Design and evaluation of corn starch-bonded Rhizophora spp. particleboard phantoms for SPECT/CT imaging

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Design and evaluation of corn starch-bonded *Rhizophora* spp. particleboard phantoms for SPECT/CT imaging

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Abstract. The aim of this study was to design and evaluate of corn starch-bonded *Rhizophora* spp. particleboards as phantom for SPECT/CT imaging. The phantom was designed according to the Jaszczak phantom commonly used in SPECT imaging with dimension of 22 cm diameter and 18 cm length. Six inserts with different diameter were made for insertion of vials filled with 1.6 µCi/ml of $^{99m}$Tc unsealed source. The particleboard phantom was scanned using SPECT/CT imaging protocol. The contrast of each vial for particleboards phantom were calculated based on the ratio of counts in radionuclide volume and phantom background and compared to Perspex® and water phantom. The results showed that contrast values for each vial in particleboard phantom is near to 1.0 and in good agreement with Perspex® and water phantom. The paired sample $t$-test result showed no significant difference of contrast values between images in particleboard phantoms and that in water. The overall results showed the potential of corn starch-bonded *Rhizophora* spp. as phantom for quality control and dosimetry works in SPECT/CT imaging.

1. Introduction
The potential use of *Rhizophora* spp. wood as phantoms for dosimetry and diagnostic imaging had been studied [1-4]. The fabrication of particleboards made of *Rhizophora* spp. wood have the advantages over its solid raw wood including enable to be fabricated at various sizes and shapes and density homogeneity across the particleboards. The potential use *Rhizophora* spp. particleboards as phantom had been studied in various applications using external beam of X-rays including mammography, diagnostic radiography and computed tomography (CT) imaging [4-8]. To date, there are limited information regarding the potential use of *Rhizophora* spp. particleboards for in-vivo dosimetry and imaging. A previous study by Bradley et al. [2] suggested that the solid raw wood of *Rhizophora* spp. having similar dose characteristics to solid water phantoms when measured using $^{192}$Ir brachytherapy sources. The present study focused on the in-vivo detection and imaging using phantoms made of *Rhizophora* spp. particleboards based on the single photon emission computed tomodraphy (SPECT) imaging.
SPECT is an imaging technique that provides three dimensional maps of in-vivo radiopharmaceuticals distribution [9]. CT is an imaging of cross-sectional transmission acquired by using a high output X-ray tube. The integrated SPECT/CT systems provide precise localization of physiologic data from nuclear medicine studies. SPECT imaging is superior to planar imaging with regard to abnormal localization by improving the object contrast [10]. Image contrast refers to different intensity in image corresponding to different levels of radioactive uptake in patient. Contrast is the ratio of signal change of an object of interest, such as lesion, relative to the signal level of surrounding parts of the image. Tomographic contrast is important to determine the detectability of small lesions.

2. Materials and methods

2.1. Fabrication of Rhizophora spp. Particleboards

The Rhizophora spp. wood trunks were obtained from charcoal factory in Kuala Sepetang, Perak, Malaysia. The wood trunks were cut and chipped into wood chips using planner machine. The wood chips were ground into wood particles using a grinder machine. The wood particles were filtered using horizontal sieving machine to obtain only wood particle with ≤ 74 µm sizes range. The commercial corn starch was used as bio-adhesive with 10% treatment level. The dry mass of wood particles and corn starch were calculated based on target density of particleboard (1.0 g/cm³). The wood particles and corn starch were mixed well and distributed uniformly on the mould. The mixture was pressed without temperature applied for 5 minutes to removes air trapped. Then, the mixture was compressed at 190°C for 20 minutes using hot press machine into particleboard. The elemental compositions of Rhizophora spp. particleboard were determined using energy dispersive X-ray analysis (EDXA). The effective atomic number, \( Z_{\text{eff}} \) of the particleboard was calculated based on the study by Duvauchelle et al. [11] shown by the equation:

\[
Z_{\text{eff}} = \sum_{i=1}^{N} (\alpha_{i}Z_{i}^{m})^{1/m}
\]

with \( \alpha_{i} \) and \( Z_{i} \) are the electronic fraction and atomic number of the \( i^{th} \) element in the compound respectively. The experimental coefficient \( (m) \) for biological material such as water, wood or human organs has been evaluated to be equal to 3.4 [11]. The electronic fraction of the \( i^{th} \) element was calculated using the equation:

\[
\alpha_{i} = \frac{w_{i}(\frac{Z_{i}}{A_{i}})}{\sum w_{i}(\frac{Z_{i}}{A_{i}})}
\]

with \( w_{i} \) and \( A_{i} \) are the fractional weight and atomic mass of the \( i^{th} \) element respectively.

2.2. Design of Rhizophora spp. Particleboard Phantoms for SPECT/CT

The Rhizophora spp. particleboards were fabricated based on the study by Abd Hamid et al. [12]. An amount of 10% of corn starch was added into the particleboards as adhesive material based on the dried weight of the wood particles. The particleboards were fabricated at 1.0 g/cm³ target density. A number of 18 particleboards were fabricated with thickness of 1.0 cm. The particleboards were then trimmed circularly to obtain particleboards with diameter of 22 cm similar to the diameter of Jaszczak phantom used for SPECT imaging. A number of 6 particleboards were prepared with six inserts with diameters between 1.6 cm and 4.1 cm for insertion of vials as shown in figure 1. The particleboards were stacked together using 4 long rods to minimize the air spaces between the particleboards. The Perspex® phantom was constructed with the similar design and dimension to particleboards phantom. The hollow tank of Jaszczak phantom filled with water was used as reference. A number of 6 vials with diameter between 1.9 and 4.1 cm diameter were constructed using Perspex® for containing $^{99m}$Tc.
radionuclide. The details of the dimension of the Perspex® vials are presented in Table 1. The vials were constructed with rubber cap to prevent spillage of the radionuclide.

![Diagram of vials](image)

**Figure 1.** (a) The layout design of SPECT/CT phantom made of corn starch-bonded *Rhizophora* spp. particleboards and Perspex®, (b) the constructed *Rhizophora* spp. particleboards phantom and, (c) Perspex® phantom.

| Vial no. | Diameter (cm) | Length (cm) | Volume (cm³) |
|----------|--------------|-------------|--------------|
|          | Internal     | External    |              |
| 1        | 1.3          | 1.9         | 6.0          | 6.0          |
| 2        | 1.6          | 2.2         | 6.0          | 8.6          |
| 3        | 1.9          | 2.5         | 6.0          | 11.6         |
| 4        | 2.5          | 3.1         | 6.0          | 21.5         |
| 5        | 3.0          | 3.6         | 6.0          | 30.0         |
| 6        | 3.5          | 4.1         | 6.0          | 41.5         |

**Table 1.** The external dimensions of vials used to contain the $^{99m}$Tc radionuclide for *Rhizophora* spp. particleboard phantoms.

2.3. **Tomographic Contrast Study on SPECT/CT Images**

The vials of different volumes and diameters were filled with $^{99m}$Tc radionuclide with activity of 1.6 µCi/ml calibrated using a dose calibrator. The vials were inserted into the *Rhizophora* spp. particleboards. The phantom was positioned on the couch of gamma camera model Discovery NM/CT/670. A SPECT/CT imaging was performed and the SPECT images were reconstructed into
transaxial view using an ordered-subsets expectation maximization (OSEM) algorithm with Butterworth filter at 0.48 filtration frequency. The details of the SPECT/CT imaging parameters are presented in Table 2. These same acquisition and reconstruction parameters were used for Perspex® and Jaszczak phantoms imaging.

Table 2. The SPECT/CT imaging parameters on the Rhizophora spp. particleboards, Perspex® and water phantoms.

| Parameter                      | Description          |
|--------------------------------|----------------------|
| Matrix size                    | 128 × 128            |
| View angle per projection      | 3°                   |
| No. of view                    | 120                  |
| CT scan exposure factors       | 120 kVp, 20 mA       |

Regions of interest (ROI) were drawn on the SPECT/CT images of radionuclide within each vial and at background region. The contrast of the image from each vial was measured using the equation:

\[
\text{Contrast} = \frac{C_{\text{sph}} - C_{\text{bgd}}}{C_{\text{bgd}}}
\]

with \( C_{\text{sph}} \) and \( C_{\text{bgd}} \) are the sphere and background count respectively. The contrast values from the particleboards phantom were compared to that in Perspex® and water phantoms.

3. Results and discussion

3.1. Analysis of Physical and Attenuation Properties of Rhizophora spp. Particleboards

The calculated \( Z_{\text{eff}} \) of the corn starch bonded Rhizophora spp. particleboards in comparison to the previous works on Rhizophora spp. particleboard phantoms is presented in Table 3. The result showed that the \( Z_{\text{eff}} \) of corn starch bonded Rhizophora spp. particleboards was close to the value of water [13]. Two materials are said to have similar attenuation properties towards ionizing radiations when the effective atomic numbers are equal [11]. Therefore, it is postulated that the attenuation properties of the corn starch bonded Rhizophora spp. particleboards are close to water as indicated by the effective atomic number.

Table 3. The calculated effective number (\( Z_{\text{eff}} \)) of Rhizophora spp. particleboards in comparison to water and Perspex®.

| Sample                        | Percentage of elemental composition (%) | \( Z_{\text{eff}} \) |
|-------------------------------|----------------------------------------|----------------------|
|                               | Carbon (C) | Hydrogen (H) | Oxygen (O) | Nitrogen (N) |                        |
| Water \(^a\)                 | -          | 11.11        | 88.89      | -            | 7.480                  |
| Perspex\(^a\)                | 59.98      | 31.97        | 8.05       | -            | 5.210                  |
| Binderless Rhizophora spp.\(^c\) | 32.93     | -            | 38.98      | 28.08        | 7.186                  |
| Corn Starch\(^b\)           | 46.82      | 6.94         | 46.24      | -            | 6.877                  |
| Corn starch bonded Rhizophora\(^b\) | 27.20     | -            | 72.55      | 0.25         | 7.587                  |
| Rhizophora spp. raw wood\(^d\) | 40.16      | 3.78         | 47.90      | 3.78         | -                      |

\(^a\)AAPM-21 [13], \(^b\)Current study, \(^c\)Mohd Yusof et al. [8], \(^d\)Bradley et al. [2]

3.2. Analysis of SPECT/CT Images using Rhizophora spp. Particleboard Phantoms

The SPECT/CT images of the corn starch bonded Rhizophora spp. particleboards in comparison to Perspex and water (Jaszczak) phantoms are illustrated in figure 2. The contrast values of vials of different diameter at different time of projections are presented in figure 3. The results showed
similarity of SPECT/CT image by *Rhizophora* spp. particleboard in comparison to water and Perspex® phantoms. The images of radionuclide in the vials were also consistent with their CT images. The measured contrast of different diameter of vials showed good agreement between *Rhizophora* spp. particleboard to water phantom. The contrast values were increase when the vials diameter larger at all time of projections.

![Figure 2.](image)

**Figure 2.** The SPECT/CT images of (a) *Rhizophora* spp. particleboard (b) Perspex® and (c) water (Jaszczak) phantoms.

![Figure 3.](image)

**Figure 3.** The contrast values at different vial volumes on *Rhizophora* spp. particleboards, Perspex® and water at (a) 10 sec, (b) 20 sec and (c) 30 sec times of projection.
A paired sample t-test was performed to compare the contrast between water-\textit{Rhizophora} spp. particleboards and water-Perspex® and presented in Table 4. The results showed that there were no significant different of contrast values between images of water and \textit{Rhizophora} spp. particleboard phantoms when 20 sec and 30 sec of times of projection were used shown by the \textit{p}-values higher than 0.05. This had indicated the similarity of attenuation and construction of SPECT/CT images between the particleboards and water. The overall results had indicated the suitability of corn starch bonded \textit{Rhizophora} spp. particleboards to be fabricated and constructed as phantom for SPECT/CT imaging.

**Table 4.** The paired sample \textit{t}-test of average contrast values of water-\textit{Rhizophora} spp. particleboards and water-Perspex at different time of projections.

| Time per projection (sec) | \textit{p}-value of paired sample \textit{t}-test (2 tailed) | Water - \textit{Rhizophora} spp. particleboards | Water - Perspex® |
|--------------------------|----------------------------------------------------------|-----------------------------------------------|------------------|
| 10                       | 0.003                                                    | 0.009                                         |
| 20                       | 0.079                                                    | 0.016                                         |
| 30                       | 0.070                                                    | 0.017                                         |

4. Conclusions
The corn starch bonded \textit{Rhizophora} spp. particleboards showed close value of effective atomic number to water. The constructed SPECT/CT phantom made of \textit{Rhizophora} spp. showed remarkable attenuation properties and contrast resolution in comparison to water and Perspex® at all sizes and volumes of radionuclide using $^{99m}$Tc. The contrast of SPECT/CT images in \textit{Rhizophora} spp. particleboards also showed an excellent agreement to water and Perspex® at all times of projection set ups. The results had indicated the potential use of \textit{Rhizophora} spp. particleboards as phantom for SPECT/CT imaging.

5. References
[1] Banjade D P, Tajuddin A A and Shukri A 2001 A study of \textit{Rhizophora} spp. wood phantom for dosimetric purposes using high energy photon and electron beams Appl. Radiat. Isotopes 55 (3) 297-302
[2] Bradley D A, Tajuddin A A, Che Wan Sudin C W A and Bauk S 1991 Photon attenuation studies on tropical hardwoods Appl. Radiat. Isotopes 42 771-773
[3] Shakhreet B Z, Bauk S, Tajuddin A A and Shukri A 2009 Mass attenuation coefficients of natural \textit{Rhizophora} spp. wood for X-rays in the 15.77 to 25.27 keV range Radiat. Prot. Dosim. 135 47-53
[4] Marashdeh M W, Bauk S, Tajuddin A A and Hashim R 2012 Measurement of mass attenuation coefficients of \textit{Rhizophora} spp. binderless particleboards in the 16.59–25.26 keV photon energy range and their density profile using X-ray computed tomography Appl. Radiat. Isotopes 70 656-62
[5] Ababneh B, Tajuddin A A, Hashim R and Shuaib I L 2016 Investigation of mass attenuation coefficient of almond gum bonded \textit{Rhizophora} spp. particleboards equivalent human tissue using XRF technique in the 16.6 – 25.3 keV photon energy Australas. Phys. Eng. Sci. Med. 39(4) 871-76
[6] Abuarra A, Hashim R, Bauk S, Kandaiya S and Tousi E T 2014 Fabrication and characterization of gum Arabic bonded \textit{Rhizophora} spp. particleboards Mater. Design 60 108-15
[7] Tousi E T, Hashim R, Bauk S, Jaafar M S, Abuarra A and Ababneh B 2014 Some properties of particleboards produced from \textit{Rhizophora} spp. as a tissue-equivalent phantom material bonded with \textit{Eremurus} spp. Measurement 54 14-21
[8] Mohd Yusof M F, Abd Hamid P N K, Tajuddin A A, Hashim R, Bauk S and Sulaiman O 2017 Characterization of tannin-added \textit{Rhizophora} spp. particleboards as phantom materials for
photons beams *Ind. Crop Prod.* **95** 467-74

[9] Artlett M L, Bacharach S L, Voipio-Pulkki L M and Dilsizian V 1995 Artifactual in-homogeneties in myocardial PET and SPECT scans in normal subjects *J. Nucl. Med.* **36** 188-95

[10] Scott C W 2001 General nuclear medicine *J Nucl. Med.* **42** 1499-1507

[11] Duvauchelle P, Peix G and Babot D 1999 Effective atomic number in the Rayleigh to Compton scattering ratio *Nucl. Instrum. Meth. B* **155** 221-28

[12] Abd Hamid P N K, Mohd Yusof M F, Tajuddin A A and Hashim R 2017 Measurement of mass attenuation coefficients for corn starch-bonded *Rhizophora* spp. particleboards at 16.59 – 25.26 keV photons using X-ray fluorescence configuration *Jurnal Sains Nuklear Malaysia* **29**(2) 47-54

[13] AAPM-21 1983 Protocol for the determination of absorbed dose from high energy photon and electron beams, Task Group 21 *Med. Phys.* **10** 741-71

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