



## News from the Heart Rhythm Society

### Occupational hazards in cardiac electrophysiology: Insights from an HRS member survey

Kamala P. Tamirisa, MD, FHRS,<sup>1</sup> Sana M. Al-Khatib, MD, MHS, FHRS,<sup>2</sup>  
Juan Carlos Zerpa Acosta, MD, FHRS,<sup>3</sup> Kenneth A. Ellenbogen, MD, FHRS,<sup>4</sup> Sabine Ernst, MD,<sup>5,6</sup>  
Tara Parham Graham, DNP, CRNP,<sup>7</sup> Melanie A. Gunawardene, MD, FHRS,<sup>8</sup> Jodie Hurwitz, MD, FHRS,<sup>9</sup>  
Dhanunjaya Lakkireddy, MD, MBA, FHRS,<sup>10</sup> Prashanthan Sanders, MBBS, PhD, FHRS,<sup>11</sup>  
Andrea M. Russo, MD, FHRS<sup>12</sup>

From the <sup>1</sup>Texas Cardiac Arrhythmia Institute, Austin, Texas, <sup>2</sup>Duke University Medical Center, Durham, North Carolina, <sup>3</sup>Hospital do Coração, São Paulo, Brazil, <sup>4</sup>Virginia Commonwealth University School of Medicine, Richmond, Virginia, <sup>5</sup>Royal Brompton Hospital, Guy's and St. Thomas' NHS Foundation Trust, London, United Kingdom, <sup>6</sup>National Heart and Lung Institute, Imperial College, London, United Kingdom, <sup>7</sup>Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania, <sup>8</sup>Cardioangiologic Center Bethanien, Markus Hospital, Frankfurt am Main, Germany, <sup>9</sup>North Texas Heart Center, Dallas, Texas, <sup>10</sup>Kansas City Heart Rhythm Institute, Overland Park, Kansas, <sup>11</sup>Centre for Heart Rhythm Disorders, University of Adelaide and Royal Adelaide Hospital, Adelaide, Australia, and <sup>12</sup>Cooper Medical School of Rowan University, Camden, New Jersey.

## ABSTRACT

**BACKGROUND** Cardiac electrophysiologists and electrophysiology (EP) laboratory professionals face underexplored occupational hazards, including direct and indirect effects of radiation exposure, orthopedic strain, and pregnancy-related concerns. Despite advances in radiation-reduction strategies, cumulative exposure continues to merit attention.

**OBJECTIVE** This study aimed to better understand these occupational risks.

**METHODS** A 20-question global (multiple-choice and open-ended) survey was distributed to Heart Rhythm Society members, including EP physicians and nonphysician members (nurses, technologists, allied professionals, and clinical specialists). The survey collected data on health risks, including pregnancy-related challenges.

**RESULTS** Of 30,663 contacted, 1336 (4.4 %) responded, including 974 physicians (72.9%), 299 nonphysicians (22.4%), and 63 clinical specialists (4.7%). Respondents included 413 women (30.9%), 910 men (68.1%), 3 nonbinary (0.22%), and 10 preferring not to disclose (0.7%). Malignancies were reported by 97 (7.8%), including various solid tumors in 29 (29.9%), thyroid cancer in 15 (15.5%), and breast cancer in 11 (11.3%). Among 242 women who had been pregnant (63.5%), 121 (50%) reported complications, including miscarriage in 64 (27.1%), in vitro fertilization in 35 (14.8%), hypertensive disorders of pregnancy in 21 (8.9%), and fetal growth problems/preterm labor in 23 (9.8%). Premature cataracts (<50 years) were reported by 46 (3.7%). Orthopedic injuries were reported by 481 (41%); 325 (67.6%) required physical therapy or exercise, and 109 (22.7%) had surgery.

**CONCLUSION** EP professionals reported notable health challenges, highlighting the need for greater awareness, preventive strategies, policies, and further research to enhance workplace safety in the EP laboratory.

**KEYWORDS** Occupational hazards; Radiation; EP procedures; Electrophysiologists; Pregnancy-related complications

(Heart Rhythm 2026;23:e307–e318) © 2025 Heart Rhythm Society. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

## TABLE OF CONTENTS

|                                             |      |                                                                |      |
|---------------------------------------------|------|----------------------------------------------------------------|------|
| Preamble .....                              | e308 | Pregnancy-related issues (complications and infertility) ..... | e311 |
| Editorial independence .....                | e308 | Premature cataracts (before the age of 50 years) ....          | e311 |
| Organization of the writing committee ..... | e308 | Orthopedic injuries .....                                      | e311 |
| Document review and approval .....          | e308 | Discussion .....                                               | e311 |
| Document updates .....                      | e308 | Malignancy rates .....                                         | e311 |
| Document scope and rationale .....          | e308 | Pregnancy-related issues (complications and infertility) ..... | e312 |
| Methods .....                               | e309 | Premature cataract risk .....                                  | e313 |
| Survey design and distribution .....        | e309 | Orthopedic injuries .....                                      | e313 |
| Eligibility criteria .....                  | e309 | Radiation exposure mitigation strategies .....                 | e313 |
| Data collection and analysis .....          | e309 | A call for policy and future direction .....                   | e313 |
| Results .....                               | e309 | Limitations .....                                              | e315 |
| Demographics .....                          | e309 | Conclusion .....                                               | e315 |
| Procedure details .....                     | e309 | Acknowledgments .....                                          | e315 |
| Health outcomes .....                       | e309 | Funding Sources .....                                          | e315 |
| Specific health-related issues .....        | e311 | References .....                                               | e315 |
| Malignancy rates .....                      | e311 |                                                                |      |

### Preamble

The Heart Rhythm Society (HRS) has developed scientific and clinical documents guiding the management of cardiac arrhythmias since 1996. This HRS statement discusses the results and implications of a cross-sectional survey of electrophysiologists (EPs) identifying occupational hazards of clinical EPs and electrophysiology (EP) laboratory (lab) professionals.

### Editorial independence

The statement is sponsored by the HRS and was developed without commercial support. All writing committee members and peer reviewers volunteered their time to the writing and reviewing efforts.

### Organization of the writing committee

HRS has rigorous policies and methods to ensure that documents are developed without bias or improper influence. The HRS policy on relationships with industry and other entities can be found in the HRS Code of Ethics and Professionalism: Appendix C and the HRS Scientific Documents Methodology Manual. A comprehensive list of relationships with industry and other entities disclosed by the writing committee members is presented in [Appendix 1](#).

### Document review and approval

This statement was approved by the writing committee and underwent internal review by the HRS Scientific Documents Committee.

### Document updates

The HRS Scientific Documents Committee reviews each scientific document for currency every 2–5 years after publication.

### Document scope and rationale

Occupational hazards of clinical EPs and EP lab professionals (nurses, technologists, allied professionals, and clinical specialists) have not been well studied. These include both direct and indirect effects of radiation exposure, orthopedic, and pregnancy-related concerns. Although advances such as intra-cardiac echocardiography and electroanatomic mapping have reduced radiation exposure for ablation operators, cardiac implantable electronic device (CIED) implanters and extractors continue to get exposed to cumulative radiation.<sup>1</sup> Radiation exposure has been linked to an increased risk of malignancies and premature cataracts.<sup>1,2</sup> Understanding these occupational hazards for EP professionals is important for developing strategies to mitigate those risks.

Studies indicate that cardiac procedure lab staff have a measurable and non-negligible lifetime attributable risk of malignancies owing to cumulative radiation exposure.<sup>1,2</sup> The malignancy risk from occupational radiation exposure is dose dependent, with ionizing radiation-induced DNA damage serving as the primary mechanism for cancer development.<sup>3</sup> Therefore, collecting long-term data is crucial to evaluating the effects of radiation exposure on the risk of malignancies among EP professionals.

Pregnancy-related complications among women practicing EP have not been adequately evaluated. Although the fetal radiation exposure has been reported to be well below the established safety limits, the occupation-specific effects are underexplored.<sup>4,5</sup> The clinical training required to become an EP physician often extends into childbearing years, necessitating strategic family planning and institutional support. Factors such as prolonged standing and wearing heavy lead during pregnancy may add additional strain. More research is needed to understand the full burden for women professionals in EP.

It has been shown that interventional cardiology professionals have a 3-fold increased risk of posterior subcapsular cataracts, a characteristic of ionizing radiation exposure.<sup>6</sup> More data are needed on the real risks of premature cataracts in EP professionals.

The physical demands of prolonged standing while wearing heavy lead aprons have been linked to a high prevalence of orthopedic injuries in interventional cardiology.<sup>7</sup> EP professionals face similar risks, intensified by long procedures with increased cumulative musculoskeletal strain. For women, these risks are further compounded by the need to wear additional protective gear during pregnancy.

We conducted a cross-sectional survey of EP professionals to quantify their occupational hazards risks. The improved characterization of EP occupational hazards will facilitate raising awareness and advocating for policy reform to protect EP clinicians and staff from radiation-related risks and orthopedic injuries to ensure a sustainable and healthier EP practice environment.

## Methods

### Survey design and distribution

The survey consisted of 20 multiple-choice and open-ended questions and was distributed via the HRS e-mail list ([Supplemental File](#)). The survey components are presented in [Table 1](#). The survey link was distributed by individual international EP physician representatives in their work circles (Australia, Asia, Africa, South America, and Europe) to ensure global representation. The target audience included EP physicians, nurses, technologists, allied professionals, and clinical specialists involved in EP procedures. We use the term “EP professionals” to reflect all the above mentioned professionals who are involved in EP procedures. Data were collected separately for women and men, with a particular focus on assessing pregnancy-related issues ([Table 2](#)).

### Eligibility criteria

Only individuals actively working in an EP lab were eligible to complete the survey. Respondents who had permanently left procedural work owing to health concerns or other reasons could indicate their reason for stopping to do procedures, but they did not receive and could not complete the sections focused on the current EP work environment. We use the term “currently working” to refer to those professionals who were working (performing procedures or working alongside the operator) at the time they took this survey.

### Data collection and analysis

Responses to the survey were collected through SurveyMonkey and were aggregated and analyzed. Categorical data were reported as frequencies (n = number) and percentages (%). Comparisons were performed to evaluate differences

**Table 1** Survey components

| Component                                           | Subcategory                                                                            |
|-----------------------------------------------------|----------------------------------------------------------------------------------------|
| Demographics                                        | Gender<br>Age<br>Race/ethnicity<br>Location<br>Role in EP lab                          |
| Procedure details                                   | Type of procedures performed<br>Years of exposure                                      |
| Career decisions influenced by occupational hazards | Stopped procedural participation<br>Reason for stopping                                |
| Health outcomes                                     | Malignancies<br>Pregnancy-related issues<br>Premature cataracts<br>Orthopedic injuries |

EP = electrophysiology; lab = laboratory.

based on sex, except for pregnancy-/childbearing-related data, and a *P* value is considered significant if *P* < .05.

## Results

### Demographics

The survey was sent to 30,663 EP professionals, including 14,339 physicians (46.8%), 2868 allied professionals (9.4%), and 5113 nurses (16.7%), and the remaining 8343 (27.2%) include technologists, clinical specialists, fellows, students, industry members, scientists, and others. Of these professionals, 1336 (4.4%) responded to the survey, with 413 women (30.9%), 910 men (68.1%), 3 nonbinary (0.22%), and 10 preferring not to disclose (0.7%). Given that not all respondents completed every question, denominators were adjusted appropriately throughout the analysis. Of the respondents, 974 (72.9%) were physicians, 299 (22.4%) were nonphysician clinical team members (nurse practitioners, physician assistants, nurses, scrub and radiation technologists), and 63 (4.7%) were other clinical specialists. Of the respondents, 692 (54.3%) were from North America, 140 (11%) were from Europe, 154 (12.1%) were from Asia, 120 (9.4%) were from Australia, 147 (11.5%) were from South America, and 22 (1.7%) were from Africa. Region was not specified by 61 respondents ([Table 2](#)).

### Procedure details

Respondents reported performing ablations (1189 [95.5%]), CIED implantations (1148 [92.2%]) and CIED extractions (622 [50%]), left atrial appendage occlusion device insertions (508 [40.8%]), and other procedures (230 [18.5%]) ([Table 2](#)).

### Health outcomes

Among women who responded to the health-focused questions (total = 381), 53 (13.9%) stopped doing procedures permanently and 328 (86.1%) worked in the EP lab at the time of survey completion. Among men who responded to the health-focused questions (total = 865), 98 (11.3%)

**Table 2** Demographics<sup>‡</sup>

| Category                                                                | Women, n (%) | Men, n (%)  | P value           |
|-------------------------------------------------------------------------|--------------|-------------|-------------------|
| (N = 1336)                                                              | 413 (30.9)   | 910 (68.1)  | N/A               |
| Race/ethnicity                                                          |              |             |                   |
| White                                                                   | 247 (61.1)   | 387 (44.2)  | 9.33              |
| Asian                                                                   | 92 (22.8)    | 264 (30.1)  | .03 <sup>†</sup>  |
| Hispanic or Latino                                                      | 30 (7.4)     | 119 (13.6)  | .003 <sup>†</sup> |
| Prefer not to answer                                                    | 16 (3.9)     | 35 (4.00)   | .95               |
| Mixed                                                                   | 11 (2.7)     | 23 (2.6)    | .86               |
| Middle Eastern or North African                                         | 7 (1.7)      | 52 (5.9)    | .001 <sup>†</sup> |
| Black or African American                                               | 13 (3.2)     | 10 (1.1)    | .08               |
| American Indian or Alaska Native                                        | 1 (0.2)      | 7 (0.8)     | .25               |
| Native Hawaiian or Pacific Islander                                     | 0 (0.00)     | 1 (0.1)     | .50               |
| Location                                                                |              |             |                   |
| North America                                                           | 266 (66.0)   | 426 (48.8)  | 1.44              |
| Europe                                                                  | 38 (9.4)     | 102 (11.7)  | .31               |
| Asia                                                                    | 36 (8.9)     | 118 (13.5)  | .03 <sup>†</sup>  |
| Australia                                                               | 35 (8.7)     | 85 (9.7)    | .65               |
| South America                                                           | 21 (5.2)     | 126 (14.5)  | 1.02              |
| Africa                                                                  | 7 (1.7)      | 15 (1.7)    | .93               |
| Age, y                                                                  |              |             |                   |
| <25                                                                     | 5 (1.2)      | 0 (0.0)     | .008 <sup>†</sup> |
| 25–34                                                                   | 48 (11.9)    | 72 (8.2)    | .03 <sup>†</sup>  |
| 35–44                                                                   | 139 (34.4)   | 247 (28.2)  | .03 <sup>†</sup>  |
| 45–54                                                                   | 108 (26.7)   | 310 (35.6)  | .01 <sup>†</sup>  |
| 55–65                                                                   | 74 (18.3)    | 176 (20.1)  | .62               |
| >65                                                                     | 30 (7.4)     | 72 (8.2)    | .72               |
| Profession                                                              |              |             |                   |
| Physician                                                               | 195 (48.5)   | 737 (84.0)  | 4.33              |
| Allied Professional (NP, PA, nurse, technologist)                       | 182 (45.3)   | 105 (11.97) | 3.58              |
| Other clinical specialists                                              | 25 (6.22)    | 35 (3.99)   | .07               |
| Clinical practice in EP lab                                             |              |             |                   |
| Yes, currently                                                          | 316 (78.4)   | 806 (91.8)  | .03 <sup>†</sup>  |
| Not currently                                                           | 67 (16.6)    | 64 (7.3)    | 5.59              |
| Never                                                                   | 20 (4.96)    | 8 (0.9)     | 3.70              |
| Years of experience, y                                                  |              |             |                   |
| <10                                                                     | 183 (45.4)   | 251 (28.6)  | 3.28              |
| 10–20                                                                   | 131 (32.5)   | 346 (39.4)  | .08               |
| >20                                                                     | 89 (22.1)    | 281 (32.0)  | .003 <sup>†</sup> |
| Type of procedures <sup>‡</sup>                                         |              |             |                   |
| Ablations                                                               | 366 (96.3)   | 823 (95.1)  | .85               |
| CIED                                                                    | 351 (92.4)   | 797 (92.1)  | .73               |
| CIED extraction                                                         | 189 (49.7)   | 433 (50.1)  | .72               |
| LAAO                                                                    | 137 (36.1)   | 371 (42.9)  | .04 <sup>†</sup>  |
| Other procedures                                                        | 70 (18.4)    | 160 (18.5)  | .84               |
| Procedural status                                                       |              |             |                   |
| Permanently stopped doing procedures                                    | 53 (13.9)    | 98 (11.3)   | .27               |
| Did not stop doing procedures permanently                               | 328 (86.1)   | 767 (88.7)  | .42               |
| Reason for not performing or participating in EP procedures             |              |             |                   |
| Personal reasons (alternate career interests/retirement/choice)         | 43 (81.1)    | 75 (85.2)   | 6.84              |
| Orthopedic injuries (not caused by sports or outside EP lab activities) | 8 (15.1)     | 19 (21.6)   | .03 <sup>†</sup>  |
| Malignancy                                                              | 5 (9.4)      | 8 (9.1)     | .56               |
| Pregnancy related (choice)                                              | 4 (7.6)      | N/A         | N/A               |
| Pregnancy related (complications)                                       | 0 (0.00)     | N/A         | N/A               |

CIED = cardiac implantable electronic device; EP = electrophysiology; LAAO = left atrial appendage occlusion; lab = laboratory; N/A = not available; NP = nurse practitioner; PA = physician assistant.

\*Denominators vary by question owing to incomplete responses. Percentages reflect the number of respondents per item.

<sup>†</sup>Statistically significant ( $P < .05$ ).

<sup>‡</sup>Type of procedures are not mutually exclusive.

permanently stopped doing EP procedures and 767 (88.7%) worked in the EP lab at the time of survey completion. The reasons for permanent cessation of working in the EP lab are presented in Table 2.

## Specific health-related issues

### Malignancy rates

Of 53 women (13.9%) and 98 men (11.3%) who stopped doing procedures for any reason, 5 (9.4%) and 8 (8.1%), respectively, reported malignancy as the reason for doing so.

Of the respondents, 1237 (98.6%) had no history of malignancy before working in the EP lab. Of those who currently work in the EP lab, 97 (7.8%) had malignancy after starting to work in the EP lab. Of these, 34 (35.1%) were women and 63 (64.9%) were men. Among the participants diagnosed as having malignancy after working in the EP lab, reported types included thyroid cancer in 15 individuals (15.5%), breast cancer in 11 (11.3%), other solid tumors (prostate, uterine, ovarian, renal, tongue, and sarcoma) in 29 (29.9%), hematologic cancers in 10 (10.3%), gastrointestinal and hepatopancreatobiliary cancers in 4 (4.1%), lung cancer in 3 (3.1%), skin cancers (melanoma, basal cell, and squamous cell) in 23 (23.7%), and brain cancer in 1 (1%) (Figure 1).

### Pregnancy-related issues (complications and infertility)

Of the 381 women who responded (92.3%), 242 (63.5%) reported being pregnant, 132 (34.7%) were never pregnant, and 7 (1.8%) preferred not to answer. Age at first pregnancy was younger than 30 years for 105 (43.6%), between the ages of 30 and 39 years for 123 (51%), and older than 39 years for 13 individuals (5.4%). Of the women who were never pregnant, 33 (25%) were younger than 35 years, 76 (57.5%) were between 35 and 54 years, and 23 (17.4%) were older than 55 years. Pregnancy-related complications were

encountered in 121 women (50%). Of all the women who were pregnant, 64 (27.1%) experienced pregnancy loss or miscarriages, 35 (14.8%) underwent in vitro fertilization, 23 (9.8%) experienced preterm labor or fetal growth problems, 21 (8.9%) experienced hypertensive disorders of pregnancy, 12 (5.1%) experienced placental complications, 4 (1.7%) experienced maternal arrhythmias or postpartum cardiomyopathy, and 23 (9.8%) experienced other complications (Figure 2).

### Premature cataracts (before the age of 50 years)

Of the 1237 respondents, 46 (3.7%) reported being diagnosed as having cataracts before the age of 50 years (Figure 3).

### Orthopedic injuries

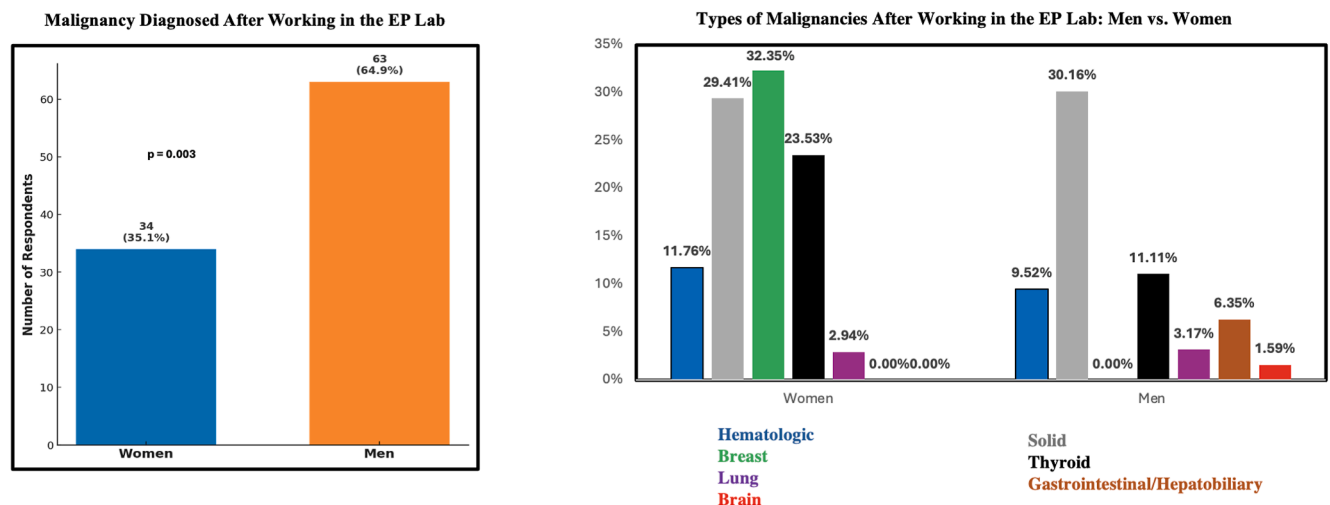
Of the 1174 respondents who currently work in the EP lab, 693 (59%) reported no orthopedic issues related to working in the EP lab, whereas 481 (41%) reported orthopedic injuries possibly related to working in the EP lab. Of those with orthopedic injuries, 109 (22.7%) underwent surgery, 325 (67.6%) had physical therapy and/or rehabilitation, and 234 (48.6%) were treated with medications. Specific types of orthopedic injuries were not asked in the survey (Figure 4).

## Discussion

Our survey explored the burden of occupational hazards among EPs and EP lab professionals, with the intention of informing future strategies to reduce risk and improve workplace safety.

### Malignancy rates

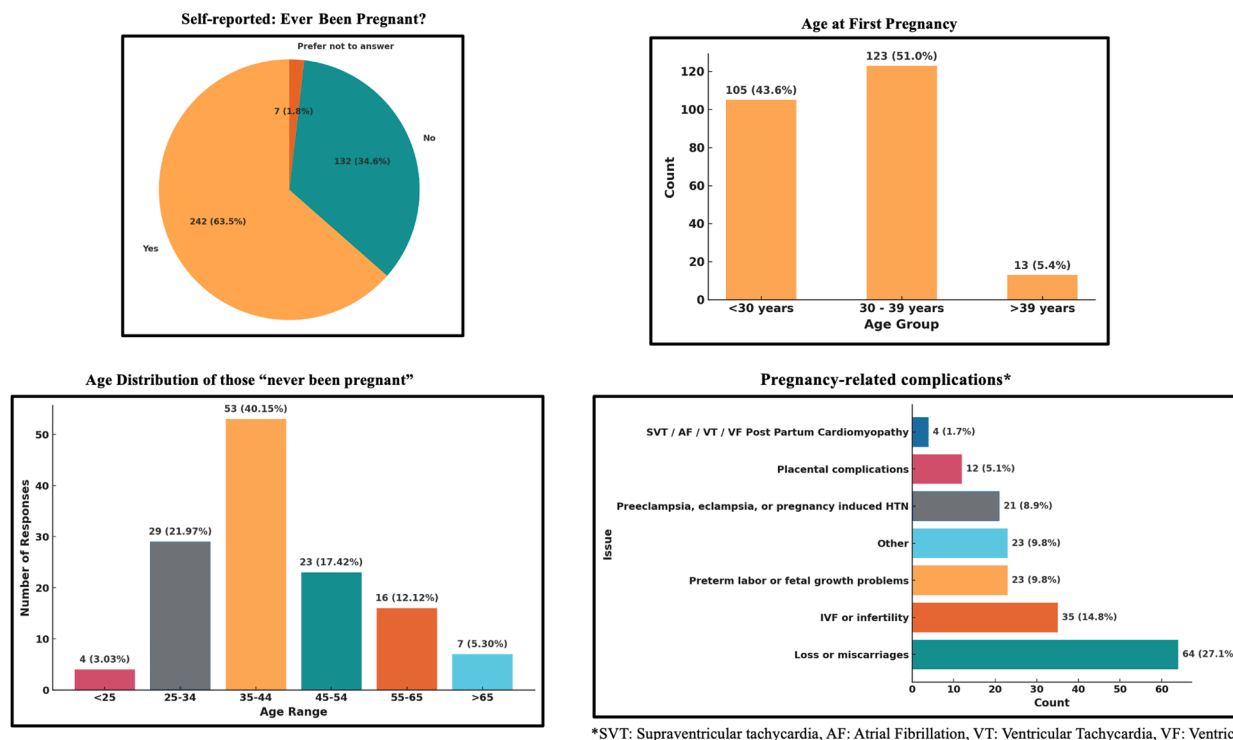
Malignancy was reported in 7.8% participants during their time in the EP lab. The most common cancers were solid



\*p value = 0.038 for Thyroid cancer and Stomach/Pancreas/GI cancer. Others are not statistically significant.

Figure 1

Malignancies AFTER working in the EP lab. EP = electrophysiology; GI = gastrointestinal; lab = laboratory.

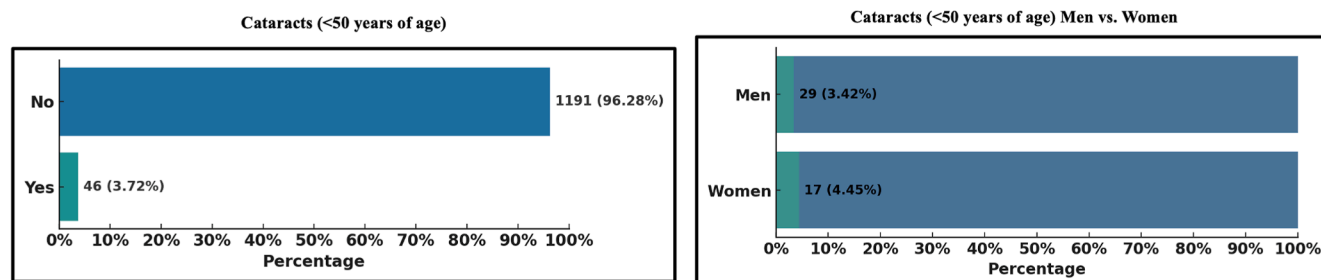
**Figure 2**

Pregnancy information and pregnancy-related issues. AF = atrial fibrillation; SVT = supraventricular tachycardia; VF = ventricular fibrillation; VT = ventricular tachycardia.

tumors in 29.9%, thyroid cancer in 15.5%, and breast cancer in 11.3%. Apart from breast cancer, women reported higher rates of thyroid cancer and men reported higher rates of gastrointestinal and hepatobiliary cancers. Thyroid cancer rates in our cohort were 4 times higher than the general population (15.5% vs 3.9%), and leukemia/myelodysplastic syndromes occurred more than 3 times more frequently (10.3% vs 3.2%).<sup>8</sup> Our findings are consistent with a previous study, which reported increased cancer risk in cardiac catheterization lab workers with  $\geq 16$  years of exposure (odds ratio 8.7; 95% confidence interval 1.4–52;  $P = .02$ ).<sup>9</sup> Stochastic effects of ionizing radiation, such as malignancy, are dose independent and have a long latency for disease manifestation. Understanding the causality requires longitudinal data collection over several years, but ionizing radiation exposure in the EP lab remains a growing concern.<sup>10</sup>

### Pregnancy-related issues (complications and infertility)

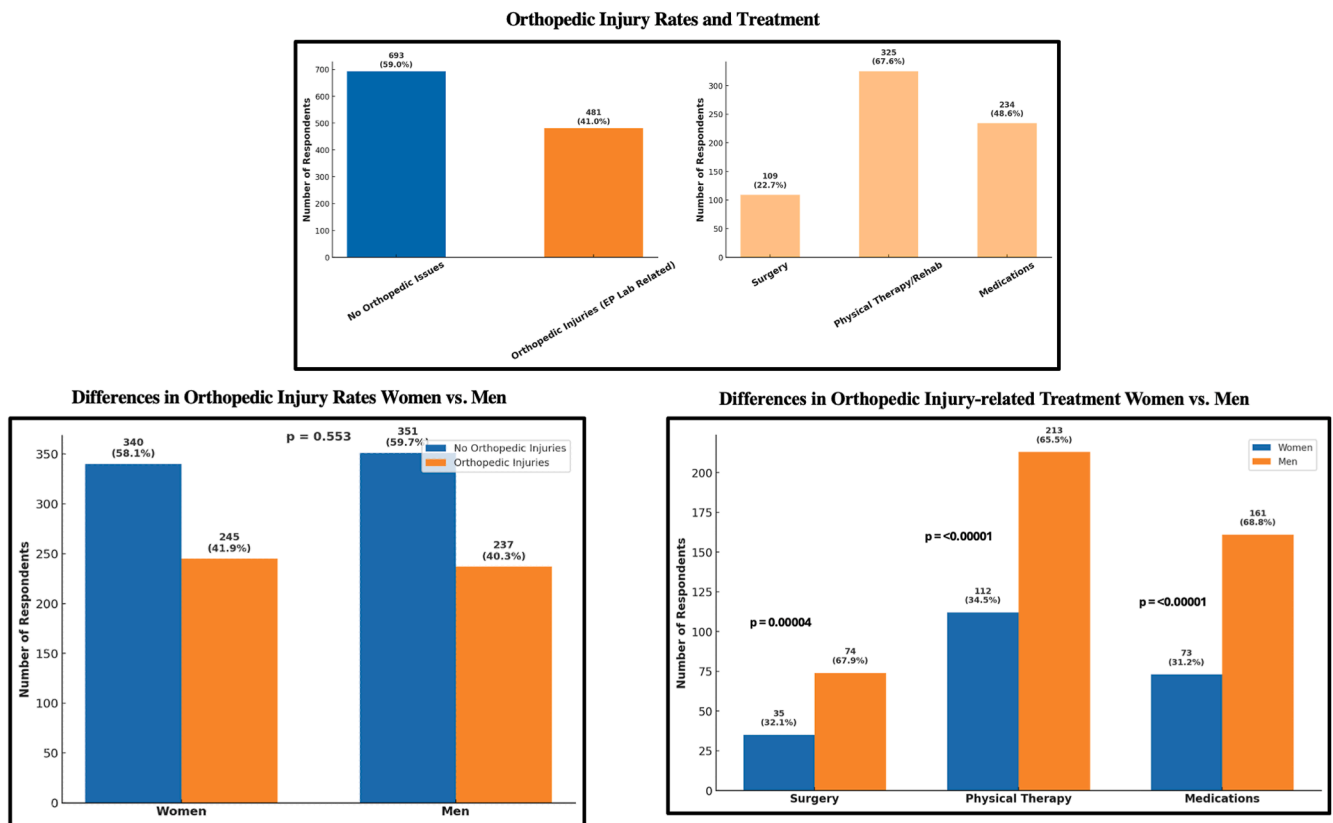
Among women participants, 63.5% reported being pregnant, with complications occurring in 50%, most commonly miscarriage in 27.1%. Miscarriage rates among EPs were nearly double those in the general population (27.1% vs 15.3%).<sup>11</sup> Approximately 35% were nulliparous, although reasons were not assessed in this survey. Of women who were never pregnant, 57.5% were between 35 and 54 years old. The trend of delayed pregnancies in our survey reflects patterns observed in women in medicine and surgery, with significantly higher rates of first pregnancy occurring at advanced maternal age (>35 years) than the general population (56.4% vs 18.2%).<sup>12–15</sup> Although delayed pregnancy may contribute, the 27.1% miscarriage rate still exceeds the 20% expected average for ages 35–39 years, suggesting additional occupational factors.<sup>16</sup> Advanced maternal age



p value = 0.41. Not statistically significant.

**Figure 3**

Premature cataracts.



**Figure 4**  
Orthopedic issues.

is associated with increased maternal and fetal complications, potentially contributing to the higher rates of complications and infertility rates seen in EP. Although previous studies report fetal radiation exposure to be well below the established safety limits with appropriate shielding, occupational factors, including heavy lead use, prolonged procedures, and radiation exposure concerns, and deferring pregnancy during training may affect pregnancy-related issues.<sup>4,5</sup> A 2021 study reported that women fellows in training are more likely than men to avoid pursuing EP owing to radiation concerns.<sup>17</sup> Similarly, 68% of EP professionals in a European Heart Rhythm Association survey expressed concern about radiation's impact on fertility and offspring, with 80% preferring no radiation exposure during pregnancy.<sup>18</sup> These findings call for a multipronged approach, including radiation safety education, institutional support for reproductive planning, and further age-stratified studies.

#### Premature cataract risk

Premature cataracts were reported in 3.72% respondents, higher than the 2.51% noted in the general population (ages 40–49 years).<sup>19</sup> Given that both stochastic and deterministic radiation effects contribute to cataract formation, these findings reinforce the need for improved protective measures, longitudinal data collection, and fluoroscopy-reduction tools in EP.

#### Orthopedic injuries

Approximately 40% of respondents reported orthopedic injuries potentially related to EP lab work. Similar trends were observed in other medical specialties that involve fluoroscopic procedures.<sup>7,8,20</sup> These findings highlight the prevalence of work-related orthopedic injuries and call for ergonomic enhancements and accessible and preventive musculoskeletal wellness programs to support clinician health.

#### Radiation exposure mitigation strategies

To minimize exposure to radiation scatter, EP professionals must wear protective equipment and adhere to the principles of distance, time, and shielding, using tools such as personal protective gear, ceiling-suspended shields, and table-mounted drapes.<sup>21</sup> Several technologies to eliminate fluoroscopy or reduce scatter are currently under investigation or are available only in select areas or regions (Table 3).<sup>22–29</sup>

#### A call for policy and future direction

These data raise the concern that the average career of an EP professional could be adversely affected. More than 50% report experiencing at least 1 occupational risk, such as malignancy, pregnancy-related complications, premature cataracts, or orthopedic injuries. This global survey highlights

**Table 3** Radiation minimizing technologies

| Technology/system                                        | Function                                                           |
|----------------------------------------------------------|--------------------------------------------------------------------|
| EggNest <sup>22</sup>                                    | Full-body shielding under the table                                |
| RAMPART <sup>23</sup>                                    | Transparent shielding booth with mobile arms                       |
| CABIN <sup>24</sup>                                      | Leaded enclosed booth                                              |
| RADPAD <sup>25</sup>                                     | Drapes to reduce scatter                                           |
| Niobe (Stereotaxis) <sup>26</sup>                        | Remote-controlled magnetic navigation                              |
| MRI-guided ablation <sup>27</sup><br>(ceramic catheters) | MRI guidance, limited by signal noise                              |
| Zero Gravity <sup>8</sup>                                | Weightless radiation protection                                    |
| Protego System <sup>29</sup>                             | Rigid and flexible shielding; certified in Michigan, United States |
| Zero-fluoroscopy tools                                   | Electroanatomic mapping, intravascular ultrasound                  |

MRI = magnetic resonance imaging.

the urgent need for data-driven and coordinated policies to safeguard EP lab professionals. Occupational risks demand sustained, intentional, and multilevel action at institutional, regional, and global levels (Figure 5).

Health care institutions must recognize that the loss of the EP workforce to occupational hazards directly affects clinical productivity. Radiation safety needs to be prioritized. Institutions must invest in modern fluoroscopy systems, lighter and more reliable protective gear, ergonomic infrastructure, and

real-time dose monitoring.<sup>30</sup> Standardizing low- or zero-fluoroscopy techniques is critical. Institutional support and dedicated funding are essential to ensure ongoing data monitoring and development of evidence-based interventions. Industry partnerships to subsidize and scale these innovations worldwide are essential.<sup>31</sup> Longitudinal tracking of these safety interventions will be vital to evaluate long-term impact on occupational health.

Despite increasing awareness of occupational hazards in procedural labs, gaps remain in our understanding of the full burden. A lack of formal reporting systems on occupation-related injuries and complications limits accurate assessment of the problem. Advancing this effort will require longitudinal data collection, registry development, collaboration with other professional societies, and integration of occupational safety sessions into annual meetings.

Institutions and academic programs must foster supportive environments promoting flexibility during pregnancy, normalizing family planning during training, potentially shortening training duration without compromising quality, and ensuring protected maternity leave. Standardizing fluoroless techniques during fellowship is essential to ensure scalable adoption across the spectrum of EP procedures. Radiation safety education should be embedded in the training curriculum. Finally, stronger state and federal oversight is required to enforce workplace and As Low As Reasonably Achievable standards.<sup>32</sup>

Often, personal health and physical well-being may not be on the priority list for many EP professionals owing to

**Figure 5**

Occupational hazards and mitigation strategies. 3D = 3-dimensional; HDP = hypertensive disorders of pregnancy; ICE = intracardiac echocardiography; IVF = in vitro fertilization.

demanding schedules and work-life imbalance. This calls for a cultural shift and focused programs to mitigate orthopedic injuries.

### Limitations

Our study has several limitations. The 4.4 response rate represents a key limitation, highlighting the need for further studies with broader participation. The survey provides cross-sectional data only without longitudinal information. We did not have access to the detailed demographic breakdown of the entire population who received the survey and therefore could not calculate response rates by subgroup. The survey did not assess psychological health risks. Individual radiation dosimetry data were not collected. Variations in exposure to radiation, proximity to the source, and years of exposure might have influenced the results. Data on compliance with protective gear, fluoroscopy system types, and access to safety technologies were not collected. It is important to note that the hazards identified in the survey may be directly or indirectly attributable to radiation exposure and our study does not establish causality. Given that not all respondents completed every question, resulting in variable denominators throughout the analysis, the generalizability of certain findings may be limited. Given that participation was voluntary, ascertainment bias could have influenced the findings by disproportionately capturing data from affected individuals, potentially overestimating the true prevalence of these conditions. On the contrary, reproductive challenges and malignancy rates might be underreported owing to stigma or fear of loss of employment. Moreover, the survey may not fully represent all geographic regions, with disproportionately higher representation from North America. Variations in response rates across different locations, specialties, and institutions may affect the overall diversity of the sample. Finally, self-reported data may be subject to recall bias or inaccuracy, particularly for subjective experiences.

### Conclusion

This global study revealed notable occupational hazards faced by EP professionals, particularly related to malignancies, orthopedic strain, and reproductive health risks. Although technological advances and growing awareness of the risk of radiation offer promise, meaningful and sustainable efforts remain important. Both direct and indirect effects of radiation, including cumulative physical strain from heavy protective gear, contribute to the overall burden. Greater institutional accountability, standardized safety protocols, clinician education, and supportive policies, especially for women, must be prioritized. Given the study's modest response rate, these findings should be interpreted with caution, reinforcing the need for longitudinal data, better surveillance, and standardized reporting to inform effective preventive strategies. A coordinated and multilevel commitment is needed to create a safer and sustainable EP work environment.

### Acknowledgments

The authors thank Adara Bowen and Ken Demith, Heart Rhythm Society, for their help with developing and sharing the survey and data collection.

### Appendix

#### Supplementary data

Supplementary data associated with this article can be found in the online version at <https://doi.org/10.1016/j.hrthm.2025.10.001>.

**Funding Sources:** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Disclosures:** See Appendix 1 for author disclosures.

**Address reprint requests and correspondence:** Heart Rhythm Society, 1325 G Street NW, Suite 500, Washington, DC 20005. E-mail address: [Documents@hrsonline.org](mailto:Documents@hrsonline.org)

### References

1. Venneri L, Rossi F, Botto N, et al. Cancer risk from professional exposure in staff working in cardiac catheterization laboratory: insights from the National Research Council's Biological Effects of Ionizing Radiation VII Report. *Am Heart J* 2009;157:118–124.
2. Roguin A, Goldstein J, Bar O. Brain tumours among interventional cardiologists: a cause for alarm? *EuroIntervention* 2012;7:1081–1086.
3. Andreassi MG, Cioppa A, Botto N, et al. Somatic DNA damage in interventional cardiologists: a case-control study. *FASEB J* 2005;19:998–999.
4. Fetterly KA, Schueler BA, Mihailovic JM, et al. Radiation exposure and protection for (assumed) pregnant interventional cardiologists and electrophysiologists. *J Soc CardioVasc Angiogr Interv* 2024;3:102239.
5. Saada M, Sanchez-Jimenez E, Roguin A. Risk of ionizing radiation in pregnancy: just a myth or a real concern? *Europace* 2023;25:270–276.
6. Elmarazy A, Morra ME, Mohammed AT, et al. Risk of cataract among interventional cardiologists and catheterization lab staff: a systematic review and meta-analysis. *Catheter Cardiovasc Interv* 2017;90:1–9.
7. Abudayyeh I, Dupont AG, Hermiller JB, et al. Occupational Health hazards in the Cardiac Catheterization Laboratory: results of the 2023 SCAI survey. *J Soc CardioVasc Angiogr Interv* 2025;4:102493.
8. Siegel RL, Giaquinto AN, Jemal A. Cancer statistics, 2024. *CA Cancer J Clin* 2024;74:100–121.
9. Andreassi MG, Piccaluga E, Guagliumi G, Del Greco M, Gaita F, Picano E. Occupational health risks in cardiac catheterization laboratory workers. *Circ Cardiovasc Interv* 2016;9:e003273.
10. Guagliumi G, Musumeci G, Picano E, et al. Cancer risk in the electrophysiology laboratory: is ionizing radiation the only culprit? *J Cardiovasc Dev Dis* 2023;10:121.
11. Quenby S, Gallos ID, Dhillon-Smith RK, et al. Miscarriage matters: the epidemiological, physical, psychological, and economic costs of early pregnancy loss. *Lancet* 2021;397:1658–1667.
12. Martinez GM, Daniels K. Fertility of men and women aged 15–49 in the United States: national Survey of Family Growth, 2015–2019. *Natl Health Stat Rep* 2023(179):1–28.
13. Rangel EL, Castillo-Angeles M, Easter SR, et al. Incidence of infertility and pregnancy complications in US female surgeons. *JAMA Surg* 2021;156:905–915.
14. Cusimano MC, Baxter NN, Sutradhar R, et al. Delay of pregnancy among physicians vs nonphysicians. *JAMA Intern Med* 2021;181:905–912.
15. Bakkensen JB, Smith KS, Cheung EO, et al. Childbearing, infertility, and career trajectories among women in medicine. *JAMA Netw Open* 2023;6:e2326192.
16. Early pregnancy loss. ACOG, <https://www.acog.org/clinical/clinical-guidance/practice-bulletin/articles/2018/11/early-pregnancy-loss>. Accessed July 26, 2025.
17. Abdulsalam N, Gillis A, Rzeszut A, et al. Gender differences in the pursuit of cardiac electrophysiology training in North America. *J Acc* 2021;78:898–909.
18. Adeliño R, Malaczynska-Rajpold K, Perrotta L, et al. Occupational radiation exposure of electrophysiology staff with reproductive potential and during pregnancy: an EHRA survey. *Europace* 2023;25:eua216.
19. Cataracts. National Eye Institute. <https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/cataracts>. Accessed May 3, 2025.
20. Orme NM, Rihal CS, Gulati R, et al. Occupational health hazards of working in the interventional laboratory: a multisite case control study of physicians and allied staff. *J Am Coll Cardiol* 2015;65:820–826.

21. Tamirisa KP, Alasnag M, Calvert P, et al. Radiation exposure, training, and safety in cardiology. *JACC Adv* 2024;3:100863.
22. The EggNest™: radiation protection for the entire interventional team. Egg Medical. <https://eggmedical.com/the-eggnest/>. Accessed May 3, 2025.
23. Lisko JC, Shekiladze N, et al. Radiation exposure using Rampart vs standard lead aprons and shields during invasive cardiovascular procedures. *J Soc CardioVasc Angiogr Interv* 2023;2:101186.
24. Dragusin O, Weerasooriya R, Jais P, et al. Evaluation of a radiation protection cabin for invasive electrophysiological procedures. *Eur Heart J* 2007;28:183–189.
25. Christopoulos G, Makke L, Christakopoulos GE, et al. Efficacy of the RADPAD protection drape in reducing operators' radiation exposure in the cardiac catheterization laboratory: a randomized controlled trial. *Circ Cardiovasc Interv* 2017;10:e006058.
26. Kiemeneij F, Patterson MS, Amoroso G, Laarman G, Slagboom T. Use of the stereotaxis Niobe magnetic navigation system for percutaneous coronary intervention: results from 350 consecutive patients. *Catheter Cardiovasc Interv* 2008;71:510–516.
27. Ratnayaka K, Faranesh AZ, Guttman MA, et al. Real-time MRI-guided right heart catheterization in adults using passive catheters. *J Cardiovasc Magn Reson* 2013;15:63.
28. Zellerhoff S, Van Der Bom IM, Nogueira RG. A prospective case control comparison of the Zero Gravity system versus a standard lead apron as radiation protection strategy in neuroendovascular procedures. *J Neurointerv Surg* 2016;8:1052–1057.
29. Rizik DG, Gosselin KP, Burke RF, Goldstein JA. Comprehensive radiation shield minimizes operator radiation exposure in coronary and structural heart procedures. *Cardiovasc Revasc Med* 2024;64:70–75.
30. Writing Committee Members, Hirshfeld JW Jr, Ferrari VA, et al. ACC/HRS/NASCI/SCAI/SCCT expert consensus document on optimal use of ionizing radiation in cardiovascular imaging: best practices for safety and effectiveness. *Catheter Cardiovasc Interv* 2018;92:E35–E97.
31. Preda A, Bonvicini E, Coradello E, et al. The fluoroless future in electrophysiology: a state-of-the-art review. *Diagnostics (Basel)* 2024;14:182.
32. Guidelines for ALARA – as low as reasonably achievable. Centers for Disease Control and Prevention. <https://www.cdc.gov/radiation-health/safety/alara.html>. Accessed May 3, 2025.

**Appendix 1** Writing committee member disclosure of RWI

| Writing committee member                | Employment                                                                                                                                                                                                 | Honoraria/<br>speaking/consulting                                                                                                                        | Speakers' bureau | Research*                                                                       | Fellowship support* | Ownership/<br>partnership/<br>principal/<br>majority<br>stockholder | Stock<br>or<br>stock<br>options | Intellectual<br>property/<br>royalties | Other                         |
|-----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|---------------------------------------------------------------------------------|---------------------|---------------------------------------------------------------------|---------------------------------|----------------------------------------|-------------------------------|
| Kamala P. Tamirisa, MD,<br>FHRs (Chair) | Texas Cardiac<br>Arrhythmia<br>Institute, Austin,<br>Texas                                                                                                                                                 | None                                                                                                                                                     | None             | None                                                                            | None                | None                                                                | None                            | None                                   | None                          |
| Sana M. Al-Khatib, MD,<br>MHS, FHRs     | Duke University<br>Medical Center,<br>Durham, North<br>Carolina                                                                                                                                            | None                                                                                                                                                     | None             | None                                                                            | None                | None                                                                | None                            | None                                   | American<br>Heart Association |
| Andrea M. Russo, MD,<br>FHRs            | Cooper Medical<br>School of Rowan<br>University,<br>Camden, New<br>Jersey                                                                                                                                  | PaceMate, Abbott<br>Medical,<br>Medtronic,<br>Biosense<br>Webster, Inc,<br>Atricure, Inc,<br>Bayer Healthcare<br>Pharmaceuticals,<br>Boston Scientific   | None             | Medtronic, Boston<br>Scientific, Abbott,<br>Bayer Healthcare<br>Pharmaceuticals | Medtronic           | None                                                                | None                            | UpToDate, Inc                          | ABIM                          |
| Jodie Hurwitz, MD, FHRs                 | North Texas Heart<br>Center, Dallas,<br>Texas                                                                                                                                                              | Medtronic, Inc,<br>Abbott, Impulse<br>Dynamics USA,<br>Kestra Medical<br>Technologies, Inc<br>American College of<br>Cardiology, Heart<br>Rhythm Society | None             | None                                                                            | None                | None                                                                | None                            | None                                   | None                          |
| Kenneth A. Ellenbogen,<br>MD, FHRs      | Virginia<br>Commonwealth<br>University School of<br>Medicine,<br>Richmond, Virginia                                                                                                                        |                                                                                                                                                          | None             | None                                                                            | None                | None                                                                | None                            | Wiley-<br>Blackwell,<br>Elsevier       | None                          |
| Sabine Ernst, MD                        | Royal Brompton<br>Hospital, Guy's and<br>St. Thomas' NHS<br>Foundation Trust,<br>London, United<br>Kingdom, and<br>National Heart and<br>Lung Institute,<br>Imperial College,<br>London, United<br>Kingdom | Biosense Webster,<br>Inc, Stereotaxis,<br>Inc                                                                                                            | None             | Abbott                                                                          | None                | None                                                                | None                            | None                                   | None                          |

(continued)

## Appendix 1 Continued

| Writing committee member              | Employment                                                                                                 | Honoraria/<br>speaking/consulting                                                                     | Speakers' bureau | Research*                                                                                                                         | Fellowship support* | Ownership/<br>partnership/<br>principal/<br>majority<br>stockholder | Stock or stock options | Intellectual property/<br>royalties | Other                                            |
|---------------------------------------|------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|------------------|-----------------------------------------------------------------------------------------------------------------------------------|---------------------|---------------------------------------------------------------------|------------------------|-------------------------------------|--------------------------------------------------|
| Tara Parham Graham, DNP, CRNP         | Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania                                     | iRhythm Technologies                                                                                  | None             | None                                                                                                                              | None                | None                                                                | None                   | None                                | None                                             |
| Melanie A. Gunawardene, MD, FHRS      | Cardioangiologic Center Bethanien, Markus Hospital, Frankfurt am Main, Germany                             | Farapulse, Abbott Medical, Boston Scientific, Medtronic, Biotronik, Luma Vision, Bristol Myers Squibb | None             | Medtronic, Inc                                                                                                                    | Boston Scientific   | None                                                                | None                   | None                                | Biosense Webster, Inc (travel/entertainment)     |
| Dhanunjaya Lakkireddy, MD, MBA, FHRS, | Kansas City Heart Rhythm Institute, Overland Park, Kansas                                                  | Medtronic, Inc, AtriCure, Inc, Abbott, Biosense Webster, Inc                                          | None             | None                                                                                                                              | None                | None                                                                | None                   | None                                | None                                             |
| Prashanthan Sanders, MBBS, PhD, FHRS  | Centre for Heart Rhythm Disorders, University of Adelaide and Royal Adelaide Hospital, Adelaide, Australia | Boston Scientific, Abbott Medical                                                                     | None             | Abbott Medical, Becton Dickinson, Calyan Technologies, Ceryx Medical, Biosense Webster, Inc, CathRx, Hello Alfred, Medtronic, Inc | None                | None                                                                | None                   | None                                | Advisory Boards: Medtronic PLC, PaceMate, CathRx |
| Juan Carlos Zepa Acosta, MD, FHRS     | Hospital do Coração, São Paulo, Brazil                                                                     | Abbott                                                                                                | None             | None                                                                                                                              | None                | None                                                                | None                   | None                                | None                                             |

This table is a comprehensive list of the RWI disclosed by each writing committee member for the 12 months before the initial meeting of the writing committee and up through the completion of the document. The table does not necessarily reflect the RWI of the writing committee members at the time of publication. Please refer to the HRS Code of Ethics and Professionalism for definitions of disclosure categories or additional information about the HRS policy on the disclosure of RWI.

HRS = Heart Rhythm Society; RWI = relationships with industry and other entities.

\*Research and fellowship support are classed as programmatic support. Sources of programmatic support are disclosed but are not regarded as a relevant relationship with industry for writing group members or reviewers.