Original

Evaluating the Radioactive Waste Produced per Patient by Radiopharmaceutical Sources and Measuring the Radioactive Contamination of Surfaces and Staff at the Bushehr Nuclear Medicine Department

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ABSTRACT

Background: Nuclear medicine is an integral and developing field in diagnosing and treating diseases. Monitoring individuals' protection and radiation contamination in the workplace is vital for preserving working environments.

Objective: This study aimed to monitor the nuclear medicine department's personnel, environment, and wastes to determine the level of occupational radiation and environmental pollution in Bushehr's nuclear medicine department.

Material and Methods: In this cross-sectional study, the initial activity of each radioisotope, radiopharmaceutical, and radioactive waste was measured using a "well counter" daily for three months. Three irradiators' absorbed doses were measured using a direct reading dosimeter. The contamination was determined using an indirect wipe test method on various surfaces. A Geiger Müller dosimeter was employed to examine personnel's hands, clothing, and footwear.

Results: The highest activity was observed in technetium waste (1118.31 mCi). Every irradiator received a lower absorption dose than the International Commission on Radiological Protection (ICRP) standard threshold. The majority of contamination was associated with the exercise test room (0.04 Bq/cm^2) and its work surface (0.013 Bq/cm^2), which were both below the threshold (0.5 Bq/cm^2). Staff monitoring indicated that two nurses (10 and 11 individuals) had the highest contamination rate (23.7%).

Conclusion: Daily assessment of the type, activity, and method of radiopharmaceutical administration to the patient is advantageous for waste management. Surface contamination monitoring can significantly contribute to the estimation of the level of radiation pollution in the environment.

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Keywords

Nuclear Medicine; Radioactive Waste; Radiation Protection; Radioactive Contamination

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Introduction

Nuclear medicine is one of the most significant branches of medicine due to the prevalence of radioactive materials and radiopharmaceuticals in treating and diagnosing diseases

[1, 2]. When employing radioactive materials, the risk of potential harm must always be weighed against the benefits, and appropriate diagnostic and treatment approaches must be utilized while preserving employee safety without jeopardizing patient or work process safety. Consequently, it is necessary to provide a safe environment for nuclear medicine staff, particularly irradiators. The nuclear medicine staff is responsible for producing, prescribing, and administering radiopharmaceuticals to patients, capturing, and analyzing images, and providing patient care [3].

Concerning the effects of radiation on the environment, the general public, and irradiators, there is an immediate need to extend and improve data on the annual radiation dose, the duration of radiation exposure, and the amount of activity released into the environment [4]. For radiation protection purposes, occupational radiation exposure should be assessed frequently, and doses should be maintained below standard limits [5]. Similar to the dose limits recommended by the International Commission on Radiological Protection (ICRP), the atomic energy organization of Iran's dose limit for nuclear medical personnel is 20 mSv [6]. To this end, personal dosimeters for measuring occupational radiation exposure are available in nuclear medicine. Consequently, film badge dosimeters are currently prevalent and widely utilized in Iran. Due to the high risk of nuclear medical work, leading to rapid reading and high dosimeter sensitivity, this investigation utilized an electronic dosimeter and direct reading.

Similar to the present study, Suleiman et al. used a dosimeter with direct reading to calculate the dose received by nuclear medicine and cardiology workers [7], which was also the aim of numerous studies [2, 8-11].

Nuclear medicine's increasing reliance on radiopharmaceuticals has led to an increase in radioactive waste that has raised concerns for municipal waste management. Therefore, monitoring the radioactive waste generated by nuclear medicine institutions is vital. These (Nuclear medicine's) wastes are appropriately handled and stored to modify their activity to the extent permitted by national and international law. When the waste activity is less hazardous to the environment and the general population, it can be released into municipal sewers. Radiation protection is the primary objective of waste management [12]. Thus, measuring the activity of radioactive waste generated per patient in a nuclear medicine facility can improve waste management efficacy [13].

In nuclear medicine facilities, there is a risk of contamination with radioactive materials for working individuals and different levels of these institutions. In addition to health problems, it should be noted that radioactive contaminations can affect patients' scan results and require significant effort and expense to eradicate. External contamination occurs when radioactive material touches a person's skin, hair, or clothing. Nuclear Regulatory Commission (NRC) regulations necessitate accurate and timely monitoring of surfaces and personnel in the nuclear medicine department [14]. Otherwise, pollution rapidly spreads and contaminates people, equipment, and the environment.

The permissible surface contamination level for working surfaces is 5 Bq/cm^2, while 0.5 Bq/cm^2 for non-working surfaces. These pollutants are measured over an area of 100 cm^2 [15]. Direct and indirect detection methods are available for detecting radioactive contaminants. Each of these techniques has several distinct benefits and drawbacks. The direct method uses a portable detector, while the indirect method employs absorbent paper or a wipe test. Canada and the United States nuclear regulatory authorities require these direct and indirect tests to monitor and eradicate surface contamination, conducted in both Beyki and Rostampour's studies on the pollution of nuclear medical centers [6, 16, 17].

This study aims to determine the activity of waste generated per patient and the type of radioactive material, measure the radiation exposure of three irradiators using a direct reading dosimeter and the contamination of different surfaces using an indirect wipe test, and assess the possibility of contamination on the clothing, hands, and shoes of 11 staff members at the Bushehr nuclear medical center for three months. The Bushehr nuclear medical center is staffed by three irradiators, three nurses, three receptionists, one insurance manager, and one service provider. Irradiators are responsible for preparing, measuring, and preparing radiopharmaceuticals and injecting and scanning patients at the facility.

Material and Methods

In this cross-sectional study, Bushehr nuclear medicine center was selected as the sole nuclear medicine center in Bushehr province, and preliminary research was conducted on the center's architecture, the number of employees, radiopharmaceuticals utilized, and daily patient admissions.

The first section of the study determined the radioisotope activity of waste generated per patient, including Iodine-131 (I-131), Lutetium (Lu), and Technetium (Tc). This current study aims to determine the level of pollution caused by the nuclear medicine department's radioactive waste production. Department staff utilized the following supplies for patients referred to the center over the three-month observation: injectable syringes, alcohol swabs, empty radiopharmaceutical vials, and disposable gloves. In the hot laboratory, the initial activity of the radioisotope extracted from the generator, the activity of the radiopharmaceuticals required for that day, the activity of the radioisotope prescribed separately for each day, and the activity and radiation pollution of each of these wastes were measured using a dosing calibrator (Capintec, Mirion Technologies, USA).

In the second part of this study, the equivalent dose of three irradiators employed by this department was measured over three months using the individual direct reading dosimeter Bleeper SV, which is both simple and reliable. Initially, the dose reported by each irradiator was recorded in a distinctive format. The dosimeter was worn on the chests of the irradiators until the end of their shifts when it was placed in their robe pockets, and the dose measured by the device was entered into the appropriate form. The difference between each irradiator's start and finish doses was calculated, and the three-month average dose was determined for each irradiator.

In the third section of the investigation, cross-sectional surface contamination was measured using an indirect wipe test. First, a map of the nuclear medical center with potential contamination risks was created, followed by a determination of the sites that should be investigated for radioactive contamination levels. A 100 cm^2 area was selected from the patient waiting room, control room, injection room, gamma camera room, exercise test room, radiopharmaceutical warehouse, waiting room, hallways, hot laboratory, staff restroom, and physicians' room. These locations were sampled using the following method three times, and the procedure was repeated every month (up to three months).

As a background count, a clean wet sterile gas activity was utilized, and then precise dimensions of wet sterile gas measuring 10×10 cm^2 were hauled to the designated locations. After contamination absorption, wet sterile gas was transported to the designated zipper, and the quantity of activity absorbed was calculated using a calibrator dose (Capintec, Mirion Technologies, USA).

Physical equations dependent on the detector's efficiency (E_i), the test's efficiency (E_w), the field count, and the study area's selected space were utilized to quantify the amount of radioactive contamination in the research areas. The wipe test technique has a test efficiency (E_w) of 10%. Ultimately, radioactive contamination was measured in Bq/cm^2 and compared to permissible limits as follows (1) [17]:

$$\text{radioactive contamination}(Bq/cm^2) = \frac{R_{s+b} - R_b}{E_i E_w A} \quad (1)$$

R_{s+b}, R_b, and A denote the measured activity, field activity, and research area, respectively.

The proportion of probable contamination of 11 workers was determined via a Geiger-Müller dosimeter (X5S, Graetz, Germany) to monitor staff clothing, hands, and shoes at entry and exit.

At the start and the end of each shift, three irradiators, three nurses, three receptionists, one insurance manager, and one service provider were observed to rule out the possibility of contamination. To this end, the background dose was determined, and three daily contamination assessments of each employee's body surfaces, clothing, and shoes were conducted five centimeters from the Geiger-Müller device. The percentage of staff contamination was calculated by subtracting the background count from the average count obtained through direct evaluation.

Strengths and limitations

The current study is one of the first in Bushehr province in this field of nuclear medicine. Since study type is considered a limitation, a more extended follow-up period is required.

Data analysis techniques

The mean and standard deviation of quantitative data were calculated for data analysis. The Kolmogorov-Smirnov test was used to determine the normality of the data, and a significance level of *P*-value>0.05 was deemed statistically significant based on SPSS version 26.

The Kolmogorov-Smirnov test revealed that the activity of radiopharmaceuticals and their residues was not distributed normally. As a result, the nonparametric Wilcoxon test was applied, and a statistically significant relationship was discovered between radioisotope activity and their residues.

The Kolmogorov-Smirnov test was conducted to determine the descriptive statistics for radiation dose; the *P*-value was 0.014, indicating a significant relationship between the irradiation rates of the three irradiators.

The wipe test data were analyzed using the Friedman nonparametric method, with zero *P*-values and a significant difference between the data sets.

Results

The first section of the study examined the activity of radioisotopes used by the Bushehr nuclear medicine department, including Iodine-131 (I-131), Lutetium (Lu), Technetium (Tc), and the amount of radioactive waste in each patient over three months. According to the patient statistics and radioisotopes, 161 patients received I-131, 58 received Lu, and 547 received Tc. These three radioisotopes have a relative frequency percentage of 20%, 7.6%, and 71.4%, respectively.

According to the results of the radioisotope waste activity analysis, Tc wastes with an activity of 1118.31 mCi had the highest activity compared to other wastes and thus comprised the majority of waste produced at the Bushehr nuclear medical center. I-131 wastes exhibited an activity rate of 370.63 mCi, whereas Lu wastes showed an activity rate of 221.35 mCi.

Tc is a radioisotope utilized frequently in nuclear medicine to produce numerous radiopharmaceuticals. Methoxyisobutyl Isonitrile (MIBI) was the most frequently used radiopharmaceutical in this department for cardiac patients, as it was administered 309 times over three months.

Following Tc, I-131 was the most often radioisotope in diagnosis and therapy at the cardiac center and administered to the patient in vials with the activity rate specified by the treating physician with less waste than Tc. This experiment did not analyze the waste generated in the department during the patient's quarantine, including blankets, sheets, disposable pillows, and food and beverage residues.

During the three-month research period, 58 patients consumed Lu and its radiopharmaceuticals with a waste activity of 6.820 mCi, which plays a crucial and practical role in treating cancer and metastases and managing pain in these patients. The Bushehr nuclear medicine center is one of the few nuclear medicine institutions in Iran that utilizes Lu, and its services are accessible to patients from not only the local region but also neighboring provinces and countries. The proportion of diagnostic and therapeutic radiopharmaceuticals used by the nuclear medicine department in Bushehr over three months is presented in Table 1.

Nuclear medicine irradiators used an electronic dosimeter to measure the equivalent dose for three months.

Table 2 and Figure 1 indicate that irradiator No. 2 received a higher dose than their colleagues, followed by irradiator No. 1 with the most extended shift, who received an average dose of 4.8 μSv/H, and irradiator No. 3 with

Table 1: Radiopharmaceutical usage by type and quantity over three months

Radiopharmaceuticals and treatments	Quantity of tests conducted in three months	The proportion of radiopharmaceuticals utilized over three months
Iodine therapy	64	8
Diagnostic iodine	98	12
Gastric emptying	1	0.13
Voiding Cystourethrogram	3	0.39
Thyroid	34	4
Parathyroid	2	0.26
Technetium	5	0.65
Red Blood Cells	1	0.13
Lu -PSMA	32	4
Lu-oxodotreotide	9	0.52
Lu-FAPI	10	1.3
Lu-DOTATATE	15	1
Lu-HERCEPTIN	1	0.13
TC MIBI	309	40
MIBG	1	0.13
Meckel	1	0.13
TC MDP	107	13
Tc MAA/DTPA	32	3
Lymphoscintigraphy	2	0.26
Tc ECD	5	0.39
Dacryoscintigraphy	4	0.52
Tc DMSA	30	3
Total	766	100

Lu –PSMA: Lu-prostate-specific membrane antigen, Lu-FAPI: Fibroblast activation protein targeted therapy using [Lu-177], Lu-DOTATATE: Lutetium-[DOTA, Tyr3] octreotate, TC MIBI: Tc-methoxy isobutyl isonitrile, MIBG: Meta-iodobenzylguanidine, TC MDP: Technetium 99m-methyl diphosphonate, Tc MAA/DTPA: Tc-99m macro aggregated albumin/ diethylenetriaminopentaacetic acid, Tc ECD: 99mTc ethyl cysteinate dimer, Tc DMSA: Tc-99m 2,3 dimercaptosuccinic aci

Table 2: Average doses received by irradiators based on the number of shifts

Irradiator	1	2	3
Number of work shifts in three months	52	33	27
Radiation dose (μSv)	4.8	5.09	3.95

the shortest shift, who received an average dose of 3.95 μSv/H.

The third section of the study evaluated the level of contamination on various surfaces three times over three months using the indirect method of wipe testing. The first surface monitoring, conducted at the end of the month and after center hours, revealed that the exercise test room, exercise test room desk, hot laboratory, hot laboratory desk, treatment physician desk, injection room, patient waiting room, and Iodine treatment room were all marginally contaminated. The exercise testing room and the work desk were the two surfaces with the highest level of contamination.

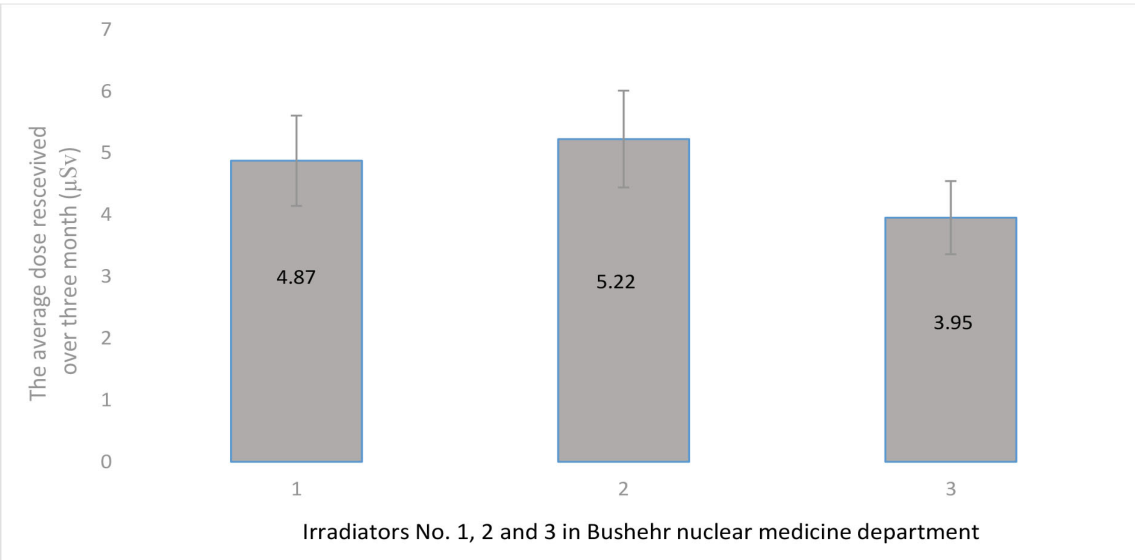

Figure 1: The average dose equivalent received by irradiators in the Bushehr nuclear medicine department

Figure 2 reveals that the exercise test room had the highest level of contamination at 0.04 Bq/cm^2, while the desk in the same room had a level of 0.013 Bq/cm^2, which is below the standard threshold of 0.5 Bq/cm^2.

In the final part of this study, the risk of contamination of personnel's clothing, hands, and shoes in the nuclear medicine department was determined over three months.

According to Table 3, personnel Nos. 10 and 11 had the highest pollution rates at 23.7%, followed by personnel Nos. 3 and No. 7, with rates of 11.11% and 9.99%, respectively.

Discussion

The generation of radioactive waste in nuclear medical facilities significantly threatens the environment and society as a challenge for urban communities. Due to the proximity of the Bushehr nuclear medicine center to the sea, waste generation and management must be closely monitored with greater priority. Since radioisotopes related to nuclear medicine are unsealed sources and their improper entry into the environmental cycle results in radiation pollution and its adverse effects, it is necessary to consider a primary method for

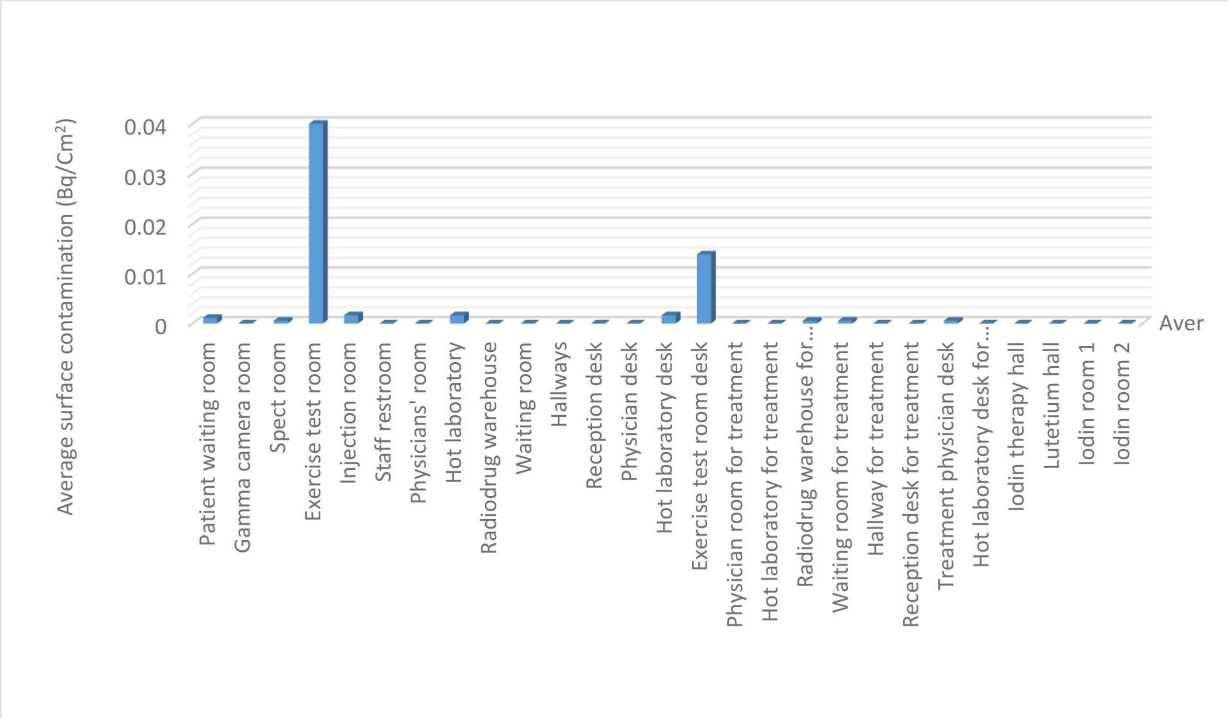

Figure 2: Bar chart depicting the average surface contamination at various sites of the nuclear medicine department throughout three indirect wipe test measurements

Table 3: Staff clothing, hands, and footwear contamination as a percentage of total work shifts

Staff	Contamination percent	Number of work shifts
1	0	52
2	5.45	33
3	11.11	27
4	1.5	65
5	0	65
6	0	55
7	9.99	55
8	0.13	27
9	0	27
10	23.7	13
11	23.7	13

removing these contaminants. However, these methods are expensive, time-consuming, and even hazardous. The best way to manage nuclear radioactive waste is to identify the contamination sources and waste prevention strategies in each ward.

This investigation's initial phase revealed that Tc is the most frequently utilized radioisotope in Bushehr nuclear medicine. Most referrals (59%) were to females, and Tc was the most frequently used radioisotope (71.4%), leaving an activity waste of 1118.31 mCi. In contrast, MIBI was the most commonly used radiopharmaceutical (40%). It must be emphasized that radioactive waste is stored in a warehouse and disposed of as regular municipal waste after ten half-lives and minimal activity.

The second phase of the trial consisted of determining the dose of three nuclear medicine irradiators using a direct electronic personal dosimeter (EPD). Several factors can affect staff exposure, including storing, distributing, preparing, and injecting radiopharmaceuticals. The average dose absorbed by three irradiators was compared at the Bushehr nuclear medical center. The ICRP recommends that workers at the Nuclear Medicine Center receive no more than 20 mSv per year, and all three irradiators meet this standard [18]. However, the As Low As Reasonably Achievable (ALARA) principle dictates that the radiation dose must be reduced to the lowest possible level [19].

The current investigation determined that the average dose received by irradiator No. 1 during 52 work shifts over three months was 4.8 µSv. During the quarter, irradiator No. 2, with 33 working shifts, received the highest average equivalent dose of the three irradiators in the section at 5.2 µSv. The third irradiator received 3.9 µSv over three months while working 27 shifts. If all three irradiators operate under the same conditions throughout the year, the average dose received by all three irradiators will be below the standard threshold (20 mSv/year).

Removing and cleaning the pollutants is time-consuming and hazardous in the event of radioactive contamination. Working with radioactive materials must be cautiously done in nuclear medicine centers, and potential contaminations must be identified.

Due to the dangers of ionizing radiation, nuclear medicine centers must perform a wipe test for contamination control at least once per week. Due to the injection syringe's looseness, there was minor contamination in the exercise test room and workstation in the range of 0.04 Bq/cm^2 to 0.013 Bq/cm^2, but it was still below the standard limit of 0.5 Bq/cm^2. On the other designated surfaces, contamination was minimal.

Prevention of contamination is an essential aspect of radiation safety and protection. When radioactive material in spherical or liquid form touches the skin, hair, or clothing, the contamination is external. Extreme care must be taken when working with radioactive materials to prevent contamination of the employee's body, clothing, equipment, and work area. In the event of contamination, radioactive particles adhere to or enter the body, exposing the individual to radiation even after leaving the contaminated area.

The Geiger-Müller instrument was used to determine the level of contamination on personnel's hands, clothing, and shoes based on work shifts. Staff Nos. 11 and 10, who worked the fewest shifts (13 in three months), were contaminated at a rate of 23%. These individuals were in charge of injecting Lu and other radiopharmaceuticals into cancer patients. Staff Nos. 3 and 7 were contaminated at 11.11% and 9.99%, respectively. The majority of these contaminants were caused by radioactive material leaking from syringes. This study estimated the extent to which employees are exposed to outside pollution. Cytogenetic analysis of personnel can detect potential chromosomal disorders caused by occupational radiation. An extended period can be selected to achieve more accurate results in monitoring air pollution.

Conclusion

Contamination with radiopharmaceuticals at nuclear medical facilities causes health concerns and requires significant time and money to remove. On the other hand, reduced occupational exposure to nuclear medicine center staff and patients referred to these departments is a pressing need. Understanding the sources and modes of exposure (external/internal) is critical for implementing effective monitoring and control methods and accurately estimating the performance of protection methods. The amount of radiation contamination in nuclear medicine centers varies based on building design, device quality control, ventilation system, workloads, type of radiopharmaceuticals, the injection method, the use of radiopharmaceuticals, and the staff's orientation. As a result, daily evaluation of radiopharmaceuticals' characteristics and staff experience with radioactive waste can contribute significantly to the estimation of the level of radiation pollution in the environment.

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Authors' Contribution

Z. Mohamadi Baghmolaei, R. Fardid, and M. Abdolahi conceived the idea. M. Haghani, Gh. Haddadi participated in study design. Z. Mohamadi Baghmolaei contributed to all experimental work and data collections, the statistical analysis and interpretation of data and the conclusion. R. Fardid proofread and supervised the research. M. Ghaderian proofread and revised the manuscript. Z. Mohamadi Baghmolaei and R. Fardid contributed equally to this work. All authors performed editing, reading, and approving the final manuscript.

Ethical Approval

The Ethics Committee of Shiraz University of Medical Sciences approved the protocol of the study (Ethic cod: IR.SUMS.REC.1400.415).

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Conflict of Interest

R. Fardid as the Editorial Board Member, was not involved in the peer-review and decision-making processes for this manuscript.

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