THEORETICAL CALCULATION OF GAMMA-RAY INTERACTION WITH DENTAL MATERIALS

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ABSTRACT

The aim of this research for investigation gamma ray interaction with dental materials such as dentures, composite resin, amalgam and glass ionomer cement. The mass attenuation coefficient, the effective atomic number and the effective electron density have been calculated by WinXCom program at energy range 1 keV to 100 keV. The result show that, the mass attenuation coefficient of all dental materials depend on photon energy and decreases with increasing of the photon energy. However, the results show that the amalgam material higher values than dentures, composite resin and glass ionomer cement after the energy above 4 keV. The photoelectric interaction decreases with increasing of photon energy and these values found to be the main interaction of all energy range. The coherent scattering found to be significant at low photon energy and rapidly decreases with increasing of photon energy for all dental materials but the Compton scattering interaction, the values were slightly increase with increasing of photon energy for all dental materials. The effective atomic number and the electron densities found to be the same trend. Whereas, the electron densities of amalgam, the result show values lower than dentures, composite resin and glass ionomer cement.

KEYWORDS: *Dental material; Mass attenuation coefficient; Effective atomic number; Electron density*

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INTRODUCTION

Dental materials or restorative materials are the most popular subjects among those who pursue continuing education, clinical dentistry and read the dental literature. On the other hand, most dental students think of dental materials as a basic science course, filled with facts and concepts that have little application to clinical dentistry. When a dentist considers the type of dental materials to place in a patient's mouth, the choice may be between different varieties of the material [1]. Therefore, many review and research articles have been written on the subject. However, the reports of dental materials in photon interaction are not extensive. Investigation of photon interaction in dental materials are very important because this data can be used for development and characterizations of clinical dentistry. There have been a great number of experimental and theoretical investigations to determine mass attenuation coefficients for various materials such as glasses (Kaewkhao and Limsuwan, 2010; Limkitjaroenporn et al., 2011) [2, 3], polymers (Kucuk et al., 2013) [4] and gemstones (Medhat, 2012) [5].

In this theoretical study, the mass attenuation coefficient, effective atomic numbers and electron densities of dentures, composite resin, amalgam and glass ionomer cement were calculated using WinXcom program in the energy range 1–100 keV which is the range to used for radiographic or X-ray in clinical dentistry. The partial interaction of all dental materials were also calculated.

Theory

The total attenuation coefficients for any chemical compound or homogeneous mixture of shielding materials are obtained as weighted sums over the corresponding coefficients for elements. The mass attenuation coefficients (μ/ρ) can be given by the following weighted summation [6]:

$$\mu/\rho = \sum_i w_i (\mu/\rho)_i \quad (1)$$

where ρ is the density of the sample and w_i and $(\mu/\rho)_i$ are the fraction by weight and mass attenuation coefficient of i_{th} constituent, respectively. The mass attenuation coefficients for total and partial interactions have been obtained from the WinXCom [7]. Equation 1, this well-known mixture rule is valid with the assumption that the effects of molecular binding and the chemical and crystalline environment are negligible. For a chemical compound, the fraction by weight is given by [6]:

$$w_i = \frac{a_i A_i}{\sum_j a_j A_j} \quad (2)$$

where a_i and A_i are the number of formula units and the atomic weight of the i_{th} element, respectively. The basic relation for calculating the effective atomic number (Z_{eff}) for all types of materials, compounds as well as mixtures can be written in terms of the fraction abundance as [8]:

$$Z_{eff} = \frac{\sum_i f_i A_i (\mu/\rho)_i}{\sum_j f_j \frac{A_j}{Z_j} (\mu/\rho)_j}, \quad (3)$$

Where $f_i = n_i / \sum_j n_j$ is the fractional abundance of constituent element i (n_i is the number of atoms, $\sum_j n_j$ is the total number of atoms present in the molecular formula), A_i is the atomic weight and Z_i is the atomic number. The effective electron density (N_{eff}) expressed in number of electrons per unit mass, is closely related to the effective atomic number and given by [8]:

$$N_{eff} = N_A \frac{Z_{eff}}{\sum_i f_i A_i} = N_A \frac{Z_{eff}}{\langle A \rangle}, \quad (4)$$

where N_A is the Avogadro's number and $\langle A \rangle = \sum_i f_i A_i$ is the average atomic number of the material.

RESULTS AND DISCUSSION

The dentures, composite resin, amalgam and glass ionomer cement evaluated in the current study and their compositions are shown in Table 1. Theoretical value of the mass attenuation coefficients of all dental materials was calculated by WinXCom program at the energy range 1 keV to 100 keV.

From Fig. 1, the mass attenuation coefficient of all dental materials depend on photon energy and decreases with increasing of the energy. However, these results show that the amalgam material higher values than dentures, composite resin and glass ionomer cement after the energy above 4 keV.

Table 1 The chemical composition of four type dental materials in fraction by weight (wt.%) [9–11].

Dental material	Element (wt.%)						
	Si	Al	Ca	Na	F	P	O
Denture	-	-	0.063	-	-	0.068	0.413
Composite resin	0.770	0.120	-	-	-	-	-
Amalgam	-	-	-	-	-	-	-
Glass ionomer	0.116	0.175	0.065	0.027	0.228	0.061	0.327

Dental material	Element (wt.%)						
Denture	Cu	Zn	Ag	Sn	Ba	Mg	Fe
Composite resin	-	-	-	-	-	0.455	0.001
Amalgam	-	-	-	-	0.110	-	-
Glass ionomer	0.130	0.010	0.590	0.270	-	-	-

The distinction of photoelectric interaction with all dental materials are shown in Fig. 2, which indicates that the photoelectric interaction decreases with increasing of photon energy. Moreover, the result show that, these values found to be the main interaction of all energy range. Furthermore, all of dental materials at the low energies discontinuities correspond to photoelectric absorption edges of the Z elements. The result show that, dentures; the calcium K edge at 4.04 keV, composite resin; the silicon K edge at 1.84 keV, the barium L_1 edge at 5.99 keV and K edge at 37.4 keV, amalgam; the tin L_3 edge at 3.93 keV and K edge at 29.2 keV, glass ionomer cement; the phosphorus K edge at 1.84 and 2.5 keV, the calcium K edge at 4.04 keV. The coherent scattering found to be significant at low photon energy and rapidly decreases with increasing of photon energy for all dental materials. For the Compton scattering interaction, the values were slightly increase with increasing of photon energy for all dental materials.

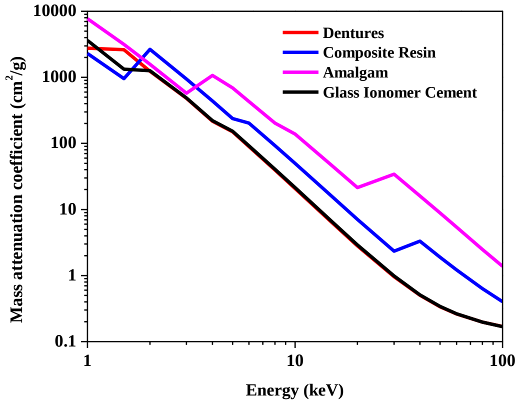

Fig. 1 Mass attenuation coefficient of all dental materials versus photon energy range 1 keV–100 keV.

The distinction of effective atomic number of all dental material from energy ranging 1 keV to 100 keV are shown in Fig. 3. The result show the peak which corresponding with the photoelectric absorption edge of each dental materials. Especially, composite resin material, the energy of these discontinuities corresponds to photoelectric absorption edges of Ba (K-edge) at 37.4 keV. Fig. 4, the effective electron densities of all dental materials, the results are shown the similar trend with effective atomic number. Whereas, the effective electron densities of amalgam, the result show values lower than dentures, composite resin and glass ionomer cement.

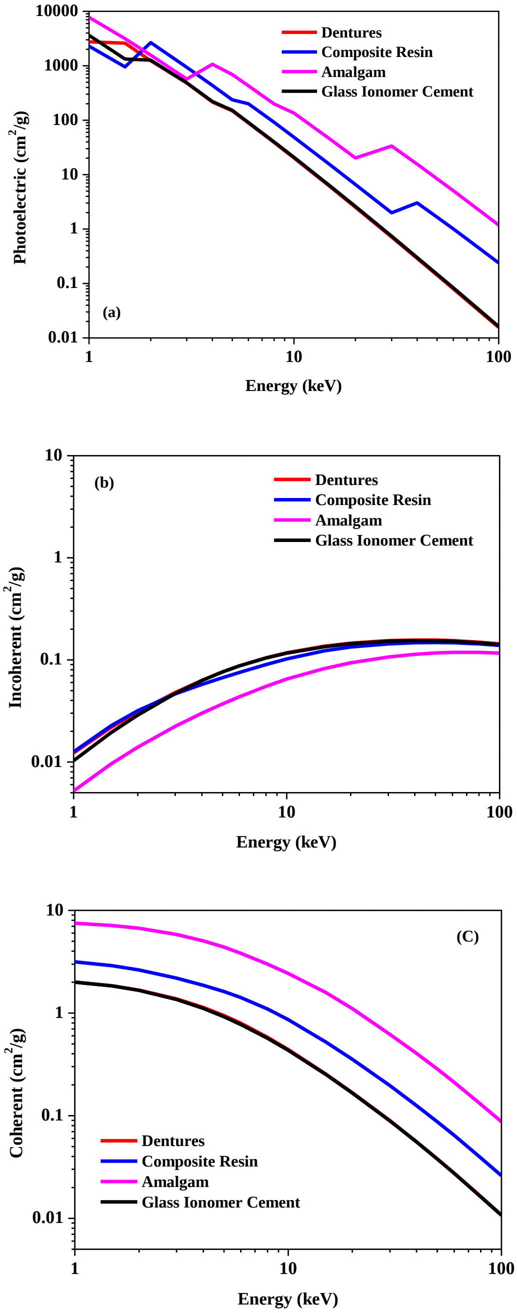

Fig. 2 Partial interaction (a) photoelectric (b) incoherent (c) coherent, of all dental materials versus photon energy range 1 keV–100 keV.

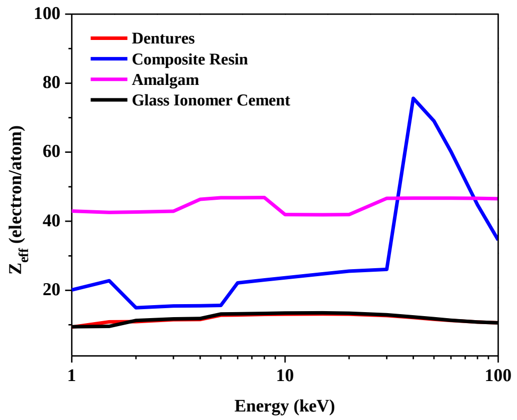

Fig. 3 Effective atomic number of all dental materials versus photon energy range 1 keV–100 keV.

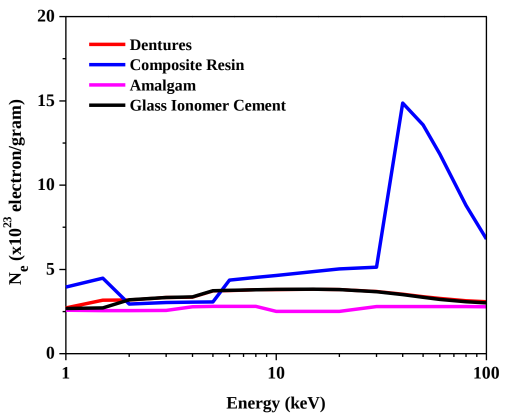

Fig. 4 Effective electron densities of all dental materials versus photon energy range 1 keV–100 keV.

CONCLUSSION

The theoretical study, were undertaken to get information on mass attenuation coefficient, effective atomic number, effective electron density and partial interaction of dentures, composite resin, amalgam and glass ionomer cement at energy range of 1 keV to 100 keV. The sample were investigated using WinXcom program. It was found that, the mass attenuation coefficient of all dental materials depend on photon energy and decreases with increasing of the energy. However, the results show that the amalgam material higher values than dentures, composite resin and glass ionomer cement after the energy above 4 keV. The photoelectric interaction decreases with increasing of photon energy and these values found to be the main interaction of all energy range. Furthermore, all of dental materials at the low energies of these discontinuities correspond to photoelectric absorption edges of the Z elements. The coherent scattering found to be significant at low photon energy and rapidly decreases with increasing of photon energy for all dental materials but the Compton scattering interaction, the values were slightly increase with increasing of photon energy for all dental materials. The effective atomic number and the effective electron densities found to be the same trend. Whereas, the effective electron densities of amalgam, the result show values lower than dentures, composite resin and glass ionomer cement.

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REFERENCES

[1] W. J. O'Brien, Dental Materials and Their Selection, Quintessence Publishing Co, Inc, Chicago, 2002.

[2] J. Kaewkhao, P. Limsuwan, Mass attenuation coefficients and effective atomic numbers in phosphate glass containing Bi_2O_3, PbO and BaO at 662 keV, Nucl. Instrum. Methods A: accelerators, spectrometers, Detect. Assoc. Equip. 619 (2010) 295–297.

[3] P. Limkitjaroenporn, J. Kaewkhao, P. Limsuwan, W. Chewpraditkul, Physical, optical, structural and gamma-ray shielding properties of lead sodium borate glasses, J. Phys. Chem. Solids. 72 (2011) 245–251.

[4] N. Kucuk, M. Cakir, N. A. Isitman, Mass attenuation coefficients, effective atomic numbers and effective electron densities for some polymers, Radiat. Prot. Dosim. 153 (2013) 127–134.

[5] M. E. Medhat, Study of the mass attenuation coefficients and effective atomic numbers in some gemstones, J. Radio Anal. Nucl. Chem. 293 (2012) 555–564.

[6] N. Chanthima, J. Kaewkhao, 38th Congress on Science and Technology of Thailand (STT38), ChiangMai, Thailand, Oct. 17–19, 2012.

[7] L. Gerward, N. Guilbert, KB. Jensen, H. Levring, WinXCom - A program for calculating X-ray attenuation coefficients, Rad. Phys. Chem. 71 (2004) 653–654.
[8] N. Chanthima, J. Kaewkhao, P. Limsuwan, Study of photon interactions and shielding properties of silicate glasses containing Bi_2O_3, BaO and PbO in the energy region of 1 keV to 100 GeV, Ann. Nucl. Energy. 41 (2012) 119–124.
[9] S. K. Sidhu, J. W. Nicholson, A Review of Glass-Ionomer Cements for Clinical Dentistry, J. Funct. Biomater. 7 (2016) 1–15.
[10] R. R. Moraes, L. S. Gonçalves, A. C. Lancellotti, S. Consani, L. Correr-Sobrinho, M. A. Sinhoreti, Nanohybrid Resin Composites:Nanofiller Loaded Materials or Traditional Microhybrid Resins?, Operative Dentistry. 34-5 (2009) 551–557.
[11] G. P. Thomas, Amalgam-Chemical Composition, Mechanical Properties and Common Applications, AZoNetwork UK Ltd. United Kingdom. 2013.