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Comparison of Megavoltage Electron Dosimetry Beams in Radiation Therapy Using Different Protocols

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Abstract

Background: International Atomic Energy Agency (IAEA) and the American Association of Physicists in Medicine (AAPM) have introduced new protocols for the dosimetry of megavoltage electron and photon beams, increasing them to more than five protocols at the beginning of the new decade. Selecting a protocol by medical physicists and acquiring skills for using reference conditions and recommended formulation by each protocol necessitates the recognition of various dosimetry protocols. This study aimed to compare the protocols TRS-277, TRS-381, and TRS-398 of IAEA for megavoltage electron beams used in radiation therapy.

Methods: The comparison of TRS-398 with other protocols was done as follows: 1. Measurement and estimation of the absorbed dose of a 6 MeV Neptun 10 linear accelerator through an ionization chamber with parallel NACP plates in water phantom and acrylic. 2- Measurement of the absorbed dose in a 17 MeV Saturn 20 linear accelerator through an ionization chamber with parallel NACP plates in a water phantom.

Results: The results indicated that the differences observed between the protocols compared to protocol TRS-398 ranged between -4.9% and 0.2%; the highest difference was related to the 17 MeV electron beam using protocol TRS-277.

Conclusion: According to the results, the considerable difference observed in 17 MeV electrons was related to TRS-277 and TRS-388 protocols. Given that the calibration ratio of the absorbed dose in the air is used in protocol TRS-277, the difference obtained was related to the application of secondary calibration used in this study.

Keywords: Dosimetry protocols, Electron, Radiation therapy

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Introduction

Dosimetry is of great importance in three main fields, including the application of ionizing beams (i.e., radiotherapy), irradiation in different materials such as products used in medicine, industrial products, and foodstuff, and protection against beams (1). The amounts of dose and precision required for measurement are different in each of the mentioned fields. As for irradiation, precision is necessary for determining the absorbed dose since there is a little interval between the precision required and the highest precision accessible in practice (2,3).

An error of about ± 3.5% in the absorbed dose at the location of the tumor could discomfit the efficacy of radiotherapy treatment (4). The difference between the dose transferred to the tumor and recommended dose affects the success or failure of irradiation. Therefore, the first aim in treatment plans using irradiation is determining the absorbed dose at target organs with high risk and minimum uncertainty. One of the most important uncertainties in treatment is the lack of certainty in beam calibration (5,6). Beam calibration for cancer treatment in patients depends on complex measurements and use of correction and conversion factors. Dosimetry protocols are used to create suitable frameworks for analysis of correction and conversion factors in the beam calibration and determination of the absorbed dose (7).

Dosimetry protocols help physicists to determine the appropriate absorbed dose by introducing the required methods and data. Thus, the aim of all dosimetry protocols is to determine the absorbed dose transferred to a water phantom for low-energy beams, Co-60 beams, or beams produced by a linear accelerator.

Dosimetry of high-energy or megavoltage electron beams was performed using the protocols recommended by international agencies until 1981 (8), in which various methods were presented for the dosimetry of electron and photon beams in irradiation. The common feature of these protocols was using ionization and calibration chambers in a standard lab (primary and secondary, based on radiation or exposure). In these methods, or generally, in the calibrated cavity theory, the amount of ionization was obtained by multiplying the amount of radiation (Nx) by changing the coefficients of the appropriate dose (C_E for electron) by the absorbed dose (D) (8,9).

International protocol TRS-277 was published by International Atomic Energy Agency (IAEA) to determine the absorbed dose of electron and photon beams in 1987. These chambers are suitable for beams, especially low-energy electron beams, because of their appropriate shape, low height, and volume of ionization chambers with parallel plates. Since the calibration and use of these chambers have not been explained in the protocol TRS-277, an international team was appointed by IAEA to revise it (10). The result of their attempts was published as TRS-381 report in 1996 (11).

In another protocol published by IAEA in 2000, ionization chambers were used as measurement tools; however, calibration coefficient of the absorbed dose in water was used ($N_{D,W}$) to convert the reading in a phantom dose instead of calibration coefficients for exposure in air (N_k and N_x) (12).

A limited number of studies have compared different dosimetry protocols in the field of radiation therapy.

Meaze et al compared DIN 6800-2 and TRS-398 protocols for photon and electron beams on the medical linear accelerators. The results of this study indicated that the measured absorbed dose by these two protocols for energies of 4, 6, 9, 12, 15, and 18 megaelectron volt showed ± 1.74, ± 1.09, ± 0.92, and ± 0.85% uncertainty, respectively (7).

Mahdavi et al compared the calculated absorbed dose using protocols TG-51 and TRS-398 and the simulation method using the MCNP code for several modes of energy. The results showed that the absorbed dose calculated using TG-51 in proportion to TRS-398 was 1.011, 1.012, 1.008, 1.003, and 1.002 for energy electrons 6, 9, 12, 15, and 18 megaelectron volt, respectively (13).

Araki and Kubo compared different protocols for electron and photon dosimetry. The results indicated that the absorbed dose for electrons calculated through TG-51 was 0.2-1.9% higher than that by TRS-277 (14).

Given the limited number of studies conducted and the lack of comprehensive studies on the comparison of the dosimetry protocols published by IAEA, this study aimed to compare the methods for measuring the absorbed dose of water in electron beams using the protocols TRS-277, TRS-381, and TRS-398, which are published by IAEA.

Materials and Methods

The instruments used in this study were linear accelerator Saturn 20 (made by CGR, France), linear accelerator, Neptun 10 (ZDAJ, Poland), ionization chamber with parallel plates model NACP (Scanditronix, Sweden), semiconductor detectors (Scanditronix, Sweden), and automatic set of water and acrylic phantom RFA-300 model 5.2 (NE, England).

Protocols TRS-277, TRS-381, and TRS-398 were surveyed precisely to compare their dosimetry. Then, parameters used in dosimetry protocols were classified, studied, and measured based on the recommended methods. The studied parameters included the quality of the beam, reference conditions, pressure, temperature, humidity, calibration, electrometer, electron stopping power, perturbation factor, polarity effect, recombination effect, determination of beam energy at the depth Z inside the phantom, coefficients of comparison and change of plastic dose to water dose, and types of the phantom and dosimeter.

Dosimetry of the 6 MeV electron beam was performed on linear accelerator Neptun 10 and the 17 MeV electron beam was performed on linear accelerator Saturn 20 based on the above-mentioned protocols. Ionization chambers with NACP parallel plates were used for the dosimetry of 6 and 17 MeV electron beams. Furthermore, in all protocols, water was used as a reference substance. It must be mentioned that acrylic phantom, in addition to water, was used for the dosimetry of the 6 MeV electron beam, although the use of plastic phantom for electrons with an energy level less than 10 MeV is permissible. Determination of the absorbed dose in air (protocols TRS-277 and TRS-381) and calibration coefficient for the absorbed dose in water (protocols TRS-381 and TRS-398) were necessary, so ionization chamber with NACP parallel plates and electrometer (Farmer model 2570 NE) used in this research were sent to the dosimetry department of Secondary Standard Dosimetry Laboratory (SSDL) of the agriculture research and nuclear medicine center of atomic energy organization in Karaj, Iran.

Determination of percentage depth dose (PDD)

Ionization chamber model NACP, semiconductor detector, and automatic water phantom were used to determine the PDD for 6 MeV and 17 MeV electrons, respectively. In this case, the field size was 10 × 10 cm^2, and the source to skin distance (SSD) was 100 cm.

Dosimetry

For the measurement of the absorbed dose in water, the reference conditions included calibration depth, field size, dimensions of the phantom, and effective point for measurement. One of the main problems is locating the ionization chamber at a suitable depth. An effective point was used in protocol TRS-277 for measurement. It is located 0.5 r from the central axis for electron beams (r is the radius of the ionization chamber). Table 1 illustrates the depth of dose measurement for electron beams in different protocols.

Also, Table 2 shows the reference conditions for the dose of electron beams based on the recommendation of different protocols.

Dosimetry of a 6 MeV electron beam was performed

Table 1. The depth of dose measurement for electron beams in different protocols

Protocol	TRS-277	TRS-398	TRS-381
Depth of measurement	R 100 (E_0<5) 1 cm or R 100 (5<$\bar{E}_0$<10) 2cm or R 100 (10<$\bar{E}_0$<20) 1 cm or R 100 (20<$\bar{E}_0$<50)	06R_{50}-0.1	R 100 (E_0<5) 1 cm or R 100 (5<$\bar{E}_0$<10) 2 cm or R 100 (10<$\bar{E}_0$<20) 1 cm or R 100 (20<$\bar{E}_0$<50)

Table 2. Reference conditions for dose measurement of different electron beams based on the recommendation of different protocols

Protocol	Condition				
	Effective point of measurement	Phantom	Ionization chamber type	SSD (cm)	Field size (cm²)
TRS-277	r+0.5r	Water, Styron or acrylic (E_0<10 MeV) Water (E_0>10 MeV)	Cylindrical or parallel plate	100	10×10
TRS-381	-	Water	Cylindrical or parallel plate	100	10×10
TRS-398	r+0.5r	Water (R50≥4 cm) Water or plastic (R50<4 cm)	Cylindrical or parallel plate (R50≥4 cm) parallel plates (R50<4 cm)	100	10×10

using NACP parallel-plate ionization chamber inside the automatic water phantom. Also, dosimetry of the 6 MeV beam was done by the same chamber inside the acrylic phantom. Figure 1 presents the dosimetry configuration of a 6 MeV electron beam inside the acrylic phantom on Neptun 10 linear accelerator. Moreover, dosimetry of the 17 MeV electron beam was performed by NACP ionization chamber inside the automatic water phantom. Depth of measurement for electron beams ranged from $d_{ref}=0.6R_{50}$ to $0.1d_{max}$ in different protocols. This depth was calculated at 1.2 cm for the dosimetry of the 6 MeV electron beam inside water and at 1.1 cm inside the acrylic phantom. The position of the chamber was adjusted by lasers after placing it inside the phantom. It should be taken into account that the sensitive volume of the chamber must be toward the beam. SSD was equal to 100 cm, and the field size was 10×10 cm²; also, a dose of 100 MU was applied in all cases. Since, the average and standard deviation of each series of electrometer readings should be less than 1%, four readings for positive potential and four readings for negative potential were recorded. To determine the ion recombination effect, we used V/2 and V/4 potentials.

Determination of the quality of the beam

There are various parameters used to determine the absorbed dose, which depends on the energy of the electron beam. Some of these factors, such as electron stopping power and perturbation factor, are necessary for precise measurement of the quality of the beam.

Determination of $\bar{E}_0$ (average energy of input electrons) in protocol TRS-277 was performed using the existing data in the protocol that is $\bar{E}_0$ per R_{50}^{J} (depth at which ionization is equal to maximum ionization) and R_{50}^{D} (the depth at which 5% is the maximum dose).

In protocol TRS-381, it is recommended that the PDD should be measured at a depth at which SSD is fixed and is equal to 100 cm. Then, $\bar{E}_0$ is calculated by equations 1 and 3:

Figure 1. Dosimetry configuration of the 6 MeV electron beam by Neptun 10 linear accelerator inside the acrylic phantom

$$\bar{E}_0 = 0.818 + 1.935R_{50}^{J} + 0.040\left(R_{50}^{J}\right)^2 \quad (1)$$

$$\bar{E}_0 = 0.656 + 2.059R_{50}^{D} + 0.022\left(R_{50}^{D}\right)^2 \quad (2)$$

If the SSD is fixed and equal to 100 cm, $\bar{E}_0$ could be obtained from equation 9:

$$\bar{E}_0\left[MeV\right] = CR_{50} \quad (3)$$

In this relationship, C=2.33 MeV/cm, and R_{50} is a depth of water that is half of the maximum dose. The quality of the electron beam is defined with R_{50} in the TRS-398 protocol. Also, it is mentioned in the protocol that the field size is equal to 10×10 cm² if $\bar{E}_0$<16 MeV is selected.

Results

As mentioned, to determine the absorbed dose of a 6 MeV electron beam inside water, after putting the chamber inside the phantom, a dose of 100 MU was delivered five times, and the dose was recorded per nano colon from the electrometer. Then, the average of the recorded values was calculated. Table 3 shows the values of readings for the ionization chamber with NACP parallel plates for a 6

MeV electron beam at a depth of 12 mm inside the water phantom.

The absorbed dose was calculated using a determined formula for each protocol after determining the average of the electrometer reading for the 6 MeV electron beam inside the water. Table 4 shows the results of dosimetry for the 6 MeV electron beam inside the water phantom using different protocols.

As mentioned, since protocol TRS-398 is more recent than the other two protocols (TRS-277 and TRS-381) and fewer coefficients are used in this protocol, the results of the dosimetry of 6 MeV and 17 MeV electron beams by TRS-398 were compared with those of protocols TRS-277 and TRS-381. Figure 2 shows the comparison of the results of dosimetry using protocol TRS-277 with those of protocol TRS-398.

According to Figure 2, the absorbed dose for the 6 MeV electron beam inside water phantom in protocols TRS-277 and TRS-381 was 3.5% and 3.4% less in comparison with TRS-398 in the air, respectively. Also, the absorbed dose of this beam in protocol TRS-381 in water was 0.3% more compared to protocol TRS-398. Furthermore, the absorbed dose of the 6 MeV electron beam was measured using a parallel-plate ionization chamber at a depth of 11 mm inside the acrylic phantom. Table 5 shows the reading values of the parallel-plate ionization chamber for the 6 MeV electron beam inside the acrylic phantom.

After determining the average reading of the electrometer for the 6 MeV electron beam inside the acrylic phantom, we calculated the absorbed dose using the formula based on each protocol. Table 6 shows the results of dosimetry for the 6 MeV electron beam inside the acrylic phantom.

Figure 3 compares dosimetry results for protocols TRS-277 and TRS-381 inside the air and water with protocol TRS-398 for the 6 MeV electron beam inside the acrylic phantom.

As shown in this figure, the absorbed dose of the 6 MeV electron beam inside the acrylic phantom for protocols TRS-277 and TRS-381 in the air was 4.4% and 3.4% less than that for TRS-398, respectively. Also, the absorbed dose of this beam for protocol TRS-381 in water was 0.3% more than that for TRS-398.

Moreover, in this study, the absorbed dose of a high energy electron beam (17 MeV) was measured using an ionization chamber with NACP parallel plates at a depth of 4 cm inside the water phantom. Table 7 shows the reading values of the parallel-plate ionization chamber for the 17 MeV electron beam inside the water phantom at a depth of 4 cm.

After determining the mean readings from the electrometer for the 17 MeV electron beam inside the water phantom, we calculated the absorbed dose by the formula in each protocol. Table 8 shows dosimetry results for the 6 MeV electron beam inside the acrylic phantom.

Figure 4 compares dosimetry results for protocols TRS-277 and TRS-381 inside the water and air, with protocol TRS-398 for the 17 MeV electron beam inside the water phantom.

As shown in Figure 4, the absorbed dose of the 17 MeV electron beam inside the water phantom using protocols TRS-277 and TRS-381 inside the air was 4.9% and 3.5% less than protocol TRS-398, respectively. Also, the absorbed dose of this beam using protocol TRS-381 inside water was 0.2% more than that of protocol TRS-398.

Table 3. Recorded values of the electrometer inside the water phantom for a 6 MeV electron beam

Voltage	Reading (nano colon)	Average ± 1 Standard deviation
-V	5.285, 5.285, 5.295, 5.295, 5.290	5.290 ± 0.005
+V	5.265, 5.265, 6.275, 5.295, 5.285	5.277 ± 0.013
-V/2	5.280, 5.285, 5.285, 5.275, 5.285	5.282 ± 0.004
+V/2	5.255, 5.250, 5.255, 5.265, 5.240	5.253 ± 0.009
-V/4	5.275, 5.270, 5.265, 5.260, 5.270	5.268 ± 0.006
+V/4	5.255, 5.240, 5.235, 5.215, 5.235	5.236 ± 0.014

Discussion and Conclusion

Introduction of dosimetry protocols for megavoltage electron and photon beams by IAEA at the beginning of the new decade increased the existing dosimetry protocols to more than five. Therefore, the selection of a suitable dosimetry protocol by irradiation physicists requires recognition of different protocols, survey of their differences, and acquisition of skills to apply reference conditions and recommended formulations by each protocol and method of using it.

In the current study, it is indicated that the factors which cause differences in dose measurement among the protocols include: the correction ratio for ion

Table 4. Results of dosimetry for the 6 MeV electron beam inside the water phantom

Protocol	Condition				
	Temperature/pressure correction factor	Recombination correction factor	Stopping power ratio	Beam quality index	Absorbed dose (cGy)
TRS-277	1.207	1.0020	1.0788	0.9584	0.9723
TRS-381 (Air)	1.207	1.0019	1.0802	0.93109	0.9735
TRS-381 (Water)	1.207	1.0019	1.0802	0.93109	1.0113
TRS-398	1.207	1.0019	1.0748	0.92792	1.0079

Table 5. Reading values of electrometer inside the acrylic phantom for the 6 MeV electron beam

Voltage	Reading (nano colon)	Average ± 1 Standard deviation
-V	5.565-5.525-5.510-5.535-5.530	5.533 ± 0.020
+V	5.510-5.535-5.525-5.525-5.535	5.526 ± 0.010
-V/2	5.485-5.480-5.495-5.495 = 5.495	5.490 ± 0.007
+V/2	5.500-5.495-5.500-5.480-6.475	5.490 ± 0.012
-V/4	5.465-5.475-5.495-5.500-5.465	5.480 ± 0.017
+V/4	5.430-5.430-5.450-5.455-5.475	5.448 ± 0.019

Table 6. Results of dosimetry for the 6 MeV electron beam inside the acrylic phantom

Protocol	Condition				
	Temperature/ pressure correction factor	Recombination correction factor	Stopping power ratio	Beam quality index	Absorbed dose (cGy)
TRS-277	1.215	1.0040	1.0788	0.9584	1.0265
TRS-398	1.215	1.0039	1.0748	0.92792	1.0736
TRS-381 (Air)	1.215	1.0039	1.0802	0.93109	1.0363
TRS-381 (Water)	1.215	1.0039	1.0802	0.93109	1.0765

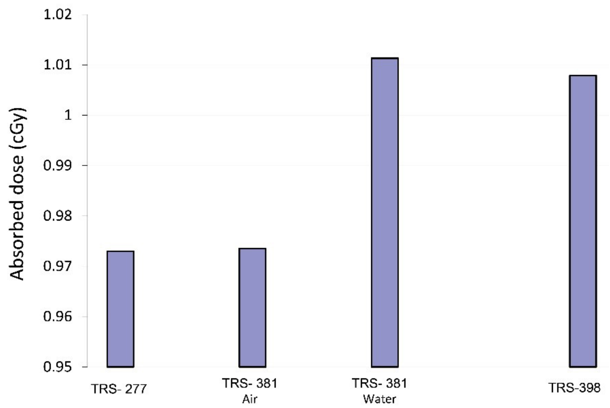

Figure 2. Comparison of the absorbed dose for the 6 MeV electron beam by protocols TRS-277 and TRS-381 with TRS-398 inside water phantom

Table 7. Reading values of the electrometer for the 17 MeV electron beam inside the water phantom

Voltage	Reading (nano colon)	Average ± 1 Standard deviation
-V	5.350-5.550-5.555-5.335	5.448 ± 0.121
+V	6.020-5.980-5.835-5.525	5.840 ± 0.225
-V/2	5.435-5.350-5.500-5.315	5.400 ± 0.084
+V/2	5.560-5.700-5.600-5.315	5.600 ± 0.071
-V/4	5.300-5.250-5.255-5.395	5.300 ± 0.067
+V/4	5.400-5.500-5.460-5.560	5.480 ± 0.067

Table 8. Dosimetry results for the 6 MeV electron beam inside the acrylic phantom

Protocol	Condition				
	Temperature/ pressure correction factor	Recombination correction factor	Stopping power ratio	Beam quality index	Absorbed dose (cGy)
TRS-277	1.226	1.030	1.0240	0.9017	1.0204
TRS-398	1.226	1.030	1.0274	0.8860	1.0736
TRS-381 (Air)	1.226	1.030	1.0300	0.8878	1.0355
TRS-381 (Water)	1.226	1.030	1.0300	0.8878	1.0758

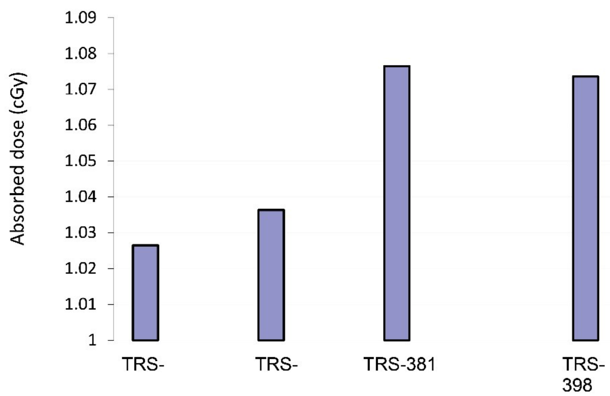

Figure 3. Comparison of the absorbed dose of the 6 MeV electron beam using protocols TRS-277 and TRS-381 with protocol TRS-398 inside the acrylic phantom

recombination, ratio of stopping power of water to air, correction coefficient of central electrode commodity (P_{cel}), calibration coefficients, beam quality conversion factor, and beams' quality.

Figures 2, 3, and 4 show the absorbed dose of low- and high-energy electron beams inside the water and acrylic for the protocols used. These values were compared to TRS-398 protocol (recent published protocol). As displayed in the figures, the highest difference for the measured absorbed dose of the 6 MeV electron beam in water phantom (-3.5%) was related to protocol TRS-277, and the lowest difference (0.3%) belonged to protocol TRS-381 (using calibration coefficient for the water absorbed dose). Also, the highest measured difference of the absorbed dose of the 6 MeV electron beam in the acrylic phantom was -4.4 %, and the lowest difference was 0.3 % which was attributed to protocol TRS-381 (using calibration coefficient for the water absorbed dose). The highest difference for the measured absorbed dose of the 6 MeV electron beam in the acrylic phantom was -4.4 %, and the lowest difference was 0.3 % which was related to protocol TRS-381 (using calibration ratio for the water absorbed dose). For the absorbed dose of the 17 MeV electron beam, the highest difference was -4.9% which was related to protocol TRS-277, and the lowest difference was 0.2% which belonged to protocol TRS-381 (using calibration coefficient for the water absorbed dose). Based on the results of this research, uncertainty in the determination of the dose using dosimetry protocols based on the calibration factor of water absorbed dose

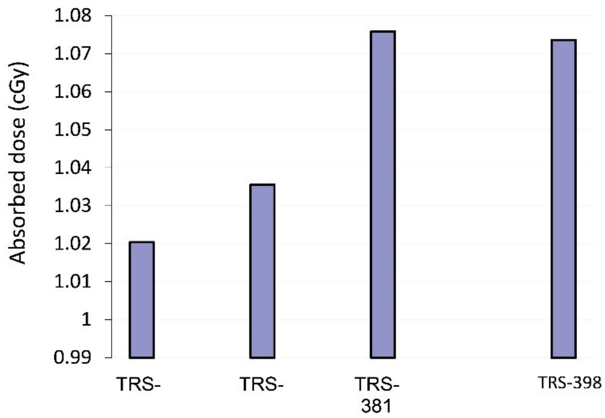

Figure 4. Comparison of the absorbed dose for the 17 MeV electron beam using protocols TRS-277 and TRS-381, with protocol TRS-398 inside the water phantom

(protocol TRS-398) is less than that for protocols with calibration factor using air in ionization chamber (protocol TRS-277).

There are various stages between the calibration of ionization chambers based on air temperature, K_{air} (determining the standard dosimetry in labs), and the determination of water absorbed dose (in hospitals) using dosimetry protocols based on calibration factor $N_{D,air}$ and N_{gas}; this leads to undesirable uncertainty in the determination of D_w. The existing uncertainties in dosimetry chains are mainly caused by changes made by users in hospitals.

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Conceptualization: Zahra Jomehzadeh.
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Funding acquisition: Zahra Jomehzadeh.
Investigation: Zahra Jomehzadeh.
Methodology: Ali Jomehzadeh.
Project administration: Parvaneh Shokrani.
Resources: Ali Jomehzadeh.
Software: Ali Jomehzadeh.
Supervision: Parvaneh Shokrani.
Validation: Ali Jomehzadeh.
Visualization: Ali Jomehzadeh.
Writing–original draft: Ali Jomehzadeh.
Writing–review & editing: Zahra Jomehzadeh.

Competing Interests
The authors declare that they have no competing interests.

Ethical Approval
KNRC/97-87/EC.

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