Polyvinyl alcohol (PVA) based bolus material for high energy photons and electrons

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Abstract. The study focused on the use of fabricated bolus materials based on the polyvinyl alcohol (PVA) to increase the surface dose on high energy photons and electrons. The PVA based bolus materials were fabricated at 2.5, 5, 7.5 and 10% PVA in water at target density of 1.0 g/cm³. The PVA based boluses were scanned by using the computed tomography (CT) scanner along with the solid water phantoms. The percentage depth (PDD) dose of the solid water phantoms and the PVA based bolus materials were measured by using the treatment planning software (TPS) at 6 and 10 MV photons and 6 and 9 MeV electrons. The PDD curves obtained were compared to that of the standard bolus material and the surface dose were measured. The results showed that the PDD curves of solid water phantoms with PVA based bolus materials were consistent within 1.4% percentage of difference for both 6 and 10 MV photons and within 2.9 and 1.4% percentage of differences in 6 and 9 MeV electrons respectively. The increment of surface dose in PVA based bolus materials in excellent agreement to the standard bolus material and the percentage of PVA did not significantly affect the surface dose. The overall results showed the potential use of the PVA to be used as bolus material for clinical photons and electrons.

1. Introduction
Bolus has been used in as tissue compensator to compensate the deficit of the anatomical surface of patients undergoing radiotherapy [1][2]. Bolus materials usually have flabby characteristics and often constructed in the form of semi-solid gel to provide better contact with the skin surface. It is constructed with density close to water and human soft tissue (1.0 g/cm³) to provide similar attenuation to the human soft tissue towards the photons and electrons. In other application, bolus materials are used to increase the surface dose especially for the treatment of near surface [3][4]. This is achieved by placing the bolus material on the surface while maintaining the source to surface distance (SSD) between the gantry and the surface of the medium. This would reduce the skin sparing effect by bringing the build-up region and the depth of maximum dose, dmax closer to the surface. The semi-solid characteristic of the bolus would reduce the air gap between the bolus and the medium that would cause dose perturbation beyond the air gap [5].

Typical bolus materials used in the radiotherapy are made of various carbohydrate based substances to simulate the human soft tissues such as rice, sugar pellets and sodium bicarbonate [1]. Several studies had been carried out by researchers to fabricate bolus materials with various non-
carbohydrate substances [6-10]. This study focused on the use of polyvinyl alcohol (PVA) as bolus material. PVA is a water-soluble synthetic polymer that would form gel-structure materials through the process of freezing and defrosting [11]. 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 for photons and electrons. A previous work suggested the suitability of PVA gel to be used as phantom for the magnetic resonance imaging due to its close MRI parameters to the human soft [12]. This study fabricated the bolus material from the PVA-water solution and measured the percentage depth dose (PDD) and surface doses in high energy photons and electrons.

2. Methodology

2.1. Preparation of the Polyvinyl Alcohol Based Bolus Materials

The polyvinyl alcohol (PVA) was purchased from the Sigma-Aldrich Inc. (Sigma-Aldrich, Darmstadt, Germany). It has the monomer unit of (CH₂CHOH)n and was prepared in a crystalline powder form by the manufacturer. It’s close density to water made it suitable to be considered as water equivalent phantom material. The PVA based bolus materials were achieved by mixing the PVA crystals into the water. An amount of water was heated during the process to enhance the solubility of PVA crystals into water. The PVA-water solutions were prepared at 4 different percentages of 2.5, 5.0, 7.5 and 10% based on the weight of the water. The PVA-water solutions were then cooled down to the room temperature to eliminate the air bubbles from the solutions. The solutions were then filled in a square-shaped containers with external dimensions of 10 × 10 cm². Each percentage of the PVA-water solutions was prepared with two different thicknesses of 0.5 and 1.0 cm based on the readily available bolus materials for radiotherapy. The PVA-water solutions were then cooled and being freeze by using the refrigerator for approximately 12 hrs to from the solid PVA-water materials. The solid PVA-water materials were then being defrosted at room temperature until the translucent gel PVA bolus materials were achieved as shown in Figure 1.

![Figure 1](image)

**Figure 1.** (a) The fabricated PVA bolus material and (b) the standard carbohydrate based bolus material commonly used in radiotherapy.

2.2. Measurement of Percentage Depth Dose in High Energy Photons and Electrons

The PVA bolus materials were placed onto a set of solid water phantoms with approximate thickness of 25 cm and being scanned by using a computed tomography (CT) scanner. The PVA bolus materials and the solid water phantoms were scanned at abdominal scanning protocols with exposure factors of 120 kVp and 250 mAs and slice thickness of 0.1 cm. The CT images of the PVA bolus materials and the solid water phantoms were transferred into the treatment planning software (TPS) commonly used in radiotherapy. The photon and electron beams were simulated from the TPS on the solid water
phantoms and the PVA bolus materials. The simulations were based on the IAEA TRS 398: 2000 codes of practice (100 cm source to surface distance and 10 × 10 cm$^2$ field size). Two energies of photons of 6 and 10 MV and two energies of electrons of 6 and 9 MeV were simulated as shown in Figure 2. The percentage depth dose (PDD) in the solid water phantoms were measured based on the equation:

\[
\text{Percentage Depth Dose} = \frac{D}{D_{\text{max}}} \times 100\%
\]

with $D$ and $D_{\text{max}}$ is the dose at depth and maximum dose respectively.

\[\text{Percentage difference} = \frac{\text{dose with bolus} - \text{dose without bolus}}{\text{dose without bolus}} \times 100\% \]

\[\text{Figure 2. The simulation of (a) photon and, (b) electron beams on the solid water phantoms by using the treatment planning system (TPS) software.}\]

The PDD curves were plotted for all photon and electron energies. The PDD curves were compared to that in the available bolus material and the open field beams (without bolus). The surface doses at the presence of bolus and without the use of bolus were determined and the percentage differences of the surface dose were calculated by using the equation:

3. Results and Discussion
The PDD curves were plotted from all the photons of 6 and 10 MV and electrons of 6 and 9 MeV based on the calculation in Equation 1. Figure 3 shows the PDD curves in the 6 and 10 MV photons measured with the use of PVA bolus materials in comparison to the available bolus material in the radiotherapy department. The results showed that the PDD curves obtained by using the PVA bolus materials were in excellent agreement to the standard bolus material. The different percentage of PVA also did not significantly change the measured PDD. The comparison to the PDD curve measured in open field (without bolus) showed a slight shift of the PDD measured in the PVA bolus materials and standard bolus material to the left. The use of bolus significantly increased the surface dose on the solid water phantom as shown in Table 1. The use of bolus increased the surface dose in comparison to the open field to 95.44 and 95.66% to the $D_{\text{max}}$ [4,8,9]. This satisfied with the primary function of the standard bolus materials used in radiotherapy. The surface dose was increased when bolus is applied due to the shortening of the source to surface distance (SSD) as well as the additional attenuation volume by the bolus materials before the beams interacts with the phantom or human soft
tissues. The surface dose measured by using the PVA bolus showed an agreement to the standard bolus material within maximum percentage of discrepancy of 1.4% for both 6 and 10 MV photons. The percentage of the PVA used in the bolus did not significantly change the percentage of surface dose.

Figure 3. The PDD curves in high energy photons of (a) 6 MV and (b) 10 MV for all PVA bolus materials in comparison to the available bolus material and open field.

Table 1. The percentage of surface dose in comparison to the maximum dose, $D_{\text{max}}$, measured with the presence of PVA bolus materials in comparison to the standard bolus and open field (without bolus) measured in 6 and 10 MV photons.

| Energy (MV) | Percentage of surface dose to $D_{\text{max}}$ (%) |
|-------------|-----------------------------------------------|
|             | Open field | Standard bolus | 2.5% PVA | 5.0% PVA | 7.5% PVA | 10.0% PVA |
| 6           | 45.91      | 95.44          | 96.77     | 95.77     | 95.56     | 96.78      |
| 10          | 36.95      | 95.66          | 96.71     | 96.69     | 97.00     | 96.78      |

The PDD curves in electrons of 6 and 9 MeV energies are illustrated in Figure 4. Similarly to that in high energy photons, the results showed that the use of bolus shifted the PDD curves to the left in comparison to the open field. The displacement of PDD curve was more significant at higher electron
energy (9 MeV) compared to that in 6 MeV. The surface dose was also increased between 94 and 97% to the \( D_{\text{max}} \) compared to 76.34 and 83.85% in the open field of 6 and 9 MeV electrons respectively [3,10]. The PDD curves measured by using the PVA bolus materials showed excellent agreement to the standard bolus material in both 6 and 9 MeV electrons. The measured surface dose in the PVA bolus materials in comparison to the standard bolus and open field is shown in Table 2. The results showed that the use of different percentage of PVA in the fabricated bolus materials did not significantly influence the surface dose in the electrons. The overall results suggested that the PVA gel materials can be fabricated as bolus at any percentage of PVA between 2.5% and 10%.

![Figure 4](image-url)  
*Figure 4. The PDD curves in electrons of (a) 6 MeV and (b) 9 MeV for all PVA bolus materials in comparison to the available bolus material and open field.*

| Energy (MeV) | Open field (%) | Standard bolus (%) | 2.5% PVA (%) | 5.0% PVA (%) | 7.5% PVA (%) | 10.0% PVA (%) |
|-------------|----------------|--------------------|--------------|--------------|--------------|--------------|
| 6           | 76.34          | 96.68              | 95.65        | 95.48        | 93.8         | 96.91        |
| 9           | 83.85          | 96.68              | 95.28        | 95.48        | 95.8         | 96.7         |

4. Conclusion
The measurement of PDD showed that the PVA bolus materials increased the surface dose close to the values measured in the standard bolus material at all measured photon and electron energies. The percentage of the PVA used did not significantly change the measured surface dose. The overall results indicated the potential use of the fabricated PVA based bolus materials to be used as bolus in for high energy photons and electrons.

5. References
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