Original Article

Tissue composition effect on dose distribution in radiotherapy with a 6 MV photon beam of a medical linac

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ABSTRACT

Aim: The aim of this study is to evaluate soft-tissue composition effect on dose distribution for various soft tissues in radiotherapy with a 6 MV photon beam of a medical linac.

Background: The compositions of various soft tissues are different which could affect dose calculations.

Materials and Methods: A phantom and Siemens Primus linear accelerator were simulated using MCNPX Monte Carlo code. In a homogeneous cubic phantom, six types of soft tissue and three types of tissue-equivalent materials were defined separately. The soft tissues were muscle (skeletal), adipose tissue, blood (whole), breast tissue, soft tissue (9-component), and soft tissue (4-component). The tissue-equivalent materials included water, A-150 tissue equivalent plastic and perspex. Photon dose relative to dose in 9-component soft tissue at various depths on the beam's central axis was determined for the 6 MV photon beam. The relative dose was also calculated and compared for various MCNPX tallies including *F8, F6, and *F4.

Results: The results of the relative photon dose in various materials relative to dose in 9-component soft tissue using different tallies are reported in the form of tabulated data. Minor differences between dose distributions in various soft tissues and tissue-equivalent materials were observed. The results from F6 and F4 were practically the same but differ with the *F8 tally.

Conclusions: Based on the calculations performed, the differences in dose distributions in various soft tissues and tissue-equivalent materials are minor but they could be corrected in radiotherapy calculations to upgrade the accuracy of the dosimetric calculations.

KEY WORDS: Dose distribution, photon beam, radiotherapy, tissue composition

INTRODUCTION

The main purpose of radiotherapy is to deliver a lethal dose of radiation to the tumor while preserving nearby healthy tissues.[1] Different tissues have various different properties that influence a range of dosimetric results for various combinations of tissues. Dosimetry in radiotherapy is done in water and tissue equivalent materials which are different than true body dosimetry. This difference is due to variations in tissue and phantom components and the composition of said components. According to the International Commission on Radiation Units (ICRUs) report 24, the maximum error in dose delivery to the patient should be within ±5%. To achieve this level of accuracy in all the processes of treatment, including the delivered dose calculation in treatment planning system, this amount of error should be estimated lower than ±5%. With considering all interaction types of the photon beam including, coherent and noncoherent scattering, pair production; photo-electric absorption combined with fluorescent emission as the physics of photon the accuracy of the delivered dese can be calculated.[2]

Monte Carlo simulation is a statistical method for radiation transport problems. This method can accurately model complex physical processes involved in radiotherapy with any geometry. It is widely accepted that Monte Carlo simulation of radiation transport is one of the most accurate methods for describing the distributions of the absorbed dose in radiotherapy.[1] Nedaie *et al*.[3] using MCNP-4C code determined the dose distribution of 8 and 15 MeV electrons produced

Cite this article as: Ghorbani M, Noghreiyan AV, Tabatabaei ZS, Pakravan D, Davenport D. Tissue composition effect on dose distribution in radiotherapy with a 6 MV photon beam of a medical linac. J Can Res Ther 2019;15:237-44.

Access this article online
Website: www.cancerjournal.net
DOI: 10.4103/jcrt.JCRT_706_16
Quick Response Code:

by the linear accelerator in a homogeneous phantom and in the heterogeneities around it. The results of the research demonstrate a good agreement between the results obtained from the measurements in a homogeneous phantom. The results between the simulation and measurements in a heterogeneous phantom generally have a difference of about 2%.

White *et al*.[4] examined the dosimetric effects of small amounts of elements in tissue for low-energy photon sources used in brachytherapy by Monte Carlo calculations for normal and cancerous tissues. The results of the study showed that the presence of these elements in tissue creates a different dose distribution which depends on the atomic number and the ratio of the elements, and the greater the atomic number, the more the dose distribution is affected. The results demonstrated that the trace elements have nonnegligible effect on dose distribution in the tissues in low-energy photon brachytherapy. Ghorbani *et al*.[5] compared dose distribution in different soft tissues with the scope of the effect of soft-tissue composition. Different photon-emitting brachytherapy sources were used as radiation sources. The simulations were made using MCNPX Monte Carlo code. The materials evaluated were adipose tissue, breast tissue, brain, muscle, lungs, blood, water, 4-component soft tissue, and 9-components soft tissue. Absolute dose and relative dose compared to 9-components soft tissue were calculated for different tissues, sources, and distances. They concluded that ignoring the differences in dosimetric characteristics (density, composition, etc.) of soft tissues and tissue-equivalent materials cause errors in the treatment planning and in dose delivery in brachytherapy with photon-emitting sources.

Ghorbani *et al*.[6] evaluated the effect of tissue composition on dose distribution in radiotherapy with 8, 12, and 14 MeV electron beams. Various issues and tissue-equivalent materials were investigated. Negligible differences were observed between dose distributions in these materials, which were related to the uncertainties in Monte Carlo calculations. Khosroabadi *et al*.[7] assessed the effect of the composition of materials on dose distribution in neutron brachytherapy/neutron capture therapy. A commercial ^{252}Cf source was simulated as a neutron source. In phantom relative total dose rate, relative neutron dose rate, total dose rate, and neutron dose rate were calculated for various soft tissues and tissue-equivalent materials. The difference in dose rate in these materials depended on the compositions of the materials and the radial distance from the source. Finally, it was concluded that taking the same composition for various materials lead to error in treatment planning in brachytherapy with a neutron source and this effect should be taken into account in radiotherapy.

Several studies in this field have been performed, evaluating the effect of composition of soft tissue/tissue-equivalent material on dose distribution in various radiotherapy beams including brachytherapy, electron therapy, and neutron brachytherapy/neutron capture therapy.[5-10] However, such study has not been performed in the case of 6 MV photon beams of a medical linac. Since this photon beam energy is a most frequently used beam in radiotherapy such evaluation is of high relevance. In addition, the previous studies are on electron and neutron beams, but the type of electron and neutron interactions are quite different from photon interactions; therefore, the influence of tissue composition on the electron (or neutron) and photon dosimetery are completely different. The aim of this study is to evaluate the differences in dose distribution in several soft tissues and soft-tissue-equivalent materials in radiotherapy with 6 MV photon beam of a medical linear accelerator. Since the difference between different tissues with regard to dosimetry for the 6 MV photon beam was not quantified in the literature, it is determined in this research.

MATERIALS AND METHODS

Validation of linac simulation

The input simulation program used in this study of the head of a Siemens Primus linac was validated in a previous study.[11] In the previous study on this linac, the criterion for validation of the simulations has been the agreement between the percent depth dose data from simulations and in-phantom measurements for 10 cm × 10 cm, 15 cm × 15 cm, and 25 cm × 25 cm applicators. Comparisons have been performed based on gamma index calculations. Gamma index values were <1.0 for most data points, indicating agreement between the two sets of data. This accelerator is routinely used for patient radiotherapy in Reza Radiotherapy and Oncology Center (Mashhad, Iran). The head of this linac for a 6 MV photon beam includes a target, primary collimator, flattening filter, ionization chamber, mirror, and secondary collimators. In this linear accelerator, electrons are striking the target and Bremsstrahlung X-rays are created. The target includes cylindrical layers of air, gold, graphite, and water of different radii and thicknesses. Detailed information on the geometry of the Siemens Primus linac can be found in a previous MC study.[11] In the previous study on the simulation and validation of this linac, percent depth dose values for 6 cm × 6 cm, 10 cm × 10 cm, and 20 cm × 20 cm photon fields were calculated through simulations. The head components of Siemens Primus linac were simulated by MCNPX (version 2.4.0, Los Alamos, New Mexico)[12] MC code. Dose profiles for 6 cm × 6 cm field were calculated for 5 cm, 10 cm, and 20 cm depths in a water phantom. The Monte Carlo data were compared with the in-phantom measured data using a diode. The agreement between these two data sets was evaluated based on the percentage dose difference between the data sets. The results showed that agreement between the Monte Carlo calculations and measurement.

Dose distribution in various materials

MCNPX code (version 2.4.0) was used for simulation of a cubic 30 cm × 30 cm × 30 cm phantom at the source to surface distance (SSD) of 100 cm from the source of the Siemens

Primus linac. The 6 MV photon beam of the linac was used as the photon source in these simulations. The phantom was defined containing various soft tissues and tissue-equivalent materials, each evaluated separately. The materials were as follows: adipose tissue, breast tissue, muscle, blood, 4-component soft tissue, 9-components soft tissue, water, and A-150 tissue-equivalent plastic and perspex. For the calculation of MCNP tallies, cylindrical cells were defined on the central axis of the phantom. These cells were 2 cm in diameter and 2 mm in height. The doses in these cells at depths of 1 mm to 25 cm were calculated [Figure 1].

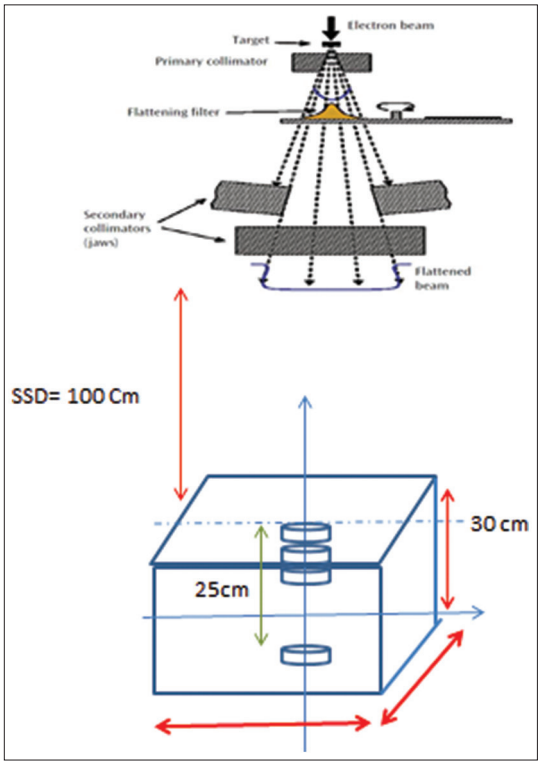

Figure 1: A schematic diagram illustrating the position of phantom, dose calculation cells, and the head of the linac

Atomic densities and chemical compositions of the soft tissues and tissue-equivalent materials were adopted from the report No. 44 of the ICRUs and measurements.[13] These data are presented in Table 1. For a better comparison and interpretation of the dose data in these materials, effective atomic number for total photon energy absorption (Z_{PEAeff}) and the mass energy absorption coefficient ($\propto_{en}/\rho$) of these compositions were also listed in this table. These data are related to 0.5 MeV photon energy.[14-16] This energy was selected since the most probable energy on the phantom surface with an SSD of 100 cm for the 6 MV nominal energy of Siemens Primus line was reported as 0.5 MeV.[17]

The SSD was defined 100 cm in the input programs. All calculations were for the case of a 10 cm × 10 cm field. The Monte Carlo input programs for the soft tissues and tissue-equivalent materials were run and the relative dose for each material was obtained as the ratio of the dose for that material at depth to the dose at the same depth in 9-component soft tissue. The composition of 9-components soft tissue is more accurate than 4-components soft tissue, and the purpose is to compare these two components. And whether, there is a difference between these two tissues, and how accurately it will increase if we consider the tissue as a 9-components soft tissue. To score the absorbed dose in various depths, cylindrical cells with 2 cm diameter and 2 mm height were defined on the beams central axis inside the phantom. Then, *F8 tally was applied to score energy deposition (MeV) in the tally cells with a 10 keV energy cutoff as the only variance reduction method used. The outputs of *F8 (MeV) were divided to the mass of the tally cells to obtain the energy deposition per gram. To speed up the running process and to minimize the Monte Carlo statistical uncertainties, two input files were defined and run for each case. In the first program, a plane was defined below the secondary collimators, and the flux and energy of photons and electrons were scored on this plane. This program was run for 1.5 × 109 electrons, and 2.89 × 10^8 particles were registered on this plane. In the

Table 1: Mass densities, effective atomic number for total photon energy absorption (Z_{PEAeff}), mass energy absorption Coefficient and compositions of the soft tissues, and tissue-equivalent materials

	Adipose tissue	Soft tissue (4-component)	Breast tissue	Muscle (skeletal)	Blood (whole)	Soft tissue (9-component)	Water	A-150 plastic	Perspex
Density (g/cm^3)	0.95	1.00	1.02	1.05	1.06	1.06	1.00	1.12	1.19
Z_{PEAeff} (for 0.5 MeV photon)	3.0739	3.4547	3.2855	3.4324	3.4473	3.4342	3.35	-	-
μ_{en}/ρ (for 0.5 MeV photon)	0.03304	0.03267	0.03281	0.03269	0.03269	0.03269	0.03299	0.03265	0.03206
H	0.114000	0.101174	0.106000	0.102000	0.102000	0.102000	0.111898	0.101330	0.080538
C	0.598000	0.111000	0.332000	0.143000	0.110000	0.143000	-	0.775498	0.599848
N	0.007000	0.026000	0.030000	0.034000	0.033000	0.034000	-	0.035057	-
O	0.278000	0.761826	0.527000	0.710000	0.745000	0.708000	0.888102	0.052315	0.319614
F	-	-	-	-	-	-	-	0.017423	-
Na	0.001000	-	0.001000	0.001000	0.001000	0.002000	-	-	-
P	-	-	0.001000	0.002000	0.001000	0.003000	-	-	-
S	0.001000	-	0.002000	0.003000	0.002000	0.003000	-	-	-
Cl	0.001000	-	0.001000	0.001000	0.003000	0.002000	-	-	-
K	-	-	-	0.004000	0.002000	0.002000	-	-	-
Ca	-	-	-	-	-	-	-	0.018377	-
Fe	-	-	-	-	0.001000	0.001000	-	-	-

second program, this plane was used as the source, and the tally in the phantom was calculated. Since the second program terminated automatically after reading of 2.89 × 108 particles from this plane, and the related uncertainty was not acceptable with a single second program, for each material 5 s programs with different seed numbers were run and the average dose of the five programs was reported as dose. Utilizing this method, the statistical uncertainty in the tally cells with *F8 tally was <1.2%.

As another evaluation, the dose values from *F8 tally with 10 keV energy cutoff were compared with those from F6 to *F4 tallies with 10 keV energy cutoff. This evaluation was performed for all the materials relative to 9-component soft tissue. In the case of F6 and *F4 tallies, only 1 s program was run for each material. In each program, 2.89 × 10^8 particles were tracked and the maximum statistical uncertainty was 0.43%.

Relative dose in water relative to 9-component soft tissue with *F8 tally in the cases of 10 keV and 1 keV energy cutoffs were calculated and compared. Five seconds type programs were run for each case. In each program, 2.89 × 10^8 particles were tracked, and the maximum statistical uncertainty was 1.2%.

RESULTS

The relative dose results of adipose tissue, breast tissue, muscle, blood, 4-component soft tissue, water, A-150 tissue-equivalent plastic and perspex are listed in Table 2. These results are related to a 6 MV photon beam at different depths ranging from 0.1 to 25 cm and were obtained using *F8 tally with 10 keV energy cutoff. The relative dose was calculated as the ratio of dose in the material of interest relative to the dose at the same point in 9-component soft tissue. Absolute doses (cGy/100 MU) in these materials and 9-component soft tissue for a 6 MV photon beam were obtained using *F8 tally and energy cutoff of 10 keV are listed in Table 3.

The relative dose in the soft tissues and tissue-equivalent materials in a 6 MV photon beam obtained by F6 and *F4 tallies are listed in Tables 4 and 5, respectively. The data in these two tables were calculated with 10 keV energy cutoff.

Relative dose in water relative to the dose in 9-component soft tissue obtained using *F8 tally with energy cutoffs of 10 keV and 1 keV is presented in Figure 2.

DISCUSSION

In the present study, the effect of the composition of various soft tissues and tissue-equivalent materials on dose distribution in radiotherapy with a 6 MV photon beam was evaluated. Relative doses in different soft tissues and tissue equivalent materials were calculated relative to 9-component soft tissue to evaluate the possible errors in assuming different tissues possess the same properties. Some differences were observed between dose distributions in various materials [Tables 2 and 3]. The differences were up to 10% (a relative

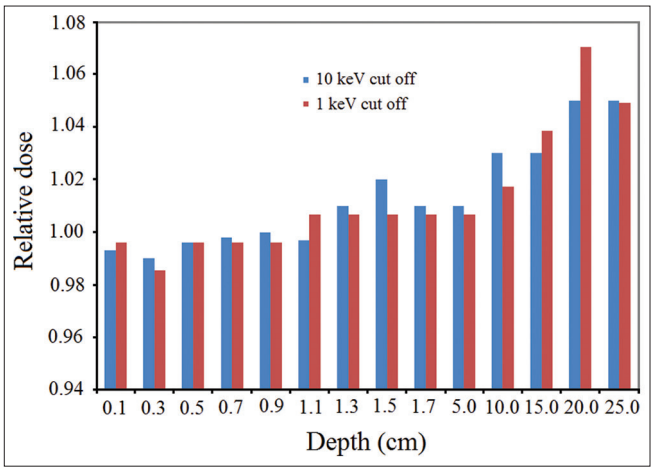

Figure 2: Relative dose in water relative to the dose in 9-component soft tissue with 10 and 1 keV energy cutoffs. The results were calculated using *F8 tally

Table 2: Relative dose in soft tissues and tissue-equivalent materials relative to dose in 9-components soft tissue obtained using *F8 tally with 10 keV energy cut off

Depth (cm)	Adipose tissue	Softtissue (4-component)	Breast tissue	Muscle (skeletal)	Blood (whole)	Water	A-150 plastic	Perspex
0.1	0.95	0.98	0.98	1.00	1.00	0.99	1.01	1.01
0.3	0.96	0.97	0.98	1.00	1.00	0.99	1.01	1.01
0.5	0.96	0.98	0.98	1.00	1.00	1.00	1.00	1.00
0.7	0.97	0.99	0.99	1.00	1.00	1.00	0.99	1.00
0.9	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1.1	0.99	0.99	0.99	1.00	1.00	1.00	0.99	0.98
1.3	0.99	1.00	1.00	1.00	1.00	1.01	1.00	0.98
1.5	1.01	1.01	1.01	1.00	1.00	1.02	1.00	0.99
1.7	1.00	1.00	1.00	1.01	1.00	1.01	0.99	0.97
5.0	1.01	1.00	1.01	1.01	1.01	1.01	0.99	0.96
10.0	1.03	1.02	1.01	1.00	1.00	1.03	1.00	0.97
15.0	1.04	1.01	1.00	1.00	1.00	1.03	0.96	0.93
20.0	1.06	1.05	1.03	1.02	1.00	1.05	0.96	0.92
25.0	1.07	1.05	1.03	1.02	1.00	1.05	0.95	0.90

Table 3: Absolute dose (cGy) obtained using *F8 tally with 10 keV energy cut off

Depth (cm)	Adipose tissue	Soft tissue (4-component)	Breast tissue	Muscle (skeletal)	Blood (whole)	Soft tissue (9-component)	Water	A-150 plastic	Perspex
0.1	37.98	38.91	39.24	39.86	40.07	39.89	39.66	40.37	40.39
0.3	64.82	65.69	66.46	67.94	67.83	67.73	67.17	68.25	68.65
0.5	78.64	79.50	80.13	81.56	81.42	81.46	81.25	81.92	81.42
0.7	87.39	88.41	89.01	89.84	89.7	89.91	89.88	89.50	90.01
0.9	92.56	93.08	94.28	94.46	94.85	94.53	94.86	94.98	94.31
1.1	96.98	96.52	97.46	98.03	97.89	98.06	97.90	97.39	96.51
1.3	98.49	98.34	99.29	99.41	98.9	98.92	99.88	99.04	97.00
1.5	99.42	98.61	99.16	98.42	98.52	98.12	100.00	98.33	96.88
1.7	98.75	98.55	98.88	99.53	98.91	98.80	99.89	97.74	95.98
5.0	87.48	86.59	87.26	87.27	87.44	86.42	87.29	85.72	83.31
10.0	68.20	66.76	66.86	66.03	66.02	65.8	67.74	65.71	63.63
15.0	52.41	50.90	50.63	50.31	50.40	50.31	51.80	48.57	46.62
20.0	40.61	39.80	39.44	38.82	38.12	38.16	40.19	36.79	35.14
25.0	31.04	28.53	29.89	29.37	28.94	28.88	30.50	27.44	25.96

The dose values in defferent depths is calculated based on the prescriped dose at 1.5 cm depth in the water phantom, which is 100 cGy (equal to 100 MU)

Table 4: Relative dose in soft tissues and tissue-equivalent materials relative to dose in 9-components soft tissue obtained using F6 tally with 10 keV energy cutoff

Depth (cm)	Adipose tissue	Soft tissue (4-component)	Breast tissue	Muscle (skeletal)	Blood (whole)	Water	A-150 plastic	Perspex
0.1	1.00	1.00	1.00	1.00	1.00	1.01	0.99	0.98
0.3	1.00	1.00	1.00	1.00	1.00	1.01	0.99	0.98
0.5	1.00	1.00	1.00	1.00	1.00	1.01	0.99	0.98
0.7	1.00	1.00	1.00	1.00	1.00	1.01	0.99	0.98
0.9	1.00	1.00	1.00	1.00	1.00	1.01	0.99	0.98
1.1	1.00	1.00	1.00	1.00	1.00	1.01	0.99	0.98
1.3	1.01	1.00	1.00	1.00	1.00	1.01	0.99	0.98
1.5	1.01	1.00	1.00	1.00	1.00	1.01	0.99	0.98
1.7	1.01	1.00	1.00	1.00	1.00	1.01	0.99	0.98
2.0	1.01	1.00	1.00	1.00	1.00	1.01	0.99	0.98
5.0	1.01	1.00	1.00	1.00	1.00	1.01	0.99	0.97
10.0	1.03	1.01	1.01	1.00	1.00	1.02	0.98	0.95
15.0	1.05	1.02	1.02	1.00	1.00	1.03	0.97	0.93
20.0	1.07	1.04	1.02	1.01	1.00	1.04	0.96	0.92
25.0	1.09	1.05	1.03	1.01	1.00	1.05	0.95	0.90

Table 5: Relative dose in soft tissues and tissue-equivalent materials relative to dose in 9-components soft tissue obtain using *F4 tally with 10 keV energy cutoff

Depth (cm)	Adipose tissue	Soft tissue (4 component)	Breast tissue	Muscle (skeletal)	Blood (whole)	Water	A-150 plastic	Perspex
0.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5.0	1.01	1.01	1.00	1.00	1.00	1.01	0.99	0.99
10.0	1.03	1.02	1.01	1.00	1.00	1.01	0.99	0.97
15.0	1.05	1.03	1.02	1.00	1.00	1.02	0.98	0.96
20.0	1.06	1.04	1.02	1.01	1.00	1.03	0.97	0.94
25.0	1.08	1.05	1.03	1.01	1.00	1.04	0.96	0.93

dose of 0.90 in perspex at 25 cm depth). Among the considered soft tissues, adipose tissue demonstrated the maximum difference with the others. Perspex showed the maximum dose difference among the three tissue-equivalent materials evaluated. Current treatment planning systems only consider the electron densities of inhomogeneities. Therefore, taking the same composition for all soft tissues introduces errors in dose calculations. Since ICRU No. 24 has recommended that the uncertainty in dose delivery in radiotherapy should be within ±5%, these errors should be minimized in radiotherapy

by correcting radiotherapy calculations to upgrade the accuracy of the dosimetric calculations.

The data presented in Table 2 indicates that the relative dose varies with depth in phantom. In other words, the relative dose for special material is not constant at various depths. This implies that the differences in dose distributions depend on the depth in phantom. This effect would be related to the variation of photon energy spectrum and also photon attenuation with depth. A more detailed calculation of photon energy spectrum for different depths could be illuminating on this effect. It is evident from Table 2 that there is not a simple increasing or decreasing trend for the relative dose with in-phantom depth.

The interpretation of the relative dose data in Table 2 indicates that there is not a simple dependence of difference in dose distribution of a material with the effective atomic number or mass energy absorption coefficient in 0.5 MeV photon energy. This is because those although effective atomic number and mass energy absorption coefficient are two important quantities in radiation dosimetry, there are other factors affecting the dose distribution. Some factors in this case are having polyenergetic photon spectrum, having various types of photon interactions, the differences in photon attenuation in various media, etc. It can be also mentioned that in this photon energy range (with 6 MV nominal photon energy) Compton scattering is dominant, which does not depend on the atomic number of medium.

Water is normally used for dosimetry in external beam radiotherapy. In other words, in the commissioning step of a linac, relative dose data (percentage depth dose and dose profile) are measured inside a water phantom, and they are introduced into the treatment planning system. The system then calculates the dosimetric distribution in various tissues based on the data in water. From the results in this study [Table 2], it is obvious that the dose data in water are different from the other soft tissues. Therefore, an extension of the dosimetric data of water to all other soft tissues incorporates some errors in dosimetry. The errors are higher in deep depths. Modern treatment planning systems account for heterogeneity correction factors, but they do not have corrections for soft-tissue differences. Therefore, by applying corrections for this errors or searching materials with more similar characteristics to soft tissue, it will be possible to overcome this effect.

The relative dose values in tissue-equivalent materials indicate that there are also differences in dose distributions in these materials. The highest difference is related to perspex. Since these materials are routinely used as substitutes for soft tissues in radiation dosimetry, this incorporates errors in the dosimetry. Selection of a material with closer mass density and composition to those of soft tissues in radiation dosimetry can minimize such errors. The results presented in the current study can be a reference for this purpose, while a more comprehensive study on other tissue equivalent materials can be a participant for the future studies.

The absolute doses (cGy/100 MU) presented in Table 3 indicate that the dose in various tissues have differences up to a few percent relative to the dose in water. These data were calculated such that the prescribed dose at 1.5 cm depth (the d_{max} in 6 MV photon beam of Siemens Primus linac) in the water phantom is 100 cGy. This condition is similar to what routinely exists in clinical radiotherapy by a medical linac, and this dose level equals 100 MU. Commercial treatment planning systems account for the electron densities of inhomogeneity (bone, etc.); however, they do not take into account the differences in the mass densities and compositions between water and soft tissues. This will result in errors in dose delivery in external beam radiotherapy. Since the cancer treatment outcome depends on the dose delivery errors and due to limited level of errors recommended in radiotherapy, this effect should be taken into account in radiotherapy. In the present study, a homogeneous phantom fully including a soft tissue or tissue-equivalent material was defined in the calculations. However, the human body is not made up of a single, homogeneous soft tissue and includes a variety of soft and hard tissues with different thicknesses. Therefore, the suggestion of simple algorithms to account for this effect in treatment planning is not feasible. However, with Monte Carlo-based treatment planning systems, when the thicknesses, positions, mass densities, and compositions of various soft tissues are introduced, such errors can be minimized. Limitations of such treatment planning systems are the costs of high processing powers needed for such systems and the long running time needed for treatment planning calculations.

A comparison of the relative dose data presented in Table 2 (with *F8 tally), Table 4 (with F6 tally) and Table 5 (with *F4 tally), indicates that there are not significant differences between various tally types at depths in the build-up region (depths within 1.5 cm). However, at steeper deeps, the results by *F8 tally have differences with those by F6 and *F4 tallies, while the F6 and *F4 tallies have relatively similar relative doses. This is acceptable because *F8 tally scores the absorbed energy but F6 and *F4 tallies (with relevant conversion factors) scores kerma. Beyond the buildup region, in which electronic equilibrium does exist, kerma can be used as an approximation of the absorbed dose. The above-mentioned results prove this effect. Therefore, it can be recommended that for dose calculation in the build-up region *F8 tally be used, while in other depths F6 or *F4 (with the related conversion factors) tallies can be used. In MCNP code, the use of *F8 tally has the limitation of higher computer processing time for Monte Carlo calculations. It should be noted that these comparisons were made with the same energy cutoffs and similar levels of Monte Carlo statistical uncertainties existed for these three tally types in the present calculations.

A comparison of the relative dose in water relative to the dose in 9-component soft tissue obtained with 10 and 1 keV

energy cutoffs [presented in Figure 2] implies that there is not a significant difference between these two datasets. This means that while 1 keV has lower approximations in Monte Carlo calculations and needs to a longer time for running the programs, it could not increase the accuracy of the calculations compared to the case of 10 keV cutoff. It should be noted that the Monte Carlo statistical uncertainties with these energy cutoffs were similar (maximum type an uncertainty of 1.2% for both 10 and 1 keV energy cutoffs).

Differences were observed between dose distributions in various soft tissues and tissue materials herein. There is not any similar study to compare the obtained results with at this time. However, there are other studies on dose distribution differences in various soft tissues. While there are major physics differences between these studies, a discussion on those studies are relevant. It is also suggested that as a future research tissue composition effect for 10 cm × 10 cm and other field sizes be evaluated using an ion chamber which is an accurate device for this purpose.

Ghorbani *et al.*[5] evaluated dose differences between various soft tissues in brachytherapy with photon sources. They have reported large differences, especially with low-energy sources. The reason for this effect is due the importance of photoelectric interaction in low photon energy ranges. In the present study, compton, and pair production are the common photon interactions in the photon energy range lower than 6 MV. Since there are large differences on the dependence of photoelectric, Compton and pair production on the atomic number of media, the differences between these results are expectable. Khosroabadi *et al.*[7] have studied the effect of soft-tissue composition in neutron brachytherapy/neutron capture therapy. They reported major differences in neutron dose and total dose of various materials. All these studies indicate that errors in dose delivery exist due to not taking into account the compositions for soft tissues in treatment planning. On the other hand, Ghorbani *et al.*[6] have seen negligible differences between various soft tissues in radiotherapy with various electron beams of a medical linac. The physics of interactions of electrons with a media is quite different than photons. The stopping power in an electron beam has very low dependence on the atomic number of a medium; therefore the negligible differences are justified.

CONCLUSIONS

Based on the calculations performed, there are differences in dose distributions in various soft tissues and tissue-equivalent materials. The differences depend on the depth in the phantom. Current treatment planning systems only consider the electron densities of inhomogeneities. Therefore, taking the same composition for all soft tissues introduces errors in dose calculations. Since ICRU No. 24 has recommended that the uncertainty in dose delivery in radiotherapy should be within ±5%, these errors should be treated in radiotherapy. In other words, these differences should be corrected for in radiotherapy calculations to upgrade the accuracy of the dosimetric calculations. For relative dosimetry water is universally accepted. This may be due the fact that the human body is composed of 80% water and the remaining are other inhomogenous structures. It is a known fact that Monte Carlo is an accurate method which can be used for dose calculations and Monte Carlo-based treatment planning systems can treat these differences, but they need a high power of data processing and need a relatively long time for their dosimetric calculations, and their hardware costs are considerable. Another alternative solution related to upgrade the accuracy of treatment planning systems in taking into account soft-tissue composition is performed by modifying the computed tomography images and specifying computed tomography number for each tissue and applying it into the treatment planning system. By this method, this discrepancy may be reduced, and this method does not need to a high computational time. The differences between various MCNP tallies in dose calculations indicate that *F8 has a higher accuracy, but it needs a longer time of computer processing in running the Monte Carlo simulations.

Acknowledgment

The authors are grateful to Mashhad University of Medical Sciences for financial support of this work.

Financial support and sponsorship

Mashhad University of Medical Sciences has financially supported the work.

Conflicts of interest

There are no conflicts of interest.

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