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# Radiation exposure in spine surgeries. A review of risks, consequences, and prevention strategies

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## ABSTRACT

Radiation exposure is a significant concern in spine surgeries due to the extensive use of fluoroscopic imaging. This review aims to evaluate the risks, consequences, and prevention strategies associated with radiation exposure in spine surgeries. The risks of radiation exposure include potential biological damage to patients and surgical staff, such as skin burns, cataracts, and an increased risk of developing cancer. The consequences of radiation exposure can have long-term health implications and may result in substantial healthcare costs. To mitigate the risks, various prevention strategies are recommended. These include optimizing the use of fluoroscopy by adopting low-dose imaging techniques, minimizing the duration of exposure, and ensuring proper shielding of personnel. Additionally, the use of alternative imaging modalities, such as intraoperative three-dimensional (3D) navigation systems, can reduce reliance on fluoroscopy and subsequently decrease radiation exposure. Furthermore, implementing a culture of radiation safety through education, training, and awareness programs is crucial. This involves educating surgeons, nurses, and other healthcare professionals about the potential risks, proper use of equipment, and radiation protection measures. Strict adherence to radiation safety guidelines and continuous monitoring of radiation doses are essential to ensure the well-being of both patients and healthcare providers. In short, radiation exposure in spine surgeries poses significant risks and potential consequences. However, with the adoption of appropriate prevention strategies, such as optimizing imaging techniques, implementing alternative modalities, and fostering a culture of radiation safety, the potential risks can be mitigated. By prioritizing radiation safety, healthcare facilities can provide better outcomes for patients and minimize the long-term health implications associated with radiation exposure in spine surgeries.

## INTRODUCTION

The utilization of fluoroscopic imaging and intraoperative imaging techniques has become increasingly prevalent in spine surgeries. These imaging modalities provide valuable real-time visualization and guidance during complex spinal procedures, leading to improved surgical outcomes. However, one significant concern associated with these techniques is the potential for radiation exposure to both patients and healthcare professionals involved in these procedures. Radiation exposure in medical procedures has been extensively

## Keywords

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studied, and its detrimental effects on human health are well-established.<sup>1</sup> The primary sources of radiation exposure in spine surgeries include X-ray fluoroscopy and computed tomography (CT) scans. These imaging techniques provide high-resolution images but also expose patients and medical staff to ionizing radiation.<sup>2</sup> While the radiation doses received during individual procedures may appear low, cumulative exposure from repeated or prolonged surgeries can potentially lead to adverse health effects.

The potential risks associated with radiation exposure in spine surgeries are of significant concern. Acute effects may include skin injuries, radiation sickness, and other immediate consequences for both patients and healthcare professionals. Moreover, long-term risks, such as an increased risk of cancer, genetic effects, and cataracts, have been observed in individuals exposed to high levels of ionizing radiation.<sup>3</sup> Understanding these risks is crucial for developing effective preventive strategies.

To address the risks associated with radiation exposure, numerous preventive measures have been proposed and implemented in clinical practice. These strategies aim to minimize radiation exposure without compromising the quality of surgical outcomes. Examples include the use of shielding devices and personal protective equipment (PPE), optimization of imaging techniques to reduce radiation dose, and the adoption of low-dose imaging modalities like cone-beam computed tomography (CBCT). Additionally, radiation dose monitoring and tracking systems play a vital role in assessing the radiation exposure of both patients and medical staff.<sup>4</sup>

The implementation of preventive strategies requires education and training for healthcare professionals involved in spine surgeries. Radiation safety education programs, training on proper technique and equipment use, and ongoing professional development are essential to ensure compliance with radiation safety guidelines. Furthermore, interdisciplinary collaboration between surgeons, radiologists, medical physicists, and other healthcare providers is crucial for developing comprehensive radiation safety protocols and promoting a culture of safety. In short, radiation exposure in spine surgeries poses risks to both patients and healthcare professionals.

Understanding the potential consequences of radiation exposure and implementing effective preventive strategies are paramount in ensuring the safety and well-being of individuals involved in these procedures. This review will delve into the risks, consequences, and preventive measures associated with radiation exposure in spine surgeries, shedding light on the importance of radiation safety awareness and the implementation of appropriate strategies.

## DISCUSSION

### Overview of the growing prevalence of fluoroscopic imaging in spine surgeries

Fluoroscopic imaging has witnessed a significant increase in its utilization within spine surgeries. This imaging modality offers real-time visualization and guidance during complex spinal procedures, leading to enhanced surgical outcomes. However, this increased usage has raised concerns regarding radiation exposure for both patients and healthcare professionals involved in these procedures. Fluoroscopy, a technique that employs X-rays to generate dynamic images, plays a pivotal role in various spine surgeries, including spinal fusion, discography, and minimally invasive procedures. It enables surgeons to visualize anatomical structures, guide instrument placement, and verify the accuracy of spinal implant positioning. The real-time nature of fluoroscopy allows for immediate adjustments and ensures precise intraoperative decision-making. The growing prevalence of fluoroscopic imaging in spine surgeries can be attributed to several factors. Firstly, advancements in imaging technology have led to improved image quality, reducing the risk of diagnostic errors and facilitating more precise surgical interventions. Additionally, the rise in minimally invasive spine surgeries has driven the need for real-time imaging guidance, making fluoroscopy an indispensable tool in such procedures.<sup>5</sup>

Fluoroscopic imaging also offers potential benefits, including reduced surgical invasiveness, shorter hospital stays, and faster recovery times for patients. These advantages have contributed to its increased adoption among spine surgeons, as they strive to provide optimal patient care and outcomes. However, the widespread use of fluoroscopy has raised concerns about radiation exposure. The continuous and prolonged exposure to ionizing

radiation during these procedures poses potential health risks for both patients and healthcare professionals.<sup>5</sup> Therefore, it is essential to address radiation safety measures and implement preventive strategies to minimize radiation-related complications.

#### **Statement of the problem: Radiation exposure and its potential health risks**

Radiation exposure is a significant concern in spine surgeries due to the utilization of fluoroscopic imaging and other intraoperative imaging techniques. The risks associated with radiation exposure are well-established. Ionizing radiation has the potential to cause both acute and long-term effects on human health. Acute radiation effects include skin injuries, radiation sickness, and other immediate consequences for patients and healthcare professionals exposed to high doses of radiation. Furthermore, long-term risks have been observed, such as an increased risk of cancer, genetic effects, and the development of cataracts. Studies have demonstrated a direct link between radiation exposure and the development of radiation-induced cancers. The risk of cancer is dose-dependent, meaning that higher cumulative radiation doses over time increase the likelihood of malignancies.<sup>6</sup> For patients undergoing multiple spine surgeries or those requiring long-term follow-up with imaging, the cumulative radiation dose can become a significant concern.

The potential genetic effects of radiation exposure are also noteworthy. High doses of radiation can induce DNA damage, which may result in genetic mutations and hereditary effects in future generations.<sup>7</sup> Healthcare professionals exposed to radiation during spine surgeries should be particularly cautious due to the occupational hazards associated with chronic exposure. Another important long-term consequence of radiation exposure is the increased risk of cataract development. Studies have shown that healthcare professionals who frequently use fluoroscopy or work in interventional radiology departments have a higher prevalence of radiation-induced cataracts.<sup>8</sup> This emphasizes the need for protective measures and careful monitoring of radiation exposure in spine surgeries. Understanding the potential health risks associated with radiation exposure in spine surgeries is crucial for developing effective

preventive strategies and ensuring the safety of patients and healthcare professionals. By implementing appropriate measures to minimize radiation exposure and adopting strict radiation safety protocols, the potential risks and long-term consequences can be mitigated.

#### **Types of radiation used in spine surgeries: X-ray, fluoroscopy, and computed tomography (CT)**

Radiation plays a crucial role in various imaging modalities used in spine surgeries, including X-ray, fluoroscopy, and CT. Each of these techniques utilizes different forms of radiation to generate detailed images of the spine and guide surgical interventions. An overview of these radiation types and their applications in spine surgeries is given below:

1. **X-ray:** X-ray imaging employs electromagnetic radiation to produce two-dimensional images of the spine. It is commonly used to assess the bony structures, alignment, and presence of fractures or deformities. X-rays provide valuable information on spinal anatomy and pathology, aiding in preoperative planning and intraoperative guidance. However, X-rays deliver a relatively higher radiation dose compared to other imaging techniques.<sup>9</sup>
2. **Fluoroscopy:** Fluoroscopy is a real-time imaging technique that utilizes X-rays to generate dynamic images of the spine. It provides continuous visualization during spine surgeries, enabling surgeons to guide instrumentation, assess intervertebral motion, and verify the accuracy of implant placement. Fluoroscopy provides valuable real-time feedback, facilitating precise intraoperative decision-making. However, it involves prolonged radiation exposure due to continuous imaging.<sup>9</sup>
3. **Computed Tomography (CT):** CT scans utilize X-ray radiation in combination with advanced computer processing to create cross-sectional images of the spine. CT offers detailed information about bony structures, spinal alignment, and soft tissue components, aiding in the evaluation of complex spinal pathologies. CT imaging can be particularly useful in surgical planning, as it provides three-dimensional reconstructions and enhances visualization of anatomical structures.<sup>9</sup>

### Quantification of radiation exposure levels in different spine procedures

Quantifying radiation exposure levels in different spine procedures is an important aspect of radiation safety. While specific radiation exposure levels can vary depending on various factors such as the type of procedure, imaging technique, equipment used, and individual patient characteristics, the following information provides a general overview of radiation exposure levels in commonly performed spine procedures:

1. **Pedicle Screw Placement:** Pedicle screw placement (PSP) is a common procedure in spinal instrumentation, which involves the insertion of screws into the vertebral pedicles for stabilization. The radiation exposure levels in PSP procedures can vary depending on several factors, including the imaging technique used (such as fluoroscopy or CT), the complexity of the procedure, the number of fluoroscopic images taken, and the surgeon's experience. Studies have reported varying radiation exposure levels in PSP procedures. For instance, a study by Smith H et al.<sup>10</sup> found that the mean radiation dose to the patient during lumbar PSP using fluoroscopy ranged from 1.15 to 8.53 mSv per procedure. They also compared fluoroscopy-guided PSP with computer-assisted image guidance and reported a mean radiation dose of 1.29 mSv for the fluoroscopy group and 0.47 mSv for the image guidance group. This highlights the variability in radiation exposure levels and the potential for reducing exposure through the use of image guidance techniques.
2. **Minimally Invasive Spine Surgery (MISS):** Minimally invasive spine surgery techniques aim to minimize tissue trauma and promote faster recovery compared to traditional open surgical approaches. These procedures often involve the use of fluoroscopy or other imaging guidance for visualization and instrument guidance. The radiation exposure levels in MISS procedures can vary depending on the specific technique used, the complexity of the procedure, the duration of fluoroscopy, and the number of imaging acquisitions.
3. **Image-Guided Spine Interventions:** Image-guided spine interventions, such as vertebroplasty or kyphoplasty, involve the use of imaging guidance, usually fluoroscopy or CT, to

assist in the precise placement of instruments and delivery of therapeutic agents. These procedures can have varying radiation exposure levels depending on factors such as the complexity of the intervention, the number of imaging acquisitions, and the duration of fluoroscopy.

It is important to note that the actual radiation exposure levels can vary widely based on individual patient characteristics, operator technique, equipment used, and adherence to radiation safety measures. To minimize radiation exposure, it is crucial to implement radiation safety protocols, optimize imaging techniques, and utilize appropriate shielding and PPE. Adhering to ALARA principles (As Low As Reasonably Achievable) is essential in maintaining radiation doses as low as possible while still achieving the required diagnostic and procedural objectives.<sup>11</sup>

### Factors influencing radiation exposure: duration, technique, and patient characteristics

Certainly! Factors influencing radiation exposure in spine surgeries can include the duration of the procedure, imaging technique utilized, and patient characteristics. Some of these factors are:

1. **Duration of Procedure:** The duration of a spine surgery procedure can have a significant impact on radiation exposure. Prolonged surgical durations generally lead to increased radiation exposure due to the extended use of fluoroscopy or other imaging techniques. The longer the fluoroscopy time, the higher the radiation dose to both the surgeon and the patient. Studies have shown a positive correlation between surgical duration and radiation exposure in spine surgeries.<sup>12</sup> It is important for surgeons to minimize fluoroscopy time and optimize procedural efficiency to reduce radiation exposure.
2. **Imaging Technique:** The choice of imaging technique during spine surgeries can greatly influence radiation exposure levels. Fluoroscopy and CBCT are commonly used imaging modalities. Fluoroscopy provides real-time imaging but may result in higher radiation exposure due to continuous imaging. On the other hand, CBCT provides 3D imaging with lower radiation doses but may require longer imaging

acquisition times. Surgeons need to balance the need for image quality with radiation exposure and choose the most appropriate imaging technique for each procedure. Additionally, utilizing low-dose imaging protocols and minimizing unnecessary imaging acquisitions can further reduce radiation exposure.

3. **Patient Characteristics:** Patient characteristics, such as body habitus and the number of levels treated, can influence radiation exposure in spine surgeries. A recent study on PSP in adult idiopathic scoliosis patients found that higher body mass index (BMI) was associated with increased radiation exposure.<sup>13</sup> This is because patients with higher BMI may require more fluoroscopic images or longer imaging times to visualize and place pedicle screws accurately. Similarly, procedures involving a greater number of levels treated may require additional imaging acquisitions, leading to increased radiation exposure. Surgeons should be mindful of these patient-related factors and take appropriate measures to minimize radiation exposure, such as optimizing imaging parameters and adjusting technique based on patient-specific considerations.

To effectively mitigate radiation exposure in spine surgeries, it is crucial to implement comprehensive radiation safety protocols. This includes utilizing appropriate shielding and personal protective equipment, adhering to ALARA principles, optimizing imaging techniques, and promoting ongoing education and awareness among healthcare providers about radiation safety practices. It is important to note that the specific influence of these factors may vary across different surgical procedures and patient populations. Surgeons and healthcare providers should stay updated with the latest research and guidelines in the field of radiation safety to ensure the best possible outcomes for both patients and medical personnel.

### Risks and Consequences of Radiation Exposure

Risks and consequences associated with radiation exposure are:

1. **Increased Risk of Cancer:** Exposure to ionizing radiation, such as that used in spine surgeries, has been associated with an increased risk of cancer. The long-term effects of radiation

exposure can lead to the development of various malignancies, including leukemia, thyroid cancer, breast cancer, and lung cancer. The risk of cancer is cumulative and increases with higher radiation doses and prolonged exposure.<sup>14</sup> It is crucial to minimize radiation exposure in order to reduce the potential long-term risks of cancer development.

2. **Radiation-Induced Tissue Damage:** Radiation exposure can cause acute and chronic tissue damage. Acute effects include radiation dermatitis, erythema, and radiation sickness. Chronic effects can manifest as tissue fibrosis, radiation necrosis, and damage to organs within the radiation field. The severity of tissue damage is dependent on factors such as the radiation dose, fractionation, and sensitivity of the irradiated tissues.<sup>15</sup> Minimizing radiation exposure through proper technique and adherence to radiation safety measures is essential to mitigate the risk of tissue damage.
3. **Genetic Effects and Birth Defects:** Prolonged exposure to radiation can have genetic effects, including DNA damage and mutations. These genetic alterations can be passed onto future generations, increasing the risk of hereditary diseases and birth defects.<sup>7</sup> It is particularly important to minimize radiation exposure in reproductive-age individuals and pregnant patients to safeguard against potential genetic effects.
4. **Occupational Hazards for Healthcare Providers:** During spine procedures, medical professionals, such as surgeons and operating room personnel, are exposed to radiation. Long-term occupational radiation exposure can raise the risk of radiation-related health issues such as cataracts, skin lesions, and an increased risk of cancer. Protecting healthcare professionals requires appropriate radiation shielding, the use of personal protective equipment, and adherence to radiation precautionary measures.<sup>16</sup>

### Acute radiation effects: skin injury, radiation sickness

Acute radiation effects can manifest as skin injury and radiation sickness. The details of these specific consequences of radiation exposure are:



1. **Skin Injury:** Radiation-induced skin injury, also known as radiation dermatitis or radiation burns, can occur as a result of high-dose radiation exposure. The severity of skin injury depends on the radiation dose, fractionation, and sensitivity of the skin. Acute effects can include erythema, dry or moist desquamation, blistering, and ulceration. The extent and severity of skin injury can vary based on individual factors and the specific radiation therapy technique employed.<sup>17</sup>
2. **Radiation Sickness:** Radiation sickness, also referred to as acute radiation syndrome (ARS) or radiation poisoning, occurs when the whole body is exposed to high doses of radiation over a short period. ARS manifests as a collection of symptoms that occur in stages based on the radiation dose received. The symptoms can include nausea, vomiting, diarrhea, fatigue, fever, dizziness, and, in severe cases, bone marrow suppression and central nervous system dysfunction. The severity of radiation sickness is directly related to the radiation dose.<sup>18</sup>

#### Long-term risks: cancer, genetic effects, cataracts

Long-term risks associated with radiation exposure include an increased risk of cancer, genetic effects, and the development of cataracts. Their long-term consequences are:

1. **Increased Risk of Cancer:** Exposure to ionizing radiation has been linked to an increased risk of cancer development. Prolonged exposure to radiation, especially at higher doses, can lead to DNA damage and mutations that may contribute to the initiation and progression of cancer. The risk of developing cancer is dependent on factors such as the radiation dose, the dose rate, and the age at exposure. Various studies have demonstrated an elevated risk of cancers such as leukemia, thyroid cancer, breast cancer, lung cancer, and others following radiation exposure.<sup>7</sup>
2. **Genetic Effects:** Radiation exposure can have genetic effects that can be passed onto future generations. These genetic effects include chromosomal abnormalities, mutations, and hereditary diseases. The risk of genetic effects is influenced by the radiation dose, dose rate, and timing of exposure. It is particularly important to minimize radiation exposure in reproductive-age individuals and pregnant patients to prevent

potential genetic effects.<sup>19</sup>

3. **Cataracts:** Cumulative exposure to radiation, especially to the lens of the eye, can increase the risk of developing cataracts. Cataracts are characterized by clouding of the eye's lens, leading to visual impairment. The risk of radiation-induced cataracts is dose-dependent, and the threshold for cataract development is relatively low. Occupational radiation exposure, such as in healthcare professionals working with fluoroscopy or radiation therapy, increases the risk of cataracts.<sup>20</sup>

#### Radiation-related complications in spine surgery

Common radiation-related complications in spine surgery are:

1. **Skin Injuries:** Excessive radiation exposure can lead to acute skin reactions, such as radiation dermatitis, erythema, desquamation (dry or moist), blistering, and ulceration.
2. **Tissue Damage and Necrosis:** High doses of radiation can cause tissue damage and delayed wound healing, resulting in tissue necrosis. This can occur in both the surgical site and surrounding healthy tissues.
3. **Neurological Complications:** Radiation exposure can lead to neurological complications, including radiculopathy and myelopathy. These complications can arise from radiation-induced damage to nerve roots or the spinal cord.
4. **Increased Risk of Secondary Malignancies:** Long-term radiation exposure in spine surgery patients may increase the risk of developing secondary malignancies, such as sarcomas or solid tumors. The risk is influenced by factors such as radiation dose, fractionation, and patient age.
5. **Radiation-Related Health Effects in Healthcare Providers:** Surgeons and operating room staff who are exposed to radiation during spine surgeries are at risk of radiation-related health effects. These can include cataracts, skin lesions, and an elevated risk of malignancies due to occupational radiation exposure.

#### Prevention strategies for radiation exposure

Prevention strategies for radiation exposure in spine surgeries aim to reduce the amount of radiation to which patients and healthcare providers are

exposed. These strategies include both technical measures and operational practices. Here are some common prevention strategies:

1. **Optimization of Imaging Techniques:** By optimizing imaging techniques, such as adjusting exposure parameters and utilizing low-dose protocols, radiation dose can be reduced while maintaining image quality. This includes the use of collimation, filtration, and pulsed fluoroscopy to minimize unnecessary radiation exposure.
2. **Shielding and Positioning:** Lead shielding devices, such as aprons, thyroid shields, and lead glasses, can be used to protect patients and healthcare providers from unnecessary radiation exposure. Proper patient positioning and immobilization techniques can help minimize the need for repeat imaging and reduce radiation exposure.
3. **Education and Training:** Ensuring that healthcare providers involved in spine surgeries receive appropriate education and training on radiation safety is crucial. This includes understanding the principles of radiation protection, proper use of imaging equipment, and adherence to ALARA principles.
4. **Radiation Monitoring and Dose Reporting:** Implementing systems for real-time monitoring of radiation dose during spine surgeries allows healthcare providers to track and optimize radiation exposure. This includes the use of dose monitoring devices, such as personal dosimeters, and establishing protocols for dose reporting and documentation.
5. **Utilization of Alternative Imaging Modalities:** Whenever appropriate, alternative imaging modalities with lower or no ionizing radiation, such as magnetic resonance imaging (MRI) or ultrasound, can be utilized to reduce radiation exposure in specific cases.

#### Radiation safety measures for healthcare professionals

Radiation safety measures for healthcare professionals involved in spine surgeries are crucial to minimize their occupational radiation exposure. Here are some commonly recommended radiation safety measures:

1. **Personal Protective Equipment (PPE):** Healthcare professionals should wear

appropriate PPE, such as lead aprons, thyroid shields, lead glasses, and gloves, to minimize direct radiation exposure to sensitive body parts.<sup>12</sup>

**Distance and Positioning:** Healthcare professionals should maintain a safe distance from the radiation source whenever possible. By positioning themselves away from the primary beam and utilizing shielding barriers, they can reduce their exposure to scattered radiation.

**Time Optimization:** Minimizing the duration of exposure to radiation is essential. Healthcare professionals should plan and perform procedures efficiently to limit their time in the radiation field. This includes optimizing surgical techniques, using proper imaging guidance, and collaborating effectively with the surgical team.

2. **Training and Education:** Healthcare professionals should receive appropriate training and education on radiation safety, including principles of radiation protection, proper use of shielding devices, and adherence to ALARA principles. Regular training updates and continuing education help ensure awareness of best practices and safety guidelines.
3. **Radiation Monitoring:** Regular monitoring of radiation exposure is essential for healthcare professionals. Personal dosimeters can measure individual radiation exposure and provide feedback to monitor cumulative doses. This information helps professionals assess their radiation exposure and take necessary precautions.
4. **Work Area Safety:** Implementing proper radiation safety protocols in the workplace is crucial. This includes posting radiation warning signs, establishing restricted access zones, and maintaining proper equipment maintenance and quality control.

#### Education and training

- a. **Importance of radiation safety education for healthcare professionals:** Radiation safety education for healthcare professionals is of paramount importance in ensuring the well-being of both patients and medical staff. It equips healthcare professionals with the necessary knowledge and skills to understand the potential risks associated with radiation exposure and implement appropriate safety measures. Here



are some key points highlighting the importance of radiation safety education:

1. **Awareness of Risks:** Radiation safety education raises awareness among healthcare professionals about the potential risks associated with radiation exposure. They gain a comprehensive understanding of the biological effects of radiation, including acute and long-term risks, as well as the factors that influence radiation dose and exposure levels. This awareness fosters a culture of safety and promotes a proactive approach to minimize radiation exposure.
2. **Compliance with Safety Guidelines:** Radiation safety education familiarizes healthcare professionals with radiation protection guidelines and regulations. They learn about the principles of radiation protection, safe handling of radiation-emitting equipment, proper use of shielding devices, and adherence to radiation safety protocols. This knowledge ensures compliance with established safety guidelines, reducing the likelihood of unnecessary radiation exposure.
3. **Optimal Use of Imaging Techniques:** Education on radiation safety helps healthcare professionals understand the appropriate utilization of imaging techniques to minimize radiation dose while maintaining diagnostic image quality. They learn about the advantages and limitations of different imaging modalities, optimization strategies, and dose reduction techniques. This knowledge enables them to make informed decisions regarding the selection and optimization of imaging techniques.
4. **Implementation of Best Practices:** Radiation safety education equips healthcare professionals with the best practices for radiation safety in clinical settings. They learn about proper positioning of patients, optimization of imaging parameters, use of dose monitoring tools, and effective communication strategies to ensure a safe environment for both patients and medical staff. By implementing these best practices, healthcare professionals minimize radiation risks and promote a culture of safety within their teams.
5. **Continual Professional Development:**

Radiation safety education should be an ongoing process to keep healthcare professionals updated with the latest advancements and guidelines in radiation safety. They should participate in regular training sessions, workshops, and conferences focused on radiation safety to enhance their knowledge, skills, and awareness of emerging trends and technologies.

By providing radiation safety education to healthcare professionals, organizations can create a safe working environment, improve patient care, and reduce the potential risks associated with radiation exposure. It empowers healthcare professionals to take an active role in protecting themselves, their colleagues, and their patients from unnecessary radiation exposure while optimizing the benefits of medical imaging procedures.

**b. Training programs on radiation protection and dose reduction techniques:** Training programs on radiation protection and dose reduction techniques are essential for healthcare professionals who work with radiation-emitting equipment, such as those involved in spine surgeries. These programs provide comprehensive education and hands-on training to ensure that healthcare professionals are equipped with the knowledge and skills necessary to minimize radiation exposure and implement best practices. Here are some key points regarding training programs on radiation protection and dose reduction techniques:

1. **Basic Radiation Safety:** Training programs start with the fundamentals of radiation safety, including the principles of radiation protection, biological effects of radiation, and regulatory guidelines. Participants learn about the concepts of time, distance, and shielding, which form the basis of radiation protection. This foundational knowledge helps healthcare professionals understand the importance of minimizing radiation exposure and adopting appropriate safety measures.
2. **Equipment Operation and Optimization:** Training programs focus on the proper operation and optimization of radiation-emitting equipment, such as fluoroscopy

machines and CT scanners. Healthcare professionals learn about the functionalities of these devices, how to adjust imaging parameters to optimize image quality while minimizing radiation dose, and how to utilize dose reduction techniques and tools. This training enables them to use the equipment effectively and responsibly.

3. **Patient Positioning and Dose Management:** Training programs emphasize the importance of proper patient positioning and dose management techniques. Healthcare professionals learn how to position patients correctly to obtain the necessary imaging information while minimizing radiation exposure. They also learn about the use of appropriate collimation, shielding, and image acquisition protocols to reduce unnecessary radiation dose. This training ensures that healthcare professionals optimize imaging practices for each patient.
4. **Radiation Monitoring and Dose Tracking:** Training programs cover the use of dosimeters, dose monitoring software, and other radiation monitoring tools. Healthcare professionals learn how to wear and use dosimeters correctly, understand dose monitoring reports, and analyze their radiation exposure trends. They also learn how to utilize dose tracking systems to identify high-exposure procedures and implement corrective measures. This training enables them to actively manage their radiation exposure and make informed decisions based on dose data.
5. **Quality Assurance and Continuous Improvement:** Training programs highlight the importance of quality assurance in radiation safety. Healthcare professionals learn about the significance of regular equipment maintenance, calibration, and quality control procedures to ensure accurate and reliable imaging results. They also gain an understanding of the importance of ongoing education, participation in radiation safety committees, and keeping up-to-date with emerging technologies and best practices. This training fosters a culture of continuous improvement in radiation safety.

Training programs on radiation protection and dose reduction techniques should be comprehensive, tailored to the specific needs of healthcare professionals, and periodically updated to incorporate advancements in technology and regulatory guidelines. By providing such training, healthcare organizations promote a culture of safety, empower their staff to minimize radiation exposure, and enhance the overall quality of patient care.

#### c. **Continuous professional development and updates on radiation safety guidelines:**

Continuous professional development and updates on radiation safety guidelines are crucial for healthcare professionals working with radiation-emitting equipment. Ongoing education and staying updated with the latest guidelines ensure that healthcare professionals have the most current knowledge and skills to protect themselves and their patients from unnecessary radiation exposure. Here are some key points highlighting the importance of continuous professional development and updates on radiation safety guidelines:

1. **Changing Regulatory Landscape:** Radiation safety guidelines and regulations evolve over time to reflect advancements in technology, emerging research, and best practices. Continuous professional development programs provide healthcare professionals with updates on regulatory changes, ensuring compliance with the latest standards. It helps them stay informed about any new requirements or recommendations that may impact their daily practice.
2. **Advancements in Imaging Technology:** The field of medical imaging constantly evolves, introducing new imaging modalities, techniques, and equipment. Continuous professional development programs keep healthcare professionals up to date with the latest advancements, such as the introduction of low-dose imaging modalities or novel dose reduction techniques. This knowledge allows professionals to leverage new technologies effectively and optimize radiation practices accordingly.
3. **Emerging Research and Evidence-Based Practice:** Continuous professional development programs provide healthcare

professionals with access to the latest research findings and evidence-based practice guidelines in radiation safety. They learn about new studies that may influence radiation dose management, the understanding of radiation risks, and the implementation of dose reduction strategies. Staying updated with the current evidence enables professionals to make informed decisions and deliver the best possible care to their patients.

4. **Quality Assurance and Performance Improvement:** Continuous professional development programs promote quality assurance and performance improvement in radiation safety practices. They provide opportunities for healthcare professionals to assess their own practices, participate in case discussions, and engage in peer-to-peer learning. This process allows professionals to identify areas for improvement, share experiences, and implement strategies to optimize radiation safety and patient care.
5. **Collaboration and Networking:** Continuous professional development programs offer opportunities for healthcare professionals to collaborate and network with colleagues from various disciplines. Interdisciplinary conferences, workshops, and seminars allow professionals to exchange knowledge, share experiences, and discuss challenges and solutions related to radiation safety. Collaboration and networking foster a culture of continuous learning and improvement in radiation safety practices.

Continuous professional development and updates on radiation safety guidelines ensure that healthcare professionals have the necessary knowledge and skills to provide safe and effective care to their patients. It empowers professionals to stay informed about advancements in technology, regulatory changes, and evidence-based practices, promoting a culture of excellence and continuous improvement in radiation safety.

**d. Implementation and Compliance:** Implementation and compliance are essential aspects of radiation safety in spine surgeries. It involves the practical application of radiation safety measures and ensuring that healthcare

professionals adhere to established guidelines and protocols. Here are some key points regarding the implementation and compliance of radiation safety measures:

1. **Standard Operating Procedures (SOPs):** The development and implementation of standard operating procedures are crucial for ensuring consistent and safe practices in radiation safety. SOPs outline the specific steps and protocols to be followed during spine surgeries involving radiation-emitting equipment. These procedures may include guidelines for patient positioning, equipment operation, image acquisition, and radiation dose optimization. Healthcare facilities should establish clear SOPs and ensure that all relevant staff members are trained and knowledgeable about their contents.
2. **Regulatory Compliance:** Healthcare facilities must comply with regulatory guidelines and standards pertaining to radiation safety. These regulations may include requirements for equipment calibration and maintenance, use of personal protective equipment, and adherence to radiation dose limits. Compliance with these regulations is essential to ensure the safety of patients and healthcare professionals. Regular audits and inspections can help monitor compliance and identify areas for improvement.
3. **Interdisciplinary Collaboration:** Radiation safety in spine surgeries involves collaboration among different healthcare professionals, including surgeons, radiologists, anesthesiologists, and radiologic technologists. Effective communication and collaboration among these professionals are essential to ensure proper implementation of radiation safety measures. Interdisciplinary meetings, pre-operative planning sessions, and ongoing discussions can facilitate collaboration and ensure a comprehensive approach to radiation safety.
4. **Quality Assurance Programs:** Quality assurance programs play a vital role in monitoring and maintaining radiation safety in spine surgeries. These programs involve regular assessments, audits, and performance monitoring to ensure that radiation safety protocols are followed

consistently. They may include equipment performance checks, dose monitoring, and evaluation of staff compliance with radiation safety guidelines. Regular quality assurance activities help identify areas for improvement and ensure ongoing compliance with radiation safety standards.

5. **Training and Education:** Adequate training and education are crucial for healthcare professionals to understand and implement radiation safety measures effectively. Facilities should provide comprehensive training programs on radiation safety, covering topics such as radiation physics, radiation protection principles, dose optimization techniques, and proper use of personal protective equipment. Ongoing education and training sessions should be provided to keep healthcare professionals updated with the latest guidelines and advancements in radiation safety.
6. **Continuous Monitoring and Improvement:** Continuous monitoring and improvement are essential to ensure the long-term effectiveness of radiation safety measures. This can involve regular assessment of radiation exposure levels, tracking of radiation-related incidents or complications, and the implementation of corrective measures when necessary. Data analysis and feedback mechanisms can help identify areas of concern and drive improvement initiatives.

By implementing radiation safety measures and ensuring compliance, healthcare facilities can minimize the risks associated with radiation exposure in spine surgeries. This requires a comprehensive approach, including the development of SOPs, regulatory compliance, interdisciplinary collaboration, quality assurance programs, and continuous training and education.

**e. Regulatory frameworks and guidelines for radiation safety in spine surgeries:** Regulatory frameworks and guidelines play a crucial role in ensuring radiation safety in spine surgeries. They provide standards and recommendations that healthcare facilities and professionals must follow to protect patients and staff from unnecessary radiation exposure. Here are some

key regulatory frameworks and guidelines relevant to radiation safety in spine surgeries:

1. **International Commission on Radiological Protection (ICRP):** The ICRP is an independent organization that provides guidance and recommendations on radiation protection. They publish reports and recommendations based on scientific evidence and expertise. The ICRP's recommendations include dose limits for occupational exposure and principles for optimizing radiation protection in medical settings.<sup>21</sup>
2. **International Atomic Energy Agency (IAEA):** The IAEA is an international organization that promotes the safe use of nuclear energy and radiation in various fields, including healthcare. They develop safety standards, guidelines, and training materials related to radiation safety. The IAEA's Safety Standards Series includes specific guidelines for radiation safety in medical imaging and interventional procedures.<sup>22</sup>
3. **National Radiological Protection Board (NRPB) - UK:** The NRPB, now part of the Public Health England, is responsible for advising the UK government on radiation protection matters. They have published guidance documents on radiation protection in medical and dental exposures, including specific recommendations for interventional procedures.<sup>23</sup>
4. **United States Nuclear Regulatory Commission (NRC):** The NRC is the regulatory agency responsible for overseeing the civilian use of radioactive materials, including in medical settings. They establish and enforce regulations to ensure the safe use of radiation and protect public health. The NRC provides guidance on radiation safety for medical personnel and facilities, including specific recommendations for interventional procedures.<sup>24</sup>
5. **European Directive 2013/59/Euratom:** The Euratom Directive is a legal framework established by the European Union (EU) to regulate the protection of individuals against the dangers of ionizing radiation. The directive sets out basic safety standards for the medical use of radiation, including requirements for

equipment quality assurance, justification and optimization of procedures, and training and education of healthcare professionals.<sup>25</sup>

6. **National and Regional Guidelines:** Many countries and regions have their own specific guidelines for radiation safety in healthcare settings, including spine surgeries. These guidelines may be developed by national radiation protection authorities, professional organizations, or healthcare regulatory bodies. They provide specific recommendations on radiation dose limits, equipment quality assurance, patient and staff safety, and training requirements.

It is important for healthcare facilities and professionals involved in spine surgeries to familiarize themselves with these regulatory frameworks and guidelines. Compliance with these standards ensures the implementation of best practices in radiation safety, minimizing unnecessary radiation exposure and promoting the well-being of patients and healthcare professionals.

**f. Challenges and barriers in implementing preventive strategies:** Implementing preventive strategies for radiation exposure in spine surgeries can face several challenges and barriers. These obstacles may vary based on factors such as healthcare facility resources, staff compliance, and organizational culture. Here are some common challenges and barriers that can arise:

1. **Lack of Awareness and Education:** Limited awareness and understanding of radiation risks and preventive strategies among healthcare professionals can hinder the implementation of preventive measures. Insufficient training and education programs on radiation safety may contribute to a lack of knowledge regarding dose optimization techniques, proper use of shielding devices, and adherence to radiation safety protocols. Addressing this challenge requires comprehensive and ongoing education initiatives to ensure healthcare professionals are well-informed about radiation risks and preventive strategies.
2. **Time Constraints and Workflow Considerations:** In a fast-paced healthcare environment, time constraints and workflow considerations can impede the proper implementation of preventive strategies. Healthcare professionals may feel pressured to prioritize efficiency over radiation safety, leading to suboptimal practices. Integration of radiation safety measures into existing workflows, efficient communication between team members, and streamlining processes can help overcome this challenge.
3. **Resistance to Change:** Resistance to change can be a significant barrier to implementing preventive strategies for radiation exposure. Healthcare professionals may be resistant to adopting new techniques or equipment due to unfamiliarity or a perceived disruption in their established practices. Overcoming resistance requires effective communication, collaboration, and providing evidence-based information to demonstrate the benefits of preventive strategies in terms of patient and staff safety.
4. **Resource Limitations:** Limited availability of resources, such as radiation protection equipment and personnel, can pose challenges to implementing preventive strategies. Insufficient access to shielding devices, personal protective equipment, and radiation monitoring tools may hinder the consistent application of preventive measures. Healthcare facilities should prioritize resource allocation and consider the long-term benefits of investing in radiation safety infrastructure and equipment.
5. **Organizational Culture and Leadership Support:** The culture within healthcare organizations can influence the implementation of preventive strategies. A culture that prioritizes patient and staff safety, encourages open communication, and fosters a proactive approach to radiation safety is essential. Lack of leadership support or a culture that does not prioritize radiation safety can create barriers to implementing preventive measures. It is crucial for organizational leaders to promote a culture of safety, provide resources and support, and actively engage staff in radiation safety initiatives.
6. **Cost Considerations:** Cost can be a



significant barrier to the implementation of preventive strategies. Upgrading equipment, implementing new imaging techniques, and providing adequate training and education programs can incur expenses. Healthcare facilities may be hesitant to invest in preventive measures due to budgetary constraints. However, it is important to consider the long-term benefits and potential cost savings associated with reducing radiation-related complications and improving patient outcomes.

Overcoming these challenges requires a multifaceted approach that includes education and awareness, resource allocation, organizational support, and a commitment to a culture of safety. Collaboration among healthcare professionals, administrators, regulatory bodies, and professional organizations can help address these barriers and ensure the successful implementation of preventive strategies for radiation exposure in spine surgeries.

**g. Importance of interdisciplinary collaboration and communication:** Interdisciplinary collaboration and communication are essential in promoting radiation safety and minimizing radiation exposure in spine surgeries. Here are some points highlighting the importance of interdisciplinary collaboration and communication:

1. **Comprehensive Patient Care:** Spine surgeries involve a team of healthcare professionals from various disciplines, including surgeons, anesthesiologists, radiologists, nurses, and medical physicists. Collaborative efforts among these disciplines ensure comprehensive patient care, taking into account not only the surgical procedure but also radiation safety considerations. By working together, healthcare professionals can integrate radiation safety measures into the overall treatment plan, minimizing unnecessary radiation exposure while optimizing patient outcomes.
2. **Shared Knowledge and Expertise:** Each discipline brings unique knowledge and expertise to the table. Interdisciplinary collaboration allows for the exchange of information, sharing of best practices, and integration of diverse perspectives. For example, radiologists can provide guidance on appropriate imaging techniques and dose optimization, while surgeons can share insights on specific surgical approaches and patient positioning. By leveraging the collective knowledge and expertise of the team, strategies can be developed to minimize radiation exposure without compromising the surgical outcome.
3. **Consistent Application of Radiation Safety Protocols:** Consistent application of radiation safety protocols is crucial for effective radiation dose reduction. Interdisciplinary collaboration ensures that all team members are aligned in implementing these protocols, including proper use of shielding devices, adherence to imaging guidelines, and adherence to radiation safety policies. Clear communication among team members promotes a standardized approach to radiation safety, reducing the risk of errors or inconsistencies.
4. **Proactive Identification of Radiation Safety Concerns:** Effective interdisciplinary collaboration allows for proactive identification of radiation safety concerns. By openly discussing and sharing experiences, the team can identify potential risks or challenges related to radiation exposure in spine surgeries. This collaborative approach enables the implementation of preventive strategies and the development of solutions to address specific concerns, enhancing patient and staff safety.
5. **Continuous Quality Improvement:** Interdisciplinary collaboration promotes a culture of continuous quality improvement. By regularly reviewing and analyzing radiation exposure data, sharing experiences, and discussing lessons learned, the team can identify areas for improvement and implement targeted interventions. This ongoing collaboration helps to refine radiation safety practices, optimize imaging techniques, and enhance overall patient care.
6. **Education and Training:** Interdisciplinary collaboration plays a critical role in education and training initiatives related to radiation safety. By working together, healthcare

professionals can develop comprehensive educational programs that address the specific needs of different disciplines. This collaboration ensures that all team members receive appropriate training on radiation safety principles, techniques for dose reduction, and the proper use of radiation protection measures.

Overall, interdisciplinary collaboration and communication foster a team-based approach to radiation safety in spine surgeries. By leveraging the collective expertise, sharing knowledge, and promoting open communication, healthcare professionals can work together to implement effective radiation safety measures, minimize radiation exposure, and optimize patient outcomes.

#### **Future directions: Areas of further research and technological advancements**

The field of radiation exposure in spine surgeries is constantly evolving, and there are several areas of further research and technological advancements that can contribute to improving radiation safety. Here are some potential future directions:

1. **Advanced imaging techniques:** Continued research and development of advanced imaging techniques can contribute to reducing radiation exposure while maintaining high-quality images. This includes the exploration of novel imaging modalities, such as intraoperative MRI or ultrasound, that provide real-time imaging guidance with reduced radiation exposure.
2. **Dose optimization algorithms:** The development of dose optimization algorithms specific to spine surgeries can help healthcare professionals tailor radiation doses to individual patient characteristics and procedure requirements. These algorithms can take into account factors such as patient size, complexity of the surgery, and specific anatomical considerations to optimize imaging parameters and minimize unnecessary radiation exposure.
3. **Radiation dose tracking and feedback systems:** Implementing robust radiation dose tracking and feedback systems can provide real-time data on radiation exposure during spine surgeries. These systems can help healthcare professionals monitor and assess their radiation dose levels, identify areas for improvement, and

make informed decisions to optimize radiation safety practices.

4. **Radiation protection devices:** Research on the effectiveness of radiation protection devices, such as lead shielding, protective aprons, and thyroid collars, can contribute to the development of more ergonomic and efficient designs. Advances in materials and technology can enhance the effectiveness and comfort of these devices, further reducing radiation exposure for healthcare professionals.
5. **Simulation and training programs:** Simulation-based training programs can play a crucial role in educating healthcare professionals about radiation safety practices in spine surgeries. Virtual reality simulations can provide a realistic environment to practice radiation safety techniques, enhance situational awareness, and improve decision-making skills related to dose optimization and radiation protection.
6. **Long-term studies on radiation-related risks:** Conducting long-term studies to assess the incidence and long-term effects of radiation-related risks, such as cancer development and genetic effects, in patients undergoing spine surgeries can provide valuable insights. These studies can help refine radiation safety guidelines, identify high-risk patient populations, and guide future preventive strategies.
7. **Collaboration and knowledge sharing:** Continued collaboration among healthcare professionals, researchers, and regulatory bodies is essential to exchange knowledge, share best practices, and promote standardized radiation safety protocols. This includes conducting multicenter studies, establishing registries for radiation exposure data, and creating platforms for interdisciplinary discussions and knowledge dissemination.

By focusing on these future directions, the field of radiation exposure in spine surgeries can make significant advancements in radiation safety practices, minimize risks associated with radiation exposure, and improve patient outcomes. Continued research, technological innovations, and collaboration will pave the way for a safer and more effective approach to radiation safety in spine surgeries.

## CONCLUSIONS

Radiation exposure in spine surgeries is a significant concern due to its potential health risks for both patients and healthcare professionals. The prevalence of fluoroscopic imaging in spine surgeries is growing rapidly, leading to increased radiation exposure. This highlights the need for effective preventive measures to mitigate the risks associated with radiation exposure. Quantification of radiation exposure levels in different spine procedures has revealed significant variations, emphasizing the importance of implementing optimized imaging techniques and dose monitoring systems. Radiation-related complications in spine surgery, including acute effects such as skin injury and radiation sickness, as well as long-term risks like cancer, genetic effects, and cataracts, underscore the importance of minimizing radiation exposure.

The evidence presented in this review highlights the potential adverse outcomes of radiation exposure in spine surgeries, emphasizing the urgency of implementing preventive strategies. Prevention strategies for radiation exposure in spine surgeries involve a multi-faceted approach, including the proper use of shielding devices and personal protective equipment, optimization of imaging techniques, adoption of low-dose imaging modalities, radiation dose monitoring, and comprehensive education and training programs.

The interdisciplinary collaboration and communication among healthcare professionals are essential in implementing and ensuring compliance with radiation safety measures. However, several challenges and barriers exist in implementing preventive strategies, such as lack of awareness, time constraints, resistance to change, resource limitations, and organizational culture. Overcoming these challenges requires concerted efforts from healthcare professionals, administrators, regulatory bodies, and professional organizations. By addressing these challenges and implementing preventive strategies, healthcare professionals can significantly reduce radiation exposure, mitigate associated risks, and improve patient and staff safety in spine surgeries.

In short, a comprehensive and interdisciplinary approach to radiation safety in spine surgeries is crucial to minimize radiation exposure and its potential health consequences. Continued research, education, and collaboration are essential to further

advance radiation safety practices and optimize patient care in spine surgery settings.

## List of Abbreviations

3D: Three-dimensional;  
ALARA: As Low As Reasonably Achievable;  
ARS: Acute radiation syndrome;  
BMI: Body mass index;  
CBCT: Cone-beam computed tomography;  
CT: Computed Tomography;  
EU: European Union;  
IAEA: International Atomic Energy Agency;  
ICRP: International Commission on Radiological Protection;  
MISS: Minimally invasive spine surgery;  
MRI: Magnetic Resonance Imaging;  
NRC: National Commission;  
NRPB: National Radiological Protection Board;  
PPE: Personal Protective Equipment;  
PSP: Pedicle screw placement;  
SOPs: Standard Operating Procedures.

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