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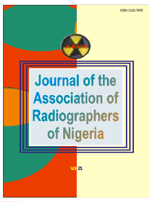

Scattering of the Exit Beam at the Patient–Cassette Front Material Interface by Ebony Wood

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Abstract

As part of the search for substitute materials for use as radiographic equipment accessories in developing countries, scattering of the exit beam at phantom-material (simulating the patient-cassette) interface has been investigated for Ebony wood and aluminium, for comparison, using thermoluminescent detectors (TLD). Results for significance of independent samples showed that, there was no statistical difference in the scattering of the exit beam towards the phantom, by the two tested materials ($P = 0.3$) at the 95% confidence interval, with changes in tube potential. Variation of radiation field size however produced a marked difference. This suggests the possible use of Ebony wood as a substitute for aluminium as a radiographic accessory, subject however, to further radiographic tests and confirmation.

Introduction

The practice of the Radiological science in developing economies is replete with lack of sometimes very basic requirements for good practice. One area of this lack is evident in the inability of such nations to procure capital intensive Medicare facilities, including equipment for most modern imaging modalities like Magnetic Resonance Imaging (MRI), Proton Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT) and other imaging methods. The result of this is a heavy dependence on conventional Radiography, with all its limitations, for Medical diagnosis. This feature is common to nations that fall into the healthcare level IV, according to the classification by the United Nations

Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)[1]. The prevailing circumstances make for poor standards, which are often compromised for convenience, a case of ‘using what you have to get what you need’.

Combating this position in Nigeria has given rise to attempts to develop some of the very basic accessories and appliances. The target of these efforts is wealth creation and employment, as well as bridging the lacuna that is often created when accessories need to be changed, and resources are not forthcoming to achieve that. To achieve these goals, studies and research are going on to facilitate the development of pieces of radiographic equipment and accessories like grids, cassettes, shielding materials and formulation of processing chemicals. Thus, several such local materials, which are abundant in the country, have been earmarked for use as the basis for these researches.

African Ebony (*Diospyros spp*) is a mostly black, with occasional grey streak, wood with a fine structure and a straight to wavy grain. A hard wood type with a density of $1.12 gcm^3$, its odour and taste are not distinct[2,3]. It is reported to produce mid range radiographic contrast of bone/water phantoms exposed at a tube output of 67 kVp and 40 mAs, and has an attenuation coefficient of $0.119\ cm^{-1}$ at the same energy [4].

The production and effects of scatter (forward and backscatter) and its contribution to patient skin doses, has been widely studied at the entrance surface of the patient [5,6]; so has the contribution of scatter to the image, as well as dose perturbation at interfaces for different types of radiation beams [7-10]. Scattered photons have been applied in imaging [11]. Scattering contributes to attenuation of the beam, and is dependent on the photon energy and irradiation conditions, including field size [12] as well as the characteristics of the scattering material [7, 13-14].

The radiation attenuation property of a material is the basic criterion for its adoption as a radiographic accessory. This depends on several factors like the type, atomic number, and electron density of the material and the energy of the radiation involved in the interaction. Reports have it that the exposure of cells and tissues in contact with high Z materials increase cell killing and tissue damage [15-19], because the use of high Z material in kV beams could result to significantly high dose increase caused by back scatter radiation [20-21]. However, such dramatic effects may not occur at the level of doses encountered in the exit beam, reported to be between 0.1% & 1.0% of the incident beam [22].

In this study, the x-rays transmitted through a water phantom and scattered by Ebony wood, is investigated and compared with that scattered by aluminium, which has been used in several applications in Radiology over the years. The results will provide reference information towards the utility of Ebony wood for cassette design, as a cassette front or even a complete cassette material or as a table top material in Radiology practice. Work is currently being undertaken to obtain parameters of the wood for application in cassette design.

Materials and Method

Ebony wood was obtained from Akin timber market in Calabar, Nigeria and air dried in the laboratory with regular checks on the mass until it was completely dried and no more changes in mass observed. This was to ensure that the moisture in the wood, which could affect x-ray transmission [23], was completely eliminated and the measured thickness was maintained throughout the study. The wood was then cut into pieces of 2 mm, cleaned using alcohol and allowed to dry for 72 hours. For comparison, an aluminium sheet, 2mm thick was obtained from a local metal dealer and used for this work without further analysis to ascertain level of purity. Figure 1 illustrates the experimental set up.

The International Atomic Energy Agency (IAEA) standard 30 x 30 x 30 cm^3 water phantom made of polymethyl-methacrylate, (PMMA) was used in this work. Water was filled 20 cm above the base of the phantom and the phantom levelled so that the water surface matched the x-ray tube focus to surface distance properly. The positioning of the phantom was reproducible to ± 0.1 cm. The effect of the phantom base will not be significant since its thickness did not change when both the aluminium and ebony were exposed. The depth of the water in the phantom was slightly less than the 21.5cm reported in literature for the abdomen of the average human patient [24] to compensate for the thickness of the phantom base. A lead plate of thickness 1 cm, sufficient to maximally attenuate the X-ray range of interest, was drilled 8 cm diameter at the centre so that x-rays transmitted through the phantom could pass straight through to the centre of the test material. This position shielded the scatter out-with the cut out area on the lead sheet from passing through and provided a place for attachment of thermoluminescent detectors (TLDs). The lead plate was then placed and held 1.0 cm above the test material. TLD chips were then place as shown in Figure 1 so as to measure entrance surface dose (ESD), scattered dose and exit dose.

A three phase high frequency x-ray generator, model R501 by GEC® Medical, with its central ray pointing vertically downward was calibrated with kVp and exposure accuracies of ±2 kVp and ±3% respectively and used for the irradiation. The generator's focus to surface distance and exposure rate were set to 90 cm and 60 mAs (300 mA and 0.2s) and maintained throughout the experiment. Total tube filtration was 2.5 mmAl, with no additional filtration.

TLD chips were calibrated for sensitivity and linearity using known exposures of radiation and a RADCAL® radiation multi-o-meter to obtain direct readings in milliGray (mGy). Exposed TLDs were read out with a Vinten Toledo reader Model 654D, having liquid nitrogen flush system as coolant and operating at 280°C and 410°C, and 20 and 12 seconds for the read and anneal, respectively, at the Radiation Protection Laboratory of the Department of Biomedical Physics and Bioengineering, Univeristy of Aberdeen, UK.

Exit beam scattered doses were obtained for varied tube potentials of 50 – 150 kVp, at a reference field size of 225 cm^2, in the first instance. The irradiation of field sizes of 25 cm^2, 100 cm^2, and 225 cm^2, 400 cm^2, 625 cm^2, 900 cm^2 and 1225 cm^2 followed. These field sizes fall within the range of cassette sizes used in conventional Radiography, except for the 43 x 35 cm^2 film size. The aperture in the lead sheet used to absorb the unwanted forward scatter, was maintained at 8cm, so that any variation in the exit beam could only be attributed to the field size used. Exposure for the varied field sizes was done at 110 kVp while the other exposure parameters were maintained as at the initial exposures made for variable kVp. A two tailed test for significance was carried out using the Mann-Whitney test for independent samples, to check the difference between the performances of the two tested materials for both tube potential and field size variations.

Results

Data for ESDs measured and the values of the exit doses as well as the quantity scattered by both materials is given in Table 1, while Figure 2 shows the percentage of the exit beam dose scattered by the test materials. This was determined form the quotient of the transmitted dose for each material and the dose transmitted through the phantom. Figure 3 shows the doses scattered by the materials with at different field sizes.

Analysis of the results reveal that the transmitted or exit beam is dependent on the tube potential, ranging from 1.95% to 4.03% for the lowest and highest kVp values used respectively, with a significant outlier at 90 kVp. These figures are very much higher than those proposed by Dendy and Heaton [22], probably because of the thickness of the water phantom used.

The values of ESD, with an uncertainty of 0.05 (Table 1), as well as the dose of the transmitted beam measured at the surface of the test material, show increase with the tube potential used. A similar pattern is obtained for the exit dose and kV, with Pearson's correlation coefficient, r = 0.65 and P = 0.03 at 95% confidence interval. The quantity of radiation scattered from the surface of the test materials for the two materials show a decreasing trend with increase in tube kVp (Figure 2). The scattering of the exit beam by Aluminium is slightly higher than that of Ebony wood. The Mann-Whitney test for significance of independent samples showed that, there was no statistical difference in the performance of the two tested materials (P = 0.33) at the 95% confidence interval.

Increasing the field of irradiation produced higher values of doses scattered back from the exit beam (Figure 3), at a constant kVp and mAs. The exit beam itself varied with the field size in the same direction (r = 0.96). The variation is statistically significant at P = 0.0004 at 95% confidence interval. The Mann-Whitney test for difference in performances between the two materials showed a significant difference at P = 0.01.

Discussion

Radiation dose received by the patient is a major concern in radiology. This informs the search for means of optimising dose and technique that would offer minimal risk of radiation effects, with greatest benefits, to the patient. There are reports on radiation dose, risk and detriment from single examinations and whole techniques. Computation of these doses has been with the assessment of entrance surface exposures (ESE) [25,26] including ESD, entrance surface air kerma (ESAK) and kerma area product (KAP) and Dose area product (DAP) [27,28] without consideration for the quantity arising from the scattering of the exit beam as it makes contact with either the table top or the cassette front below the patient. This quantity is relevant in diagnostic examinations because there is direct patient contact with the cassette or the table top material [22] . A material used in contact with the patient body should therefore not produce appreciable backscatter doses during radiation exposure [29].

We have observed a lower degree of radiation scattered back from what we describe as the cassette front/table top interface with the object of irradiation, when Ebony wood is used as the material at the interface. The quantity scattered backwards decreases with increased kV,
(Table 1 and Figure 2) because more of the primary beam is transmitted by the phantom at higher kVps, with the possibility of a higher degree of forward scatter towards the image recording medium. The quantity scattered backwards, which in practice would be towards a patient in contact with the surface (without the benefit of the distance) has been said to have great implication for radiation protection especially when using the over couch tube for fluoroscopy [22]. In this study, low exit beam doses occurred at the lower tube energies. This might be due to poor beam penetration and, perhaps, increased absorption and scattering within the phantom. These lower dose exposures recorded greater back scattering with possibility of interaction with the tissue they exited from.

The increase in the exit beam dose with field size with strong positive correlation (r = 0.96) could be due to the increased scattered radiation by the phantom introducing forward moving secondary photons into the transmitted beam. This did not affect the quantity of the exit beam scattered by each individual material significantly. However, comparing the performances of the tested materials, showed a significant difference between them ($p = 0.01$), with Ebony wood scattering less of the beam than aluminium (Figure 3). This difference may be due to the difference in elemental composition and density of the materials. Aluminium has a higher density (2.70 g cm^3) than ebony wood (1.12g cm^3).

Conclusion

The prevailing circumstances in developing countries where poor and lack of many radiographic accessories are common occurrence, necessitates the search for cheap, available and accessible alternatives for these. Such materials are expected to maintain or improve radiation dose reduction measures, in addition to satisfying other requisite requirements for their use. One of such alternative would be the adoption of wood as a radiographic accessory material. This study has established that Ebony wood could provide a suitable substitute for Aluminium with respect to scattering of the beam at the interface of the patient with the tabletop, or cassette front in non-grid examinations. However, direct radiographic tests with ebony are required to confirm this.

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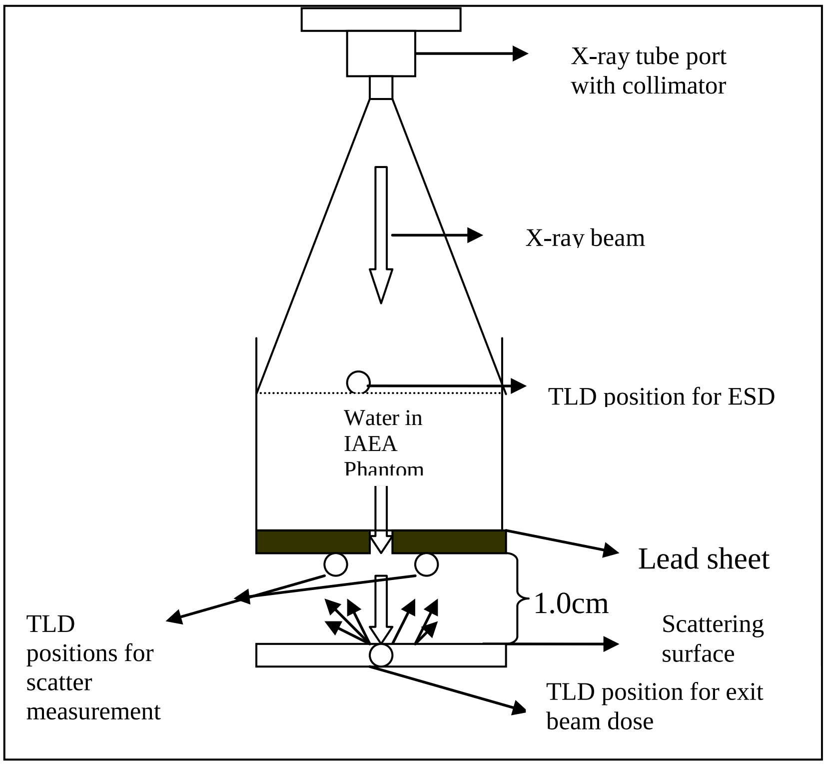

Figure 1: Experimental set up

Table I: Tube potential, ESD with standard deviation in brackets, Exit dose and scattered dose values for tested materials.

Tube Potential (kVp)	Measured doses from TLDs (mGy)			
	Mean ESD	Exit Dose	Scattered dose by test materials	
			Aluminium	Ebony
50	19.12 (0.02)	0.08	0.021	0.023
60	17.92 (0.01)	0.08	0.020	0.019
70	15.82 (0.01)	0.12	0.020	0.020
80	15.33 (0.01)	0.36	0.040	0.037
90	14.19 (0.05)	1.29	0.140	0.087
100	13.65 (0.02)	0.47	0.050	0.030
110	12.38 (0.04)	0.54	0.040	0.030
120	10.39 (0.04)	0.57	0.038	0.030
130	8.29 (0.02)	0.69	0.033	0.032
140	6.69 (0.02)	0.74	0.032	0.035
150	4.33 (0.02)	0.86	0.035	0.038

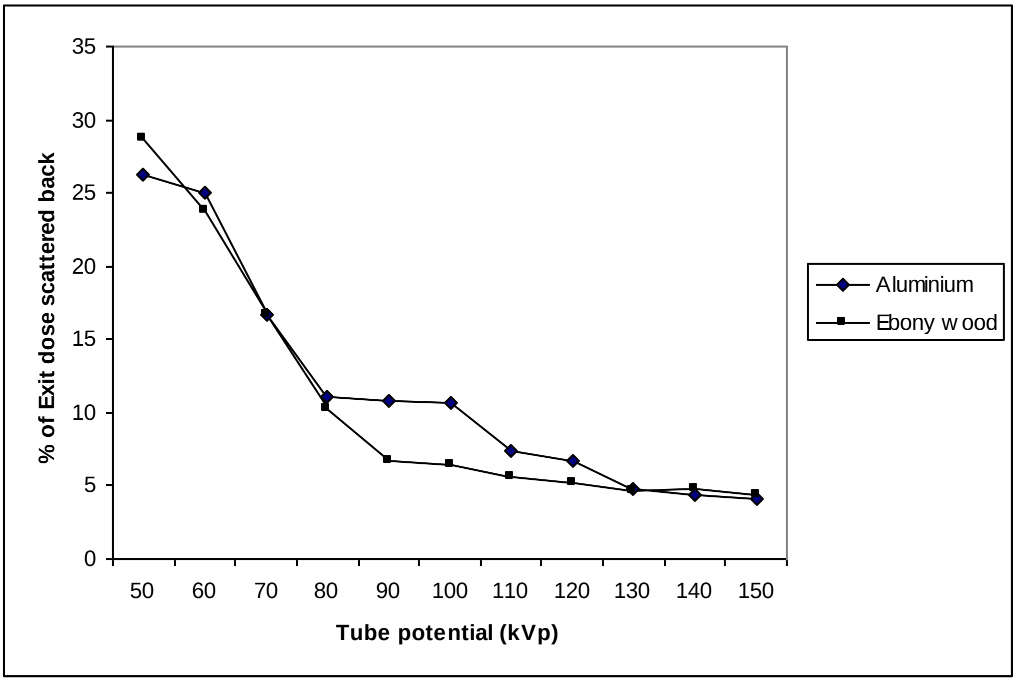

Figure 2: % backscatter of the exit beam at phantom/test material interface by Aluminium and wood, with tube potential.

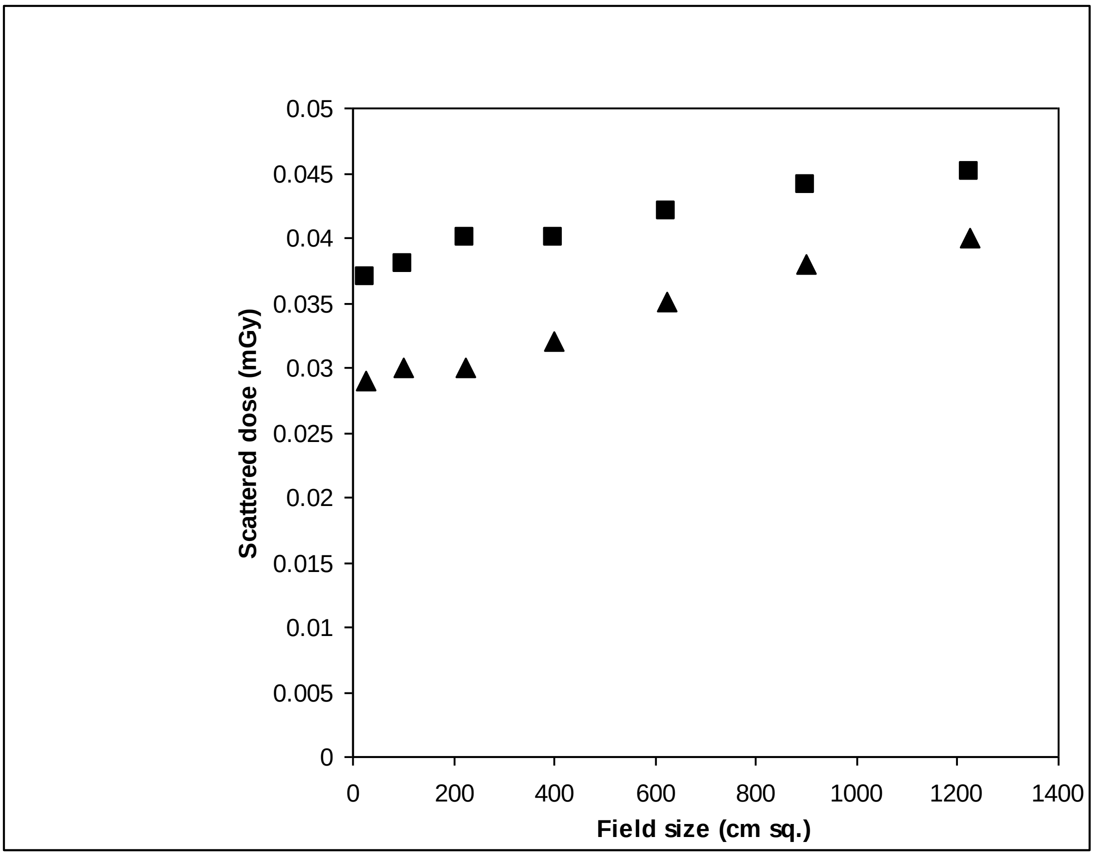

Figure 3: Plot of scattered doses from the test materials' surfaces with irradiation Field sizes. ▲Ebony wood showed higher response than ■ Aluminium for the same tube energy.