Systematic Review

Radiation Exposure in Interventional Pain Management Physicians: A Systematic Review of the Current Literature

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Background: Millions of interventional pain procedures are performed each year to address chronic pain. The increase in these procedures also raises the concern of health risks associated with ionizing radiation for interventional pain management physicians who perform fluoroscopy-guided operations. Some health concerns include cancers, cataracts, and even pregnancy abnormalities. Little is known regarding the long-term and cumulative effects of small radiation doses.

Objectives: The objective of this systematic review was to identify common body parts that are exposed to ionizing radiation during interventional pain procedures and examine methods to help physicians reduce their radiation exposure.

Study Design: The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) checklist was used to comprehensively identify articles from 2 medical databases. The radiation dose to interventional pain management physicians obtained from relevant peer-reviewed articles were aggregated and used for analysis.

Methods: PubMed was first used to collect the articles for two broad keyword searches of "radiation exposure pain management" and "radiation exposure interventionalist" with years ranging from 1956 – February 2023. EMBASE was also used to collect the articles for the two keyword searches of "radiation exposure pain management" and "radiation exposure interventionalist" with years ranging from 1969 – February 2023. This systematic approach yielded a total of 2,736 articles; 24 were included in our paper. The risk of bias for these articles was performed using the Cochrane Risk of Bias tool and the National Institutes of Health tool.

Results: Through our systematic literature search, more than 3,577 patients were treated by 30 interventional pain management physicians. Some areas of exposure to radiation include the physician's neck, chest, groin, hands, and eyes. One common body region that is exposed to radiation is the chest; our review found that wearing lead aprons can lower the radiation dose by more than 95%. Wearing protective equipment and managing the distance between the operator and fluoroscope can both independently lower the radiation dose by more than 90% as well. Our literature review also found that other body parts that are often overlooked in regard to radiation exposure are the eyes and hands. In our study, the radiation dose to the outside (unprotected) chest ranged from 0.008 ± 27 mrem to 1,345 mrem, the outside neck ranged from 572 mrem to 2,032 mrem, the outside groin ranged from 176 mrem to 1,292 mrem, the hands ranged from 0.006 ± 27.4 mrem to 0.114 ± 269 mrem, and the eyes ranged from 40 mrem to 369 mrem. When protective equipment was worn, the radiation exposure to the inside chest ranged from 0 mrem to 108 mrem, the inside neck ranged from 0 mrem to 68 mrem, and the inside groin ranged from 0 mrem to 15 mrem.

Limitations: Limitations of this study include its small sample size; only the radiation exposure of 30 interventional pain management physicians were examined. Furthermore, this review mainly consisted of observational studies rather than randomized clinical trials.

Conclusion: Implementing safety precautions, such as wearing protective gear, providing educational programs, and keeping a safe distance, demonstrated a significant decrease in radiation exposure. The experience of interventional pain management physicians also factored into their radiation exposure during procedures. Radiation is a known carcinogen, and more research is needed to better understand its risk to interventional pain management physicians.

Key words: Chronic pain management, radiation exposure, fluoroscopy, anesthesiology, nerve blocks, x-ray, ultrasound

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Chronic pain is a persistent problem that affects over 100 million Americans annually; it is believed that the prevalence of this medical condition may be as high as 34.5% in the United States (1). To tackle this problem, millions of interventional pain management procedures are performed each year, with more than half of them being guided under fluoroscopy (2). C-arm fluoroscopy is frequently used to ensure precise and safe needle or probe positioning in pain management procedures, especially when they involve anatomical positions that may be hard to visualize with the naked eye or ultrasound (3). Despite the effectiveness of fluoroscopy-guided procedures in interventional pain management, physician health is at risk due to exposure to radiation emitted during the procedure. Even though the radiation doses that pain interventionalists experience during each procedure may be negligible, the gradual accumulation of these exposures may lead to more severe health consequences.

Previous studies have shown increased health risks for physicians who perform procedures under fluoroscopy. In 1994, the US Food and Drug Administration released statements issuing precautions concerning skin burn vulnerabilities for patients, health care staff, and doctors who are exposed to radiation (4). Roguin, et al (5), found that 85% of interventionalists with head and neck malignancies had left-sided lesionsto their brain; many of them operated with the left side of their heads toward the C-arm fluoroscopy machine (5). Other health risks include disproportionate cataract development in providers who are exposed to ionizing radiation (6). As a result, pain management interventionalists must take safety precautions when performing epidural steroid injections, radiation frequency ablation, and other procedures that require fluoroscopic guidance.

The radiation that pain management interventionalists experience when using C-arm fluoroscopy involves primary, scattered, and leakage x-ray beams (3). Of the 3, interventional pain management physicians are most vulnerable to scattered radiation, which are the x-ray beams that bounce off the patients, tables, and rooms during a procedure (7). To minimize radiation exposure, it is advised to wear protective equipment, attend training courses, and implement pulsed fluoroscopy instead of live imaging (8,9). Many studies have been conducted on the radiation exposure of cardiologists, radiologists, and orthopedic surgeons. There has been little published literature on radiation exposure for interventional pain management physicians. Our study aimed to examine the different levels of radiation exposure for various interventional pain management procedures and evaluate methods to reduce this exposure in the clinical setting.

Methods

Study Design

In order to obtain articles for this review, the systematic literature Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) review model was used (10). A comprehensive search of the PubMed (MEDLINE) and Excerpta Medica (EMBASE) databases was employed to execute this study. The search was restricted to English language articles.

Articles were selected for inclusion based on relevance following 5 eliminatory screens per the PRISMA methodology guidelines, including physicians who practice and are board-certified in pain medicine. These physicians should perform pain management procedures under the guidance of fluoroscopy and other equipment that may expose them to ionizing radiation. Additional exclusions included physicians who were not board-certified in pain medicine such as internists, general surgeons, cardiologists, etc. The research studies chosen focused on the radiation exposure of the operators and not solely on the dose received by patients.

Lastly, these articles were selected only if they had been peer-reviewed and published. The database searches on EMBASE consisted of using a broad keyword search with the phrases "radiation exposure pain management" yielding a total of 1,947 results from years 1969 – February 2023 and "radiation exposure interventionalist" yielding a total of 107 results from years 1984 – February 2023. PubMed (MEDLINE) search results for "radiation exposure pain management" yielded a total of 566 results from the years 1956 – February 2023 and "radiation exposure interventionist" yielding a total of 116 results from years 1999 – February 2023. The criteria for inclusion and exclusion are shown in Fig.1.

This systematic review is registered in PROSPERO. Its registration number is CRD42023394811. The protocol and data are available upon request.

Study Selection

Step 1 screened articles based on the relevance of their titles (Fig. 1, Step 1). Step 2 removed duplicate studies (Fig. 1, Step 2). The remaining articles were then screened for relevance in Step 3 based on their abstracts (Fig. 1, Step 3). Step 4 involved reading the entire article to determine its applicability for use in our study (Fig. 1, Step 4). Step 5 excluded papers that did not discuss radiation exposure of interventional pain management physicians. This process yielded qualitative information that amounted to a total of 24 relevant articles. The qualitative articles were used to compose the systematic literature review. Relevant studies are listed in Table 1. Three researchers carried out the procedures to obtain the final sample. The investigation team agreed on the final selection of the literature.

After selecting the final articles, the manuscripts were then divided into their topics of assessment. The main categories included the various factors that may increase or decrease radiation exposure, such as protective gear, work experience, coaching/education, and the types of procedures that pain interventionalists perform. Out of the 24 qualitative articles, 12 directly measured the radiation exposure of physicians during procedures while the other 12 reported on surveys and gave suggestions on how to reduce radiation exposure.

Study Screening

The broad search phrases used to gather relevant studies for our systematic literature review yielded a total of 173 articles with relevant titles, 47 of which were

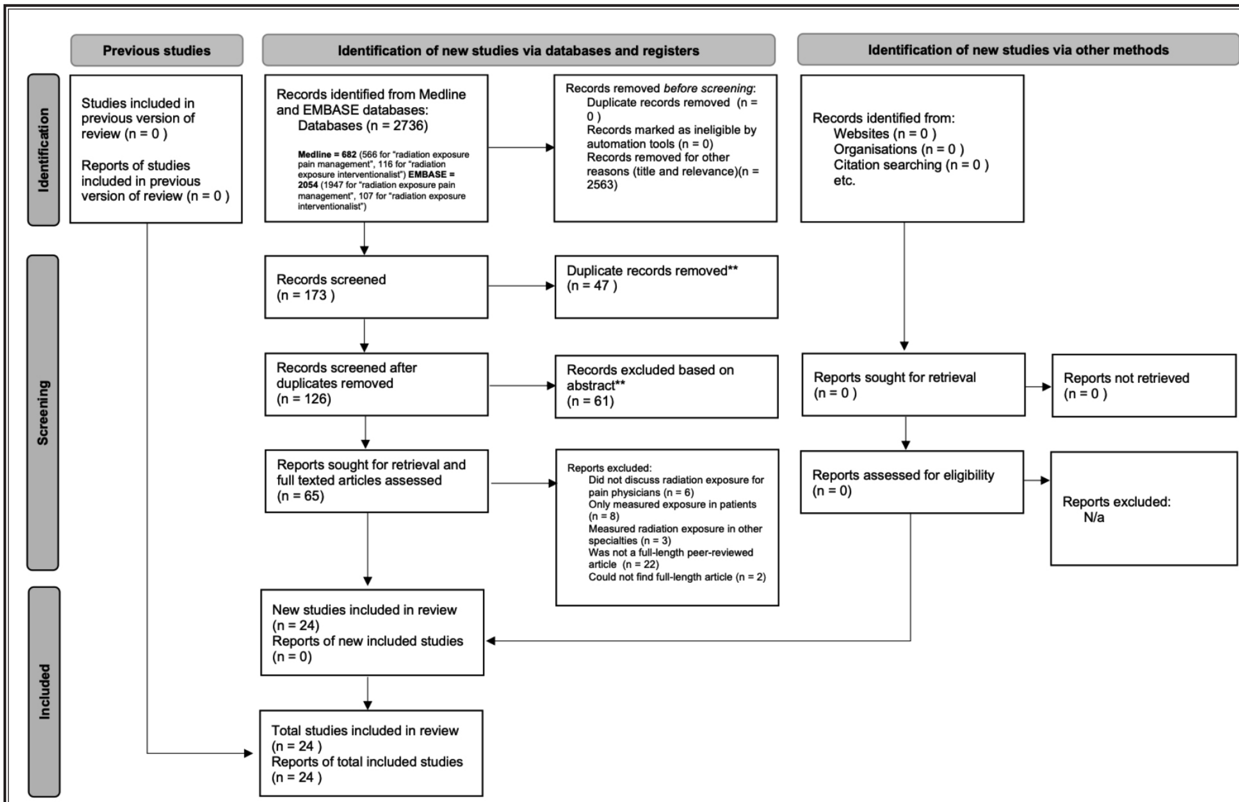

Fig. 1. *Study flow chart.*

Table 1. *Systematic literature final study selection.*

Article	Study Type	Year	Country	Types of Procedures	Key Findings	Risk-of-Bias Assessment
Baek, et al (24)	Randomized controlled study	2012	Republic of Korea	Medial Branch Block	Evaluated radiation exposure of physicians performing collimation fluoroscopy	Good
Botwin, et al (25)	Prospective observational study	2003	United States	Lumbar discography	Fluoroscopy time and exposure was measured in 4 pain physicians performing lumbar discograms	Good
Botwin, et al (8)	Prospective observational study	2002	United States	Transforaminal epidural joint injections	Measured radiation exposure of physicians performing transforaminal epidural joint injections	Good
Botwin, et al (26)	Prospective observational study	2001	United States	Caudal epidural joint injections	Radiation exposure of physicians performing fluoroscopy-guided epidural joint injections	Good
Broadman, et al (37)	Literature review	2004	United States	Multiple procedures	Shared the most effective way to reduce radiation exposure, such as magnification, distance, shielding, etc	N/A
Cheon, et al (21)	Literature review	2005	Republic of Korea	Multiple procedures	Gave suggestion on the various sources of radiation in pain procedures and ways to lower radiation exposure.	N/A
Dietrich, et al (27)	Prospective observational study	2019	Switzerland	Facet joint injections or transforaminal epidural injections	Compared radiation exposure of interventionalists under CT-guided or fluoroscopy-guided steroid injections	Good
Hofmeister, et al (39)	Systematic review	2019	Canada	Fluoroscopy and ultrasound guided injections	Compared the efficacy of fluoroscopy vs ultrasound guided injections, where it discussed the radiation differences in the 2 methods as well	N/A
Kelly, et al (30)	Prospective observational study	2018	Ireland	Various procedures to the Cervical, thoracic, lumbar, sacroiliac, and facet joint regions	Ocular radiation exposure was measured in three pain physicians in real time and found that the doses were below the recommended guidelines	Good
Kim, et al (22)	Retrospective observational study	2010	Republic of Korea	Epidural blocks, epidurograms, medial branch blocks, etc.	Radiation exposure was measured in an operator and an assistant at a single medical center and found that radiation was higher in unprotected parts	Good
Kim, et al (36)	Survey questionnaire	2017	Republic of Korea	Multiple procedures	Pain physicians were found to lack knowledge of radiation safety. The number of physicians receiving radiation safety education was found to be low.	Good
Komiya, et al (29)	Prospective observational study	2008	Japan	Epiduroscopy	Radiation time and dose was measured in a humanoid model of pain physicians and patients	Fair
Manchikanti, et al (28)	Prospective observational study	2002	United States	Intercostal, ganglion, lumbar sympathetic, etc. (Varied)	Radiation exposure and time were in patients undergoing multiple procedures as well as the exposure in the one pain physician performing all of these procedures	Good

Table 1 cont. *Systematic literature final study selection.*

Article	Study Type	Year	Country	Types of Procedures	Key Findings	Risk-of-Bias Assessment
Manchikanti, et al (23)	Prospective observational study	2003	United States	Facet nerve blocks, transforaminal, and epidurals	Radiation exposure in a non-university setting was compared in a group with a group from previous year	Good
Manchikanti, et al (4)	Prospective observational study	2003	United States	Joint nerve blocks, transforaminal epidural, joint injections, etc.	3 interventional pain physicians wore dosimeters that measure upper body, as well as lower body radiation exposure	Good
Plastaras, et al (31)	Retrospective observational study	2013	United States	Epidural injections, medial branch blocks, joint injections, etc	Measured radiation reduction before and after changes were made to equipment and procedure techniques	Fair
Park, et al (14)	Literature review	2022	Republic of Korea	Multiple procedures	Different types of radiation were explained as well as recommendations to reduce radiation exposure	N/A
Pitcher, et al (35)	Observational study	2010	United States	Various interventional pain procedures	The radiation exposure of staff in a pain clinic was lowered after a peer training program was implemented on the safe use of fluoroscopy and radiation protection	Good
Provenzano, et al (9)	Survey questionnaire	2019	United States	Multiple procedures	The surveyed revealed that the understanding of radiation safety by pain physicians is low despite many of them conveying health concerns for it	N/A
Slegers, et al (7)	Retrospective observational study	2015	Netherlands	Nerve blocks (lumbar, head, neck, pelvis, etc) and epiduroscopy, nucleoplasty, neuromodulation	Active feedback from the dosimeter and coaching decreased scatter radiation experienced by the pain interventionalist	Good
Theilig, et al (33)	Retrospective observational study	2020	Germany	Periradicular therapy	Compared radiation dose in CT-guided procedures performed by male and female interventionalists	Good
Wininger (34)	Retrospective observational study	2012	United States	Percutaneous spinal cord stimulation	Fluoroscopy time and radiation skin exposure was measured in novice and advanced physicians performing percutaneous spinal cord stimulation	Good
Wininger, et al (40)	Retrospective observational study	2010	United States	Percutaneous spinal cord mapping	Fluoroscopy time was measured in one interventionalist who treated 110 patients using spinal cord stimulation trialing procedures	Good
Zhou, et al (2)	Retrospective observational study	2005	United States	Facet joint blocks, epidural joint injections, lumbar discography, etc	Radiation exposure was measured in 7 physicians and in the various types of interventional in a university hospital. Radiation is higher in university settings than private practice.	Fair

removed due to their being duplicates. The remaining 126 studies were screened and 61 of them were removed based on their abstracts. Finally, 40 papers were excluded after the full text was analyzed, generating 24 manuscripts for our study. Reasons for the exclusion of articles during abstract and full-text screening include, but are not limited to, articles pertaining to radiation exposure of patients but not physicians, articles focusing on specialties not relevant to interventional pain management, articles written in a language other than English, and not being completely published peer-reviewed articles.

Quality Assessment and Data Abstraction

In order to assess quality and bias within the randomized clinical trials that were identified for use in this study, the Cochrane risk-of-bias tool was used to classify each trial as having "high," "medium," or "low" bias across 6 domains (11) (Fig. 2).

Bias assessment was made on each article reviewed, including the randomization method, deviation from the intended intervention, missing outcome data, the outcome measure, and selection of the reported results. Each assessment was done at the study level, where 3 independent reviewers assessed the risk of bias in each article. A fourth senior reviewer double-checked their assessments and helped resolve any disagreements that arose (11).

In order to assess the quality and bias of the observational and case series studies, we used the recommended National Institute of Health recommended tool used to assess for quality (12) (Table 2). The assessment of the quality of these trials is available in Table 3. The study quality assessment tool provided by the National Institute of Health consists of 14 questions that evaluate the credibility of studies. The score that is received from this survey determines the quality of the study, with a score between 11-14 being good, 7-10 being fair, and 0-6 being poor (12).

Study Quality

Ten articles used were labeled good quality and 8 were labeled fair quality according to the Cochrane risk-of-bias tool and the National Institutes of Health tool (11,12). The risk-of-bias assessment was not applied to 6 of the manuscripts because they were either literature reviews or surveys on interventional pain management;. they did not specifically measure radiation exposure or fluoroscopy time.

Ionizing Radiation and Definitions

The 2 main types of radiation are ionizing radiation (e.g., x-ray machines or radioactive substances) and nonionizing radiation (microwaves, radio waves, visible light) (13). The main difference between the 2 is that ionizing radiation has enough energy to ionize atoms by stripping away electrons while nonionizing radiation does not have enough energy to participate in this reaction (13).

Ionizing radiation is frequently used in the medical setting to assist in diagnosing and treating diseases. It is believed that over 3.6 billion diagnostic radiology tests are performed each year (13). Physicians may experience radiation in many ways during medical procedures that use x-rays, computed tomography (CT) scans, magnetic resonance imaging, nuclear imaging, and other imaging modalities. For interventional pain management, physicians often use fluoroscopy to guide their procedures, which in turn exposes them to 3 main types of ionizing radiation exposure (14). The first type is primary x-ray, which occurs when the beams from the x-ray directly make contact with the physician's body or extremities.

Fig. 2. *Cochrane risk-of-bias tool for randomized control trials assessment.*

Table 2. *Quality Assessment Tool for clinical case series.*

Criteria	Yes	No	Other (CD, NR, NA)*
1. Was the research question or objective in this paper clearly stated?			
2. Was the study population clearly specified and defined?			
3. Was the participation rate of eligible persons at least 50%?			
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?			
5. Was a sample size justification, power description, or variance and effect estimates provided?			
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?			
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?			
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?			
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?			
10. Was the exposure(s) assessed more than once over time?			
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?			
12. Were the outcome assessors blinded to the exposure status of participants?			
13. Was loss to follow-up after baseline 20% or less?			
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?			

(https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). *CD, cannot determine; NA, not applicable; NR, not reported.

The second type is scatter x-ray. This form contributes to most of the radiation that interventional pain management physicians experience. The x-ray beams first make contact with the patient and lose energy, where they then deflect and scatter throughout the room. The last form is leakage x-ray, which typically occurs when defective equipment causes the beams to leak out of the machine and head in an unintended direction (14).

Radiation exposure can be quantified in terms of absorbed dose and dose equivalent (15). The absorbed dose is the amount of energy that is transferred from the ionizing beams to tissues, whereas the dose equivalent takes into account the biological effects of tissues along with the amount of energy absorbed (15). The main units recognized by the International Commission on Radiological Protection is the gray (Gy) for absorbed dose and the sievert (Sv) or roentgen equivalents man (rem) for dose equivalent (1 Sv = 100 rem) (15,16).

Dosimeters are used to measure the absorbed dose and dose equivalent during operations; the ICRP recommends that at least 2 of these devices should be worn by providers in the operating room (15). Regulations are set to protect medical staff from prolonged radiation exposure throughout the year. The National Council on Radiation Protection and Measurements recommends that the annual maximum dose limit for physicians should be 500 mSv (50,000 mrem) for the thyroid, 500 mSv (50,000 mrem) for the extremities, 500 mSv (50,000 mrem) for the gonads, 50 mSv for the lens (5000 mrem), 50 mSv (5000 mrem) for the whole body, and 5 mSv (500 mrem) for pregnant individuals (14).

Physicians are susceptible to several health risks due to radiation exposure. Immediate reactions to dangerous amounts of radiation can cause skin burns, hair loss, vomiting, and nausea (13). More serious diseases may arise due to long-term exposure to radiation, such as thyroid malignancy, breast cancer, and leukemia (17,18). These adverse effects are attributed to ionizing radiation leading to DNA injury, impaired immune response, and excessive production of reactive oxygen species (17).

The exact effects of low radiation exposure and its direct harm on human health is relatively unknown. Some studies have suggested that low radiation dose may lead to statistically significant increased risk for certain cancers (19-21). Pediatric patients who received a mean total thyroid dose of 50 mSv -100 mSv (5000

Table 3. *Quality assessment of case series using the National Institutes of Health tool.*

Author	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Final Quality Score	Rating
Botwin, et al (25)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	12	Good
Botwin, et al (8)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N	12	Good
Botwin, et al (26)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N	10	Fair
Dietrich, et al (27)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N	10	Fair
Kelly, et al (30)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N	10	Fair
Kim, et al (22)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N	10	Fair
Komiya, et al (29)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N	10	Fair
Manchikanti, et al (28)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	Y	11	Good
Manchikanti, et al (23)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	Y	11	Good
Manchikanti, et al (4)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	Y	11	Good
Plastaras, et al (31)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N	10	Fair
Pitcher, et al (35)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N	10	Fair
Slegers, et al (7)	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	12	Good
Theilig, et al (33)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N	11	Good
Wininger, et al (40)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N	11	Good
Wininger (34)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	12	Good
Zhou, et al (35)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	Y	N	10	Fair

Y: yes; N: no.

Q1: Was the research question or objective in this paper clearly stated? Q2: Was the study population clearly specified and defined? Q3: Was the participation rate of eligible persons at least 50%? Q4: Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants? Q5: Was a sample size justification, power description, or variance and effect estimates provided? Q6: For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured? Q7: Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?Q8: For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)? Q9: Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants? Q10: Was the exposure(s) assessed more than once over time? Q11: Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants? Q12: Were the outcome assessors blinded to the exposure status of participants? Q13: Was loss to follow-up after baseline 20% or less? Q14: Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?

Quality score of 11-14 = Good, Quality score of 7-10 = Fair, Quality score of 0-6 = Poor

mrem - 10,000 mrem) were more likely to get a thyroid cancer diagnosis than those who never received radiation (19). Other studies have suggested that there is some cancer correlation in those who are exposed to 10 mSv – 100 mSv (1000 mrem - 10,000 mrem), where 1000 mSv (100,000 mrem) may lead to a 5% cancer risk in a person's lifetime (20). Cheon, et al (21) shared in their review article that an accumulation of 65 μSv (6.5 mrem) per procedure elevates the likelihood of thyroid cancer development over time. It is also important to note that as individuals age, their likelihood of developing thyroid malignancy caused by radiation exposure diminishes (21). For comparison, there is background radiation of 3 mSv (300 mrem) every year (15).

Results

Study Characteristics

Of the 24 articles that discussed radiation exposure over time, 12 directly measured radiation exposure with (Table 4). These 12 articles reported on 32 interventional pain management physicians who performed more than 7,590 procedures on more than 3,577 patients. These studies include retrospective and prospective observational studies as well as randomized controlled trials. They all suggest a common theme, which is the idea that precautions, such as protective equipment and personnel training, can reduce radiation exposure.

Neck Radiation Exposure

One common area of radiation exposure during interventional pain management procedures is at the operator's neck (Table 4). Kim, et al (22) conducted a retrospective observational study over a 3-month period on an interventional pain management fellow and a resident who performed 505 procedures, including medial branch blocks, epidurograms, lumbar sympathetic nerve blocks, and others. Of the 3 body parts that they measured using a dosimeter, they found that the estimated annual radiation dose to the unprotected neck was 2,032 mrem and 572 mrem for the fellow and resident respectively (22). Manchikanti, et al (4) conducted a prospective observational study that measured radiation exposure in 3 physicians with varying levels of work experience over a 3-month period. Dosimeters were placed over the thyroid region and under their lead aprons. Radiation exposure inside the neck was 68, 25, and 0 mrem for physicians with less than 2 years of experience (Group 1), 2-5 years of experience (Group 2), and over 5 years of experience (Group 3) respectively (4).

Chest Radiation Exposure

he chest is another area of the physician's body that is frequently exposed to ionizing radiation (Table 4). Many articles have measured the radiation exposure outside and inside the lead apron in order to evaluate the effectiveness of protective equipment. Manchikanti, et al (23) conducted an observational study at a private pain management practice that compared the radiation exposure of one interventional pain management physician under 2 different conditions: without extra lower body protection (Group 1) and with extra lower body protection (Group 2). The study found that Group 1 had scatter radiation of 690 mrem to the outside of the protected chest. This equates to 0.834 mrem per procedure. The radiation to the outside of the chest apron in Group 2 was 313 mrem, which equates to 0.362 mrem per procure.

Manchikanti, et al (4) studied radiation exposure to interventional pain management physicians with different years of experience. Group 1 encompassed providers with fewer than 2 years of work experience, Group 2 encompassed providers with 2-5 years of work experience, and Group 3 encompassed of providers with over 5 years of experience (4). The study found that the scatter radiation exposure outside of the chest was 510 mrem for Group 1, 535 mrem for Group 2, and 690 mrem for Group 3. Baek, et al (24) investigated the effects of collimation in medial branch blocks on radiation exposure and reported that the 3 physicians in the collimation group experienced an average dose of 50 ± 70 mrem (100 ± 90 mrem in the control group) outside of the protected left chest. Botwin, et al (25) reported that an interventional pain management physician who completed 106 lumbar discographies experienced a scatter radiation dose of 251 mrem outside the lead apron. Botwin, et al, (26) reported a measurement of 398 mrem in an interventional pain management physician who performed 100 caudal epidural steroid injections. Botwin, et al (8) measured the radiation exposure outside of the chest apron to be 30 mrem in physicians who performed 100 lumbar transforaminal epidural steroid injections (8). Dietrich, et al (27) compared radiation exposure in CT-guided versus fluoroscopy-guided lumbar steroid injections and discovered that radiation exposure to the body was 0.042 ± 99 mrem for fluoroscopy-guided lumbar transforaminal epidural injections, 0.038 ± 110 mrem for fluoroscopy-guided lumbar facet joint steroid injections, 0.011 ± 44 mrem for CT-guided lumbar transforaminal epidural injections, and 0.046 ± 93 mrem for CT-guided lumbar facet joint steroid injections. Overall, there was more exposure to the chest in fluoroscopy-guided procedures compared to CT-guided operations (27). Manchikanti, et al (28) measured the exposure of interventional pain management physicians who performed 1,729 procedures, ranging from cervical facet joint nerve blocks to medial branch neurotomy. The exposure to the outside of the chest apron was 1,345 mrem (28). Komyia, et al (29) conducted a unique study where humanoid models were used to detect the radiation dose of physicians in epiduroscopy. They found that in 10 minutes of fluoroscopy exposure, the outside chest apron exposure to one physician was 67 mrem (0.67 mGy) and to another physician was 33 mrem (0.33 mGy) (29).

Some of the articles measured the radiation exposure inside of the chest leaded aprons as well. They reported that radiation was lower inside the leaded chest apron. Manchikanti, et al (23) found no radiation exposure inside the leaded chest apron for physicians in Group 2. Kim, et al (22) compared the radiation exposure between a resident (assistant) and a fellow (operator); their radiation exposureunderneath the apron was only 82 mrem and 108 mrem respectively. Botwin, et al (25) measured chest radiation exposure underneath the apron at 19 mrem; Botwin et al (8) measured chest radiation exposure underneath the apron at 0

Table 4. *Radiation exposure (dose equivalent) measured with dosimeters during interventional pain procedure.*

Author/Year	Procedures	Unit	Number of Physicians	Number of Patients	Number of Procedures	Neck (Outside)	Neck (Inside)	Chest (outside)	Chest (Inside)	Groin (Outside)	Groin (Inside)	Hands	Eyes
Baek, et al (24)	Control Group - medial branch block	mrem	3	30	62	NA	NA	100 ± 90	NA	NA	NA	NA	NA
	Collimation Group - medial branch block	mrem		32		NA	NA	50 ± 70	NA	NA	NA	NA	NA
Botwin, et al (26)	Procedures for radicular pain from lumbar spinal stenosis and herniated nucleus pulposus	mrem		100	100	NA	NA	398	15	NA	NA	410	247
Botwin, et al (25)	Discogram	mrem	1	37	106	NA	NA	251	19	NA	NA	390	NA
Botwin, et al (8)	Transforaminal epidural steroid injection	mrem	6		100	NA	NA	30	0	NA	NA	70	40
Dietrich, et al (27)	Fluoroscopy lumbar transforaminal epidural injection	mrem	8	55	199	NA	NA	0.042 ± 99	NA	NA	NA	0.144 ± 269	NA
	CT lumbar transforaminal epidural injection			70		NA	NA	0.011 ± 44	NA	NA	NA	0.014 ± 55	NA
	Fluoroscopy lumbar facet joint steroid injection			24		NA	NA	0.038 ± 110	NA	NA	NA	0.046 ± 93	NA
	CT lumbar facet joint steroid injection			50		NA	NA	0.008 ± 27	NA	NA	NA	0.006 ± 27.4	NA

Table 4 cont. *Radiation exposure (dose equivalent) measured with dosimeters during interventional pain procedure.*

Author/Year	Procedures	Unit	Number of Physicians	Number of Patients	Number of Procedures	Neck (Outside)	Neck (Inside)	Chest (outside)	Chest (Inside)	Groin (Outside)	Groin (Inside)	Hands	Eyes
Kelly, et al (30)	Consultant 1 - multiple types of nerve blocks and procedures	mrem	3		682	NA	NA	NA	NA	NA	NA	NA	369
	Consultant 2 - multiple types of nerve blocks and procedures					NA	NA	NA	NA	NA	NA	NA	351
	Consultant 3 - multiple types of nerve blocks and procedures					NA	NA	NA	NA	NA	NA	NA	99
Kim, et al (22)	Assistant (Resident) - lumbar transforaminal epidural blocks, epidurograms, etc	mrem	2		505	572	NA	NA	82	504	NA	NA	NA
	Operator (Fellow) - lumbar transforaminal epidural blocks, epidurograms, etc					2032	NA	NA	108	1292	NA	NA	NA
Komiya, et al (29)	Dr. A - epiduroscopy	mrem	2	14		NA	NA	67	0.84	NA	NA	NA	NA
	Dr. B - epiduroscopy					NA	NA	33	0.4	NA	NA	NA	NA
Manchikanti, et al (28)	Multiple types of nerve blocks, from intercostal to ganglion blocks	mrem	1	1000	1729	NA	NA	1345	0	NA	NA	NA	NA

Table 4 cont *Radiation exposure (dose equivalent) measured with dosimeters during interventional pain procedure.*

Author/Year	Procedures	Unit	Number of Physicians	Number of Patients	Number of Procedures	Neck (Outside)	Neck (Inside)	Chest (outside)	Chest (Inside)	Groin (Outside)	Groin (Inside)	Hands	Eyes
Manchikanti, et al (4)	Group 1 - Multiple types of nerve blocks and procedures	mrem	3	1156	1819	NA	68	510	NA	1260	0	NA	NA
	Group 2 - Multiple types of nerve blocks and procedures					NA	25	535	NA	400	0	NA	NA
	Group 3 - Multiple types of nerve blocks and procedures					NA	0	690	NA	1152	15	NA	NA
Manchikanti, et al (23)	Group I Multiple Types of nerve blocks	mrem	1	509	827	NA	0	690	NA	1152	15	NA	NA
	Group II Multiple types of nerve blocks			500	865	NA	0	313	0	176	13	NA	NA
Slegers, et al (7)	Blind - Multiple types of nerve blocks	mrem	3		596	NA	NA	265	NA	NA	NA	NA	NA
	Open - Multiple types of nerve blocks					NA	NA	264	NA	NA	NA	NA	NA
	Open coaching - Multiple types of nerve blocks					NA	NA	120	NA	NA	NA	NA	NA
						NA	NA	NA	NA	NA	NA	NA	NA
						NA	NA	NA	NA	NA	NA	NA	NA

mrem; and Botwin (26) measured chest radiation exposure underneath the apron at 15 mrem. Manchikanti, et al (28) also reported no radiation exposure under the apron in physicians performing facet joint nerve blocks, transforaminal epidural injections, interlaminar epidural injections, and other procedures. Lastly, in 2008, Komiya, et al (29) examined the chest exposure underneath the apron of 2 humanoid models simulating interventional pain management physicians. They found that radiation exposure under the apron was 0.84 mrem (0.0084 mGy) and 0.40 mrem (0.004 mGy) respectively (29). These articles suggest that with leaded protection, radiation exposure inside the aprons was significantly lower than outside the apron.

Groin Radiation Exposure

Although often overlooked, radiation exposure to the groin during interventional pain management procedures is still problematic (Table 4). Previous articles have mentioned that 200,000 mrem (2 Gy) is the limit for infertility, which equates to around 1,000 minutes of fluoroscopy (29). Other articles have suggested that methods to lessen radiation exposure to the upper body do not necessarily work in reducing exposure to the lower body. Manchikanti, et al (4) reported that the radiation exposure outside of the groin parment was 1,260 mrem, 400 mrem, and 1,152 mrem for Groups 1, 2, and 3 respectively. The radiation exposure under the groin garment for these 3 groups were 0 mrem, 0 mrem, and 15 mrem; this highlights the importance of leaded protection for the lower body (4). These groups represented providers with different levels of experience, with Group 3 having physicians with the most years of work experience.

Similarly, Manchikanti, et al (23) measured the radiation exposure outside of the groin garment in Groups 1 and 2, with the measurements being 1,152 mrem and 176 mrem respectively. The radiation exposure under the groin garment was 15 mrem and 13 mrem. Group 1 did not have lead protection from the operating table to the ground whereas Group 2 had lead protection from the operating table to the ground. Because Group 2 had extra lower body protection, the radiation exposure to the outside groin garment was significantly lower even though the inside of the groin garment measurement was quite similar (23). Kim, et al (22) also measured groin radiation exposure of an operator (fellow) and assistant (resident). The dosimeter was placed over the physicians' legs, where the outside of the groin apron was 1,292 mrem and 504 mrem for the operator and assistant respectively (22).

Hand Radiation Exposure

Hands are another commonly exposed body part during interventional pain management procedures that require fluoroscopy, CT, or other imaging modalities (Table 4). Using a dosimeter ring badge, in 2003 Botwin, et al (25) measured the hand radiation exposure of a physician performing lumbar discography to be 390 mrem or 3.66 mrem per procedure. Botwin, et al (8) examined the exposure of interventional pain management physicians performing lumbar transforaminal epidural steroid joint injections, measuring overall hand exposure to be 70 mrem. Botwin, et al (26) reported that the hand exposure of physicians performing caudal epidural steroid injection under fluoroscopy was 410 mrem. Dietrich, et al (27) found that fluoroscopy-guided lumbar transforaminal epidural and facet joint steroid injections yielded 0.144 ± 269 mrem and 0.046 ± 93 mrem to the wrist respectively. CT- guided lumbar transforaminal epidural and facet joint steroid injections yielded 0.014 ± 55 mrem and 0.006 ± 27.4 mrem respectively.

Eye Radiation Exposure

The eyes are one of the more sensitive organs to radiation exposure. Long-term radiation exposure to them can lead to cataract formation (30) (Table 4). Botwin, et al (8) measured eye radiation exposure in physicians performing lumbar transforaminal epidural steroid joint injections to be 0.39 mrem. Their paper broke down the physicians who did these procedures into 2 groups: those treating patients with stenosis and those treating patients with a herniated nucleus pulposus. Radiation exposure to the eyes were 0.41 mrem and 0.37 mrem respectively (8). Similarly, in 2001 Botwin, et al (26) reported that eye radiation exposure in those performing caudal epidural steroid injections in 100 patients was 247 mrem. Kelly, et al (30) measured eye radiation exposure in 3 different physicians who performed 682 procedures. They reported radiation numbers of 369 mrem, 351 mrem, and 99 mrem. This article found that these eye radiation exposures were well below the ocular dose limit set by the medical community (30).

Discussion

Interventional pain management physicians complete more than 19 million procedures in patients with chronic pain each year; a majority of them are guided under C-arm fluoroscopy (31). Some of these interventional pain management procedures include interlaminar and transforaminal epidural steroid injections, lumbar facet joint nerve blocks, medial branch radiofrequency ablation, stellate ganglion blocks, caudal epidurals, and more (28). Although many studies suggest that the radiation exposure of interventional pain management physicians is within the acceptable annual limits, it is still important for them to take the necessary precautions to minimize radiation exposure and health risks.

The health risks for long-term exposure to small doses of radiation are still unclear (26). The National Council on Radiation Protection and Measurements has regulations for medical personnel that limit the amount of radiation that they receive each year; this amount varies depending on the organ involved. For example, the maximum annual dose is 500 mSv for the thyroid, 500 mSv for the limbs, 500 mSv for the gonads, 50 mSv for the whole body, and 50 mSv for the eyes (32). Interventional pain management physicians can effectively minimize their risk of serious radiation exposure by understanding sources of radiation, wearing protective gear, and being cognizant of their exposure (3).

Protective Gear

Interventional pain management physicians were more likely to experience reduced radiation exposure during procedures if they wore protective equipment, such as lead aprons, gloves, thyroid shields, protective glasses, and even leaded skirts for the groin. Provenzano et al (9) released a comprehensive survey answered by 708 physicians across the United States, Europe, and Asia. They found that only 66% wore thyroid shields (9). Less than 50% of them wore a lead apron that was at least 0.5 mm thick and fewer than 30% of them wore protective gloves, glasses, and head equipment (9). Interventional pain management physicians are encouraged to be more consistent with wearing protective gear, as articles in our systematic review demonstrate the effectiveness of leaded garments in lowering skin radiation exposure.

Manchikanti et al (23) demonstrated the importance of wearing safety materials in the upper and lower regions of the body. In the 2 groups they examined, dosimeter readings showed that radiation exposure was substantially higher outside than on the inside of the protective garments. Furthermore, this prospective observational study shared that Group 2, which had additional shielding to the groin area, exhibited lower radiation dose readings than Group 1. They discussed that the additional garment at the groin level reduces scatter radiation to the outside apron and upper regions of the physician. However, scatter radiation to the inside of the groin was still the same in both groups (23). Botwin et al (26) and Manchikanti et al (4) showed similar reduction in radiation exposure when wearing protective garments.

Plastaras, et al (31) compared 685 and 385 interventional pain management procedures done before and after implementing safety modalities, respectively. Some of these safety measures include leaded table skirts or leaded plastic walls. The article reported that the radiation exposure to the entire team dropped from 315 mrem to 3 mrem, with the effective dose per procedure decreasing for each member as well (31). With scatter radiation to medical personnel being 2 to 3 times greater than a patient's absorbed radiation dose, it is important that operating rooms implement additional protective barriers to reduce radiation exposure (31).

Work Experience

An additional factor that contributes to the radiation exposure of interventional pain management physicians is their work experience. Manchikanti, et al (4) compared the radiation exposure of the chest (outside), neck (inside), groin (outside), and groin (inside) in 3 physicians who in total performed 1,819 procedures in 1,156 patients. Not only did they emphasize the effectiveness of protective gear in minimizing radiation risks, but they demonstrated that there were differences in radiation measurements among physicians with less than 2 years of experience (Group 1), between 2-5 years of experience (Group 2), and more than 5 years of experience (Group 3). Upper body radiation under of the neck garment was higher in Groups 2 and 3 compared to Group 1. Furthermore, radiation under the groin apron was remarkably higher in Group 3 compared to Groups 1 and 2 even though Groups 1 and 3 had higher groin exposure outside of the garment than Group 2 (4). Although the authors did not identify reasons for these differences, they did suggest that the differences in radiation exposure among the 3 groups can be attributed to the behaviors of the physicians standing close or far away from the source of radiation. They also found that behaviors that lowered radiation exposure to the chest did not apply to lowering radiation exposure in the lower parts of the body (4).

Theilig, et al (33) retrospectively examined 4,380 cases of physicians who used CT-guided techniques for periradicular therapy, lung biopsy, liver biopsy, and more. They reported that the more experienced physicians experienced a smaller radiation dose. Women physicians had shorter procedure times and took fewer images; the article suggested that physicians of child-bearing age may be more mindful of their radiation exposure (33).

Interventional pain management physicians in academic hospitals generally receive higher radiation exposure doses and longer procedure times. Zhou, et al (2) suggested that in 5 different types of interventional pain management procedures, such as epidural steroid joint injections or facet joint blocks, radiation exposure time can be 3 times as much in an academic setting as that in private practice. The study found differences in radiation exposure among 7 different attending physicians performing epidural steroid joint injections. This may suggest that different work experience may contribute to differences in radiation exposure, because attending physicians have to spend more time training trainees in academic settings. This may lead them to take longer times when performing these procedures under fluoroscopy (2).

Wininger, et al (34) compared the radiation exposure of novice and expert interventional pain physicians who perform percutaneous spinal cord stimulation mapping procedures. Although there were no statistically significant differences in radiation exposure time between the novices and experts, they found that more experienced physicians had decreased fluoroscopy time when compared to a benchmark. They suggested that expert physicians may have the opportunity to rely on past work experiences in order to find or use more efficient epidural techniques and routes (34).

Coaching/Education

Several observational studies have highlighted the positive effects of education on reducing radiation exposure in interventional pain management physicians. Pitcher, et al (35) evaluated the radiation exposure of medical personnel at a US Army pain clinic before and after the staff underwent a peer training program. The study found that the cumulative dose to each medical personnel was 1,814 mrem before the training and 955 mrem after the training (35). Slegers, et al (7) reported that interventional pain management physicians who saw their scatter radiation measurement in real time, along with receiving active coaching to stand in less exposed areas, received a smaller radiation dose than those who were blinded to the findings of those that did not receive the active coaching (7). Even when the physicians were only allowed to monitor their dosage in real time but did not have active coaching, radiation exposure did not improve relative to the control group (7).

Radiation safety training is essential for minimizing radiation harm. The 2 observational studies above highlight the significant decrease in radiation exposure after implementing training or coaching programs. An anonymous survey sent to Korean interventional pain management physicians in 2016 reported that 39% of respondents said that they had formerly received radiation safety training (36). Interventional pain management physicians should be taught to frequently check their equipment's quality as well. In 2022 Park et al (14) conducted a study at Rwandan Public Hospital. They found that only 41% of the physicians examined the integrity of their protective garments (14). Given the improvements in radiation protection, it is important that more training opportunities are given to interventional pain management physicians.

Positioning

Kim, et al (22) found different radiation exposure levels between the operator (fellow) and assistant (resident) performing various procedures, including cervical nerve root blocks, lumbar sympathetic nerve blocks, and more. The article reported that radiation at the neck and leg for the fellow was higher than that of the resident, with the annual radiation dose being 2,032 mrem over the collar and 1,292 mrem over the leg for the operator. The measurements for the resident were 572 mrem and 504 mrem over the collar and leg, respectively (22). The article reported that this difference was due to the fellow standing one meter closer behind the x-ray machine than the resident (22).

Radiation dose is inversely proportional to the square of the distance between the physician and x-ray source (14,37). Standing 2 meters away from the imaging machine can lower the radiation exposure by up to 75%, compared to those standing one meter away from the source (14). Broadman, et al(37) pointed out that physicians performing facet joint and medial branch nerve blocks bilaterally may often expose themselves to unnecessary radiation exposure. These physicians position themselves across from the fluoroscope when operating on one side, but when they perform the blocks on the other side, they usually operate on the same side as the C-arm cone (37). This change in position prevents a curtain from protecting the physician's lower body parts from excessive scatter radiation.

Type of Procedures

Our systematic search revealed that different types of interventional pain management procedures may result in increased or decreased radiation exposure to physicians. Kelly, et al (30) noted the presence of radiation risks to the eyes of 3 pain interventionalists performing 682 fluoroscopy procedures, including lumbar epidural injections, nerve root blocks, sympathetic block injections, and more. The study suggested that procedures with different screening time durations and dose area product resulted in different radiation exposure levels, which was seen in one of the physicians who experienced close to 3 times the ocular dose per unit dose area product. The article suggested that specializing in certain procedures may expose them to more or less radiation (30). Although not seen in this paper, other studies have mentioned that the left eye may be more prone to radiation exposure due to their positions relative to the x-ray source (38).

Botwin (8) studied the radiation exposure of interventional pain management physicians who completed 100 fluoroscope-guided lumbar transforaminal epidural steroid injections in 100 patients. They found that physicians performing epidural injections for lumbar spinal stenosis experienced more radiation time and exposure than those who treated patients for a herniated nucleus pulposus. The cumulative readings for all of the physicians in both groups at the ring, glasses, and outside apron levels were 0.70 mrem, 0.39 mrem, and 0.30 mrem, respectively. However, these numbers were 0.73 mrem, 0.41 mrem, and 0.32 mrem for those who treated patients with stenosis and 0.65 mrem, 0.37 mrem, and 0.28 mrem for physicians who treated patients with a herniated nucleus pulposus (8).

Komiya, et al (29) measured the radiation exposure of interventionalists who performed epiduroscopy, a technique that treats patients with back and leg pain. Using a humanoid model, the study found that radiation exposure from performing epiduroscopy was only around 1.4% of the yearly dose restriction suggested by the International Commission on Radiological Protection. This study highlights that compared to other interventional radiologic procedures, such as vertebroplasty or coronary angiography, radiation exposure to physicians and patients is lower with epiduroscopy. The article also supported the importance of wearing protective garments, considering that the radiation dose inside the lead apron of one physician model was only 1.3% of the dose outside of the garment (29).

Baek, et al (24) conducted a randomized controlled study that compared the radiation exposure of physicians who performed fluoroscope-guided medial branch blocks with or without collimation. Collimation involved narrowing of the x-ray field, dropping the width from 26 cm to 14.5 cm. Under this procedure, the collimation group had better image quality and a 46% drop in radiation exposure to the interventional pain management group (24).

Dietrich, et al (27) also found in their prospective observational study that fluoroscope-guided procedures yielded more radiation exposure to the physician than CT-guided procedures. The article examined 8 interventional pain management physicians whose experience ranged from 4 to 18 years. They concluded that for lumbar transforaminal epidural and lumbar facet joint steroid injections, the radiation exposure to physicians who performed fluoroscope-guided procedures was 3.7 to 10 times higher than those who performed CT-guided procedures (27). However, this finding contrasts the radiation that the patients experienced in this study, considering that they received less radiation under fluoroscopy than CT (27).

Hofmeister, et al (39) also found in their systematic review that although ultrasound or fluoroscope-guided injections did not yield significant differences in terms of reducing lower back pain for patients, radiation exposure was higher in the fluoroscopy group compared to the ultrasound group (39).

Other techniques that may lower radiation exposure include the use of pulsed fluoroscopy. Compared to procedures done under continuous fluoroscopy, pulsed fluoroscopy reduces unnecessary radiation to the physician (31). One of the safety measures that Plastaras, et al (31) implemented was pulsed fluoroscopy controlled by a radiology technician. They discovered that radiation exposure to staff dropped by almost 100% (31). Similarly, Wininger et al (40) compared a case with a pulsed fluoroscopy time of 123.8 seconds to a second case with a pulsed fluoroscopy time of 16.3 seconds during spinal cord stimulation implantation (40). The continuous fluoroscopy times were 75.1 seconds and 182.6 seconds for these 2 respective cases (40). The investigators found that the incident air kerma was 39.4% higher in the case with the shorter pulsed fluoroscopy and longer continuous fluoroscopy times (40). This supports the idea that using fluoroscopy in a pulsatile manner helps reduce radiation exposure to interventional pain management physicians (40).

Limitations and Future Directions

One of the limitations in this systematic review is that we only searched 2 medical databases. The 2 databases were PubMed and EMBASE, which are 2 of the most comprehensive databases available. There is a possibility that other relevant studies were not indexed in these 2 databases. Even though we had just about 2,736 initial research results, only 24 papers were included to be part of our review. Of these 24, only 12 papers directly measured the radiation exposure of interventional pain management physicians. Future systematic reviews should include using more databases to include a more broad range of articles. Nonetheless, the research conducted on the radiation exposure of interventional pain management physicians is limited, as our systematic review comprised only one randomized controlled trial. To our knowledge, our systematic review encompassed the majority of the literature available on this subject.

Another limitation to our study was the small sample size of the number of physicians examined in this review. Even though our systematic review included over 3,577 patients, only 30 physicians were included in these articles. The physicians who performed interventional pain management procedures in these patients may not be representative of the interventional pain management community. Some of these physicians may be the same or are in the same system as the multiple papers that we included. For example, 3 of Manchikanti's papers (4,23,28) and 3 of Botwin's papers (8,25,26) were included in our study; this could possibly lead to more of a homogenous sample size rather than a heterogenous one.

Publication bias may be a limiting factor for our systematic review. There were many studies found on EMBASE that were excluded from our systematic review because they were poster presentations and were not peer-reviewed. However, they did report the radiation exposure of physicians at various body parts. Also, our systematic review mainly consisted of observational studies, where we only had one randomized controlled trial. The lack of diversity in the types of articles included in our systematic review may have weakened our study.

Another limitation to this systematic review is that only the radiation dose of interventional pain management physicians is examined. The actual prevalence and incidence of medical complications, such as cancer or cataracts, associated with radiation exposure in interventional pain management were not included. Future works should include an analysis of diseases that physicians may develop due to their workplace exposure while performing interventional pain management procedures, although this may be difficult because such studies require decades of observation. However, follow-up studies can be done on our systematic review in order to increase sample size as well as to follow-up on changes in radiation exposure as new equipment and regulations are created. Furthermore, future works should include an evaluation of radiation exposure in interventional pain management physicians vs radiation exposure in patients undergoing interventional pain management procedures. This would allow for a comparison to see who is more at risk during interventional pain management procedures. Overall, our systematic review provides a comprehensive analysis of radiation exposure in certain interventional pain management procedures and provides recommendations on how to lower the exposure for interventional pain management physicians.

Conclusion

Interventional pain management physicians are frequently exposed to ionizing radiation to the neck, chest, hands, groin, and eyes. The literature included in this systematic review suggests that the neck, chest, and groin receive most of the radiation exposure, whereas the hands and eyes receive the least amount of radiation exposure. Our systematic review also shows the importance of taking safety precautions when physicians are performing interventional pain management procedures, such as wearing protective equipment and implementing training programs. The incorporation of these safety measures into interventional pain management procedures consistently lowered the ionizing radiation dose that physicians received in multiple studies. This systematic review also highlighted some of the factors that contribute to an increase or decrease in radiation exposure experienced by interventional pain management physicians. Some of these factors include the provider's level of experience, positioning in the operating room, and specialization in various interventional pain management procedures.

The long-term health effects of cumulative low-dose radiation exposure to interventional pain management physicians is still not clearly understood. It is important that these physicians take the necessary steps needed to minimize their radiation exposure in the operating room. Future studies should continue to examine the best modalities to reduce radiation exposure to medical staff and to identify health risks for interventional pain management physicians who are exposed to small doses of radiation over long periods of time.

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