Introducing a simple tissue equivalent anthropomorphic phantom for radiation dosimetry in diagnostic radiology and radiotherapy

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ABSTRACT

It is important to measure organ dose in diagnostic radiology & radiotherapy. Because measurement on patients has some limitations, phantoms are being constructed to be implemented. One kind of several phantoms which is being used so far is anthropomorphic phantom which is similar to a man. In this work, using human natural bone as phantom skeletal tissue & paraffin plus *NaCl* (as impurity) as soft tissue substitute an anthropomorphic phantom was constructed which consists of three parts: 1. head & neck 2.torso 3.hip. Phantom dimensions were selected from the standard man. To measure absorbed dose in tissues, at the sites of parotid, thyroid, sternum, diaphragm, abdomen and hip some cylinders were inserted which were constructed from phantom material and had some cavities to insert *TLD*s in different depths. Due to importance of photoelectric effect in diagnostic radiology & Compton effect in radiotherapy, two important parameters which should be considered in construction of a phantom is effective atomic number and electronic density were6.57& 3.36×10^{23} electron.gr^{-1} , respectively.

Key words: Tissue equivalent phantom; Dosimetry; Radiology; Radiotherapy

INTRODUCTION

Tissue equivalent anthropomorphic phantoms are being constructed from several chemicals which interaction with ionizing radiation is similar to human body. Historically, the first anthropomorphic phantom was designed and constructed by Bush in 1946. This phantom consisted several polyethylene parts with elliptical and circular cross sections in which some polyethylene tubes were considered along body axis and each part was analogue to its similar body organ such as abdomen, limbs[1]. In 1949, Bush constructed a simple phantom similar to his primary prototype without any tubes. Today, several phantoms have been constructed and developed for different applications from radiation dosimetry to quality control in medical imaging and radiotherapy [1-6].Primary data on dose distribution are usually obtained in a water phantom in which gamma and X-ray absorption and scattering characteristics are very similar to soft tissue. Due to several difficulties in working with dosimeters in water, these phantoms have been replaced by solid phantoms in some circumstances which are under continues development. Ideally, for a material to be tissue equivalent in respect to absorption and scattering of photons, it should have the same density, effective atomic number, electron density (e/gr) and same tissue inhomogeneity as human body. In diagnostic radiology and radiotherapy, anthropomorphic phantoms have been used for radiation dosimetry besides homogenous water phantoms like Bush phantom. One of these phantoms which are commercially available is Alderson-Rando. In this phantom there exist several materials similar to different tissues such as muscle, bone and lungs. The physical shape of this phantom is similar to human body and several transverse sections have been considered in it for dosimetric applications [7].

In construction of a phantom, there exist some important parameters which should be considered carefully: first of all, spatial distribution of phantom materials should be very similar to human body and second, physical dimensions and spatial distribution of phantom materials should be reproducible to enable accurate dosimetric measurements [8]. In construction of complicated phantoms, one of the most difficult aspects is designation and construction of phantom mold. One way to overcome this problem is to use human body. Although this method has certain limitations and difficulties, but if it done carefully, the constructed phantom will be very accurate anatomically [7].

The goal of the current study was to introduce and construct a tissue equivalent anthropomorphic phantom to be used for radiation dosimetry primarily for several organs such as thyroid, parotids, chest, abdomen and hip at the surface and several depths. Due to its resistivity to physical shock, one is able to use it at different working conditions without any worry. Besides, it has the capability to change the place of measurement and dosimeter easily although it is primarily constructed for *TLD*dosimetry.

MATERIALS AND METHODS

Selection of materials

Natural human skeleton was used as bone material and for the soft tissue and fat, paraffin wax with different amounts of *NaCl* as impurity was used. For the lung tissue, because of its low density (0.25 gr/cm^3) two pieces of porous wood with average density of 0.3 gr/cm^3 was considered as tissue equivalent material. Paraffin wax was selected from suggested materials by White for soft tissue which has general formula of C_nH_{2n+2} and average density of 0.9 gr/cm^3[7]. Using the following relationship (equation 1):

$$\rho_e = \rho_m . N_A . \sum_i a_i \left(\frac{Z_i}{A_i}\right) \quad (1)$$

Electron density of soft tissue was calculated. In this equation, N_A is the Avogadro number, a_i is weighting fraction of material with atomic number of $Z_i$and mass number of A_i[9].

Construction of phantom

After selection of phantom materials, phantom was constructed in three parts as head & neck, torso and hip. To construct head & neck, a mold of human head was constructed from gypsum; then the vertebrates in the neck was fixed in place at the correct distance and order. To consider trachea and esophagus, two hollow plastic tubes were placed at their anatomical position near neck vertebrates. It is notable that these tubes were assessed on radiographs at clinical conditions and their visual aspects such as optical density and contrast was very near to that of human trachea and esophagus. To consider the mouth cavity, a hollow plastic box similar to mouth cavity was constructed and placed between mandibles. Because brain tissue mainly composes from fat and protein which density is smaller than water, the skull was filled with pure paraffin without any additives. After cooling of this part, the neck vertebra with trachea and esophagus was placed at their anatomic position in the mold and a transverse cylinder was placed at the position of parotid which connects the left parotid to the right parotid; besides, two cylinders was considered at the position of the thyroid lobes.

(A) (B) (C)

Figure 1: Head & Neck phantom (A) with its AP (B) andlateral (C) radiographs

After placement of these cylinders, paraffin wax with required amount of NaCl filled in this part of the mold and when it cooled down after about 2 hours, the cylinders removed to form a hollow place at the position of these glands. This part of phantom with its AP and lateral radiographs are shown in figure 1. It is notable that the place of cylinders is observable on the radiographs.

After completing this step, three cylinders with same material as phantom material in which TLD placement positions considered at distances of 1 cm from each other made which were removable from their positions in phantom. These cylinders, which were used for in depth dosimetery, are shown in figure 2.

To construct the torso, first of all the vertebral column and ribs were fixed together as their correct anatomical order and then the porous wood parts which were considered as lungs were placed in rip cage and fixed to it. Then a cylindrical mold with elliptical cross section made and all of these parts placed in it. Then it filled with certain mixture of *NaCl* and paraffin wax layer by layer to avoid *NaCl* to form sediment in phantom.

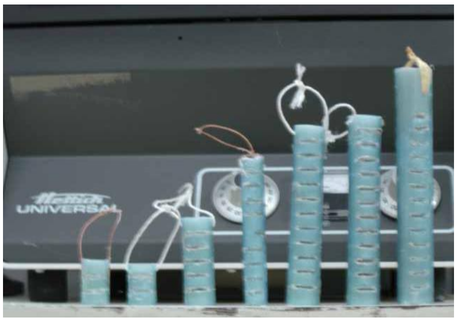
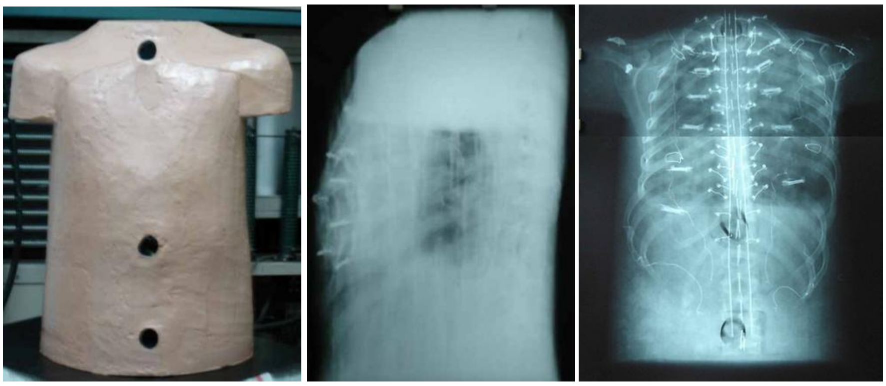


Figure 2: TLD placement cylinders for different parts of phantom

After filling the entire mold, it placed in a cool place for 3 hours and then the mold removed and with the aid of certain anatomical markers and radiographs, the excess parts of phantom carefully removed. After completion of this step, the torso was somewhat similar to human torso (fig. 3). In this part of phantom, three places considered for placement of *TLD*s: one at the junction of clavicle to sternum, other at diaphragm and the last at abdomen with heights of 6cm, 13cm and 12.5cm respectively (fig. 2). It is notable that in these cylinders *TLD* placement positions were spaced with 1cm distance.



(A) (B) (C)

Figure 3: Torso phantom (A) with its lateral (B) and AP (C) radiographs on which the position of cylinders is observed

Construction of hip part was similar to the torso but a 15cm height cylinder with 1cm TLD placement spaces considered at the position of uterus, which enables measurement of fetus dose at different ages (fig. 4). Finally, the entire phantom covered with a thin layer of color.

(A) (B)

Figure 4: Hip part of phantom (A) with its radiograph (B) on which the place of cylinder is observed.

RESULTS

By addition of *NaCl* as an impurity to paraffin wax, its density for different parts of phantom was in the range of 0.9-0.97 gr/cm^3. Using Maynord empirical relationship [9], effective atomic number of the phantom because it consists of 4% of *NaCl* and 96% of paraffin wax was obtained as 6.57. The effective atomic number of phantom material is between fat effective atomic number (5.92) and soft tissue atomic number (7.42).

Table 1: Physical dimensions (mean±SD) of Indo-Mediterranean ethnic group with phantom dimensions

	Phantom	Standard man
Height (cm)	103*	166.7±2.6
Weight (kg)	37**	57.9±5.8
Bi-acromial width (cm)	38	37.7±2.4
Bi-iliac width (cm)	29	26.3±1.1
Chest diameter (AP) (cm)	20	19
Chest diameter (lateral) (cm)	26	26.7

*without considering length of legs
**without considering weight of arms and legs

According to atomic and mass number of Sodium (11 & 23) and its density (0.97 gr/cm^3) and atomic and mass number of Chlorine (35 & 17) and its density of $3.2\times10^{-3} gr/cm^3$ (at 0° C), electron density of the material which was used as soft tissue in phantom was obtained from equation 1 as 3.34×10^{23}*electron/gr* which is very near to soft tissue electron density which is 3.36×10^{23}*electron/gr*[9]. Dimensions of phantom with the dimensions of standard man from *ICRU* report no.48 is shown in table 1[10].

DISCUSSION AND CONCLUSION

Because the electron density of phantom soft tissue and its effective atomic number to the values of human soft tissues and using natural human skeleton, it is concluded that, the constructed phantom has the same ionizing radiation interactions as human body in the energy range of diagnostic radiology and radiotherapy (20keV-20Mev). This problem may be observed from the optical density and contrast of radiographs obtained from phantom at conventional exposure conditions.

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