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Research Article

Intersections of Ergonomics and Radiation Safety in Interventional Radiology

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Abstract: Interventional radiology is a rapidly developing field of medicine that offers diagnosis and treatment opportunities with minimally invasive techniques. However, healthcare professionals working in this field face serious occupational risks such as both ergonomic difficulties and ionizing radiation exposure. It has been reported in the literature that fixed positions, repetitive movements and heavy protective equipment used in interventional procedures cause musculoskeletal disorders in approximately 60% of workers. At the same time, long-term radiation exposure during procedures performed with fluoroscopy and other imaging techniques can trigger long-term health problems such as DNA damage, cataracts and various types of cancer. This review examines the intersections of ergonomics and radiation safety in interventional radiology practice from an interdisciplinary perspective. Topics such as the physical load caused by lead aprons, the effect of equipment placement on ergonomics and exposure, and the advantages provided by robot-assisted systems are examined. In addition, it is discussed how ergonomics and radiation safety principles can be applied in a holistic manner in line with the recommendations of international authorities such as ICRP and IAEA. The integration of ergonomically designed equipment, workstation arrangements and regular training for employees offers sustainable solutions in terms of both occupational health and patient safety. The aim of this study is to contribute to the creation of a safer and healthier working environment for healthcare professionals working in the field of interventional radiology.

Keywords: Radiation safety,Interventional radiology,Ergonomics

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1. Introduction

With technological advances in the field of medicine, imaging techniques have become indispensable in both diagnosis and treatment processes. Interventional radiology, one of the most important application areas of these techniques, facilitates the treatment processes of patients and shortens recovery times by enabling procedures performed with minimally invasive methods. However, in addition to these advantages, healthcare professionals and patients are also exposed to various risk factors in interventional radiology practices. The most important of these risks are ergonomic difficulties and the harmful effects of ionizing radiation.

Interventional radiologists and related healthcare personnel perform interventions that require standing for long periods of time, working in fixed positions, and repetitive movements. This situation can cause musculoskeletal disorders over time. At the same time, imaging methods such as fluoroscopy used during procedures increase the risk of radiation exposure for personnel and patients. Therefore, ergonomics and radiation safety are two important issues that need to be addressed together in terms of the sustainability of interventional radiology.

In this review, the effects of ergonomic conditions on healthcare professionals in interventional radiology and the interactions between radiation safety practices will be examined; how both fields meet on common ground will be

evaluated in the light of current practices and future trends. At the same time, strategies to reduce radiation exposure and ways to create a healthier, safer and more productive work environment with the integration of ergonomic improvements will be discussed. In this way, it is aimed to provide a holistic perspective in terms of both the well-being of healthcare professionals and patient safety.

2. Working Conditions and Physical Loads in Interventional Radiology

Interventional radiology constitutes one of the fastest growing and developing branches of modern medicine. In this field, the aim is to treat and diagnose diseases with generally minimally invasive procedures. Interventional radiologists intervene with advanced imaging technologies, usually with minimal incisions or needles made into the patient's body. However, the physical challenges and workload faced by professionals working in this field are often overlooked.

Working conditions in interventional radiology practices carry certain risks for both employees and patients. Employees are often forced to work in fixed positions for long periods of time. This can lead to musculoskeletal disorders, waist, neck and back pain [7]. In addition, factors such as the large and generally fixed size of the devices used, the narrowness of the area, and the need to stand for long periods of time also increase the physical burden on employees.

Long-term operations and the difficulty of the job often result in minimal mobility. Radiologists, especially when working in difficult and narrow areas, may have to hold their bodies at certain angles. Ergonomically inappropriate working positions can lead to muscle tension and chronic disorders. In this context, constantly staying in the same position can cause excessive tension, especially in the neck and waist muscles. Over time, employees may experience permanent pain and musculoskeletal problems in the back, shoulder and neck regions [11].

However, some equipment used in the workplace can also increase physical burdens. For example, although lead aprons are mandatory protective equipment to ensure radiation safety, they create an additional physical burden for healthcare professionals due to their excessive weight in long-term use [1]. Long-term use of lead aprons can increase pressure, especially on the waist and spine, and can have negative effects on the musculoskeletal system. In addition, most of these aprons lack ergonomic design and often prevent employees from moving comfortably.

A significant challenge for interventional radiologists is the difficulty of changing patient positions and providing appropriate viewing angles. During interventional procedures, patients often remain motionless for long periods of time, which forces healthcare professionals to constantly move different parts of their bodies. At the same time, since the devices used during the procedure must be in the correct position, radiologists may have to constantly adjust and position these devices correctly.

Considering all these factors, it is clear that the physical loads encountered in interventional radiology can have long-term effects on healthcare professionals. Therefore, in order to protect the health of healthcare professionals and increase work efficiency, it is vital to make ergonomic arrangements and improvements. Improving the health of employees is important not only for personal but also for institutional success. Ergonomic factors should be taken into consideration for healthcare professionals to work efficiently, prevent long-term health problems and reduce work accidents.

3. Ergonomics Principles and Their Application to Interventional Radiology

Ergonomics is a branch of science that advocates that people should be arranged in the most appropriate way for their working environments, physical and psychological needs. In interventional radiology practices, ergonomic principles are a critical factor that directly affects both the health of healthcare professionals and work efficiency. The physical load, musculoskeletal disorders, pain and fatigue that healthcare professionals encounter during long-term procedures are usually due to ergonomic deficiencies [3]. Therefore, ergonomic arrangements are an indispensable requirement to protect the health of employees and increase their productivity in interventional radiology practice.

Interventional radiology often involves procedures that last for long hours, require high attention and are performed in fixed positions. While employees constantly interact with the patient, they usually move in narrow spaces. In this environment, ergonomically unsuitable positions can increase musculoskeletal disorders. Standing in the same

position for a long time can lead to excessive muscle tension and increased fatigue. For example, neck, back and shoulder muscles pose a great risk to healthcare professionals who often work in fixed positions for long periods of time. Such disorders not only lead to individual health problems, but can also negatively affect work efficiency [11].

The first step in applying ergonomic principles to interventional radiology is to properly arrange the workstation. The layout of the equipment should be designed in a way that does not hinder the natural mobility of the employees. It should be ensured that radiologists can easily reach the equipment without bending or turning excessively. In particular, the placement of the patient table and radiation devices should be adjusted in a way that suits the body structure of the healthcare professionals. While employees facilitate the patient's movement during the procedure, they should also be able to maintain a proper posture themselves [7]. In this way, employees can perform their duties with less physical stress and the risk of musculoskeletal problems can be reduced.

Ergonomic workstations also balance the workload of employees, allowing them to work longer and more efficiently. In particular, the placement of equipment such as interactive screens and computers, imaging devices used during the procedure should be designed to suit the body structure. Screens should be at eye level and should be placed in a way that eliminates the need to constantly look. In addition, the control panels of the devices used should also be ergonomic and should be at a convenient distance for the person performing the procedure. In this way, employees can focus only on the procedure while ensuring their physical comfort [3].

Personal protective equipment used in the field of interventional radiology also has an important place in terms of ergonomics. Radiation protective aprons are generally one of the most commonly used equipment. However, these equipment can cause excessive load over time. Especially during long-term use, the weight of lead aprons can put pressure on the waist and spine, which can lead to musculoskeletal disorders. Therefore, light and comfortable lead aprons with ergonomic designs allow healthcare professionals to move comfortably and keep physical fatigue to a minimum even during long-term use [11].

Ergonomically unsuitable working conditions not only threaten the physical health of healthcare professionals, but can also negatively affect radiation safety. Long-term exposures, working in incorrect positions, and inadequate protective aprons pose great risks to employees who may be sensitive to radiation. Ergonomic arrangements minimize these risks while creating a better working environment for employees in terms of both physical and radiation safety. Therefore, integrating ergonomic and radiation safety measures is an important requirement for interventional radiology practice. As a result, the application of ergonomic principles to interventional radiology is of great importance in terms of protecting the health of healthcare professionals, increasing work efficiency, and creating safe working environments. These principles improve work performance at both individual and institutional levels, while also helping to prevent health problems that healthcare professionals may encounter in the long term. Ergonomic designs and arrangements not only create a healthy working environment, but also contribute to the efficient and safe application of interventional radiology.

4. Radiation Safety: Risks and Protection Methods

A significant part of interventional radiology is the accurate diagnosis and treatment of patients. However, the high-energy radiation used during these procedures can pose serious risks to healthcare professionals. Radiation can have short- and long-term adverse effects on the human body, so it is of great importance that interventional radiologists are protected from these risks. This section will discuss in detail the radiation risks encountered in interventional radiology and the methods used to protect against these risks.

Radiation can cause DNA damage at the cellular level and lead to serious health problems such as cancer and genetic mutations. X-rays and other types of ionizing radiation used in interventional radiology procedures pose a continuous risk to healthcare professionals. The long-term effects of radiation exposure can cause permanent damage to the body's organs and tissues, which poses serious dangers to healthcare professionals. Interventional radiologists, in particular, can be exposed to high doses of radiation for many hours, which creates a cumulative effect [6]. Therefore, radiation safety is of critical importance in interventional radiology practices.

One of the basic principles of radiation safety is to minimize exposure. Various methods are used to reduce the risks caused by radiation. The most common of these methods is the use of protective equipment. Lead aprons, lead sleeves, and goggles are the most commonly used protective equipment against radiation. Lead aprons reduce

the doses to which workers will be exposed by preventing radiation from passing into the body. However, it should not be forgotten that long-term use of lead aprons creates physical burden and causes musculoskeletal problems. Therefore, the use of ergonomically designed, lightweight, and comfortable protective equipment is important [11].

Another important safety measure is the correct positioning of the devices used during the procedure. Placing X-ray devices and other radiation sources at the right angles prevents radiation from spreading to non-target areas and reduces worker exposure. In addition, it should be ensured that the radiation dose is kept as low as possible. For this purpose, appropriate calibrations should be made for the devices and unnecessary radiation exposure should be avoided [7].

The "As Low As Reasonably Achievable" principle should also be applied to ensure radiation safety. This principle aims to use the lowest possible dose of radiation. Using only the amount of radiation necessary at each stage of interventional procedures creates the safest approach for both the patient and the worker. One way to reduce radiation dose is to limit the duration of use of the devices during imaging. In addition, unnecessary procedures should be avoided and radiation should be used only when clinically necessary [3].

However, one of the most important elements in increasing radiation safety is education. Regular training of interventional radiologists and other healthcare professionals on radiation safety contributes to the creation of safe working environments. Radiation safety training ensures that workers learn the correct techniques, recognize the risks, and take appropriate protective measures. In addition, healthcare institutions should regularly review and update radiation safety protocols to create safe work environments [11].

Another important method is to establish continuous monitoring and auditing systems. Personal dosimeters that monitor radiation exposure allow employees to monitor daily radiation levels. These dosimeters indicate whether radiation levels are within safe limits and provide early warning in case of overexposure. In addition, continuous monitoring is important to ensure continuity of radiation safety.

Finally, regular health checks should be performed for the health of professionals who will work in interventional radiology. These checks are critical for early detection of any radiation effects. Regular health screenings allow potential health problems to be detected in advance and health problems can be prevented with early intervention. Radiation safety in interventional radiology not only protects individual healthcare professionals, but also increases patient safety. High radiation doses also pose a potential risk to patients, so healthcare professionals need to take the right safety measures. Radiation safety measures play a fundamental role in protecting the health of both professionals and patients.

5. Development of Ergonomic Equipment and Technologies

The development of ergonomic equipment and technologies plays a critical role in the efficient and safe application of interventional radiology. In order to improve the working conditions of healthcare professionals, reduce musculoskeletal problems and increase work efficiency, ergonomically designed equipment has made significant progress in recent years. In this section, the development of ergonomic equipment used in interventional radiology, the benefits of this equipment to healthcare professionals and possible future innovations will be discussed.

The biggest goal in the development of ergonomic equipment is to provide solutions that will protect the physical health of healthcare professionals and allow them to do their jobs more efficiently. One of the most common ergonomic equipment used in interventional radiology applications is patient tables. Modern patient tables have adjustable features that allow radiologists and other healthcare professionals to have a more comfortable posture. These tables can be easily adjusted to change the body positions of patients, while ensuring that healthcare professionals constantly maintain the correct position during the procedure. Such table systems minimize physical fatigue for both the patient and the healthcare professional and prevent musculoskeletal problems [7].

However, the other most commonly used ergonomic equipment in the field of interventional radiology is lead aprons. Lead aprons, which are critical in terms of radiation safety, have become lighter and more ergonomic with advanced technologies. While traditional lead aprons have heavy designs that limit the user's body movements, ergonomic aprons produced with lighter materials today allow healthcare professionals to move comfortably. These innovations help prevent musculoskeletal disorders by reducing physical load during long-term procedures [3].

Another important step in the development of ergonomic equipment was seen in the ergonomic designs of imaging devices. The devices used in interventional radiology procedures are usually large and complex, which can cause healthcare professionals to have difficulty using the devices. However, today, manufacturers are making ergonomic improvements in their designs to make these devices more useful. The control panels of the devices are placed in accordance with the natural positions of healthcare professionals, thus preventing employees from using the devices without bending over or reaching. In addition, screens and other visual aids are designed to be at eye level, eliminating the need for users to bend their heads excessively [11].

Technological developments are not limited to equipment design. In recent years, robotic surgery and digital technology have created a significant revolution in the field of interventional radiology. In particular, robot-assisted systems allow interventional radiologists to perform procedures more precisely and safely. These robotic systems offer healthcare professionals the opportunity to work in more ergonomically appropriate positions. Robots not only assist the person performing the procedure, but also help reduce radiation exposure. Robots positioned away from the radiation source prevent healthcare professionals from being directly exposed to radiation [6].

Another important aspect of developing ergonomic designs of interventional radiology equipment is to prevent long-term health problems of employees. Healthcare professionals, in particular, frequently encounter musculoskeletal disorders. These disorders are usually caused by working in fixed positions for long periods, using heavy equipment, and inadequate workstations. Ergonomic equipment offers an important solution to prevent such disorders. Innovations in the design of equipment allow healthcare professionals to perform procedures more comfortably while minimizing their effects on their bodies [3]. The future of technological developments is quite promising. Artificial intelligence (AI) and machine learning will allow faster and more accurate results to be obtained in imaging systems. In addition, AI-based systems will aim to reduce physical load by suggesting ergonomically correct positions to healthcare professionals. In the future, the integration of such technologies will further increase both patient and employee safety. More flexible structures and ergonomic designs of robotic systems that can mimic the movements of the human body will enable healthcare professionals to work more efficiently and safely.

As a result, the development of ergonomic equipment and technologies is of great importance in interventional radiology practice. These equipment protect the physical health of healthcare professionals while also increasing work efficiency. Technological innovations and ergonomic designs create a safer and more efficient working environment for both healthcare professionals and patients. Therefore, ergonomic solutions in interventional radiology practices are an area that needs to be continuously developed

6. Intersection Points of Ergonomics and Radiation Safety

Interventional radiology offers a work environment that requires both a high level of attention and is physically challenging. Standing for long periods, performing procedures in fixed positions, and using protective equipment such as lead vests can have negative effects on the musculoskeletal health of healthcare professionals. In addition to these difficulties, methods applied for radiation protection can also bring about ergonomic problems. Therefore, there is a strong intersection between ergonomics and radiation safety, and when these two areas are considered together, a healthier and safer working environment can be provided.

Ergonomic Effects of Protective Equipment: While radiation protective equipment such as lead aprons, thyroid protectors and lead glasses aim to protect the user against ionizing radiation, they can have significant disadvantages in terms of ergonomics. Lead aprons usually weigh 4–7 kg, and this load can cause musculoskeletal complaints, especially in the waist, shoulder and neck regions. Studies show that healthcare personnel who use such equipment for long periods of time may experience chronic pain, disc herniation and spinal deformities [10,14]. Therefore, the development of lightweight versions of lead equipment and the use of designs that provide balanced weight distribution are of great importance.

Physical Effects of Long-Term Exposure: During interventional radiology procedures, personnel are often forced to work in a standing and fixed position for several hours. Repetitive movements during this process can lead to muscle fatigue and circulatory disorders caused by static posture. At the same time, these fixed positions can also reduce the effectiveness of positional protection against radiation. For example, when workers are positioned

closer to the X-ray tube, they may be exposed to more radiation dose. In this context, a non-ergonomic posture contributes not only to physical fatigue but also to increased radiation risk [8].

Contribution of Equipment Placement and Ergonomic Optimization to Radiation Safety: Ergonomically optimized work areas offer advantages not only in terms of musculoskeletal health but also in terms of radiation safety. For example, placing viewing screens at the appropriate height and angle reduces the load on the operator's head and neck area, while ceiling-mounted screen systems facilitate flexible and safe positioning in the field. Similarly, effective placement of mobile lead barriers reduces exposure by increasing the distance between the worker and the radiation source. In addition, equipment such as adjustable-height tables, monitor arms and supportive shoes support ergonomics and safety together [2].

The contribution of ergonomic optimization to radiation safety can be made more effective, especially with staff awareness and training programs. Knowing which postures result in less radiation and which equipment placement contributes to physical load allows healthcare professionals to make more informed choices in daily practice [12].

7. Existing Guidelines, Standards and Good Practice Examples

Many national and international guidelines have been developed to reduce radiation risks and ergonomic difficulties to which healthcare professionals working in the field of interventional radiology are exposed. These guidelines set minimum standards in both radiation safety and ergonomics and provide examples of good practice. In this section, the basic contents of these guidelines will be summarized, evaluated with examples from clinical practice, and the importance of these documents for practitioners will be emphasized.

7.1 Overview of International Guidelines

Organizations such as the International Atomic Energy Agency (IAEA), the World Health Organization (WHO) and the International Commission on Radiological Protection (ICRP) provide leading guidelines on limiting medical radiation exposure and ensuring personnel safety. ICRP Report No. 103 (2007) is based on the basic radiation protection principles of "justification", "optimization" and "dose limitation". These principles aim to minimize exposure for both patients and personnel in interventional radiology [4]. Within the scope of the “Radiation Protection of Patients” program published by the IAEA, there are technical and organizational recommendations for the protection of operators, especially during interventional procedures [5]. At the same time, the EURATOM Directives (2013/59/EURATOM), which are in force in Europe, regulate the mandatory practices regarding the safe use of medical radiation.

7.2 National Standards and Clinical Protocols

In Turkey, the Turkish Atomic Energy Authority (TAEK) has put into effect the regulations and guidelines regulating the radiation exposure of healthcare professionals. However, studies in the domestic literature also reveal various deficiencies in the knowledge and practice levels of individuals working or receiving education in the field of healthcare services regarding radiation safety. In their study conducted on healthcare vocational school students, Soyal and Sarıhan (2024) emphasized that measurements made with the use of dosimeters can be effective in increasing the radiation safety awareness of students. Some university hospitals provide examples of good practice by developing training modules that include both ergonomics and radiation safety [13]. For example, in surgical and interventional units, practices such as proper storage of lead aprons, ergonomic monitor placement, and routine use of protective barriers have become standard [15].

7.3 Examples from Clinical Practices

In some examples abroad, the establishment of multidisciplinary teams that address ergonomics and radiation safety together is noteworthy. For example, in the USA, the interventional radiology department at Massachusetts General Hospital developed specially adapted protection solutions for personnel by performing ergonomic analyses and radiation exposure measurements in collaboration with biomedical engineers [2].

In addition, in some interventional clinics in Japan, radiation exposure to workers is monitored live throughout the procedure with "real-time dosimetry systems", which reduces exposure by causing behavioral changes [9].

7.4 Implementation and Sustainability

The effectiveness of the guidelines is possible not only with the existence of written rules, but also with the applicability of these rules in the field and the awareness of healthcare workers. Continuity of training, administrative support and follow-up of technological innovations directly affect the effectiveness of these standards. Therefore, it is essential that implementing institutions not only comply with the regulations, but also adopt an ergonomics and radiation safety culture at the institutional level.

4. Conclusions

Interventional radiology, while offering advanced diagnostic and therapeutic opportunities, also poses serious ergonomic and radiation-related risks for healthcare professionals. This review study focuses on the intersection of these two important risk areas and evaluates the current situation in the field from a multidimensional perspective. The findings reveal that improving ergonomic conditions not only reduces musculoskeletal problems but also indirectly positively affects radiation safety. Protective equipment design should be improved ergonomically; work areas should be rearranged in accordance with ergonomic principles. Ergonomics and radiation safety training should be combined, exposure should be monitored with real-time dosimeter systems, and this should be sustained through systematic, multidisciplinary teamwork. The implementation of these recommendations will not only increase employee safety; it will also directly positively affect the efficiency, quality, and patient safety of interventional radiology procedures.

Author Statements:

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