry and commercial elastography devices: MRE (*Resoundant, Inc., Rochester, MN, USA*) and classical ARFI (*Acoustic Radiation Force Imaging*) ultrasound-based elastography (*Acuson 3000, Siemens AG, Erlangen, Germany*). In addition to controlled mechanical properties, plastisol appears as an ideal candidate for the development of multi-modality elasticity imaging methods. This part of the study indicates clearly how to prepare a robust and controlled phantom to mimic most of the biological tissues for any elastography modality.

In this study, we have shown how the sampling preparation protocol and composition make plastisol an easy and pertinent stable candidate for tissue mimicking phantoms dedicated to researchers as well as operators training for multi-modality (MRE, ultrasound-based and optical) elastography.

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