Potential use of polyvinyl alcohol (PVAL) gel materials as mammography phantoms for the detection of calcifications

Franca Oyiwoja Okoh¹³, Mohd Fahmi Mohd Yusof²ᵃ, Siti Nor Azizah Abdullah¹

¹School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia
²School of Health Sciences, Universiti Sains Malaysia, 16150 Kelantan, Malaysia
³Federal University Wukari, 234 Wukari-Taraba State, Nigeria

ᵃmfahmi@usm.my

Abstract. The study focused on the construction of phantoms made of the polyvinyl alcohol (PVAL) gel materials for mammography based on the dimensions of available RMI phantom for quality control in mammography. The PVAL gel phantoms were fabricated at 20% percentages of PVAL to water to provide target density of 1.0 g/cm³ and physical strength similar to that of human soft tissues. The calcifications were simulated by using calcium based powders at three different depths. Mammography images were obtained based on the automatic exposure control (AEC) at different compression forces. The results showed That all samples showed good visualisation of calcifications in the mammography images of all fabricated phantoms. The calcifications were well defined with no significant differences of the visualisation of calcifications in all mammography images of all fabricated PVAL gel phantoms. The results indicated the potential of PVAL gel materials to be developed and used as phantoms for the quality control works in mammography.

1. Introduction
Mammography became the most common method for the detections of breast cancer. Mammography can be classified into two namely screening and diagnostic mammography. The screening mammography is usually conducted in healthy persons for the early detection of breast cancer whilst the diagnostic mammography is more specific to provide better localizations of the breast cancer. Calcification is often used as indicator for the detection of breast cancer using mammography imaging. Calcification is the hardening of the breast tissues due to the deposition of calcium compounds. Breast calcifications is categorized as benign, probably benign and malignancies [1][2]. The pattern of calcifications would determine between benign and the risk of malignancies [3][4]. In the quality assurance of mammography imaging, the calcification detection became one of the important criteria to be complied. The quality assurance for mammography is commonly conducted by the acrylic based phantoms such as the Mammographic Accreditation Phantom model 18-220 (Fluke Biomedical, Cleveland, USA). This phantom provides the Al₂O₃ specks to simulate the calcifications. The acrylic phantoms however did not simulate the compressing features that would change the shape and patterns of the calcifications during mammography imaging.
Several studies had been conducted to fabricate a new type of phantoms for the quality assurance in mammography that focused on the determination of glandular dose [5-7]. PVAL is a water-soluble synthetic polymer that would form gel-structure materials through the process of freezing and defrosting [8]. It has approximate mass density of 1.19 g/cm³ which is near to the value of water made it suitable to be developed as water and tissue equivalent bolus materials. A previous work suggested the suitability of PVA gel to be used as phantom for the magnetic resonance imaging and bolus materials for external beam therapy due to its close physical and radiological parameters to the human soft [9][10]. Another study also indicated the suitability of PVAL phantom for visualisation of calcifications by using dual energy technique [11].

The phantoms, made of alcohol (PVAL) in the current study, were fabricated in application for mammography. Low mammography range x-rays were used to visualise the calcifications in the fabricated PVAL gel phantoms at different depths from the surface of the phantoms.

2. Methodology

2.1. Preparation of the PVAL gel phantom materials

The polyvinyl alcohol (PVAL) material was purchased from the Sigma-Aldrich Inc. (Sigma-Aldrich, Darmstadt, Germany). It has the monomer unit of (g)n and was prepared in a crystalline powder form by the manufacturer. PVAL crystals were mixed into an amount of water and heated to enhance its solubility. The PVAL-water solutions were prepared at 20% based on the weight of the water to provide sufficient physical strength of the PVAL gels [10]. The mixtures were filled in a container with dimensions of 5 × 7 × 5 cm. The PVAL-water solutions were cooled down into room temperature to eliminate the air bubbles from the solutions before being frozen by using a refrigerator for approximately 12 hrs to form solid PVAL-water materials. The solid PVAL-water materials were then being defrosted at room temperature until the translucent gel PVAL bolus materials were achieved. Calcifications were simulated by using the CaCO₃ powders and being added onto the formed PVAL gels at different depths between of 1.5, 2.5 and 3.5 cm from the surface before another layer of PVAL gel was added as shown in Figure 1. The completed fabricated PVAL gel phantoms are shown in Figure 2.

![Figure 1](image-url)  
**Figure 1.** The schematic diagrams of fabricated PVAL gel phantoms for mammography with calcification features at (a) 1.5 (b) 2.5 and (c) 3.5 cm depths.
2.2. Mammography imaging of the fabricated PVAL gel phantoms

The mammographic images of the fabricated PVAL gel phantoms were obtained by using a computed mammography unit in the Radiology Department, Hospital Universiti Sains Malaysia (HUSM). The mammography imaging was carried out by using the automatic exposure control (AEC) based on the thickness and the compression loads of the mammography unit towards the fabricated PVAL gel phantoms. The mammography images were analysed by using the ImageJ software to evaluate the visual of the calcifications at various exposure factors and depths in the fabricated PVAL gel phantoms.

3. Results and discussion

The exposure factors by the AEC setups on the fabricated PVAL gel phantoms are shown in Table 1. The thickness of the fabricated PVAL phantoms reduced when higher compression forces were applied. The exposure factors of the mammography by the AEC were generally decreased when the thickness of the fabricated PVAL gel phantoms decreased. This is due to the exposure factors by the AEC that were based on the size and thickness of the tissue being imaged [12][13]. A few increment of mAs were also seen when the compression forces were increased due to variation of entrance surface air kerma (ESAK) when AEC is used [14].

Table 1. The force of compression, resulting thickness and exposure factors (kVp and mAs) on the fabricated PVAL gel phantom A, B and C during the mammography imaging.

| Depth of calcifications (cm) | Force (N) | Thickness (cm) | kVp | mAs |
|-----------------------------|-----------|----------------|-----|-----|
| 1.5                         | 0         | 4.4            | 28  | 333 |
|                              | 22.72     | 4.0            | 28  | 286 |
|                              | 68.18     | 3.7            | 27  | 304 |
|                              | 113.64    | 3.2            | 26  | 284 |
|                              | 159.10    | 2.9            | 26  | 259 |
| 2.5                         | 0         | 4.3            | 28  | 334 |
|                              | 22.72     | 4.2            | 28  | 304 |
|                              | 68.18     | 3.9            | 27  | 304 |
|                              | 113.64    | 3.4            | 26  | 312 |
|                              | 159.10    | 3.1            | 26  | 272 |
| 3.5                         | 0         | 4.7            | 28  | 345 |
|                              | 22.72     | 4.2            | 28  | 312 |
|                              | 68.18     | 3.8            | 27  | 300 |
|                              | 113.64    | 3.3            | 26  | 282 |
|                              | 159.10    | 2.9            | 26  | 255 |
The compression in mammography would provide uniform density in the breast tissues during imaging procedure. This would give better uniform attenuation by the x-ray giving better image quality as the absorption and scattering is uniform throughout the tissue being imaged.

The mammography images of the fabricated PVAL gel phantoms at all experimented compression forces are shown in Figure 3. The results showed that all the calcifications in all fabricated PVAL gel phantoms were clearly visualized at all mammography images. The calcification patterns at higher compression forces are appeared to be slightly dispersed and easier to be distinguished from each cluster. The compression forces and the resulted thickness of the fabricated PVAL gel phantoms did not significantly affect the mammography images at all experimented compression forces [15-17].

### Table 2.
The mammography images of the fabricated PVAL gel phantoms at different exposure factors (kVp and mAs) resulted from the compression forces and phantom thicknesses.

| Force (N) | Fabricated PVAL phantom images |
|-----------|--------------------------------|
| 0         | ![Image A](image1.png) ![Image B](image2.png) ![Image C](image3.png) |
| 22.72     | ![Image A](image4.png) ![Image B](image5.png) ![Image C](image6.png) |
| 68.18     | ![Image A](image7.png) ![Image B](image8.png) ![Image C](image9.png) |
| 113.64    | ![Image A](image10.png) ![Image B](image11.png) ![Image C](image12.png) |
| 159.1     | ![Image A](image13.png) ![Image B](image14.png) ![Image C](image15.png) |
The depth of the calcifications from the surface of the fabricated gel phantoms also did not significantly affect the mammography images at exposure factors. The calcifications however did not simulate the pattern of microcalcification often observed in available mammography phantoms. Specific scoring for the calcifications also was not possible due to large calcifications of the CaCO$_3$ powders used in this study. The overall results however indicated the potential of the fabricated PVAL gel materials to be used as phantoms in the quality control of mammography.

4. Conclusion
The fabricated PVAL gel phantoms were able to visualize the calcification using the mammography imaging at all experimented compression forces and exposure factors. The exposure factors used based on the phantom thickness resulted from the compression forces did not significantly affect the visualisations of the calcification features. The depth of the calcifications also did not significantly affect the visualisations of the calcification features. The overall results indicated the potential of PVAL gel materials to be developed as phantoms for the quality control of mammography imaging.

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