Iranian Journal of Medical Physics

ijmp.mums.ac.ir

# Effect of Dental Filling Materials on Electron Beam Radiotherapy Dose Distribution in Head Region: a Monte Carlo Study by FLUKA and MCNPX Codes

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**ARTICLE INFO**

*Article type:*
Original Article

*Article history:*
Received: Mar 06, 2019
Accepted: Sep 12, 2019

*Keywords:*
Radiation therapy
Electron
Monte Carlo Method
Tooth
Restoration Material

**ABSTRACT**

***Introduction:*** Radiation therapy is regarded as the mainstay treatment for head or neck cancer patients. In this method, the backscattered radiation of dental composites can damage the surrounding tissue.

***Material and Methods:*** The current study compared the effects of electron beam radiation on healthy teeth with the tooth filled with materials used in dentistry with FLUKA and MCNPX2.6 codes. The simulation was performed for a 512 mm$^3$ cubic tooth composed of Amalgam and Ceramco materials.

***Results:*** The simulation results indicated that patients with dental caries who inevitably filled their teeth with artificial restoration received a more effective dose, as compared to others. Moreover, it was revealed that Ceramco increases the radiation risk more than Amalgam does. Therefore, Amalgam is the right choice for dental filling.

***Conclusion:*** Based on the obtained results, ceramic material poses patients to increased radiation risk more than Amalgam does; therefore, it is recommended that Amalgam be used to fill dental cavities.

► *Please cite this article as:*
Rezai MR, Shahheidarypoor R, Mohammadi S, Parvaresh P. Effect of Dental Filling Materials on Electron Beam Radiotherapy Dose Distribution in Head Region: a Monte Carlo Study by FLUKA and MCNPX Codes. Iran J Med Phys 2020; 17: 183-187. 10.22038/ijmp.2019.36221.1460.

## Introduction

Dental prostheses with high -Z number are effective in dose distribution due to backscatter electrons in neck and head radiotherapy. In this regard, restorative dental materials are indispensable to restore tooth structure. In most cases, these materials are classified into four groups, namely metals, composites, ceramics, and polymers. The compositions of filling materials and soft tissue are not similar despite their homogeneous distribution. Electron beam and secondary electrons scatter in all directions since electron beam interacts with matter. The secondary scattered electrons add an additional dose relative to the primary beam dose and can change the tooth structure [1, 2]. The protection materials in high photon energies field (up to 5 MeV) produce high-energy secondary electrons in the absence of preparation shield for dentition protection [3, 4]. Therefore, the high-energy electrons can exert a major effect on the dental tissue [5]. Metallic components with high electron density were used as plate materials for the modification of dose distribution. The metallic components inflict minor damage in dental surrounding tissue [6]. The current study aimed at investigating the effects of electron beam radiation on tooth with and without the dental restoration material used in dentistry. To this end, the FLUKA and MCNPX2.6 codes were used. The dose maps in voxel size can be calculated by these codes. Dosimetry of head and neck is often calculated by Monte Carlo (MC) simulation and MIRD calculation which are comparable. The correlation of these codes with experimental results is reported to be 3-4% [7]. Therefore, the MC simulation is more cost-effective, as compared to others [8]. The electron beam therapy is used in the clinical treatment of maxillary, tongue, and oral cavity cancers, as well as all types of squamous cell carcinomas. The use of the Monte Carlo simulation method and the obtained results of present study will be presented in the next section.

## Materials and Methods

### *FLUKA and MCNPX Simulation*

FLUKA and MCNP are based on Monte Carlo calculation for particle transport. The results were suggestive of the suitability of MCNP and FLUKA codes for electron dosimetry.

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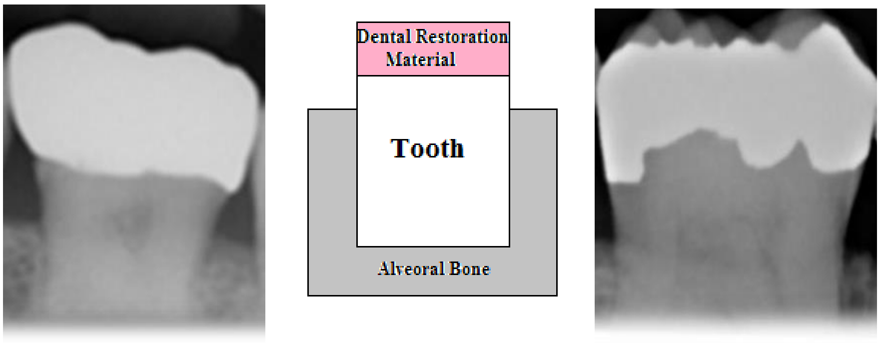



Figure. 1 Tooth and restoration material: *Middle picture*) FLUKA and MCNPX geometry *Outside pictures*) Radiographic image [9]

Table 1. The element mass percentage of soft tissue, Alveolar bone, tooth, and restoration materials [9, 10].

| Organ | Density ($g/cm^3$) | K | Cl | Zn | F | Na | Mg | N | H | P | C | O | Ca | Al | Si | Sn | Ag | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soft Tissue | 1 | 0.2 | 0.09 | 0 | 0 | 0.09 | 0.02 | 2.35 | 10.7 | 0.37 | 25.3 | 60 | 0.28 | 0 | 0 | 0 | 0 | 0 |
| Dentine | 2.18 | 0.07 | 0.03 | 0.018 | 0.02 | 0.2 | 1.1 | 2.5 | 3.08 | 15 | 11.3 | 36.14 | 30.5 | 0 | 0 | 0 | 0 | 0 |
| Ceramco | 2.6 | 7.07 | 0 | 0 | 0 | 8.32 | 0 | 0 | 0 | 0 | 0 | 38.97 | 0 | 14.65 | 15.24 | 15.76 | 0 | 0 |
| Amalgam | 8 | 0 | 0 | 1 .0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17.9 | 69.3 | 11.8 |
| Alveolar Bone | 1.8 | 0 | 0 | 0 | 0 | 0 | 0 | 2.7 | 6.4 | 7.0 | 27.8 | 41.0 | 14.7 | 0 | 0 | 0 | 0 | 0 |

However, FLUKA is better code for graphical plots than MCNP, whereas the MCNP is more appropriate for flux calculation, as compared to FLUKA. The geometry, material and energy distribution of radiation source are defined in a program as an input file for calculation of absorbed dose by FLUKA and MCNPX simulations.

The simulated geometry is a soft tissue cylindrical with a dimension of 5×10 $cm^2$ as radius and height, respectively. Inside it, a part of human jaw (Alveolar) is placed with a tooth and restorative material. Various conditions, such as healthy teeth and teeth with standard dental materials, were individually simulated. The Amalgam and Ceramco compositions were used as restorative dental material. The tooth is in cubic form with length of 8mm with 3-mm thick restoration material above it (Figure.1)

The material information in this study, including density and element percent can be derived from soft tissue, tooth, and restoration material composition data (Table 1,).

The energy of the electron beam is sampled by source routine and source card in FLUKA and MCNPX codes, respectively. The particle transport, energy deposition, and absorbed dose in sample are simulated for one disintegration. The absorbed dose per one disintegration with its error is provided in a user-defined text file. In this simulation, the electron with14 MeV energy was considered as radiation source, and electron-photons cut off energy was considered to be 10 keV. For a more accurate measurement in simulation, the energy was divided into 14 intervals. The electron beam was at a distance of 10 cm from phantom center. Its dimensions were measured at 10×10 cm in parallel with one cubic surface. In MCNPX simulation, F4 tally was used in various geometrical regions to measure the electron flux. In the FLUKA simulation, USRBIN detectors were used to measure the deposited energy and the flux of particles in various geometrical regions. For total error below $10^{-4}$, a total of $10^6$ initial particles were considered for simulation. The Monte Carlo simulation result is due to primary and backscattered electrons interaction with soft tissues, alveolar bone, teeth, and restoration materials.

## Results

Figures 2-4 demonstrate the flux of backscatter electrons in soft tissue, jaw, teeth and restoration materials.

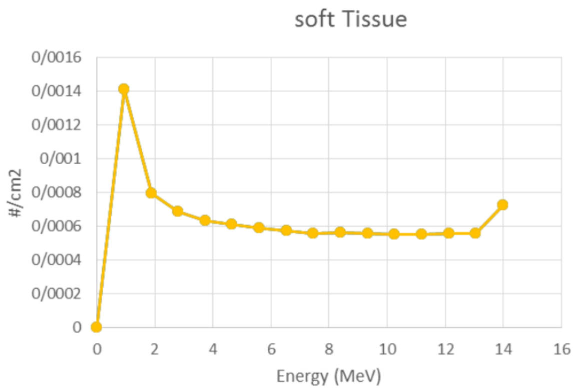



Figure 2. Flux of backscatter electrons in the soft tissue

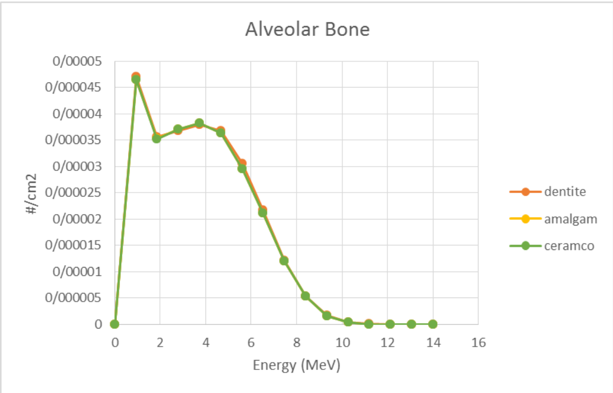



Figure 3. Flux of backscatter electrons in the jaw

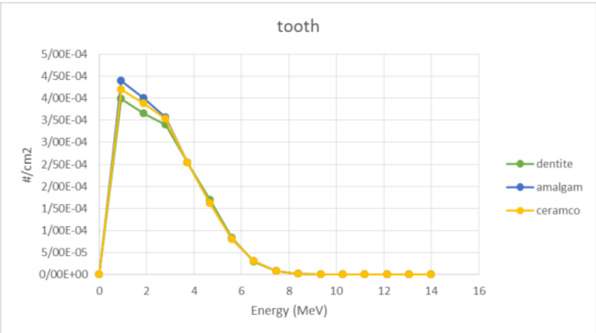



Figure 4. Flux of backscatter electrons in teeth and restoration materials

Figures 5-8 demonstrate the distribution of deposited energy in phantom with teeth, restoration materials, and the soft tissue around it.

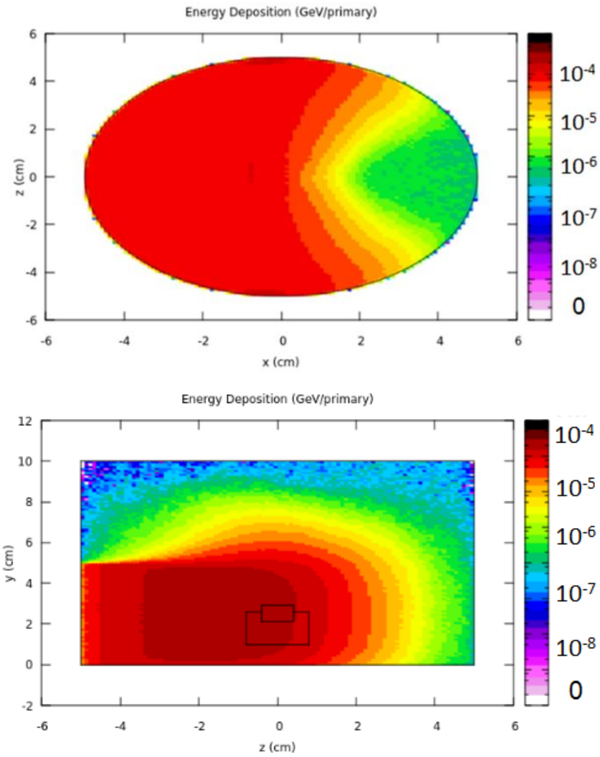



Figure 5. Distribution of the energy deposited in the phantom with teeth and the soft tissue around it: Above) x-z plan below) y-z plan

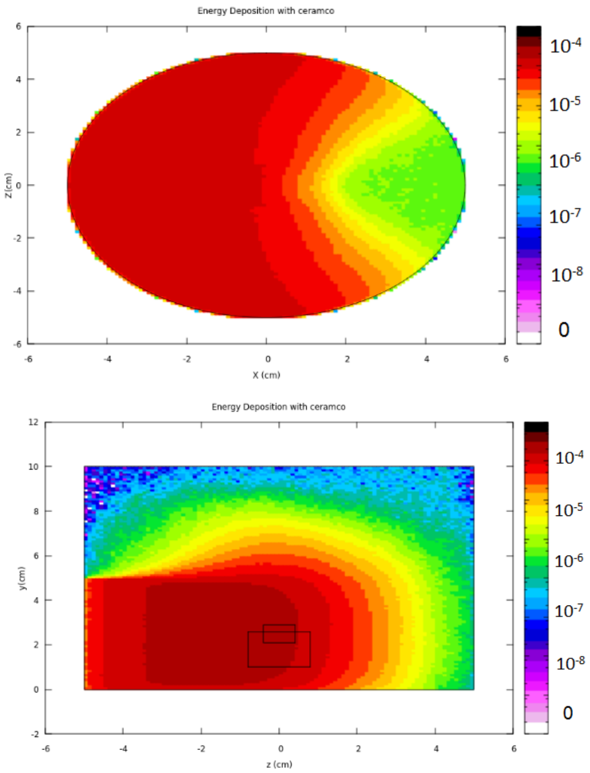



Figure 6. Distribution of the energy deposited in the phantom with teeth, Ceramco as restoration material, and the soft tissue around it: Above ) x-z plan Below ) y-z plan

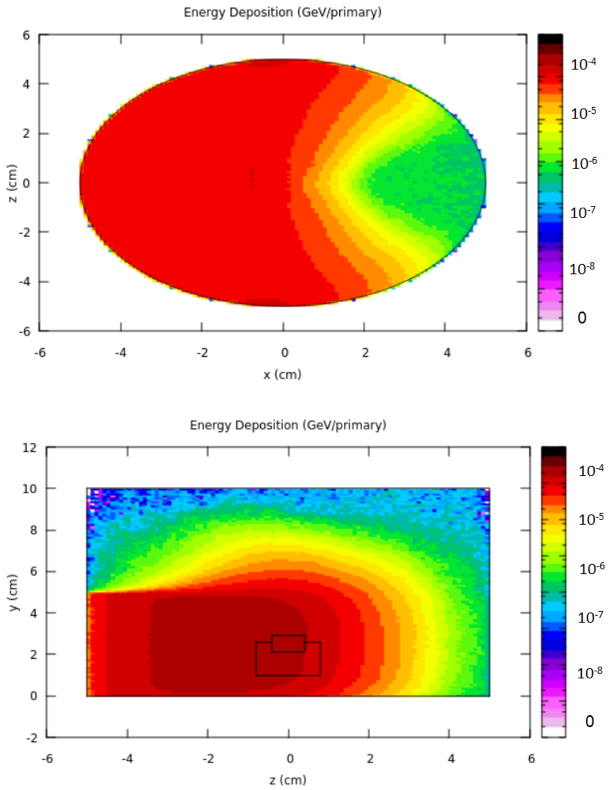



Figure 7. Distribution of the energy deposited in the phantom with teeth, Amalgam as restoration material, and the soft tissue around it: Above) x-z plan below) y-z plan

For a better comparison, the total energy deposited in geometry was calculated in various integration scenarios (Figure 8).

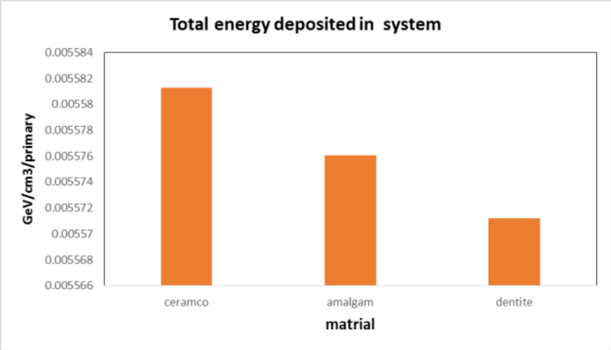



Figure 8. Energy deposited in geometry with different materials

Figures 9-11 depict the distribution of the electron flux in phantom with teeth, restoration materials, and the surrounding soft tissue.

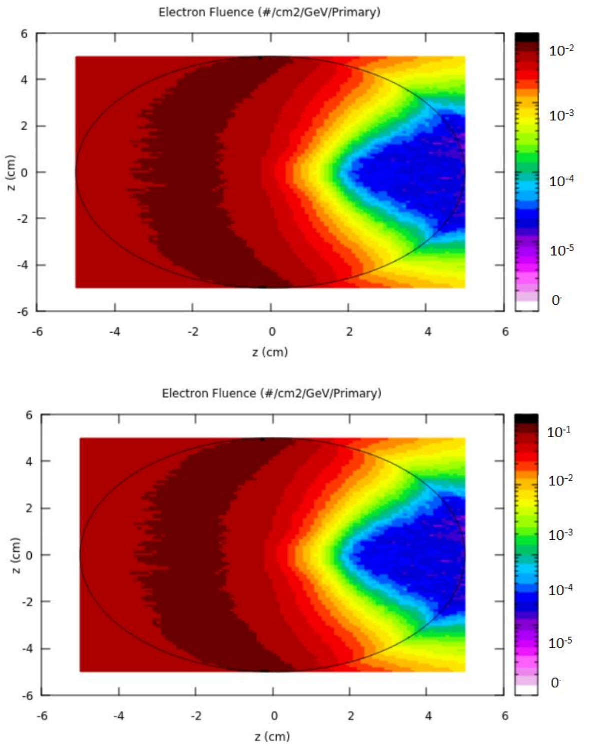
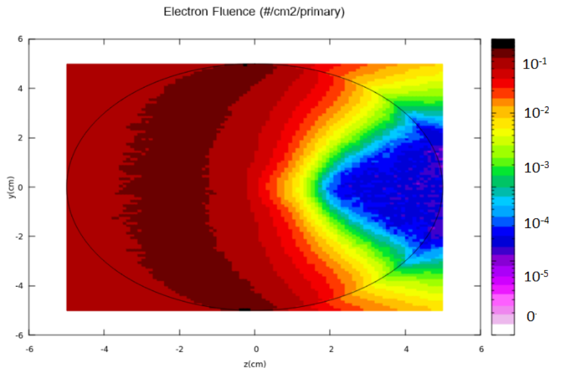



Figure 9. Distribution of the electron flux in the phantom with teeth and the surrounding soft tissue: Above) x-z plan below) y-z plan



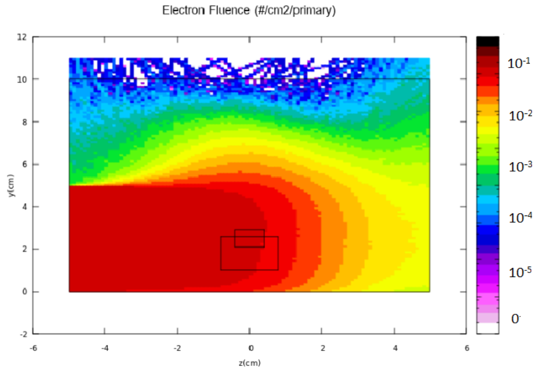




Figure 10. Distribution of the electron flux in the phantom with teeth, Ceramco as restoration material, and the surrounding soft tissue: Above) x-z plan Below) y-z plan

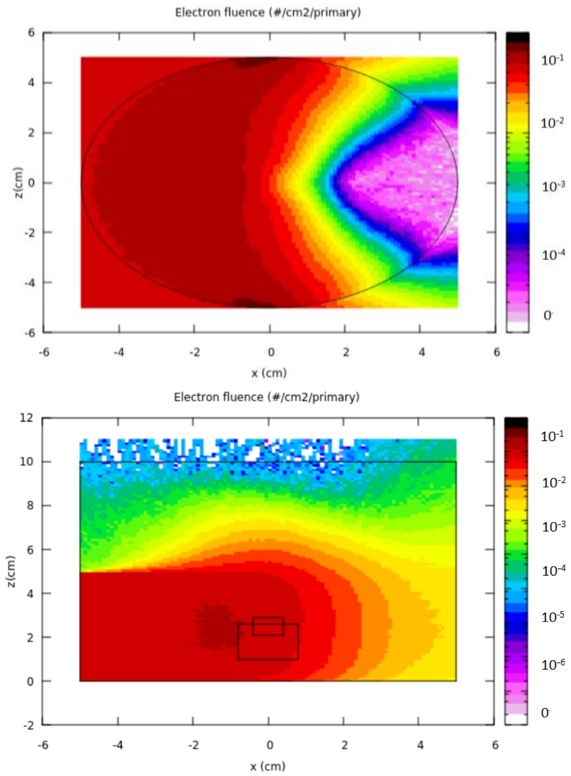



Figure 11. Distribution of the electron flux in the phantom with teeth, Amalgam as restoration material, and the surrounding soft tissue: Above) x-z plan below) y-z plan

For a better comparison, the total electron flux in geometry was calculated in various integration scenarios (Figure 12).

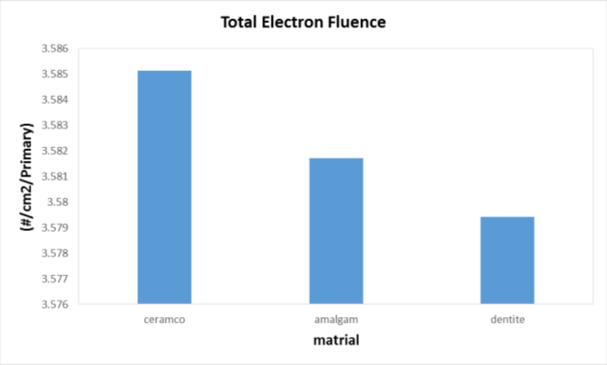



Figure 12. Electron flux in the system with different materials

## Discussion

Figures 2-4 depicts the backscatter electrons flux in the soft tissue, jaw, teeth, and restorations material (Amalgam and Ceramco) as a function of energy. Figure 2 demonstrates that the energy of backscatter electrons is reduced to 13MeV owing to 14MeV electron source in collision with the soft tissue. This figure also illustrates the penetration of several electrons into the teeth, jaw, and restorations material. Some electrons were backscattered, and their energy was reduced to 1MeV without any change in flux. These slow-down electrons generate many secondary electrons with energy of about 0.5 MeV. Thereafter, the primary and secondary electrons were stopped and absorbed in the system.

Figure 3 demonstrates the behavior of electrons in the jaw where they penetrated into the jaw, generate secondary electrons with lower energy and all of them are absorbed in it.

Apart from the jaw, Figure 4 also illustrates the same behavior in the teeth and restorations material (i.e., Amalgam and Ceramco). Nonetheless, secondary low-energy electrons generation is different in restorations material in the sense that it has a greater quantity in Ceramco, as compared to Amalgam and teeth, respectively.

Figures 9-11 indicate that the distribution of the electron flux in phantom with teeth and restoration materials depends on the filling materials. In this regard, the electron flux distribution is greater in Ceramco, as compared to Amalgam and teeth, respectively.

Accordingly, in head and neck re-irradiation, the tooth filling with Amalgam has a lower effective dose and flux than Ceramco. This can be attributed to the greater ability of Ceramco to scatter the electrons and generate secondary electrons, in comparison with Amalgam and tooth, respectively. Consequently, tooth filling with Amalgam is recommended for patients with head and neck cancer who are exposed to high-energy electrons for treatment.

## Conclusion

The results of the present study demonstrated that patients with dental caries who filled their teeth with artificial materials were more likely to be exposed to radiation, as compared to other patients with unfilled teeth. In addition, the possibility of a higher electron dose in other body parts is also increased owing to increased electron flux in teeth filled with restoration materials, the obtained results noted that Ceramco poses increased radiation risk to patients much greater than Amalgam. Moreover, based on simulation results, the electron flux produced in the tooth was reported to be higher using the Ceramco as filling material, in comparison with Amalgam utilization. Therefore, Amalgam is recommended to be used for filling cavities.

## Acknowledgment

We are thankful to Mashad PNU computer center and M.Javan for FLUKA code learning.

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