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Dosimetric investigations of some composites consisting of metallic particles distributed in silicone rubber matrix

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Different dosimetric measurements to compare the radiation attenuation of a commercial bolus from Qfix against of our composites based on silicone rubber doped with aluminum, copper and bismuth powders or without any metal powders, were performed. The samples were irradiated with a 6 MV photon beam, generated by a Unique accelerator from Varian and as dosimetric detection system, an ArcCheck phantom from Sun Nuclear was used. Considering that a radiotherapy treatment requires multiple irradiations, the samples were irradiated with 5000 MU at a distance of 100 cm from the source. The results obtained showed that the percentage difference in dose at a thickness of 1.8 cm is over 6% (for samples doped with Cu or Bi) and less than 6% (for the sample not doped or the sample doped with Al), compared to the attenuation obtained in the case of the commercial bolus from Qfix. Experimental results demonstrate that the composite samples based on silicone rubber doped with metallic particles can be used as an alternative in the treatment of some type of skin surface cancers using radiotherapy with photon radiation.

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1. Introduction

Radiotherapy is an indispensable way of treatment in modern oncology with curative potential in a wide range of malignancies. About half of the total number of cancer patients receive radiotherapy treatment during the disease, either with curative or palliative intent [1]. Radiation therapy is a way to use ionizing radiation to treat malignant neoplasia [2] and to achieve tumor control by permanently inactivating all cancer cells is the irradiated volume [1].

Some patients who have breast cancer or in the area of the head and neck, require irradiation of the tumor volume, the afferent lymph nodes that are at a distance of 2-3 cm from the skin surface, but also the skin. In order to successfully irradiate such an area, it is necessary to use X-ray photons [3], [4].

A standard linear accelerator usually uses a 6 MV photon beam [5]. The absorbed dose of a photon beam varies as it passes through a medium, as described in Figure 1. The radiation input dose is denoted by D_s and increases according to the specificity of the energy used in irradiation until it reaches a maximum D_{max} value, after which it decreases until exiting the body, at the value D_{ex}. The region between 0 and z_{max} is called the build-up region [6].

Bolus materials are used to move the maximum dose point to the surface of the skin [7]. In addition to the property of decreasing z_{max}, depending on their characteristics, bolus materials can increase or reduce the value of the maximum dose, D_{max}. These materials must mainly mimic a tissue [8]. In the specialty literature we can find various materials used as bolus, such as talc, rice

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or water bags, also we can find other commercial available boluses such as paraffin, Superflab, gels or Aquaplast [9 - 13].

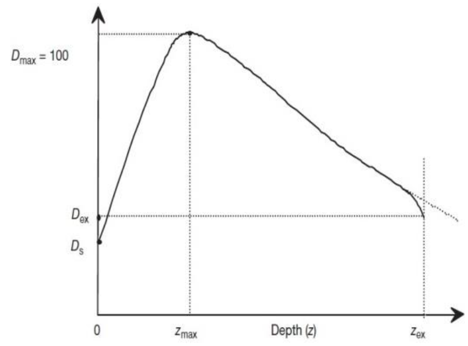

Fig. 1. Dose distribution of a photon beam through a medium.

This paper reports the results of the dosimettric investigations regarding the attenuating characteristics of some composites consisting of different metallic particles (Cu, Al or Bi) distributed in silicone rubber matrix, in order to their using in radiotherapy, as an alternative to commercial materials bolus type.

2. Materials and method

To obtain the samples, we used a silicone rubber, with the trade name, GS530SP01K1, from ProChima [14]. This kind of silicone rubber is composed of two liquid parts that combine and after 24 hours it hardens in the wanted shape. This silicone rubber has the following useful characteristics in the case of bolus materials: a) it has the property of being moldable, b) after polymerization it is elastic and can fold on non-flat surfaces, c) it does not affect the skin (is not harmful for the skin) and d) has the property of vulcanizing at room temperature [15]. Compared to other types of bolus, the samples created by us remain malleable even after 3, 4 weeks and are non-sticky compared to the Super-Flex material [16]. The composite samples were manufactured at the Faculty of Physics of the West University of Timisoara, using silicone rubber and copper (Cu), aluminum (Al) and bismuth (Bi) powders.

We used from each liquid part of the silicone rubber 32 g and poured into a mold 12 cm long, 12 cm wide and 0.3 cm thick. We performed 4 types of composites as follows: one consisting only of silicone rubber, called Sample A, a composite consisting of silicone rubber and copper powder (Sample B), a composite consisting of silicone rubber and aluminum powder (Sample C) and a composite consisting of silicone rubber and bismuth powder (Sample D). The images of samples are shown in Fig. 2.

In the all composites, copper, aluminum and bismuth, respectively, had a concentration of 5% of the sample mass and the powders used have a purity of over 99.5%. Aluminum, with the atomic number of 13, in general is used as an electron absorbent [17] and we tried to observe if the same effect can be observed with a photon beam [18]. At the same time, we used other metal particles such as copper, with the atomic number of 29 and bismuth with the atomic number of 83, in the silicone rubber matrix for manufacturing of composites and their using in dosimetric investigations with photons beam.

For each type of composite we performed 6 identical sheets having a parallelepiped shape with dimensions 12x12x0.3 (cm3), in order to evaluate the radiation attenuation depending on the thickness of the material. We proposed that because the sheet of composite is subjected to repeated irradiations and changes may occur in the structure and it may not have the same attenuating properties as in the beginning of treatment. We used a bolus sample from Qfix because the radiotherapy facility were we made our dosimetric experiments was using bolus from Qfix and we wanted to observe how our manufactured composites is attenuating photon radiations comparative with a commercial bolus.

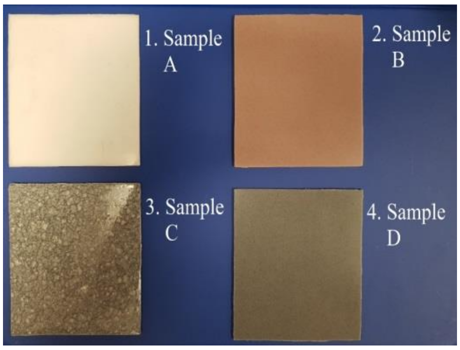

Fig. 2. The manufactured composites and used in the dosimetric experiments:1. Sample A - silicon rubber; 2. Sample B - silicone rubber with Cu particles; 3. Sample C - silicone rubber with Al particles; 4. Sample D - silicone rubber with Bi particles.

All samples were irradiated with photons that have the energy of 6 MV, at the OncoHelp Association, using a Unique linear accelerator that has only the radiation energy of 6 MV produced by Varian. All dosimetric data were taken using an ArcCheck phantom from the manufacturer Sun Nuclear which has a total of 1386 radiation detectors and 442 detectors in an irradiation field of 10 x 10 cm [19]. To obtain the irradiation plan, we scanned the ArcCheck phantom with a Siemens Somatom CT scanner. With the help of Varian's Eclipse software, we simulated a photon beam with an energy of 6 MV, which has a size of 10 x 10 cm and irradiates the detectors on the surface of the phantom. The dosimetric measurements were interpreted by the CNS Patient software, produced by Sun Nuclear and the values expressed are in percentage differences ($Diff_P$). The percentage difference is the difference in radiation dose between the point at which it is measured (D_M) and the dose point planned by the treatment plan conversion system (D_P), divided by the same planned dose point (equation (1)) [20].

$$Diff_P = \frac{D_M - D_P}{D_P} \tag{1}$$

With the aid of the ArcCheck and the multitude of detectors, we collected dosimetric data from different point of the composite, to see if the composite manufacture process leads that obtaining of some homogeneous sheets . From the same data package we could extract the way in which each type of composite attenuates the radiation compared to the commercial bolus from Qfix.

3. Experimental setup

An image of the experimental setup used in our dosimetric measurements, is presented in Fig. 3. The irradiation was performed with a photon beam from the Unique linear accelerator, with a energy of 6 MV and the field size was 10 x 10 cm.

All dosimetric measurements were performed in the mechanical isocenter of the accelerator. We positioned the ArcCheck with the help of the lasers from the treatment room and then placed the samples on the phantom.

The measuring points used in our experiments are in the detectors on the surface of the ArcCheck, which are at a distance of 89.9 cm from the radiation source of the Unique accelerator.

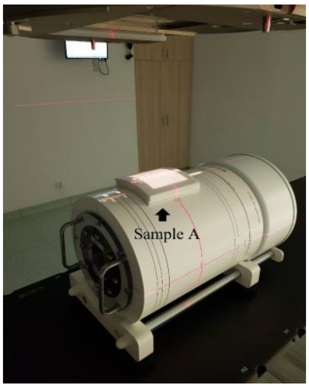

Fig. 3. Composite strips in Sample A placed on the ArcCheck phantom.

The samples were irradiated with 200 MU (monitor units) and the resulting set of measurements was compared with a bolus-free measurement to determine the attenuation of the radiation.

In order to assess the stability to irradiation (i.e. to see if the attenuation characteristics change after irradiation), all samples were placed on the treatment table and irradiated with 5000 MU. The samples were at a distance of 100 cm from the radiation source. Attenuation measurements were performed before and after irradiation with 5000 MU.

All values taken by ArcCheck and SNC Patient software were processed in the Origin program, all graphics were also made in this software.

4. Experimental results and discussions

4.1. Comparative analysis of the attenuation

The bolus materials we use frequently in radiotherapy plans are produced by Qfix. Due to this fact, we performed a comparative analysis of photon radiation attenuation, in which the attenuation characteristics of each of the composites obtained by us were compared with those of a Qfix sample. Each sample was investigated under the same experimental conditions, i.e. a photon field with an energy of 6 MV measuring 10 x 10 cm and 200 MU. The experimental results are presented in Fig. 4, in which the dotted line represents an exponential fitting expressed in equation 2.

$$y = y_0 + Ae^{R_0 x} \tag{2}$$

From Fig. 4 it can be observed that the composite manufactured by us attenuate more photon radiation than the Qfix bolus. The composites doped with copper and bismuth (samples B and D) attenuated the radiation the most, the percentage difference in dose at a thickness of 1.8 cm being over 6% compared to samples A and C, which are below 6%.

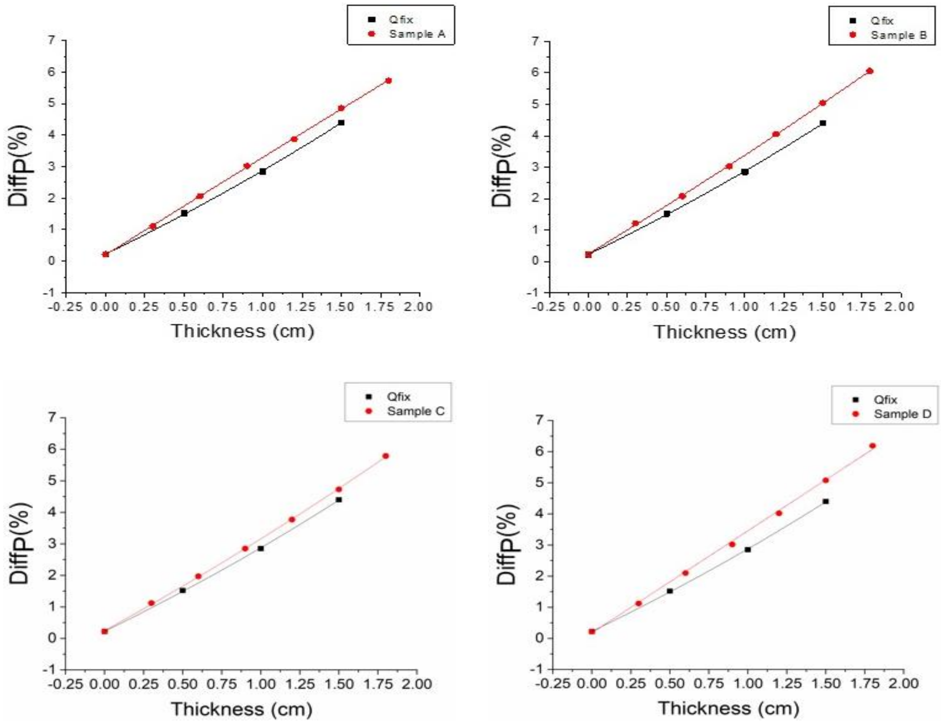

Fig. 4. Dose percentage differences between the Qfix bolus and the composites manufactured by us.

4.2. Stability of composites after irradiation

During a treatment plan, the patient undergoes several radiotherapy sessions, and maintaining the same bolus attenuation characteristics throughout the treatment period is particularly important. To analyze the irradiation stability in terms of the photon radiation attenuation property, we irradiated each composite with 5000 MU. Photon radiation attenuation was measured both before and after irradiation. The experimental results are shown in Fig. 5.

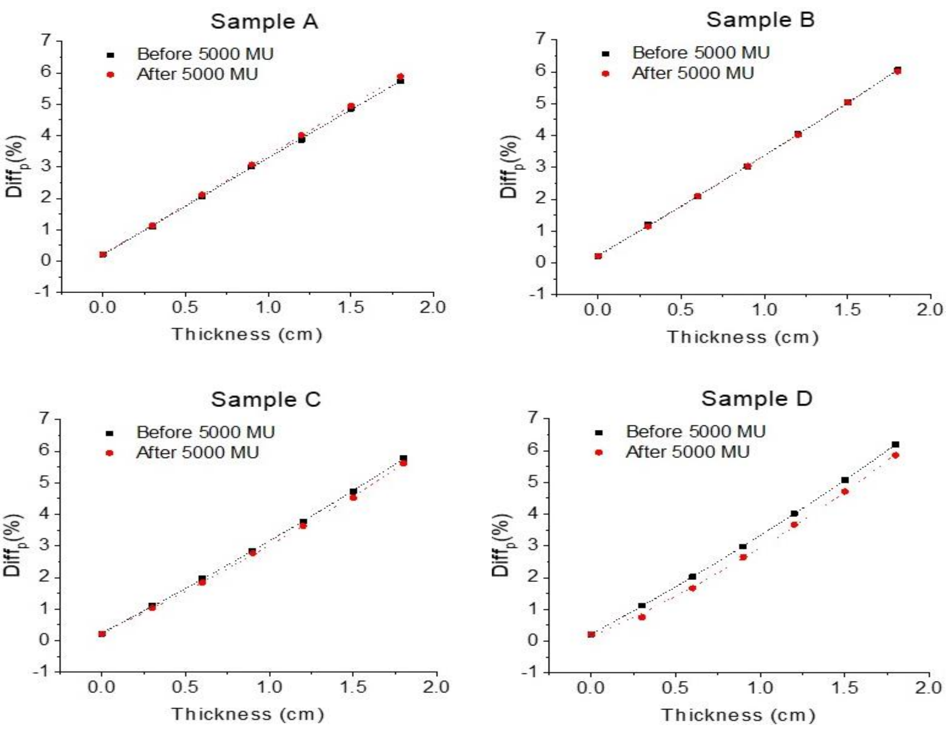

Fig. 5. Stability of the composites before and after delivery of 5000 MU.

From Fig. 5 it can be observed that the difference between the measurements before and after 5000 MU, is less than 0.2 %, which results that the composites manufactured by us are stable in terms of radiation attenuation. The biggest difference is seen in the composite D (with bismuth powder), but because the difference is about 0.35 percentage units between the two measurements, we can consider that this difference in attenuated radiation dose does not significantly change the radiotherapy treatment plan.

4.3. Homogeneity of the sheets composite

The silicone rubber sheet is composed of two different parts and we wanted to observe how homogeneous the composite sheet is after the hardening process, also how well the metal particles are distributed in the silicon rubber matrix. The ArcCheck is a cylindrical phantom so we extracted dosimetric data of the dose attenuation of the composites on the longitudinal profile of the phantom. This experimental data is show in Fig. 6.

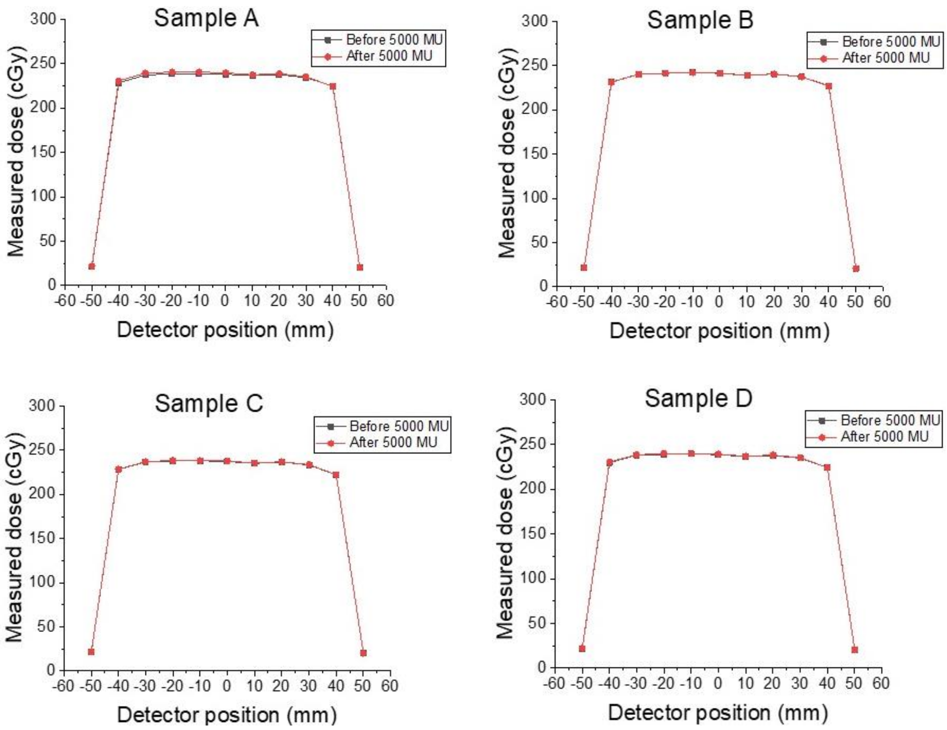

Fig. 6. Longitudinal profile of the composite.

The results from Fig. 6, showed that the manufacured composites are homogenous on the longitudinal profile of the phantom and did not change its attenuating properties after being irradiated with 5000 MU.

5. Conclusions

Dosimetric investigations were performed on four composites manufactured by us, consisting of metal particles distributed in a silicone rubber matrix: sample A, consisting only of silicone rubber, sample B, consisting of silicone rubber and copper powder, sample C. consisting of silicone rubber with aluminum powder and another sample composed of silicone rubber and bismuth powder

The attenuation properties and homogeneity of all composites were analyzed by comparing dosimetric data obtained while using a photon beam with the energy of 6 MV and an ArcCheck phantom.

The experimental results obtained for the 6 MV photon beam indicate that the silicone rubber composites attenuate the photon radiation more efficiently compared to the commercial bolus from Qfix, because of the interactions of the photon beam with the metal particles. The copper particle composite sample (Sample B) showed the highest attenuation. Also, the experimental data showed that the process of manufacturing the composites was a good one because the obtained samples were homogenous on their entire length.

In order to analyze the irradiation stability of the samples, we irradiated each sample with the photon beams of 6 MV, with 5000 MU and the measurement of photon radiation attenuation was performed before and after irradiation. The results show that, within the limits of the experimental errors, the analyzed samples maintain their photon beam attenuation characteristics. The radiation measured by the detectors linearly decrease with the thickness of the composite.

The experimental results prove the possibility of using composites based on silicone rubber with metallic particles as a cheaper substitute compared with the available commercial bolus in the radiotherapy treatment with the photon beam.

Acknowledgements

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References

[1] David J. Kerr, Daniel G. Haller, Cornelis J. H. van de Velde, Michael Baumann, Oxford Textbook of Oncology, Oxford University Press, (2016).
[2] E. C. Halperin, D. E David, C. A. Perez, L. W. Brady, Principles and practice of radiation oncology, (2018).
[3] G. H. Perkins, M. D. McNesse, J. A. Antolak, T. A. Buchholz, E. A. Strom, K. R. Hogstrom, Int. J. Radiat. Oncol. Biol. Phys. **51**(4), 1142 (2001).
[4] R. J. Kudchadker, K. R. Hogstrom, A. S. Garden et al., Int. J. Radiat. Oncol. Biol. Phys. **53**, 1023 (2002).
[5] F. M. Khan, Physics of radiation therapy, LWW Philadelphia, USA (2014).
[6] E. B. Podgorsak, Radiation Oncology Physics: A Handbook for Teachers and Students, 289 (2005).
[7] P. Mayles, A. Nahum, J. C. Rosenwald, Handbook of Radiotherapy Physics Theory and Practice, Taylor & Francis, (2003).
[8] G. C. Bentel, Radiation Therapy Planning. 2nd ed, McGraw-Hill, New York, NY, (1996).
[9] D. R. White, Med. Phys. **5**, 467 (1978).
[10] http://www.qfix.com/qfix-products/aids-and-accessories.asp?CID=10&PLID=51.
[11] http://www.orfit.com/en/bolus-materials/.
[12] K. M. Huang, C. H. Hsu, S. C. Jeng, L. L. Ting, J. C. Cheng, W. T. Huang, Anticancer Research **26,** 759 (2006).
[13] S. M. Humphries, K. Boyd, P. Cornish, F. D. Newman, Medical Dosimetry **21**, 155 (1996).
[14] http://www.prochima.it/files/Gomma-siliconica-RTV-530_versione-5.pdf.
[15] https://d5cafn4nbz2pc.cloudfront.net/documents/69be4bbd9cec70099706dc7a7d8e736d.pdf
[16] V. Vyas, L. Palmer, R. Mudge, R. Jiang, A. Fleck, B. Schaly, E. Osei, P. Charland, Med Dosim. **38**(3), 268 (2013).
[17] M. Spunei, I. Malaescu, M. Mihai, C. N. Marin, Rad. Prot. Dosim. **162**(1–2), 167 (2014).
[18] R. A. Kinhikar, C. M. Tambe, R. R. Upreti, S. Patkar, K. Patil, D. D. Deshpande, Med. Dosim. **33**, 286 (2008).
[19] https://www.sunnuclear.com/solutions/patientqa/arccheck3dvh.
[20] ArcCheck Help Manual, Comparing Data, Analysis Criteria, Percent Difference.