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Original Article

Physical Properties of Ethyl Methacrylate as a Bolus in Radiotherapy

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Abstract

Introduction
Bolus is a soft and resilient material which is used for increasing skin dose or to even out the irregular patient contour. The main property of various materials used presently as bolus is the water-equivalent electron density. Ethyl methacrylate is used as a soft-liner in dentistry and its physical and chemical properties are proved to be nontoxic for human body. The goal of this study was to assess the feasibility of using this material as bolus in radiotherapy and also evaluating some parameters such as mass, electron densities, and transmission factors.
Materials and Methods
Computed tomography data from the sample material were acquired to assess mass and electron densities with various techniques (mA and kVp). Circular ROIs were delineated on CT DICOM images and densities were calculated using CT numbers. Transmission factors were calculated for 6 and 18 MV.
Results
Evaluation of our results are evident that showed that mass and electron densities of ethyl methacrylate are similar to those of water and soft tissue. Furthermore, transmission factors are close to those of water.
Conclusion
According to the results of this study and other properties such as flexibility and harmlessness, it seems that ethyl methacrylate is a suitable material to be used as bolus in radiotherapy.
Keywords: Bolus, CT scan, Ethyl Methacrylate, Radiotherapy

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1. Introduction

Bolus is a soft and resilient material with tissue-equivalent properties which is used in direct contact with skin in order to increase the superficial dose and lessen the dose in depth and also to compensate for the missing tissue [1]. Intending to increase the skin dose, a 0.5 to 1.5 cm layer of bolus is used which doesn't make any noticeable difference in the shape of isodoses in depth. In order to compensate for the missing tissue or an inclined body surface, one side of bolus should match the irregularity of the surface while the other side is quite even and the skin sparing effect of the megavoltage beams is removed. In high energy electron beams, bolus also causes a shift in isodose curves toward the surface and compensates for the irregularities of the surface in addition to a remarkable decrease in the dose to the underlying organs. The irradiation of electron beam to an irregular surface, leads to a complex dose distribution in the tissue with hot and cold spots which can be modified using bolus on the surface [1]. Hsu and Roberson studied the skin dose as a function of bolus material in tangential technique for the treatment of breast cancer. This study showed that the Aquaplast bolus with the thickness of 2 mm and small perforation increases the skin dose by 82% [2]. Perkins et al. developed individual bolus for post-mastectomy irradiation cases using CT scan images and three-dimensional treatment planning. The bolus designed in this way had one side conformal to the superficial irregularity of chest wall for each patient and optimized dose distribution in the target while minimizing the dose to the normal tissue [3]. Nowadays, various materials are used as bolus in radiotherapy each of which has its own advantages and disadvantages, but a common property of all is electron absorption capability which is compared to that of water. These boluses include gels to cover the desired area (such as Superflab and Elastogel) or materials that have to be warmed first and then shaped to the desired form on the treatment region (such as Superstuff, Aquaplast RT, and BeesWax) [4].

In order to use a new material as bolus, properties such as plasticity and tensility should be examined. In addition, the material must be stable in all temperatures between 4 and 52 °C and have the same dosimetric properties as water. In case the mass, density of the desired substance is water-equivalent (1 g/cm^3), dosimetric factors and also electron density must be examined, since the latter has a significant impact on the dose distribution particularly in megavoltage beams. Additionally, the bolus substance must be odorless, non-sticky, and harmless to the skin [2].

The aim of this study was to assess the feasibility of using ethyl methacrylate as bolus in radiotherapy from the physical point of view. This material is now used as a soft-liner in dentistry, the main component of which, is a silicone plastic and is efficient when placed in touch with oral tissue and its mechanical stability is confirmed [5, 6].

2. Materials and Methods

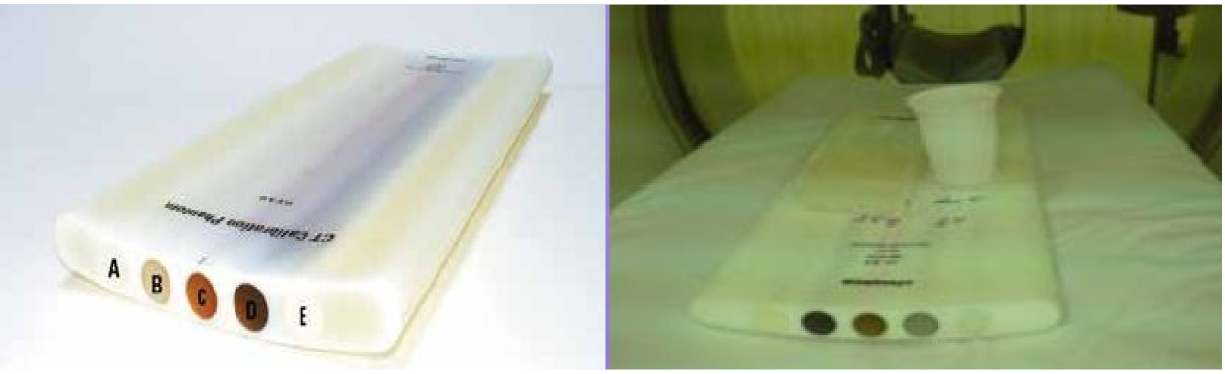
Ethyl Methacrylate sample used in this study was prepared by combining ethyl methacrylate powder, ethanol, and softener materials according to the protocols used in dentistry. The volume of the prepared sample was 15×7.5×1 cm^3. The mass density, electron density, and transmission factors were then assessed.

2.1. Mass Density

Mass density of the sample was calculated based on CT numbers acquired from the computed tomography images of the sample (by a SIEMENS Sensation 64 machine) under various protocols (Table 1) and by means of a CT calibration phantom (QCT PRO™ PHANTOM) (Figure 1.a).

Table 1. Protocols used for measuring CT numbers.

Protocol	kV	140	120	120	120	100	80	80	80
	mA	448	232	290	448	448	232	290	448



(a) (b)

Figure 1. a) CT calibration phantom contains five different materials with known densities, b) The sample and a glass of water are placed on the CT calibration phantom on the CT couch.

In each protocol, computed tomography images were acquired from sample and a glass of water was placed together on top of the CT calibration phantom (Figure 1.b). Water was used with the purpose of comparing mass and electron densities of sample with soft tissue.

On the CT images, circular Regions of Interest (ROI) were delineated on transverse sections of five phantom materials, sample, and water with the use of a DICOM viewer (eFilm Workstation 2.1) and then CT numbers were acquired (Figure 2). For each protocol, measurements were repeated in four axial slices and the mean CT numbers were calculated for each material. The changes of CT numbers were calibrated against density using data obtained from CT calibration phantom. Afterward, densities of water and the sample of ethyl methacrylate were calculated using the calibration curve.

2.2. Electron Density

For any material, it is possible to calculate the electron density (ρ_e) relative to water by using CT numbers, N_{CT}, according to the equations 1 and 2 for CT numbers greater or less than 100, respectively [7]:

$$\rho_e = 1.052 + 0.00048\, N_{CT} \qquad N_{CT} > 100 \qquad (1)$$

$$\rho_e = 1.000 + 0.001\, N_{CT} \qquad N_{CT} < 100 \qquad (2)$$

The CT numbers of water and sample from different protocols were used in the calculation of electron densities. For each protocol, measurements were repeated four times.

2.3. Transmission Factor

For two megavoltage X-rays, 6 and 18 MV, the transmission factor of the ethyl methacrylate sample was measured by means of a 0.6cc Farmer ionization chamber (PTW, TM30001 model). The sample was placed on top of the slab phantom and irradiated by 6 and 18 MV photons produced by linear accelerator (Varian, Clinac 2100 machine). Afterward, the sample was removed and the irradiation was repeated for both energies.

Dosimetric conditions were reference depths of 5 and 10 cm for low and high energies, respectively, 100 MU of irradiation, and field size equal to 15×7.5 cm^2 and SSD=100.

In the next step, instead of the ethyl methacrylate sample, a 1 cm thick Perspex slab (soft tissue-equivalent) was placed on the phantom and the reading was repeated under the same conditions as previous. The background radiation was measured by electrometer before dosimetry and was set to zero and removed from the readings. The transmission factor was calculated as the ratio of the electrometer reading with the sample in place to the reading without sample. Transmission factor of Perspex slab was calculated in the same way. Figure 3 is a scheme of the dosimetry set-up.

3. Results

The mass density of the ethyl methacrylate sample calculated from eight CT scan protocols which had different kV and mA, are shown in the Table 2 along with the results obtained for water under similar conditions. Densities are calculated in terms of mg/cc and for each protocol, are shown as mean value plus/minus standard deviation of four measurements. Data analysis indicates no significant differences between densities of water and the sample ($p<0.05$).

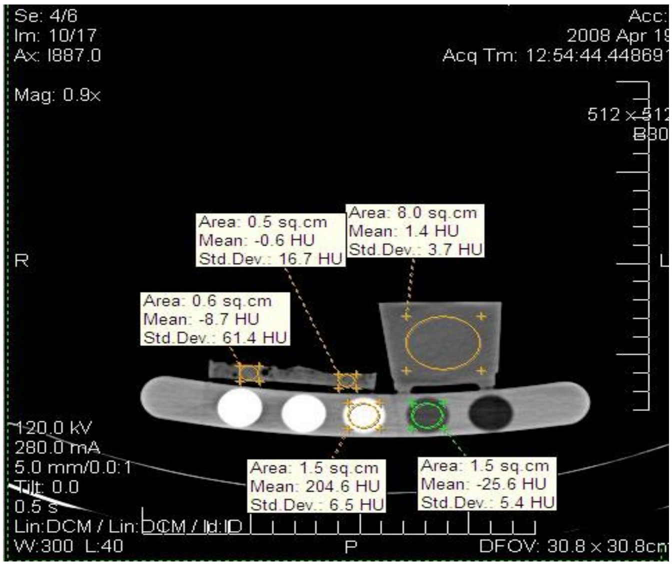


Figure 2. One of the transverse slices of CT scan images including ethyl methacrylate sample, water, and CT calibration phantom which contains five different materials with known densities. Circular ROIs were delineated on the cross section of materials to obtain CT numbers.

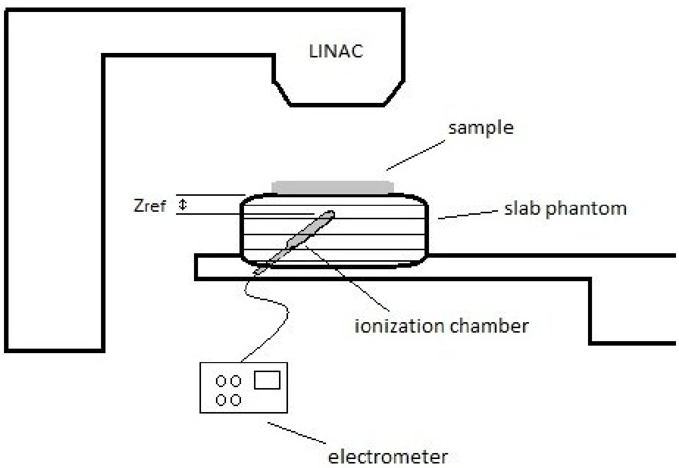


Figure 3. Schematic view of dosimetry set-up for calculation of transmission factor. The sample was placed on top of the slab phantom and dose was read in the reference depth. Moreover, the reading was performed after the sample was removed.

Table 2. Calibration equations (in terms of CT numbers) and densities for different imaging protocols.

kVp	mA	Calibration Equation	Water Density (mg/cc)	Sample Density (mg/cc)
80	448	y = 0.163x + 1066	1066.40 ± 0.135	1066.15 ± 0.659
80	290	y = 0.162x + 1066	1066.27 ± 0.827	1065.71 ± 0.865
80	232	y = 0.161x + 1061	1065.38 ± 0.932	1064.54 ± 0.368
100	448	y = 0.184x + 1064	1063.87 ± 0.156	1065.08 ± 0.582
120	448	y = 0.199x + 1062	1062.24 ± 0.383	1063.16 ± 1.077
120	290	y = 0.199x + 1062	1062.23 ± 1.222	1061.98 ± 0.899
120	232	y = 0.198x + 1062	1061.70 ± 0.265	1061.80 ± 0.348
140	448	y = 0.211x + 1061	1061.22 ± 0.340	1066.15 ± 0.659

Table 3. Relative electron density of water and ethyl methacrylate sample calculated for eight different imaging protocols.

kVp	mA	Relative Electron Density of Water	Relative Electron density of Sample
80	448	1.000 ± 0.001	0.998 ± 0.004
80	290	1.001 ± 0.005	0.998 ± 0.005
80	232	0.996 ± 0.006	0.991 ± 0.002
100	448	0.999 ± 0.001	1.006 ± 0.003
120	448	0.999 ± 0.002	1.003 ± 0.005
120	290	1.001 ± 0.006	1.000 ± 0.004
120	232	0.998 ± 0.001	1.000 ± 0.002
140	448	0.999 ± 0.002	0.998 ± 0.004

Relative electron densities of the ethyl methacrylate sample are shown in Table 3 which are calculated using Equation 1 and are compared with electron densities calculated for water under similar conditions. The statistical analysis demonstrates no significant differences between results obtained for the sample and water ($p<0.05$).

In addition, the transmission factors measured for the sample and the Perspex slab for both 6 and 18 MV photons are compared in Table 4.

4. Discussion

In this study, some of the properties of ethyl methacrylate including mass and electron densities and transmission factors were calculated in order to assess the feasibility of using the material as bolus in radiotherapy. To calculate the mass density, CT numbers were measured in the CT scan images and calibration curves were calculated in terms of Hounsfield units (HU), then the density of ethyl methacrylate was measured. In order to be certain about the independence of measured density on imaging parameters, examinations were repeated under various conditions of mA and kV. In addition, density of water was calculated under each condition and used as a measure of accuracy of the calculations and to compare the density of ethyl methacrylate with the density of soft tissues. In the computed tomography images, diagnosis is based upon spatial resolution so variations in the X-ray attenuation are considered as regional and relative quantities. Absolute values of CT numbers are rarely used; examples are measuring calcification in vessels and bone densitometry that uses calibration tables to convert CT numbers to density [8]. According to the study performed by Tavares et al., CT number of water in the diagnostic CT images is in the range of 0.5±7.3 [9].

Table 4. dosimetry outcome for transmission factors of the sample and the Perspex slab.

X-ray Energy	Reading	Measurement in the Zref. (nC)*	Measurement under Sample in Zref. (nC)	Measurement under Perspex in Zref. (nC)
6 MV	1st	12.92	12.50	12.45
	2nd	12.93	12.51	12.46
	Average	12.92	12.50	12.45
	Transmission factor		0.97	0.96
18 MV	1st	12.04	11.77	11.73
	2nd	12.04	11.76	11.73
	Average	12.04	11.76	11.73
	Transmission factor		0.98	0.97

*nC: nanocoulomb

CT numbers obtained from different imaging protocols in our study are in the 0.9±3.1 interval which is within the above range. As it is shown in Table 2, for all of the studied protocols, the differences between calculated amounts of density for water and the sample are small and less than 0.5%. As it may be noted, water density calculated under all conditions is about 1.06 g/cc which is due to the equations of CT calibration phantom and can be normalized to 1.

Heismann et al. introduced another method to calculate atomic number and mass density by means of CT images. In this method, two X-ray beams with various energies and spectral weights were used so that atomic number and density were calculated as functions of two different attenuation factors [8].

Electron density is the essential factor for calculation of dose distribution in the irradiated tissue. In order to obtain the electron density of the tissue, imaging with gamma or X-ray is an appropriate technique. CT numbers gained from kilovoltage diagnostic X-ray, are dependent on electron density and effective atomic number. For soft tissue, the effect of atomic number is small and a linear relationship between the CT number and electron density is attainable. Moreover, for other tissues such as bones which have relative electron densities bigger than 1, another linear relationship exists [7]. The accuracy of Equations 1 and 2, used in this study is evaluated by different authors and it is proved that for the materials with average atomic number near to that of water, CT number sits close to the line that passes through HU=-1000 for air and HU=0 for water [10-12]. Relative electron density of ethyl methacrylate is calculated by equation 1 using CT numbers. According to this equation, electron density is calculated relative to water, so, relative electron density of water should be equal to 1 (Table 3).

Generally, if the effective atomic number, mass density, and the number of electrons per unit mass of a material are similar to those of water, then dosimetric properties of this material in a radiation field will be the same as water or soft tissue. Nonetheless, regarding the fact that in the range of therapeutic megavoltage energies, Compton interaction is the dominant effect, a material is considered equal to water essentially on the condition that its electron density is equal to that of water [12]. Our study showed that relative electron density of ethyl methacrylate is approximately equal to the electron density of water.

The transmission factors which were calculated for ethyl methacrylate and Perspex slab for two megavoltage energies, 6 and 18, were similar and it can be concluded that the dosimetric properties of ethyl methacrylate including absorption and transmission of radiation, are also similar to soft tissue. In this study, transmission factor is measured for a sample with the thickness of 1 cm and it is assumed that the same thickness will be used as bolus. Clearly in case of need for other thicknesses, relevant dosimetry is necessary.

5. Conclusion

Ethyl methacrylate is now used as a soft-liner in dentistry and it is approved as a nontoxic material. Hence it is suitable as a bolus material for photon beam or more conveniently as a tissue compensator for electron beam radiotherapy for direct contact with the skin. Some commercially available polymers such as Elasto-gel, Bolx, Superflab and Superstuff are routinely used as tissue compensator for electron beam radiotherapy for direct contact with skin. Densities of these substances are 1.2, 1, 1.02, and 1.02 g/ml, respectively. In addition, these polymers have other properties such as high plasticity and transparency and can be easily cut into desired shapes plus being harmless to the skin [13].

Ethyl methacrylate can be shaped simply into different forms and sheets in various thicknesses. The sheets may be used in post-mastectomy radiotherapy patients where the patient's chest wall has insufficient thickness. In addition, ethyl methacrylate can be used to increase the superficial dose while making appropriate decrease in the dose to underlying normal tissue. The increase in the skin dose due to this material is under investigation in order to be compared with other bolus materials used in our department. The point which must be noted about ethyl methacrylate is that the mixing of different ingredients should be done uniformly for the best result. The simplest way is to stir the materials manually. However, it may lead to bubble formation and consequent change in the average mass and electron densities, so, bubbles should be removed during mixture formation. The cost of preparing a bolus from ethyl methacrylate polymer will be equal to or less than bolus sheets available in the market, considering the required volume of raw materials.

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