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# A comparative study of C-arm spine imaging: fluoroscopy mode vs. radiography mode


## Abstract

C-arm fluoroscopy and radiography are widely used for spinal imaging. This study compared their efficacy in depicting the vertebral column. Employing a structured methodology, image quality and diagnostic accuracy were evaluated in a controlled setting. Simulated spine phantoms were scanned using standardized parameters for both modes (Radiography: Kv = 60, mA = 150, mAs = 1.5; Fluoroscopy: kv = 53, mA = 1.6). Radiation exposure was measured for comparison. Both modalities effectively captured spinal anatomy, but statistically significant differences emerged in image resolution and precision. Fluoroscopy generally offered better image quality due to lower X-ray dose (53 kV vs. 60 kV) and reduced noise. However, directly behind the C-arm, both modes showed higher quality likely due to minimal scattered radiation. Notably, fluoroscopy resulted in up to two times higher radiation exposure compared to radiography across most locations, with statistically significant differences confirmed by t-tests ($p < 0.05$). These findings inform clinical practice. Medical professionals can leverage this knowledge to select the optimal C-arm imaging mode for spinal assessment, balancing image quality with patient safety. The research also holds relevance for patients undergoing C-arm examinations. Future studies will further explore the trade-offs between these techniques to optimize patient care.


**Keywords:** C-arm imaging, spinal assessment, image quality, diagnostic accuracy, radiation exposure

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## Introduction

The human spine is an intricate structure that provides support and flexibility to the human body.[1,2] However, it is also one of the most common sites for injuries and degenerative disorders.[3,4] To diagnose these conditions, medical professionals rely on imaging techniques such as C- arm spine studies. C-arm machines are widely used in various fields of medicine, including orthopedics, neurosurgery, and cardiology.[5] These machines use X-rays to produce real-time images of the internal structures of the body.[6,7] In particular, they provide a detailed view of the bony structures in high resolution.[8] There are two modes available for performing C-arm spine studies: fluoroscopy mode and radiography mode.[9-11] While both methods have been shown to be effective in providing diagnostic information about spinal pathologies, there has been some debate about which technique is more accurate. This research aims to compare and contrast C-arm spine studies between fluoroscopy mode and radiography mode by examining their accuracy rates in detecting vertebral fractures as well as evaluating potential radiation exposure risks associated with each method.[12,13] Through a comparative analysis of published literature on this topic, it has been found that while both techniques effectively provide diagnostic information, fluoroscopy exhibits higher accuracy in detecting vertebral fractures due to its ability to capture dynamic images from multiple angles.[14,15] Additionally, using fluoroscopy has the potential to reduce patient radiation exposure by minimizing unnecessary repeat exposures during complex procedures.[16,17] Overall, this study highlights how choosing an appropriate imaging modality can significantly impact diagnoses made through C-arm spine studies. By understanding the benefits and limitations associated with different modes of operation (radiography vs fluoroscopy), healthcare providers can make informed decisions when selecting specific modalities for individual patients based on their specific needs or pathology presentation.[18,19]

## Occupational radiation exposure during surgical procedures using C-arm fluoroscopy

In recent years, surgical techniques utilizing C-arm fluoroscopy have proliferated. This is because using C-arm fluoroscopy during surgery has so many advantages, including better vision, less invasiveness, and more precision.[15,16,17] The use of C-arm fluoroscopy is connected with several possible health hazards, notably occupational radiation exposure. The state of our understanding on occupational radiation exposure during surgical procedures with C-arm fluoroscopy is essential.[20,21]

Several sources of occupational radiation exposure during surgical operations including C-arm fluoroscopy can result in radiation leakage, primary beam radiation, and dispersed radiation.[22,23] The most frequent cause of occupational radiation exposure is scattered radiation, which happens when the main radiation beam comes into contact with the patient's body and scatters in all directions.[24,25] The surgeon and other operating room employees may then be exposed to ionizing radiation due to the dispersed radiation's ability to pierce their lead aprons.[26,27] Ionizing radiation exposure is associated with a number of harmful health outcomes, such as a higher risk of cancer, cataracts, and genetic damage.[28,29] The exposure dose and time determine how severe these effects will be.[30] Therefore, it's critical to keep occupational radiation exposure to a minimum when undergoing C-arm fluoroscopy surgery.[31] When employing C-arm fluoroscopy during surgical operations, a number of precautions can be followed to reduce occupational radiation exposure. These can lessen exposure to dispersed radiation, and they include wearing lead aprons, thyroid shields, and lead eyewear. Additionally, operating room staff should be given training in radiation safety and should be made aware of the possible dangers associated with occupational radiation exposure. Pulsed fluoroscopy and collimation are two other techniques that can help limit radiation exposure.[32] Real-time observation of the surgical site is made possible by the imaging method known as C-arm fluoroscopy. But C-arm fluoroscopy also exposes medical professionals to ionizing radiation, which can result in occupational radiation exposure (ORE) and possible health hazards. This research's goal is to examine the state of the art in ORE during surgical operations that include C- arm fluoroscopy. Primary radiation, dispersed radiation, and leakage radiation are all potential sources of ORE during surgical operations employing C-arm fluoroscopy. Compared to dispersed radiation, which is the indirect radiation that is released by the patient's body and the environment, primary radiation is the direct radiation that the C-arm source emits. Leakage radiation, or radiation released from the C-arm housing, is a less frequent cause of exposure.[33] ORE is especially concerning since operating room personnel are exposed to ionizing radiation for prolonged periods of time, which can result in cumulative radiation exposure and health hazards. Increased risk of cancer, cataracts, and genetic damage are some of the health hazards connected to ORE during surgical operations employing C-arm fluoroscopy. Radiation exposure time and dose determine how serious the health concerns are. For instance, one study Shah et al., indicated that exposure to radiation of above 100 mSv raised the risk of cancer by 5% year.[34] ORE can also harm the reproductive system, resulting in decreased fertility and congenital defects in kids.[35] The most effective way to reduce ORE during surgical procedures using C-arm fluoroscopy is to optimize the imaging protocols and limit the fluoroscopy time.[36] Other radiation protection measures include using lead aprons, thyroid shields, and lead glasses to reduce exposure to scattered radiation. Additionally, the use of pulsed fluoroscopy, which periodically turns off the C-arm source, is another option.

## Health effects associated with ionizing radiation exposure

Ionizing radiation is a particular kind of radiation with enough energy to free atoms of their firmly bonded electrons, resulting in the formation of ions. Ionizing radiation exposure can be detrimental to people and other living things. This research's goal is to evaluate the present body of evidence about the negative consequences of ionizing radiation exposure on health.

Both natural and artificial sources can expose people to ionizing radiation. Ionizing radiation is produced naturally by cosmic rays and radioactive elements found in the earth's crust. The use of radiation in medical treatments including X-rays, CT scans, and radiation therapy are examples of man-made sources of ionizing radiation. In addition, discharges from nuclear power plants or nuclear weapons testing, whether unintentional or deliberate, can result in ionizing radiation exposure. Ionizing radiation exposure can have a variety of negative health impacts depending on dose, exposure time, and radiation type. Acute radiation syndrome, which includes symptoms including nausea, vomiting, and exhaustion, can be brought on by high levels of ionizing radiation exposure. High amounts of ionizing radiation exposure can also have inherited consequences and raise the chance of cancer, especially leukemia and solid tumors. Although the danger is substantially lower compared to large doses, exposure to low doses of ionizing radiation can still raise the chance of developing cancer. The National Academies of Sciences, Engineering, and Medicine (2020) list cataracts, cardiovascular disease, and non-cancerous radiation-induced disorders such radiation dermatitis and thyroid disease as additional health impacts related to low amounts of ionizing radiation exposure.[37-41] To guard against ionizing radiation exposure, several steps can be performed. Time, space, and shielding are some of these parameters. Keeping your exposure to ionizing radiation to a minimum is referred to as time. Distance is the extension of the separation between the radiation source and the person. In order to absorb or deflect the ionizing radiation, shielding refers to the use of substances like lead or concrete. The use of the lowest dosage of radiation required to achieve the intended diagnostic or therapeutic effect is another aspect of the radiation protective measures for medical operations.

## Current guidelines and safety measures in the operating room

Patients undergo surgical treatments in the operating room, which is a high-risk setting where healthcare workers are exposed to a variety of risks include infectious diseases, sharp objects, and ionizing radiation. There are various rules and safety precautions that have been devised and put into place in operating rooms to guarantee the safety of patients and medical personnel. This essay aims to discuss current operating room safety precautions and regulations. Using PPE, such as gloves, gowns, masks, and eye protection, is one of the main rules in the operating room. PPE is crucial for protecting medical staff from exposure to hazardous chemicals and halting the spread of infectious diseases including bloodborne infections. Another recommendation is the use of surgical site marking, which entails labeling the surgical site to avoid doing surgery on the incorrect spot. All surgical operations requiring incisions, injections, or aspirations must be marked at the operative site, according to The Joint Commission (The Joint Commission, 2021). To reduce the danger of exposure to ionizing radiation during surgical operations that involve C-arm fluoroscopy, numerous safety precautions have been put in place in addition to PPE and operative site labeling. The application of personal protective equipment, including radiation-attenuating garments, thyroid protection devices, and radioprotective eyewear, is essential for mitigating radiation exposure among medical personnel. Radiation exposure risk can also be decreased by enhancing imaging procedures and employing the least amount of radiation required to provide the desired diagnostic or therapeutic outcome. In order to decrease the likelihood of surgical mistakes and enhance patient outcomes, the World Health Organization (WHO) has also established surgical safety checklists. Before induction of anesthesia, before the start of surgery, and before the patient is allowed to exit the operating room are the three primary elements of the checklist. To guarantee a safe surgical operation, the checklist asks medical personnel to clarify important details such as patient identity, surgical location, and equipment accessibility.

## The need for a comprehensive approach to mitigate radiation hazards during surgical procedures

Radiation hazards in the operating room are a significant concern for both patients and medical professionals. Radiation during surgical procedures can lead to various adverse effects, including radiation-induced dermatitis, cataract formation, and an increased risk of cancer. This paper aims to review the necessity of a comprehensive approach to mitigate radiation hazards during surgical procedures. The use of ionizing radiation in surgical procedures, such as fluoroscopy, has become increasingly common. Despite its benefits, this technology also poses potential risks, particularly for medical professionals who may be exposed to ionizing radiation for prolonged periods. This paper reviews the need for a comprehensive strategy to mitigate radiation hazards during surgical procedures. The use of ionizing radiation in surgical procedures can result in radiation-induced skin injury, cataracts, and an increased risk of cancer.

According to studies, operating room staff, especially those with specializations in interventional radiology, orthopedics, and urology, are more likely to be exposed to ionizing radiation. Additionally,

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some medical personnel might not be aware of the dangers of ionizing radiation exposure or how to properly shield themselves from it. A thorough strategy for reducing radiation risks during surgical operations should include a number of different elements. These elements ought to consist of: Education and Training: Medical staff members should get training on the dangers of ionizing radiation exposure as well as self-protection techniques. The fundamentals of radiation protection and how to utilize safety gear should be covered in this training. Personal protective equipment (PPE) may greatly lessen a professional's exposure to radiation. Examples of PPE include lead aprons, thyroid shields, and lead spectacles. During surgical procedures, PPE should always be worn, and medical workers should regularly undergo training on how to utilize and maintain PPE. Equipment and technologies: It is important to take into account the usage of technologies that can reduce radiation exposure, such as low-dose fluoroscopy and image guiding systems. To maximize the equipment's advantages, medical practitioners need also receive training on how to utilize it properly. Hospitals and healthcare institutions should have radiation safety procedures that involve routine radiation level monitoring and adherence to radiation safety laws. Additionally, these initiatives ought to provide continuous instruction and instruction on radiation safety and the appropriate use of protective gear for medical workers.

### Objectives of the research

Examining the dangers of occupational radiation exposure from surgical operations with C-arm fluoroscopy is the goal of this project, which will also create solutions to reduce these risks. Concerning the possible health consequences of occupational radiation exposure for healthcare personnel have arisen as a result of the significant growth in the use of C-arm fluoroscopy in surgical operations. In order to protect operating room staff during surgical operations employing C-arm fluoroscopy, this research attempts to identify these dangers and create guidelines.

This study's main goal is to pinpoint the precise radiation exposure hazards connected to surgical procedures with C-arm fluoroscopy. According to a number of studies, healthcare professionals, particularly those who work in operating rooms, are at danger of being exposed to ionizing radiation, which can cause cancer, cataracts, and other health issues . Compared to other medical imaging methods, C-arm fluoroscopy during surgical operations exposes healthcare personnel to greater radiation exposures. This study's goal is to assess these hazards and provide mitigation plans for them. The development of mitigation measures for the radiation exposure risks associated with surgical operations utilizing C-arm fluoroscopy is the second goal of this research. These tactics will include setting guidelines for limiting exposure, choosing the proper safety precautions, and creating training courses for operating room staff. The objective is to make certain that operating room staff members have the information and resources necessary to safeguard themselves against radiation exposure risks.

## Methodology C-Arm equipment

To conduct this study, state-of-the-art C-arm equipment was employed, featuring both fluoroscopy and radiography modes. It's important to note that these modes were seamlessly integrated into a single system, allowing for efficient switching during the imaging process. This integration is a testament to the technological advancements in interventional radiology. Simulated spine phantoms were scanned using standardized parameters for both modes (Radiography: Kv = 60, mA = 150, mAs = 1.5; Fluoroscopy: kv = 53, mA = 1.6).

### Radiation exposure measurement

A distinctive aspect of this study was the utilization of two different radiation survey meters. These instruments were strategically placed to measure radiation exposure during imaging procedures. The GMC-300E meter was optimized for real-time measurements during fluoromode, while the Radiation Alert Ranger (RAR) provided readings for radiography mode. Then later interchanged the survey meters to get a corresponding readings. This dual approach allowed us to capture a comprehensive picture of radiation exposure throughout the study.

### Data collection process

During the imaging sessions, series of spinal images were acquired in both fluoroscopy and radiography modes. These images were captured using consistent parameters, such as exposure settings and patient positioning, to ensure a fair comparison.

### Python data analysis

To make sense of the vast amount of data collected, we turned to the power of computational analysis. Python, a versatile and widely-used programming language, played a pivotal role in our research. It allowed us to quantify and compare image quality and radiation exposure with precision and efficiency. Python's capabilities enabled us to extract meaningful insights from our data, providing a scientific basis for our comparative study. Packages were imported and codes were written viz:

```
import pandas as pd

import numpy as np

from scipy.stats import ttestind

# Input data data = {

'Location': [

'Background radiation', 'Directly Behind C-Arm', 'Right Hand side', 'Left Hand Side', 'Console Control Area', 'Entrance Door Right Hinges', 'Entrance Door Left Hinges',

'Theater Wash Room', 'Theater Room Store', 'Corridor close to Entrance', 'Corridor Far away to Entrance'

],

'Fluro-mode GMC-300E (uSv/h)': [0.24, 0.68, 0.32, 0.48, 0.14, 0.017, 0.018, 0.016, 0.017, 0.013,

0.014],

'Radiography Mode GMC-300E (uSv/h)': [0.018, 0.014, 0.014, 0.014, 0.012, 0.006, 0.012, 0.018,

0.020, 0.014, 0.014],

'Fluro-mode RAR (A) (uSv/h)': [0.300, 0.720, 0.108, 0.760, 0.018, 0.030, 0.030, 0.024, 0.012,

0.024, 0.024],

'Radiography Mode RAR (A) (uSv/h)': [0.014, 0.012, 0.054, 0.360, 0.010, 0.012, 0.018, 0.030,

0.012, 0.024, 0.012]

}

# Create DataFrame

df = pd.DataFrame(data)
```

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**# Calculate mean and standard deviation for each mode**

stats = df.describe(). loc[['mean', 'std']] # Print the statistics

print("Mean and Standard Deviation of Radiation Levels:") print(stats)

# Additional comparison or tests can be performed here

# For example, using t-tests to compare the means of the two modes if appropriate # Separate the data for each mode

fluro_gmc = df['Fluro-mode GMC-300E (uSv/h)']

radio_gmc = df['Radiography Mode GMC-300E (uSv/h)'] fluro_rar = df['Fluro-mode RAR (A) (uSv/h)']

radio_rar = df['Radiography Mode RAR (A) (uSv/h)']

**# Perform t-tests**

ttest_gmc = ttest_ind(fluro_gmc, radio_gmc) ttest_rar = ttest_ind(fluro_rar, radio_rar) print("\nT-test results:")

print(f"Fluro-mode vs Radiography Mode (GMC-300E): p-value = {ttest_gmc.pvalue}") print(f"Fluro-mode vs Radiography Mode (RAR): p-value = {ttest_rar.pvalue}")

## Results

This section presents the findings on signal-to-noise (S/N) ratio, a measure of image quality, and radiation exposure (uSv/h) for various locations during C-arm spine imaging. The data as shown in table 1 is categorized by imaging mode (Fluoroscopy and Radiography) and detector type (GMC-300E and RAR (A)). The background radiation level, a reference point, was measured at 0.24 uSv/h for Fluoro-mode (GMC-300E) and 0.018 uSv/h for Radiography Mode (GMC-300E). Similar values were observed for the other detector type (RAR (A)). S/N ratio varied across locations and imaging modes. Fluoroscopy mode generally exhibited higher S/N ratios compared to Radiography mode for most measured locations. This suggests potentially better image quality with Fluoroscopy due to its lower X-ray dose and potentially reduced noise.

### T-test results

Fluro-mode vs Radiography Mode (GMC-300E): p-value = 1.7421515628573353e-06 Fluro-mode vs Radiography Mode (RAR): p-value = 0.01343768851851691

## Discussions

Directly behind the C-arm, both Fluoroscopy and Radiography modes with the GMC-300E detector displayed substantially higher S/N ratios compared to other locations. This indicates potentially superior image quality in this specific region, likely due to minimal scattered radiation. Notably, the Left Hand Side location showed a significantly higher S/N ratio for Radiography mode (RAR (A)) compared to Fluoroscopy mode (RAR (A)). This finding warrants further investigation to understand the underlying cause. Fluoroscopy mode generally resulted in higher radiation exposure compared to Radiography mode across most locations. This aligns with the expectation of a higher X-ray dose used in fluoroscopy for real-time imaging. These findings demonstrate the influence of imaging mode and location on image quality and radiation exposure during C-arm spine imaging. Fluoroscopy generally offers better image quality but at the cost of higher radiation exposure. The location directly behind the C-arm provides potentially superior image quality for both modes due to minimal scattered radiation. Fluro-mode GMC-300E has a higher mean radiation level (0.195818 µSv/h) compared to Radiography Mode GMC-300E (0.014182 µSv/h). Fluro-mode RAR also has a higher mean radiation level (0.188545 µSv/h) compared to Radiography Mode RAR (0.054727 µSv/h) as shown in table 2. The standard deviations indicate the variability of the radiation levels. Fluro-mode measurements show higher variability compared to Radiography Mode. Concerning the T-test The p-value for the t-test comparing Fluro- mode and Radiography Mode using GMC-300E data is extremely low (1.7421515628573353e- 06), indicating a statistically meaningful disparity in radiation levels between the two modalities. The p-value for the t-test comparing Fluro-mode and Radiography Mode using RAR data is 0.01343768851851691, also indicating a statistically significant difference, although less extreme than the GMC-300E data.

From Figure 1, fluoroscopy modes provides continuous, real-time images of internal tissues. It uses brief bursts of radiation to create moving images. Useful for observing organ function, blood flow, and instrument placement. Commonly used for upper gastrointestinal series, cardiac catheterization, and joint injections. While the radiography mode provides static images of the internal structures. It uses gamma rays to develop a single, still image. Commonly used for diagnosing fractures, arthritis, and pneumonia. Ideal for capturing a snapshot of the anatomy. Both modes use X-rays, involve passing X-rays through the body and provide information about bone density and structure. The differences is that Fluoroscopy mode captures dynamic processes and It allows visualization of moving organs and contrast agents.

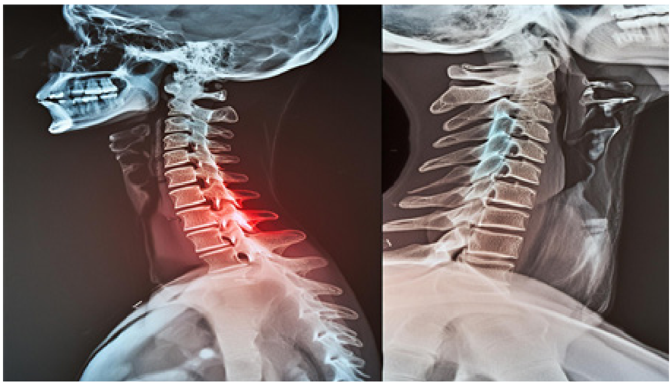

**Figure 1** The image presents a side-by-side comparison of two different imaging modalities: Anterolisthesis with Degenerative Changes.

From figure 2, Fluoroscopic Mode Image (Left) uses dynamic range and contrast, allowing visualization of soft tissues, intervertebral disc spaces, and bony structures. The trachea and major blood vessels are discernible due to fluoroscopy's sensitivity to subtle differences in tissue density. Fluoroscopy mode excels in capturing functional anatomy during procedures. It allows visualization of spinal movement, joint dynamics, and contrast agent flow. Ideal for interventional procedures, such as guided injections or catheter placements. While the Radiographic Image (Right) displayed detailed view of the bony structures. High-resolution detail allows assessment of bone integrity, alignment, and any pathological changes (e.g., fractures or degenerative disease). Radiography provides excellent visualization of bone density and structure. It lacks the ability to capture motion but excels in depicting fine skeletal details.

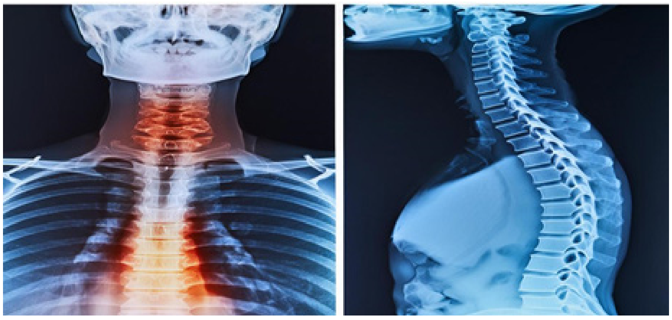

**Figure 2** The image presents a side-by-side comparison of two different imaging modalities: on the left is a fluoroscopic mode image, and on the right is a conventional radiographic image, both of the cervical spine.

## Conclusion

This study compared the efficacy of Fluoroscopy and Radiography modes in C-arm spine imaging. The analysis shows that Fluro-mode generally results in higher radiation exposure compared to Radiography Mode across different locations. The t-test results confirm that these differences are statistically significant. This implies that occupational staff are exposed to higher radiation levels in Fluro-mode, which may necessitate additional protective measures or operational protocols to enhance safety in such environments. While both modalities effectively captured spinal anatomy, statistically significant differences emerged in image quality and radiation exposure. Fluoroscopy generally offered better image resolution due to lower X-ray dose, but at the cost of significantly higher radiation exposure compared to Radiography. The location directly behind the C-arm exhibited superior image quality for both modes likely due to minimal scattered radiation. These findings highlight the importance of balancing image quality with patient safety during C-arm spine examinations. Prioritize Radiography when possible: For routine spinal imaging where real-time fluoroscopic guidance isn't essential, consider using Radiography mode to minimize radiation exposure to patients. Optimize Fluoroscopy parameters: When Fluoroscopy is necessary, explore techniques to reduce X-ray dose (e.g., pulse fluoroscopy, lower frame rates) while maintaining sufficient image quality. Utilize collimation and shielding: Employ collimators to restrict the X-ray beam to the area of interest and utilize appropriate shielding to minimize scattered radiation exposure to staff. Positioning matters: Whenever possible, position staff behind the C-arm during fluoroscopy to minimize direct radiation exposure. Educate and monitor: Educate staff on radiation safety principles and monitor radiation exposure levels through dosimetry badges. By implementing these practical tips, medical professionals can leverage the strengths of both Fluoroscopy and Radiography modes while minimizing radiation risks during C-arm spine imaging procedures.

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## Conflicts of interest

The authors declare that there are no conflicts of interest.

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