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Occupational Health Hazards of Working in the Interventional Laboratory

A Multisite Case Control Study of Physicians and Allied Staff

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ABSTRACT

BACKGROUND The occupational hazards of working in the interventional laboratory have been inadequately studied for physicians and remain unaddressed for nonphysician personnel.

OBJECTIVES This study sought to determine whether the prevalence of work-related musculoskeletal pain, cancer, and other medical conditions is higher among physicians and allied staff who work in interventional laboratories compared with employees who do not.

METHODS Mayo Clinic employees who work in affiliated hospitals with interventional cardiology or interventional radiology laboratories took an electronic survey. Results were stratified on the basis of self-reported occupational exposure to procedures that involve radiation.

RESULTS There were 1,543 employees (mean age 43 ± 11.3 years, 33% male) who responded to the survey (response rate of 57%), and 1,042 (67.5%) reported being involved with procedures utilizing radiation. These employees reported experiencing work-related pain more often than the control group before (54.7% vs. 44.7%; $p < 0.001$) and after adjustment for age, sex, body mass index, pre-existing musculoskeletal conditions, years in profession, and job description (odds ratio: 1.67; 95% confidence interval: 1.32 to 2.11; $p < 0.001$). Musculoskeletal pain varied significantly by job description, with the highest incidence reported by technicians (62%) and nurses (60%) followed by attending physicians (44%) and trainees (19%; $p < 0.001$). There was no difference in cancer prevalence between groups (9% vs. 9%; $p = 0.96$).

CONCLUSIONS Musculoskeletal pain is more common among healthcare workers who participate in interventional procedures and is highest in nonphysician employees. The diagnosis of cancer in employees who participate in procedures that utilize radiation was not elevated when compared to controls within the same departments, although any conclusion regarding causality is limited by the cross-sectional nature of the study, as well as the low overall prevalence of malignancy in our study group. (J Am Coll Cardiol 2015;65:820–6) © 2015 by the American College of Cardiology Foundation.

Fluoroscopically guided interventional procedures performed by cardiologists and radiologists have become increasingly complex as they are applied to new and higher risk patient populations (1–4). These changes can lead to increased procedural times and volumes, which result in additional radiation exposure and more time wearing a protective lead apron (5).

The occupational hazards of working in the interventional laboratory have been incompletely studied for physicians in the modern era, and no study has examined the effect on the nonphysician members of the interventional team. Studies performed over a decade ago on physicians have shown a high prevalence of orthopedic problems (6–9). Findings regarding radiation exposure to healthcare employees

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and the risk of developing cancer have been less consistent (10–15). A major limitation of many of these studies is a bias related to poor response rates on surveys that usually lacked age-matched controls and the exclusion of nonphysician allied health staff.

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Mayo Clinic consists of a large multistate network of physicians and allied health staff who participate in a wide array of interventional procedures that require wearing lead aprons and exposure to radiation. An enterprise-wide survey among all members of the interventional teams comparing results with employees from the same departments not involved in these procedures would circumvent most limitations of the prior studies by providing adequate response rates, a control group, and workplace details that may detect variables associated with work-related hazards. With that background, the aims of the present study were to determine if the prevalence of work-related musculoskeletal pain, cancer, and other medical conditions is higher among the various healthcare employees who work in interventional labs compared with similar employees who do not.

METHODS

RESEARCH SUBJECTS. The Mayo Clinic consists of 3 major patient care facilities (Rochester, Minnesota; Scottsdale, Arizona; Jacksonville, Florida), as well as the Mayo Clinic Health System facilities in Minnesota (Mankato) and Wisconsin (La Crosse and Eau Claire), which also have interventional facilities. Clinical employees working at these sites within the departments of cardiology and radiology were identified through Human Resources electronic databases. The Mayo Clinic Institutional Review Board approved the study, and medical records were not accessed as a part of this investigation.

SURVEY TOOL. With the assistance of the Mayo Clinic Survey Center, an electronic email survey was developed and administered. The survey generates self-reported baseline demographic information (age, sex, weight, and height), baseline work-related information (e.g., exposure to procedures involving radiation, use of protective equipment including the lead apron), and basic personal medical information related to employment in an interventional laboratory (history of musculoskeletal pain, medical evaluation/treatment for musculoskeletal pain, cancer, cataracts, etc.). The Pain Rating Index (PRI) and Present Pain Intensity (PPI) scores were used to assess current pain levels (16). The PRI is a numerical pain scale that ranges between 0 (no pain) and 20 (severe pain). The PPI is a descriptive pain scale using words to describe the severity of pain (none, mild, discomforting, distressing, horrible, and excruciating). The electronic survey was sent out on September 25, 2013, and was open for 6 weeks. Reminder emails were sent out weekly to nonresponders.

ABBREVIATIONS AND ACRONYMS

PPI = Present Pain Intensity

PRI = Pain Rating Index

STATISTICAL METHODS. Employees who affirmatively responded to survey questions regarding participation in procedures involving radiation were assumed to work in interventional laboratories and comprised the study group. Employees who did not respond affirmatively to these questions comprised the control group. Continuous variables are summarized as mean ± SD or median (25th, 75th percentile). Discrete variables are presented as frequency (group percentage). Missing values were excluded from the denominator for calculating percentages. Differences between groups were compared using Student's *t* test for near symmetric continuous variables, the rank sum test for skewed continuous and ordinal variables, and Pearson's chi-square test for categorical variables. Logistic regression models (with and without covariate adjustment) were used to estimate the association between occupational exposure to radiation and potential health risks, such as work-

TABLE 1 Baseline Characteristics

	Involvement in Procedures With Radiation Exposure (n = 1, 042)	Control Group (n = 499)	p Value
Age, yrs	42.7 ± 11.3	43.5 ± 11.3	0.20
Male	370 (36)	133 (27)	<0.001
Body mass index, kg/m^2	26.2 ± 4.8	25.8 ± 5.3	0.18
Pre-existing musculoskeletal condition	99 (10)	36 (7)	0.45
Department			<0.001
Cardiology	268 (26)	283 (57)	
Radiology	774 (74)	216 (43)	
Years in current profession*			0.81
0–5	224 (22)	106 (21)	
6–10	212 (21)	107 (22)	
11–15	161 (16)	84 (17)	
16–20	119 (12)	61 (12)	
20+	314 (30)	137 (28)	
Position			<0.001
Physician	160 (15)	45 (9)	
Residents/fellows	68 (7)	5 (1)	
Registered nurse	207 (20)	76 (15)	
Technician/technologist	548 (53)	288 (58)	
Other	59 (6)	85 (17)	

Values are mean ± SD or n (%). *Sixteen respondents did not answer this question and are not included in denominators for percentage calculations.

related pain, cancer, cataract, nephrolithiasis, and hypothyroidism. For all endpoints, we tested for interactions between participation in procedures with radiation exposure and department (cardiology/radiology) and position. We also adjusted for age and sex only, as well as age, sex, and other pre-specified relevant covariates. SAS version 9.3 (SAS Institute, Cary, North Carolina) was used for statistical analyses, with R (R Foundation, Vienna, Austria) employed for graphics.

RESULTS

There were 2,682 clinical employees identified within the departments of cardiology and radiology among the 6 Mayo Clinic patient care facilities. The survey response rate was 57% with 1,543 employees responding (554 cardiology, 989 radiology). The average age was 43 ± 11.3 years of age, with 33% male. There were 1,042 (67.5%) respondents who reported being involved with procedures that involve radiation. The most common job description was technician/technologist (54.3%) followed by registered nurse (18.3%), physician (13.4%), other (e.g., librarian, engineer, director, registrar; 9.3%), and resident/fellow (4.7%), with means of 15.5, 16.1, 18.8, 11.3, and 4.0 years, respectively, in their current position.

TABLE 2 Work-Related Musculoskeletal Pain and Involvement in Procedures With Radiation Exposure

	Involvement in Procedures With Radiation Exposure (n = 1,042)	Control Group (n = 499)	p Value
History of work-related pain	570 (55)	223 (45)	<0.001
+ Ergonomic evaluation	87 (8)	57 (11)	0.05
+ Sought medical care	317 (30)	122 (24)	0.02
+ Missed work	176 (17)	70 (14)	0.15
+ Short-/long-term disability	91 (16)	31 (14)	0.47
+ Currently in pain	300 (29)	117 (23)	0.03
Pain rating index			0.22
None/0	746 (72)	384 (77)	
1–5	120 (12)	48 (10)	
6–10	99 (10)	42 (8)	
11–15	49 (5)	16 (3)	
16+	28 (3)	9 (2)	
Present pain intensity			0.14
None	766 (74)	395 (79)	
Mild	113 (11)	44 (9)	
Discomforting	135 (13)	49 (10)	
Distressing	26 (2)	9 (2)	
Horrible	2 (0)	1 (0)	
Excruciating	0 (0)	1 (0)	
Type of pain			0.17
None	745 (71)	382 (77)	
Brief	10 (1)	4 (1)	
Intermittent	190 (18)	70 (14)	
Continuous	97 (9)	43 (9)	
Pain medication in last 2 weeks			0.15
Never	361 (35)	191 (38)	
Occasionally, not every day	514 (49)	231 (46)	
Almost every day	107 (10)	40 (8)	
Every day	59 (6)	37 (7)	

Values are n (%).

BASELINE CHARACTERISTICS. The baseline demographic characteristics of our study population are summarized in Table 1. Clinical employees with occupational exposure to procedures involving radiation were more likely to be men (35.5% vs. 26.7%; $p < 0.001$) and work in radiology (74.3% vs. 43.3%; $p < 0.001$). There was no difference in age, body mass index, years in current profession, or pre-existing musculoskeletal conditions among employees with occupational exposure to procedures involving radiation versus those not involved in such procedures.

MUSCULOSKELETAL PAIN. Clinical employees with occupational exposure to procedures involving radiation requiring lead apron use reported experiencing work-related pain more often than the control group (54.7% vs. 44.7%; $p < 0.001$; Table 2). These employees also were more likely to have sought medical care for their pain (30.4% vs. 24.4%; $p = 0.02$). Workers exposed to radiation requiring lead apron use were more likely to report current pain at the time of the survey (28.8% vs. 23.4%; $p = 0.03$), but there was no statistical difference in objective pain assessment scores for current pain (PRI $p = 0.22$, PPI $p = 0.14$). There was also no difference in the recent use of pain medication, missed work days, or use of disability. The association between a history of work-related pain and occupational exposure to fluoroscopically guided procedures requiring the lead apron remained significant even after adjustment for age, sex, body mass index, pre-existing musculoskeletal conditions, years in profession, and job description (odds ratio: 1.67; 95% confidence interval: 1.32 to 2.11; $p < 0.001$).

FACTORS ASSOCIATED WITH INCREASED WORK-RELATED PAIN. Employees exposed to procedures involving radiation who reported a history of work-related pain were more likely to be female (71% vs. 56%; $p < 0.001$), had more time per week exposed to radiation (median 15 vs. 5 h/week; $p < 0.001$), and wore the lead apron more (median 4 vs. 1 h/week; $p < 0.001$). Behaviors aimed at improving musculoskeletal pain were more common in employees who reported a history of work-related pain including prompt removal of lead apron ($p < 0.001$), stretch/exercise before or after procedures ($p < 0.001$), and

wearing soft-soled shoes ($p = 0.005$). The type of lead apron (1 piece vs. 2 pieces), use of glass shield, and eye protection were not associated with a history of work-related pain.

A history of work-related musculoskeletal pain varied significantly by role in the laboratory, with the highest incidence reported by technicians (62%) and nurses (60%), followed by attending physicians (44%) and trainees (19%; $p < 0.001$) (**Figure 1**). In our study, technicians and nurses tended to be younger and were more likely to be female than attending physicians ($p < 0.01$). However, similar findings were present when restricting the analysis by sex with pain reported in 63% of male nurses, 53% of male technicians, and 44% of male attending physicians, compared with 59% of female nurses, 65% of female technicians, and 41% of female attending physicians ($p < 0.001$).

RADIATION-RELATED CONDITIONS. Medical conditions potentially associated with occupational exposure to radiation and their rates of occurrence in our study population are detailed in **Figure 2** and **Table 3**. Clinical employees with occupational exposure to procedures involving radiation did not report a history of cancer, cataracts, hypothyroidism, or nephrolithiasis at a higher rate than employees without radiation exposure. A composite endpoint which included all of these conditions and musculoskeletal pain showed no statistical difference between groups ($p = 0.26$).

DISCUSSION

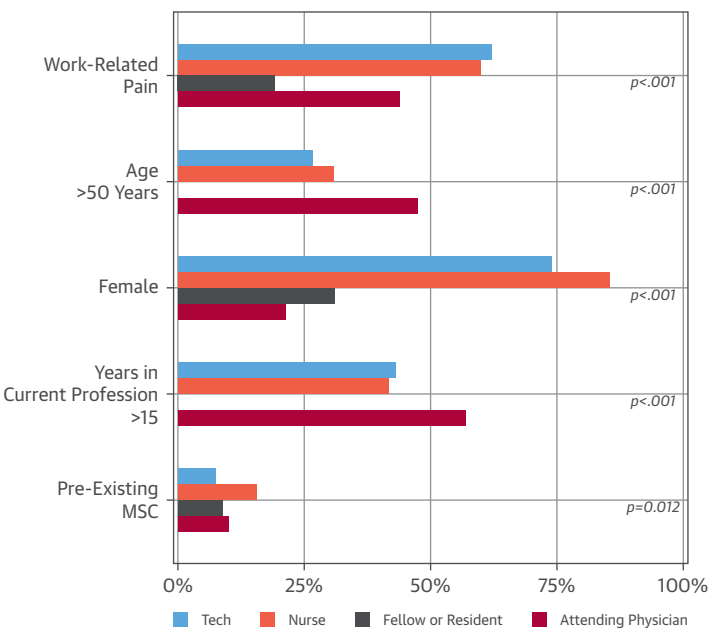
The principal findings of this investigation are 3-fold:

1. Musculoskeletal pain is more common among healthcare workers who participate in interventional procedures and is highest in nonphysician employees (**Central Illustration**).
2. Female sex, time per week participating in radiation utilizing procedures, and increasing use of the lead apron are associated with a higher prevalence of musculoskeletal pain.
3. Although we did not observe a higher rate of malignancy in employees exposed to radiation compared to controls within the same departments, conclusions regarding causality are limited by the cross-sectional survey design.

MUSCULOSKELETAL PAIN IN THE CATH LAB. In 1997, Ross et al. (6) reported that interventional cardiologists experienced more musculoskeletal pain than control groups of physicians from orthopedic surgery and rheumatology. Goldstein et al. (7) found in 2004 that 42% of responding interventional cardiologists in their study reported a history of musculoskeletal pain and that the incidence increased with higher case volumes and more years in practice. Since that time, a working group has been assembled to attempt to decrease the occupational risk to physicians working in the interventional laboratory (17,18). However, little is known about the prevalence of musculoskeletal pain in other nonphysician employees involved in interventional procedures (19) despite studies suggesting a high biomechanical risk (20).

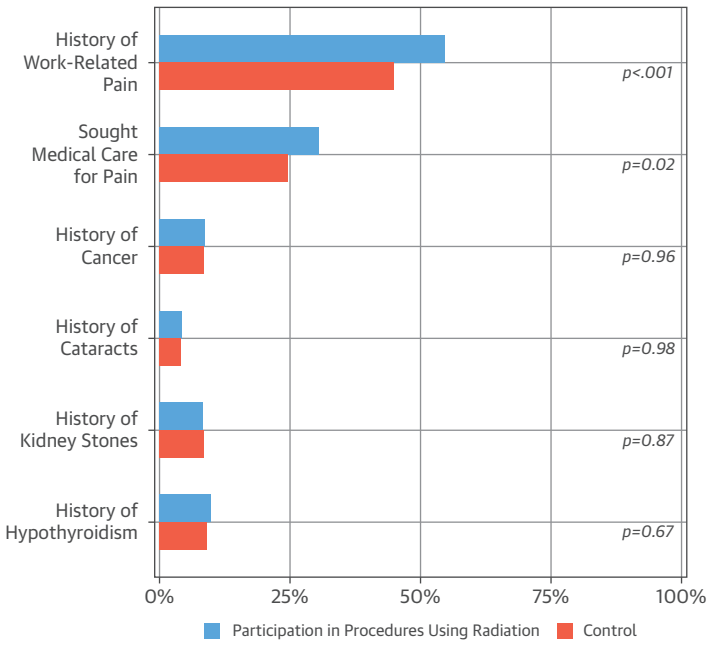
Our study is the first large, multicenter case-control study to evaluate the occupational hazards of participating in procedures involving radiation and the first study to include not only attending physicians, but also technicians, nursing staff, and trainees. Employees in our study who were involved in procedures that use radiation reported a 67% increase in the prevalence of musculoskeletal pain, were more likely to have sought medical care for their pain, and were more likely to have had an ergonomic evaluation. Female sex and increased time spent in the interventional lab wearing the lead apron were

FIGURE 1 Work-Related Musculoskeletal Pain Among Employees Involved in Procedures With Radiation Exposure, Analyzed by Job Description



Nonphysician allied staff working in the interventional laboratory reported more work-related musculoskeletal pain than interventional lab attending physicians. MSC = musculoskeletal condition.

FIGURE 2 Prevalence of Medical Conditions Potentially Related to Working in the Interventional Laboratory



Healthcare workers who perform or assist with procedures requiring radiation reported more work-related musculoskeletal pain and more often sought medical care for this pain compared to similar employees within the same departments who are not exposed to these procedures. There was no significant difference in the prevalence of other medical conditions in this 1-time cross-sectional study.

identified as major risk factors for reporting a higher incidence of pain.

Our study is also the first to demonstrate that technicians and nurses report a higher prevalence of work-related musculoskeletal pain compared with their attending physician counterparts. This occurred despite technicians and nurses being younger and having worked for fewer years. The cause of the increased prevalence of pain in the nonphysician interventional lab staff was not identified in our study, but it may relate to a more constant exposure to physical stresses. Unlike their physician counterparts who regularly rotate out of the interventional laboratory, technicians and nursing staff typically do not. An additional factor may be that technicians and nursing staff are exposed to different physical stressors than physicians. Involvement in patient transfers on and off the interventional table and applying compression after sheath removal are both examples of typical nonphysician, work-related duties that can negatively affect the musculoskeletal system.

More attention and effort needs to be directed toward improving the physical stresses that interventional lab employees endure. For all employees, continued efforts at limiting procedure times and regular ergonomic evaluations with associated training are advisable. Nonphysician employees also may benefit from periodic rotation out of the interventional lab suite. Industry efforts toward improving the protective apron such as integrating lighter, non-lead-based radioprotective material are ongoing and may reduce occupational stresses as these technologies are applied consistently in clinical practice (21). Robotic interventional equipment and remote monitoring technologies also may help to reduce both the number of personnel required for patient care inside the room and the proximity of the operator from the radiation source and thereby reduce the requirement to wear heavy lead aprons (22,23).

CANCER, CATARACTS, AND THE INTERVENTIONAL LAB.

This study did not demonstrate a statistically significant increase in the incidence of cancer, hypothyroidism or cataracts in personnel exposed to radiation. Although it did not reach statistical significance and the overall number of cases was small, among respondents with any history of cancer, there was a higher incidence of breast cancer (19% vs. 9%; $p = 0.15$) in employees with radiation exposure.

The link between occupational exposure to radiation and the subsequent development of malignancy or cataracts has been a matter of debate. A review of

TABLE 3 Medical Conditions Potentially Associated With Radiation Exposure

	Involvement in Procedures With Radiation Exposure (n = 1,042)	Control Group (n = 499)	p Value
Cancer	89 (9)	43 (9)	0.96
Brain*	2 (2)	0 (0)	0.32
Breast*	17 (19)	4 (9)	0.15
Leukemia*	5 (6)	1 (2)	0.39
Lung*	0 (0)	0 (0)	–
Lymphoma*	3 (3)	1 (2)	0.74
Prostate*	4 (4)	3 (7)	0.55
Skin*	45 (51)	22 (51)	0.95
Thyroid*	1 (1)	5 (12)	0.01
Other*	19 (21)	11 (26)	0.59
Cataract	41 (4)	20 (4)	0.98
Kidney stones	87 (8)	43 (9)	0.87
Hypothyroidism	103 (10)	46 (9)	0.67
Any of the above	212 (20)	93 (19)	0.43

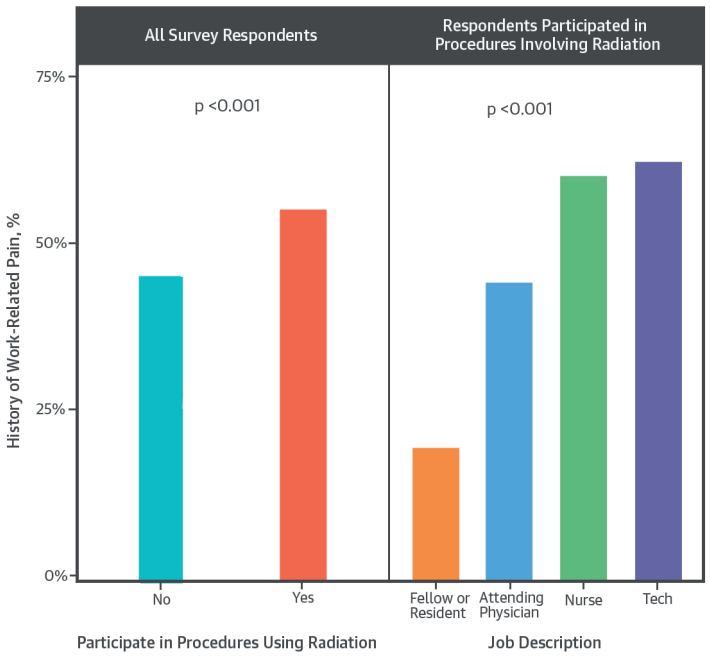
Values are n (%). *Reported percentage represents the percentage of those with a history of cancer having the specific type of cancer indicated.

epidemiological studies by Yoshinaga et al. (11) demonstrated increased mortality from leukemia in radiological healthcare workers employed before 1950 when radiation exposure levels were high, but suggested that current levels of radiation exposure have not been linked to an increased cancer risk. However, 1 large study of radiologic technologists noted a higher incidence of skin, breast, and thyroid cancer (10). Eye lens exposure similarly is dependent on the type of radiologic procedure, years of exposure, and whether radiation protection tools were used (24). Major limitations of these available studies include the nonavailability of age-matched controls and a poor response rate with only approximately one-third responding to surveys thereby introducing possible response bias (25).

The issue of radiation-related cancer in exposed interventional laboratory employees cannot be resolved from our analyses for the following reasons. First, the incidence of cancer is low in younger personnel who work in these areas. Second, the determinants of cancer may be stoichiometric or dose-dependent and as a result the length of employment in these lab areas may not be long enough for cancer detection. Additional screening tests and longer follow-up may be needed to accurately define the role of radiation. Third, once cancer is detected in an employee, he/she is likely to take retirement or move out to a nonradiation area. We are limited in our 1-time cross-sectional survey. Although, a higher incidence of breast cancers was noted on our study, it did not reach statistical significance and a larger sample size with a periodic survey that tracks the employees' health over time will be important to further study this relationship.

Regardless, continued efforts in radiation protection should be a point of emphasis in every interventional laboratory. In addition to the protective apron, operators should wear protective eyewear and use appropriate radiation shielding that can significantly decrease radiation exposure when used effectively (26). Promoting a "philosophy of radiation safety" through education and other practice improvement strategies can significantly lower radiation doses when applied systematically (27).

CENTRAL ILLUSTRATION **Self-Reported History of Work-Related Musculoskeletal Pain Stratified by Participation in Invasive Procedures Requiring Radiation and Position Within the Interventional Laboratory**



Orme, N.M. et al. J Am Coll Cardiol. 2015; 65(8):820–6.

Healthcare workers who participate in invasive procedures requiring radiation **(left panel)** report more work-related musculoskeletal pain than similar employees who do not participate in these procedures. Nonphysician allied staff working in the interventional laboratory **(right panel)** report more work-related musculoskeletal pain than interventional laboratory attending physicians.

STUDY LIMITATIONS. First, employees who developed a significant work-related medical condition before our study might have stopped working in the interventional laboratory and moved to non-interventional jobs in the same department. Although uncommon, it would have biased the results in favor of the null hypothesis. Second, although our survey response rate was adequate (57%), there is the possibility that employees without work-related pain or those not exposed to radiation might have felt less motivated to participate, leading to a response bias. However, it seems likely that the comparison between the exposed and the controls would still hold. Third, despite being 1 of the largest studies available, the non-pain-related outcomes of interest were noted in a small number, especially for cancer. A longitudinal cohort study would provide greater information for tracking the effects of radiation and working in the interventional laboratory. Fourth, our results were stratified on the basis of an affirmative response to survey questions regarding participation in procedures that involve radiation. It is possible that some employees not working in an interventional lab could have mistakenly responded to this question in the affirmative and been erroneously included in the study group.

CONCLUSIONS

Musculoskeletal pain is more common among healthcare workers who participate in fluoroscopically guided interventional procedures and is highest in nonphysician allied staff. Female sex, increasing time per week participating in procedures requiring radiation, and increasing use of the lead apron are associated with a higher prevalence of musculoskeletal pain. We did not find a higher rate of malignancy, hypothyroidism, or cataracts in interventional lab employees compared to controls within the same departments, although any conclusion regarding causality is limited by the cross-sectional nature of our study and the low overall prevalence of these medical conditions in our study group.

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PERSPECTIVES

COMPETENCY IN SYSTEMS-BASED PRACTICE: Nonphysician allied staff exposed to ionizing radiation through their employment in an interventional laboratory experience musculoskeletal pain more frequently than attending physicians performing interventional cardiovascular procedures.

TRANSLATIONAL OUTLOOK: Technological advances that reduce radiation exposure during interventional procedures should be evaluated in an effort to reduce musculoskeletal pain and other adverse effects experienced by laboratory staff.

REFERENCES

1. Lazzeri C, Valente S, Chiostri M, et al. Comorbidities in STEMI patients submitted to primary PCI: temporal trends and impact on mortality: a 6-year single center experience. Int J Cardiol 2013;167:3042–4.

2. Forman DE, Rich MW, Alexander KP, et al. Cardiac care for older adults. Time for a new paradigm. J Am Coll Cardiol 2011;57:1801–10.

3. Feldman T, Ali O. Transcatheter mitral valve interventions: current status and future perspective. EuroIntervention 2012;8 Suppl Q:Q53–9.

4. Smith CR, Leon MB, Mack MJ, et al. Transcatheter versus surgical aortic-valve replacement in high-risk patients. N Engl J Med 2011;364:2187–98.

5. Delewi R, Hoebers LP, Ramunddal T, et al. Clinical and procedural characteristics associated with higher radiation exposure during percutaneous coronary interventions and coronary angiography. Circulation Cardiovasc Interv 2013;6:501–6.

6. Ross AM, Segal J, Borenstein D, Jenkins E, Cho S. Prevalence of spinal disc disease among interventional cardiologists. Am J Cardiol 1997;79:68–70.

7. Goldstein JA, Balter S, Cowley M, Hodgson J, Klein LW. Occupational hazards of interventional cardiologists: prevalence of orthopedic health problems in contemporary practice. Catheter Cardiovasc Interv 2004;63:407–11.

8. Machan L. A web based survey of neck and back pain amongst interventional radiologists. J Vasc Interv Radiol 2001;12 Suppl:S28.

9. Moore B, vanSonnenberg E, Casola G, Novelline RA. The relationship between back pain and lead apron use in radiologists. AJR Am J Roentgenol 1992;158:191–3.

10. Sigurdson AJ, Doody MM, Rao RS, et al. Cancer incidence in the US radiologic technologists health study, 1983–1998. Cancer 2003;97:3080–9.

11. Yoshinaga S, Mabuchi K, Sigurdson AJ, Doody MM, Ron E. Cancer risks among radiologists and radiologic technologists: review of epidemiologic studies. Radiology 2004;233:313–21.

12. Finkelstein MM. Is brain cancer an occupational disease of cardiologists? Can J Cardiol 1998;14:1385–8.

13. Matanoski GM, Seltser R, Sartwell PE, Diamond EL, Elliott EA. The current mortality rates of radiologists and other physician specialists: specific causes of death. Am J Epidemiol 1975;101:199–210.

14. Carozza SE, Wrensch M, Miike R, et al. Occupation and adult gliomas. Am J Epidemiol 2000;152:838–46.

15. Roguin A, Goldstein J, Bar O, Goldstein JA. Brain and neck tumors among physicians performing interventional procedures. Am J Cardiol 2013;111:1368–72.

16. Melzack R. The short-form McGill Pain Questionnaire. Pain 1987;30:191–7.

17. Klein LW, Miller DL, Balter S, et al. Occupational health hazards in the interventional laboratory: time for a safer environment. J Vascular Interv Radiol 2009;20:147–52, quiz 53.

18. Miller DL, Klein LW, Balter S, et al. Occupational health hazards in the interventional laboratory: progress report of the Multispecialty Occupational Health Group. J Vascular Interv Radiol 2010;21:1338–41.

19. Kumar S, Moro L, Narayan Y. Perceived physical stress at work and musculoskeletal discomfort in X-ray technologists. Ergonomics 2004;47:189–201.

20. Kumar S, Moro L, Narayan Y. A biomechanical analysis of loads on x-ray technologists: a field study. Ergonomics 2003;46:502–17.

21. Mori H, Koshida K, Ishigamori O, Matsubara K. Evaluation of the effectiveness of X-ray protective aprons in experimental and practical fields. Radiol Phys Technol 2014;7:158–66.

22. Rafii-Tari H, Payne CJ, Yang GZ. Current and emerging robot-assisted endovascular catheterization technologies: a review. Ann Biomed Eng 2014;42:697–715.

23. Bonatti J, Vetrovec G, Riga C, Wazni O, Stadler P. Robotic technology in cardiovascular medicine. Nat Rev Cardiol 2014;11:266–75.

24. Vano E, Gonzalez L, Fernandez JM, Haskal ZJ. Eye lens exposure to radiation in interventional suites: caution is warranted. Radiology 2008;248:945–53.

25. Klein LW, Miller DL, Balter S, et al. Occupational health hazards in the interventional laboratory: time for a safer environment. J Vasc Interv Radiol 2009;20 7 Suppl:S278–83.

26. Fetterly KA, Magnuson DJ, Tannahill GM, Hindal MD, Mathew V. Effective use of radiation shields to minimize operator dose during invasive cardiology procedures. J Am Coll Cardiol Intv 2011;4:1133–9.

27. Fetterly KA, Mathew V, Lennon R, Bell MR, Holmes DR Jr., Rihal CS. Radiation dose reduction in the invasive cardiovascular laboratory: implementing a culture and philosophy of radiation safety. J Am Coll Cardiol Intv 2012;5:866–73.

KEY WORDS interventional laboratory, musculoskeletal pain, radiation safety