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Research Article

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Evaluation of Radiation Exposure of the Oral Cavity in C-Arm Fluoroscopy: A Dose Analysis

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Abstract:

This study investigates the radiation dose to the oral cavity during C-arm fluoroscopy imaging using an Alderson Rando phantom and thermoluminescent dosimeters (TLD-100) for precise measurements. The aim is to assess the potential risks for patients and healthcare personnel exposed to ionising radiation during these procedures. The Alderson Rando phantom, a human-equivalent model, was utilized to simulate radiation exposure in a controlled environment. TLD-100 dosimeters were strategically positioned in the 6th section of the phantom and exposed to radiation at intervals of 0.5, 1, 2, 4, and 8 minutes. The experiments were carried out at Hisar Hospital Intercontinental and the dosimeter readings were then evaluated at Çekmece Nuclear Research Centre.The study demonstrated that the mean radiation doses affecting the internal tissue of the oral cavity were 0.912 mSv (0.5 minutes), 1.604 mSv (1 minute), 2.719 mSv (2 minutes), 6.763 mSv (4 minutes), and 13.811 mSv (8 minutes). The mean radiation doses affecting the lip skin tissue were 1.423 mSv (0.5 minutes), 2.435 mSv (1 minute), 5.2 mSv (2 minutes), 10.195 mSv (4 minutes), and 17.404 mSv (8 minutes). Results indicate a direct relationship between radiation dose and exposure time, with increasing doses observed at longer exposure times.This research aims to improve patient safety during C-arm scope imaging procedures by determining precise radiation dosage levels for tissues in the oral cavity and addressing the lack of published reference values in the literature.

1. Introduction

X-rays are electromagnetic waves with very high energy capable of ionizing electrons from atoms. X-rays play a crucial role in medical imaging techniques such as radiography, computed tomography (CT), mammography, and fluoroscopy (C-arm scopy). For effective imaging, the X-ray must be absorbed by the tissue. The dose of ionizing radiation delivered to a patient during a diagnostic and interventional X-ray imaging procedure should be well within the predetermined acceptable levels to ensure that no deterministic skin injuries or stochastic radiation effects are likely to occur. Exposure to high doses of X-rays has negative effects on humans. The detrimental effects of radiation on the human body are well-documented, including cancer, radiation burns, genetic mutations, and reduced lifespan [1]. Artificial radiation used for medical purposes stands as the most common source of radiation exposure for individuals. Globally, the annual per capita exposure averages at 0.3 mSv [2]. Additionally, each organ and tissue in the body exhibits varying sensitivity to radiation, with more active tissues showing heightened susceptibility [3,4]. The effects of radiation on tissues vary depending on factors such as the type of radiation exposed, dose, duration of exposure, and the individual's overall health condition.

It has been observed that oral mucositis frequently occurs in patients after radiotherapy, which is one of the treatments in which radiation is used intensively [5]. Mucositis can cause mouth ulcers, pain and inflammation in the oral tissues. Furthermore, radiation can adversely affect salivary glands, leading to ulceration, dental caries, and jawbone complications. Given that fluoroscopy, the subject of this study, utilizes intensive ionizing radiation, it is imperative to assess its impact on both patients and healthcare personnel operating the device.

The International Commission on Radiological Protection (ICRP) has set the maximum doses of ionising radiation considered safe for humans as follows: 50 mSv and 1 mSv for a radiation worker and the whole body of any one person per year, respectively. The amount of radiation that a radiation worker and anyone else's hands, feet and skin may receive annually are 500 mSv and 50 mSv, respectively. The annual radiation exposure of the pupil of the eye of a radiation worker and anyone else is 50 mSv and 15 mSv, respectively [6].

The harm referred to here is any bodily disease or genetic effect. In order to reduce the negative consequences of radiation, it is very important to first determine the extent of radiation exposure. Significant research efforts have been dedicated to exploring diverse approaches for assessing both natural radiation levels and artificial radiation levels such as X-rays [7-16].

Numerous studies have been conducted on radiation dosage calculation [17-25]. There are studies that determine the amount of radiation to which hospital personnel are exposed during surgeries in which fluoroscopy is actively used [26] or the radiation value to which the patient's oral mucosa is exposed during CT [27]. However, there is no study in the literature that determines the amount of radiation to which patients' oral cavity is exposed during fluoroscopy imaging. Therefore, the purpose of this study is to assess the radiation dose level in the oral cavity during C-arm scope imaging. By determining the radiation dose level in the oral cavity during C-arm scope imaging, better radiation protection and optimization can be achieved for both the patient and the radiologist. Findings from this study will contribute to the development of diagnostic reference level for this type of imaging in relation to radiation protection. This may provide useful information for the healthcare personnel who are involved in C-arm scope imaging. The study was carried out using 24 Thermoluminescence Dosimeters (TLD) and Alderson Rando Female Phantom. Dosimeters placed in the oral cavity of the phantom were simulated for 0.5, 1, 2, 4, and 8 minutes. Dosimetry values were then read and absorbed radiation measurements were obtained.

2. Material and Methods

In this study, an Alderson Rando phantom (The Alderson Radiation Therapy Phantom, ART), generated to simulate the physical characteristics of an adult human, was utilized. This phantom is coated with an acrylic material having human tissue density and incorporates human bones [28]. Designed to provide realistic results in tissue and organ studies due to its human equivalent nature, the ART phantom proves to be a highly suitable option for investigations into radiation doses and effects. The phantom was obtained from the Istanbul University-Cerrahpasa, Cerrahpasa Faculty of Medicine, Department of Radiation Oncology. The selected phantom complies with ICRU-44 standards [29]. Representing a female, the phantom **(Figure 1)** stands at 155 cm in height and weighs 50 kg, with a material density of 0.985 g/cm³ [27]. It consists of 32 slices, each 2.5 cm thick, with needles for holding TLD dosimeters used for dose measurements [29]. In numerous studies, thermoluminescence dosimeters (TLDs) have been utilized to calculate radiation doses [28,30,31]. In this study, 24 TLD-100 dosimeters **(Figure 2)** were used.

Figure 1: *The Female Alderson Rando Phantom*

Each TLD-100 has a thickness of 0.89 mm, a width of 3.2 mm, and a length of 3.2 mm. The dosimeters contain LiF, Mg, and Ti [30]. All TLD-100s were initially annealed at 400°C for 1 hour followed by 100°C for 2 hours for calibration. It is essential for the TLDs involved in the research to be calibrated with a relative standard deviation of less than 3% [30]. Calibration of the used dosimeter chips and their readings after imaging with a C-arm fluoroscope were conducted at the Secondary Standard Dosimetry Laboratory (SSDL) located at the TENMAK Çekmece Nuclear Research Center. The readings of radiation dose measurements were performed using a Harshaw 4500 model reader connected to a computer via WinREMS software [32]. Nitrogen gas, which generates heat, is employed to warm up the TLD reading system. Using a typical Cs-137 gamma source, measurements were performed at SSDL in accordance with the instructions provided in the WinDEMS software user manual to determine the Element Correction Coefficients (ECCs) for the TLD chips and Reader Calibration Factor (RCF) for the TLD reader [32]. The calibration of the reader was carried out using Cs-137 source and Yxlon International MGC 41 model X-ray system. Reference standard dosimeters were used for radiation dose rate measurements [32]. The C-arm fluoroscopy device **(Figure 4)** was operated in automatic settings to acquire images. These imaging procedures were conducted at the Department of Radiology, Hisar Hospital Intercontinental.

Figure 2: *TLD-100 Dosimeters in case*

Figure 3: *Thermoluminescent Dosimeter*

The shooting process on the phantom was performed using a C-arm fluoroscopy device located at Hisar Hospital Intercontinental (figure 4).

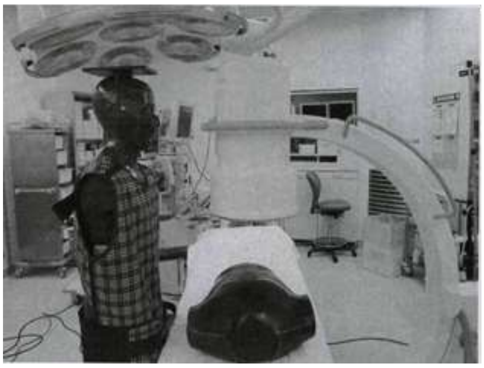

Figure 4: *The C-arm Fluoroscopy Device [33]*

After the calibration process of 24 TLD-100s was completed, they were sequentially placed into the cavities of the oral mucosa region (oral cavity) of the phantom. According to the Alderson Rando female phantom used in the study, the oral cavity region is located in section 6. 2 TLD chip was vertically positioned in the selected localization. Subsequently, images were taken from the oral cavity region under C-arm fluoroscopy separately for 0.5, 1, 2, 4, and 8 minutes. Measurements were made at two localizations: the inner part of the oral cavity and the skin of the lips.

For each time interval measurement, the previous TLD's were removed, and new TLD chips were placed. A total of 20 TLD-100 chips were used for 10 separate exposures of the oral cavity region. To calculate the radiation dose, 4 TLD-100 chips were used to determine the radiation amount in the environment (background) and the radiation exposure experienced by the operator during the irradiation process. These dosimeters were present in the background during the irradiation process. The net radiation dose experienced by the oral cavity region was calculated by subtracting the environmental dose.

Table 1: *Values of the radiation dose that affects the lip skin*

Time (minute)	Lip Skin Average Value (mSv)	Lip Skin Minimum Value (mSv)	Lip Skin Maximum Value (mSv)
0.5	1.423	1.264	1.582
1	2.435	2.198	2.671
2	5.2	4.571	5.829
4	10.195	9.137	11.253
8	17.404	15.182	19.627

After the imaging was completed, the readings of radiation exposure values for TLDs were conducted at the Çekmece Nuclear Research Center (NUKEN-TENMAK). The average radiation value obtained at 5 different time intervals was calculated separately. Using this data, graphs demonstrating the changing effect over time of the experiment were created. Resultant graphs from the tables were generated, and a mathematical model was established. Standard deviation and mean calculations were performed using basic statistical methods. Thus, the radiation dose to the oral cavity during C-arm fluoroscopy imaging was calculated.

3. Results and Discussions

In the experiments, average, minimum, and maximum values were measured for both lip skin tissue and oral cavity internal tissue. The measurements were performed at 5 different time intervals - 0.5, 1, 2, 4, and 8 minutes - to determine whether the experimental results were consistent. It was observed that the absorbed radiation values increased continuously with time. According to the result tables and graphs, it is stated that there is a direct proportional relationship between radiation dose values and time. It was also observed that the amount of radiation affecting the lip tissue was higher than the inner tissue of the mouth. Investigating the radiation exposure to the lip skin during C-arm scope imaging, the average radiation dose was determined to be: 1.423 mSv for 0.5 minutes, 2.435 mSv for 1 minute, 5.2 mSv for 2 minutes, 10.195 mSv for 4 minutes, and 17.404 mSv for 8 minutes **(Table 1).** The corresponding minimum and maximum values affecting the lip skin were found to be: 1.264 mSv and 1.582 mSv for 0.5 minutes, 2.198 mSv and 2.671 mSv for 1 minute, 4.571 mSv and 5.829 mSv for 2 minutes, 9.137 mSv and 11.253 mSv for 4 minutes, and 15.182 mSv and 19.627 mSv for 8 minutes, respectively. Notably, the regression analysis for the lip skin yielded an R^2 value of 0.992, as depicted in **Figure 5**.

Table 2: *Values of the radiation dose that affects the oral cavity interior.*

Time (minute)	Oral Cavity Interior Average Value (mSv)	Oral Cavity Interior Minimum Value (mSv)	Oral Cavity Interior Maximum Value (mSv)
0.5	0.912	0.784	1.04
1	1.604	1.461	1.747
2	2.719	2.817	2.621
4	6.763	6.189	7.338
8	13.811	11.298	16.325

Concurrently, the investigation into the radiation dose affecting the oral cavity interior revealed an average dose of: 0.912 mSv for 0.5 minutes, 1.604 mSv for 1 minute, 2.719 mSv for 2 minutes, 6.763 mSv for 4 minutes, and 13.811 mSv for 8 minutes **(Table 2).** The minimum and maximum doses affecting the oral cavity interior were observed to be 0.784 mSv and 1.04 mSv for 0.5 minutes, 1.461 mSv and 1.747 mSv for 1 minute, 2.817 mSv and 2.621 mSv for 2 minutes, 6.189 mSv and 7.338 mSv for 4 minutes, and 11.298 mSv and 16.325 mSv for 8 minutes, respectively. Furthermore, the regression analysis yielded an R^2 value of 0.9967, as illustrated in **Figure 6.** These findings elucidate the varying degrees of radiation exposure experienced by the lip skin and oral cavity interior during C-arm scope imaging. After calculating the averages of the minimum and maximum radiation doses obtained by reading the dosimeters, line graphs were created with these average values. After the equations and R^2 values of the graphs were calculated, these values were analysed.

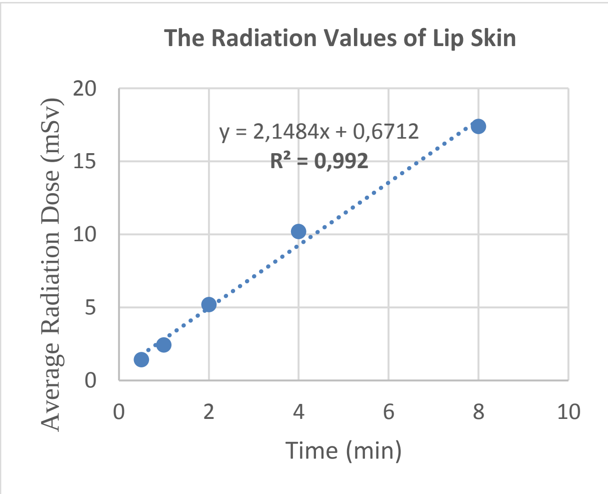

Figure 5: *Representation of the radiation dose absorbed by the outside of the lip with the equation*

Table 3: *Maximum ionising radiation dose limits stated by ICRP*

Parameter	Maximum Annual Dose Limit for General Public (mSv)	Maximum Annual Dose Limit for Healthcare Personnel (mSv)
Whole Body	1	50
Hands, Feet, and Skin	50	500
Pupil of the Eye	15	50

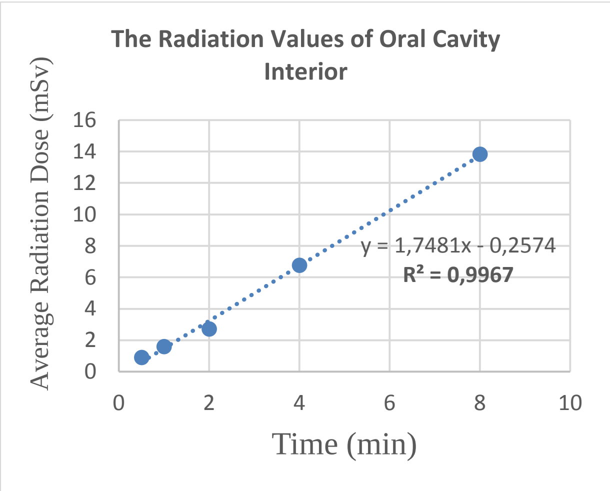

Figure 6: *Representation of the radiation dose amounts absorbed in the oral cavity interior with the equation*

The R^2 value measures the fit of a regression analysis to the data. R^2 value has no unit. This value, in the range 0.0-1.0, indicates how well the independent variables used explain the dependent variable. The higher the R^2 value, the better the model fits the data and how much of the variance in the dependent variable is explained by the independent variables [34]. The closer the R^2 value is to 1, the stronger the correlation. The R^2 value for the first graph **(Figure 5)** is 0.9967 and the R^2 value for the second graph **(Figure 6)** is 0.992. Since the results are very close to 1, it is concluded that there is a direct proportional relationship between time and radiation dose. Attaining a strong correlation is highly valuable for research. Upon analyzing the measurements in this study, it is evident that the correlation is strong, indicating the consistency of the research findings.

A table **(Table 3)** has been prepared for the maximum radiation values that ICRP considers to be non-hazardous to humans, as long as the specified annual radiation values are not exceeded. The annual radiation exposure for a radiation worker and the whole body of any other person is 50 mSv and 1 mSv, respectively. The annual radiation exposure of a radiation worker and the hands, feet and skin of any other person is 500 mSv and 50 mSv, respectively. The annual radiation exposure of the pupil of the eye of a radiation worker and any other person is 50 mSv and 15 mSv, respectively [6].

The results of the study offer crucial insights into the radiation exposure experienced by patients undergoing C-arm fluoroscopy imaging, particularly focusing on its impact on the oral cavity. In the research, radiation doses affecting both superficial and deeper tissues of the oral cavity were meticulously measured, examining various exposure times ranging from 0.5 to 8 minutes, and thermoluminescence dosimeters (TLD-100) were used for precise measurement.

According to the study of Günay et al. [27], the radiation values measured for the oral mucosa during computed tomography were 10.36 mSv (minimum), 19.47 mSv (maximum) and the mean value was 15.15±2.96 mSv. According to the results of this study, the oral cavity internal mean value for 1 minute is 1.640925 mSv. When the amount of radiation absorbed by the patient is compared, the values of 1 CT scan and approximately 9.23 minutes C-arm fluoroscopy scan are equal to each other. According to this comparison, it can be concluded that C-arm fluoroscopy has a minimal effect on the patient compared to CT.

The findings emphasise the importance of assessing radiation dose levels during C-arm fluoroscopy procedures to reduce potential risks to patient health. A direct correlation was observed between radiation dose and duration of exposure, consistent with the basic principles of ionising radiation that cumulative effects tend to increase with prolonged exposure.

When the doses to which the oral cavity and the lip were exposed were compared for the shots taken in the same period of time, it was observed that the lip values were higher. Anatomically, the lip is closer to the body surface compared to the oral cavity. Since it is closer to the body surface, more radiation affects the lip.

Furthermore, the high correlation coefficients obtained for the inside of the oral cavity and the lip support the reliability of the study findings. Likewise, the results on the relationship between radiation dose and exposure time during C-arm fluoroscopy imaging provide further evidence of the importance of dose optimisation in medical procedures.

Determining the specific effects of radiation on the oral cavity provides valuable information for the development of optimized imaging protocols aimed at improving patient safety and healthcare personnel well-being. The findings from this study, with an R^2 value close to 1, show that the results are reliable and stable. This strong correlation underlines the robustness of the data, making it a reliable source for medical staff and doctors to reference in their studies and patient treatment processes. The consistent results give medical professionals more confidence in using this information to optimise the radiation dose when using C-arm fluoroscopy on the oral cavity region, which improves patient safety and procedure efficiency.

Furthermore, the study highlights the critical role of dose optimisation and suggests potential improvements to the imaging device based on the findings. Manufacturers and medical practitioners can use these data to work towards improving the technology and protocols used in C-arm fluoroscopy, aiming for better dose management and reduced radiation exposure for both patients and healthcare professionals. The results of this paper provide a valuable reference for future research. As an analysis of radiation effects on oral tissues, it provides a strong foundation for future studies. Researchers can use the data and results obtained in this study to further investigate radiation dose optimisation, develop advanced imaging techniques and ultimately contribute to the continuous improvement of medical imaging applications.

4. Conclusions

The aim of the study was to determine the radiation dose to the patient's oral cavity and lip during C-arm fluoroscopy imaging and to emphasise the importance of developing techniques to reduce the effect of radiation. Alderson Rando Phantom was used to simulate the study and 24 Thermoluminescent Dosimeters were used for measurement. According to the measurements, the amount of radiation received varies in direct proportion to the duration. For 1 minute, the average value to which the oral cavity was exposed was 1.604 mSv, while the average value to which the lip was exposed was 2.435 mSv.

When the data of Günay et al. [27] and the data of this study are compared with each other, the radiation dose to which the patient is exposed during 1 CT scan and a 9.23-minute C-arm fluoroscopy scan is equal to each other. According to this comparison, it can be concluded that C-arm fluoroscopy has a minimal impact on the patient compared to CT.

There are not many studies on the radiation exposure of the oral cavity and lips during C-arm fluoroscopy. Therefore, by providing the necessary information, it serves as a reference for further research in the scientific and medical community. It also contributes to raising awareness of radiation safety measures and may help in the development of preventive strategies. Furthermore, the findings offer the potential to improve imaging procedures to provide a safer environment for both healthcare staff and patients.

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- **Conflict of interest:** The authors declare that they do not possess any conflicting financial interests or personal relationships that might have impacted the findings presented in this paper.

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- **Data availability statement:** The data supporting the findings of this study can be provided upon request from the respective author. However, they are not accessible to the public due to confidentiality or ethical constraints.

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