FABRICATION AND CHARACTERIZATION OF POLYVINYL ACETATE SLIME PHANTOM FOR MAGNETIC RESONANCE SPECTROSCOPY

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by

SITI SARAH BINTI BAHARUDIN

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CERTIFICATION

This is to certify that the dissertation entitled is FABRICATION AND CHARACTERIZATION OF POLYVINYL ACETATE SLIME PHANTOM FOR MAGNETIC RESONANCE SPECTROSCOPY is the genuine record of research work done by Ms Siti Sarah Binti Baharudin during the period from February 2019 to July 2020 under my supervision. I have read this dissertation and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor of Health Sciences (Honours) (Medical Radiation).

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Date: 31st July 2020

DECLARATION

I, Siti Sarah binti Baharudin hereby declare that this dissertation ENTITLED FABRICATION AND CHARACTERIZATION OF POLYVINYL ACETATE SLIME PHANTOM FOR MAGNETIC RESONANCE SPECTROSCOPY is the result of my own investigations, except where otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purposes.

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LIST OF ABBREVIATIONS

Abbreviation	**Definition**
ADP	Adenosine Diphosphate
ATP	Adenosine Triphosphate
Cho	Choline
Cr	Creatine
Cr_2	Chromate
DKI	Diffusion Kurtosis Imaging
FWHM	Full Width Half Maximum
Gln	Glutamine
Glu	Glutamate
Glx	Glutamine + Glutamate
GPC	Glycerol
Hz	Hertz
Lac	Lactate
Lip	Lipid
Mi	Myo-inositol
MRI	Magnetic Resonance Imaging

MRS	Magnetic Resonance Spectroscopy
MRSI	Magnetic Resonance Spectroscopy Imaging
NAA	N-Acetylacetate
NMR	Nuclear Magnetic Resonance
SNR	Signal to Noise Ratio
PD	Proton Density
PC	Phosphocholine
ppm	Part per million
PVA	Polyvinyl Acetate
PVA-C	Polyvinyl Alcohol-Cryogel
PVP	Polyvinylpyrrolidone
QC	Quality control
RF	Radio frequency
ROI	Region of interest
TMS	Tetramethylsilane
T1WI	T1 weighted image
T2WI	T2 weighted image
TE	Time to echo
TMS	Tetramethylsilane

TR	Time to repeat
VOI	Volume of interest

ABSTRAK

Tujuan kajian ini adalah untuk mengetahui kebolehan, kesesuaian, dan keserasian slime polivinil asetat sebagai fantom yang boleh meniru tisu manusia untuk kajian spektroskopi resonans magnetik (MRS). Fantom dibuat dengan agen gel dan sebahagian daripandanya tanpanagen gel dengan mengukur bahan dan mencampurkannya. Dalam kajian ini, terdapat tujuh jenis fantom dengan bahan yang berbeza. Empat daripadanya adalah fantom slime PVA yang dibuat dengan bahan tambahan yang berbeza seperti air, minyak, susu dan garam. Sementara tiga yang lain terdiri dari air, minyak dan susu sahaja yang dianggap sebagai kawalan. Pengimejan MRS dilakukan menggunakan sistem MRI Philips Achieva 3 Tesla yang terdapat di Jabatan Radiologi, HUSM. Semua fantom dicirikan berdasarkan spektrum MR dan anjakan kimia mereka. Spektrum MR dan anjakan kimia fantom juga dibandingkan dengan tisu normal dan tisu patologi. Hasil dari kajian ini menunjukkan bahawa anjakan kimia dan terutamanya data nisbah metabolit kemungkinan besar setara dengan tisu manusia. Dengan ini dapat disimpulkan bahawa fantom slime PVA fantom yang menyerupai tisu untuk MRS kerana ciri fantom yang sesuai digunakan di MRS.

ABSTRACT

The aim of this study is to explore the feasibility, suitability, and compatibility of polyvinyl acetate slime as tissue mimicking phantom for magnetic resonance spectroscopy (MRS) studies. Phantoms are made with gelling agents and some without by measuring the ingredient and mixing them. In this study, there are seven types of phantoms with different ingredient. Four of them are PVA slime phantoms which were fabricated with different additives that are water, oil, milk and salt. While the other three consist of water, oil and milk only which were regarded as control. MRS imaging was performed using Philips Achieva 3 Tesla MRI system available at Department of Radiology, HUSM. All phantoms were characterized base on their MR spectra and chemical shift. The MR spectra and chemical shift of the phantoms were also compared with those of normal and pathological tissue. The result from this study show that the chemical shift and especially the metabolite ratio data are much likely equivalent to human tissue. It can be concluded that PVA slime phantom can be use as tissue mimicking phantom for MRS as the characteristics of the phantom is suitable to use in MRS.

CHAPTER 1- INTRODUCTION

1.1 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI), formerly known as nuclear magnetic resonance (NMR) operates based on the interaction between the nucleus spin and magnetic field. It works around the change in the longitudinal and transversal magnetizations of tissues. Due to its high spatial and temporal resolutions and unique ability to distinguish between different types of soft tissues without using ionizing radiation, its demand in the medical field increases each year. With MRI scanners being extensively used in clinical and research settings, they are prone to technical and image quality problems. Thus, quality control (QC) is important and necessary in order to maintain good diagnostic quality of MRI images produced (Yee et al., 2019).

Proton magnetic resonance spectroscopy (MRS) provides metabolic information that is not available by conventional MR imaging. The MRS can give an estimate of brain tumor malignancy, as well as breast, prostate, and liver disease severity. In addition, it has been used for the diagnosis of schizophrenia, depression, Alzheimer's disease, and Parkinson's disease (Woo et al., 2009). Proton magnetic resonance spectroscopy (MRS) is a powerful non-invasive tool that has been widely used for the assessment of brain metabolites and the investigation of normal and abnormal metabolism in brain tissue. With the availability of improved hardware and acquisition techniques, in vivo single-voxel 1H-MRS and multi-voxel magnetic resonance spectroscopic imaging (MRSI) can offer new possibilities at high field strengths, such as

7T. Increased signal-to-noise ratio (SNR) and spectral resolution in short echo time single-voxel spectra at 7T compared to 1.5T, 3T and 4T have been demonstrated previously. This increase in SNR can be used to shorten the total acquisition time and/or increase the spatial resolution (Li et al., 2012).

In brain MRS, the principle molecules that can be analysed are N-acetyl-aspartate (NAA) (molecule that present in healthy neurons) at 2.0 ppm, Creatine (Cr) (energy metabolism molecules) at 3.0 ppm, Choline (Cho) (marker in the synthesis and breakdown of cell membranes) at 3.2 ppm, Myo-inositol (ml) (can only be found in glial tissue) at 3.5 ppm, Glutamine-Glutamate_GABA complex (Glx) (neurotransmitter) between 2.1 and 2.5 ppm, Lactate (lac) (anaerobic metabolism) doublet at 1.35 ppm and free lipids (Lip) has wide resonance and doublet at 1.3 and 0.9 ppm.

Spectroscopy uses signal intensity, line width and position to display information from molecules of interest. There are multiple chemical regions of the same molecule may contribute distinct signals to the spectrum. MRS plots hydrogen atom (proton) metabolite signal intensity versus an observation frequency. The metabolite peaks shown on x-axis reflects the local chemical and magnetic environment of the molecule. The position is described by employing the parts-per-million (ppm) scale. The metabolites NAA, Cr, Cho, the longitudinal relaxation T1 times approximate 1.2-1.4 seconds at 1.5T and increase slightly to 1.2-1.6 seconds at 4T, with Cho the shortest. These value impact the TR necessary to conduct the MRS experiment.

Acquiring proton MRS data at 3T compared with 1.5T should provide a significant with an increase in signal to noise ratio (SNR), which can be applied for increased speed of acquisition, spatial resolution and voxel size. This increase has been actually found to be about 20% for short echo (TE 20 ms) and approaching 100% for long echo single voxel proton MRS. The peaks appeared wider at 3T at short echo times than at 1.5T. When there is increase in magnetic field strength, there is a decrease in metabolite T2 relaxation times. Hence, the metabolite line widths increased. The resolution improved from the increased field strength is achieved with increased spectral dispersion. The spectrum is dispersed as the frequency between peaks is greater at higher field strength.

1.2 MRI phantom

MRI phantoms are used for the calibration and checking of MRI equipment, the development of new systems and pulse sequences, and the training of MRI operators (Kengo Hattori et al., 2013). A MRI phantom used for such purposes must have these characteristics which are relaxation times equivalent to human tissues; dielectric properties equivalent to human tissues; homogenous relaxation times and dielectric properties throughout the phantom; sufficient strength to fabricate a torso without the use of physical reinforcements; allowing fabrication in the shape of human organs; the ease of handling; and chemical and physical stability over an extended time. Two types of MRI phantoms are commonly used: those of an aqueous solution of paramagnetic ions containing $CuSO_4$, $NiCl_2$, $MnCl_2$, or $GdCl_3$ is normally used for checking MRI equipment, because of its homogenous relaxation tie throughout the phantom and its long-term stability Aqueous phantoms have several disadvantages: T1 and T2 relaxation times are approximately equal and thus do not mimic human tissue well. Human tissue T1 relaxation times are ten times longer than T2 relaxation times. Additionally, aqueous solutions do not maintain their form without a container (Hirokazu Kato et al., 2005).

Phantom are used in medical imaging research to substitute for real tissue in studies where in vivo models are inappropriate. Phantoms can be modelled on anatomical features, such as vessels and vascular trees, including structures such as white and grey matter and lesions, or mechanical structures that behave appropriately, such as a pulsating vessel wall. One benefit to modelling these features with PVA-C rather than using anatomical specimens is the phantom can be made precisely, with a known that is used as ‘truth’. This is particularly useful for segmentation algorithm development where the digitally segmented structure must be compared to known geometry (Surry et al., 2004).

1.3 Polyvinyl Acetate Slime

Slime is a cross-linked polymer. These individual chains of the PVA molecule slide across each other until a cross-linking agent is added such as borax, which is tetraborate decahydrate ($Na2B4O7 \cdot 10H2O$). The increases the viscosity of the polymer (glue) (Costello, 2018). PVA slime is safe to use and water proof as it is also remains flexible after drying. PVA slime is widely available and inexpensive.

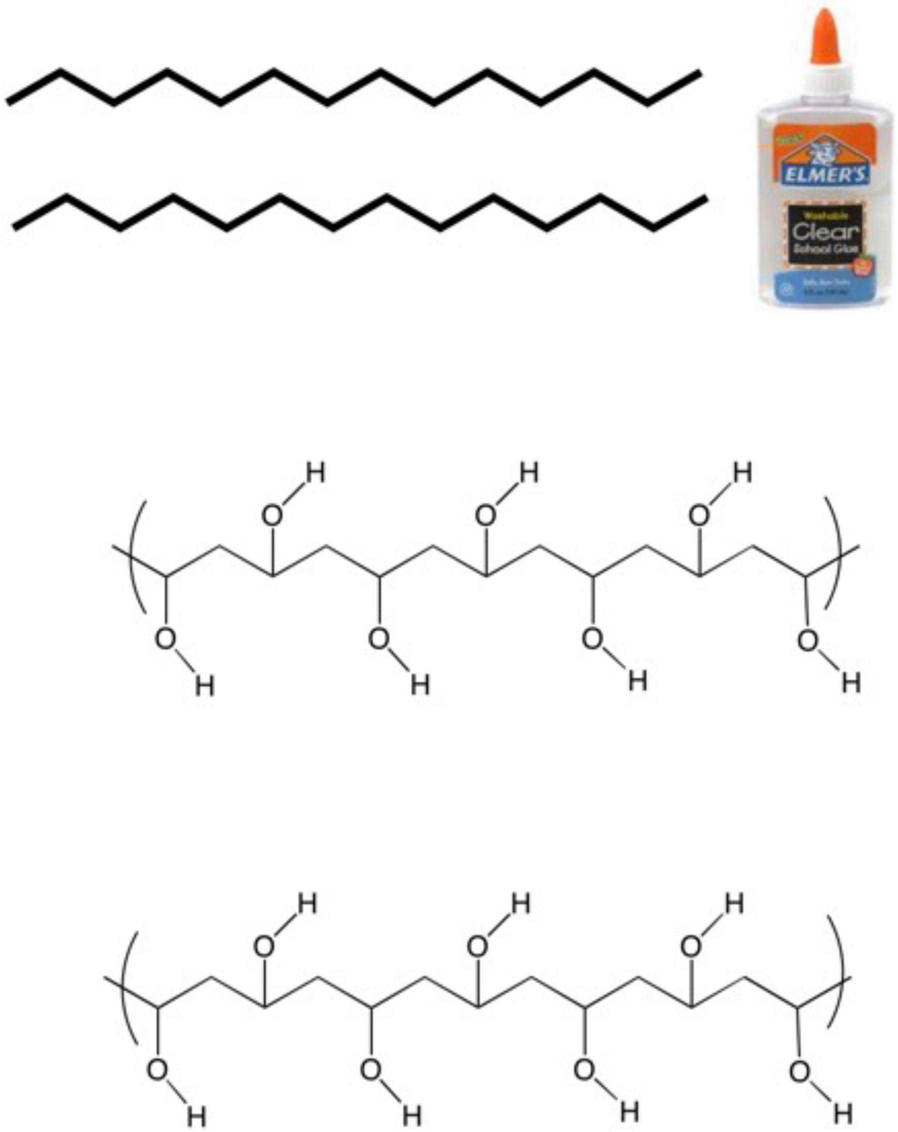

Figure 1.1: Structure of PVA that composed of many individual units of the chemical compound vinyl acetate.

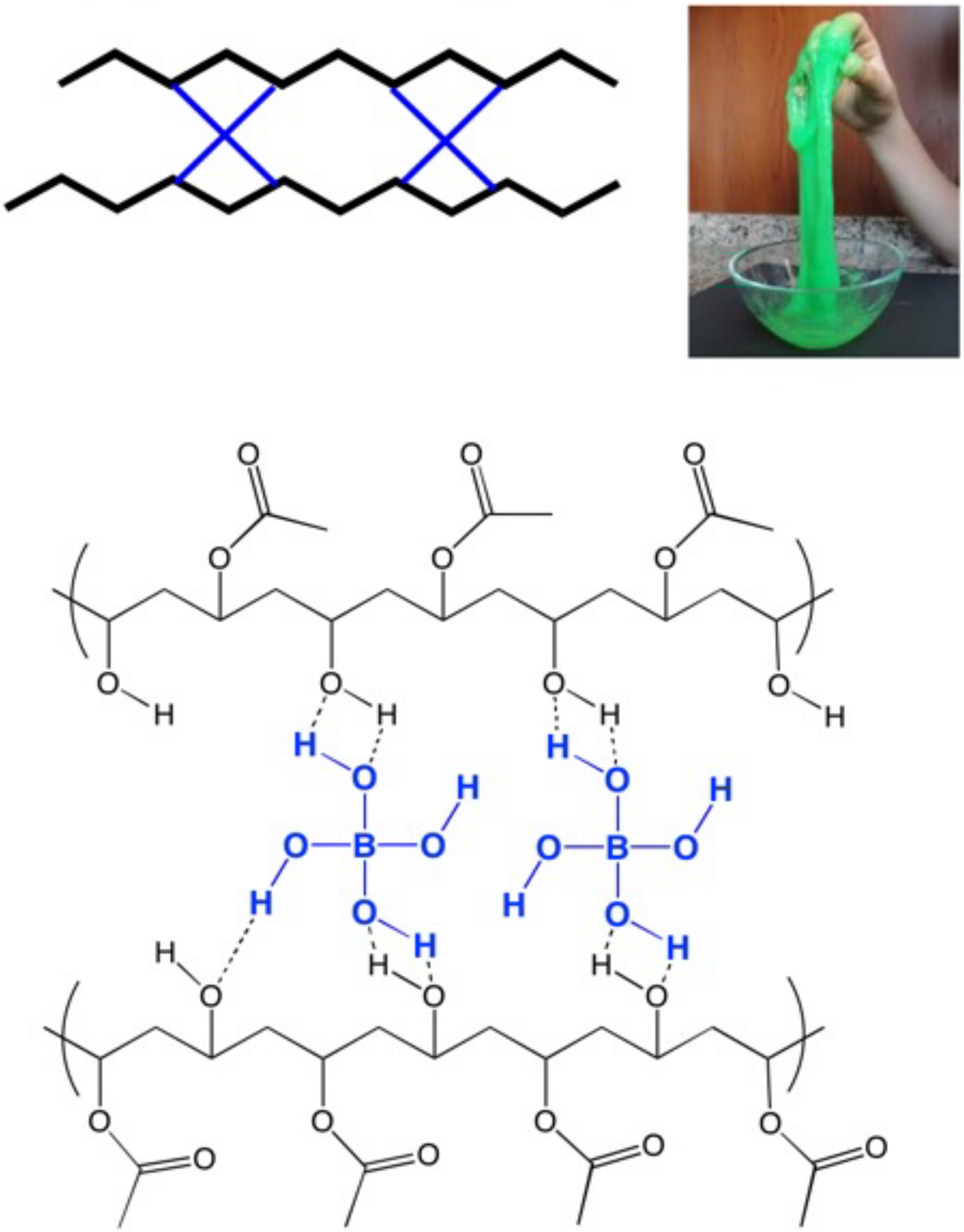

Figure 1.2: Borax cross linker

1.4 Problem Statement

Various advantages of PVA slime have been mentioned in Section 1.3. However, its suitability and compatibility to be used as tissue mimicking phantom for MRS, as well as the extent to which it has similar intrinsic characteristic with biological tissues such as its magnetic properties and chemical shift needs further investigation. This study was conducted to observe the potential of PVA slime as a phantom for MRS. The development of the new materials and techniques for fabrication of phantom which is suitable with the properties of phantom are crucial from time to time.

1.5 Objectives

1.5.1 General objective

The aim of this study is to explore the feasibility, suitability, and compatibility of polyvinyl acetate slime as tissue mimicking phantom for MRS studies.

1.5.2 Specific objective

1. To fabricate PVA slime phantoms of different additives, that are water, oil, salt, and milk as well as three control materials, that are water, oil, and milk.
2. To characterize the MR spectra and chemical shift of the fabricated phantom.
3. To compare MR spectra and chemical shift between all phantoms and with those of normal or pathological tissues.

CHAPTER 2: LITERATURE REVIEW

2.1 MRS

Nuclear magnetic resonance (NMR) spectroscopy is one of the most powerful and versatile analytical techniques that can be applied to liquid and/or solid materials and has become increasingly popular in the field of food science for the evaluation and the analysis of several foods, such as beverages, oils and lipids, vegetables, meat, and dairy products. NMR spectroscopy is an analytical technique based on the magnetic properties of certain nuclei that have an odd mass number or an even mass number but odd atomic number. These nuclei possess a nuclear spin "S," which is a form of angular momentum that does not have a macroscopic analogue (that is, nuclei do not literally rotate around themselves) and is characterized by a nuclear spin quantum number, "I" (Hatzakis, 2017).

Proton magnetic resonance spectroscopy (MRS) is a powerful non-invasive tool that has been widely used for the assessment of brain metabolites and the investigation of normal and abnormal metabolism in brain tissue (Li et al, 2012).

Proton MRS appeals to many clinicians and scientists as the application in the clinical setting can increase the specificity of MRI when implemented with appropriate questions for MRS to answer. However, enthusiasm for application of this technique is