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Team perception of the radiation safety climate in the hybrid angiography suite: a cross-sectional study

Bart Doyen, Peter Vlerick, Gilles Soenens, Frank Vermassen, Isabelle Van Herzeele

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Gilles Soenens: Conceptualization, Methodology, Writing - Review & Editing
Frank vermassen: Conceptualization, Writing - Review & Editing, Supervision
Isabelle Van Herzeele: Conceptualization, Methodology, Writing - Review & Editing, Supervision

Title page

Title

Team perception of the radiation safety climate in the hybrid angiography suite: a cross-sectional study

Short title: Radiation safety climate in the hybrid angiosuite

Authors:

Bart Doyen[a*], Peter Vlerick[b], Gilles Soenens[a], Frank Vermassen[a], Isabelle Van Herzeele[a]
[a] Department of Thoracic and Vascular Surgery, Ghent University Hospital, Ghent, Belgium
[b] Department of Work, Organisation and Society, Ghent University, Ghent, Belgium

* Corresponding author:

Bart Doyen
Department of Thoracic and Vascular Surgery
Ghent University Hospital, 2K12D
Corneel Heymanslaan 10, 9000 Ghent
Belgium
Tel.: +32 9 332 48 91
E-mail: bart.doyen@ugent.be

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Title

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Abstract

Background: Good radiation safety practice in the angiosuite is essential to protect patients and healthcare workers. Most strategies aim to advance radiation safety through technological upgrades and educational initiatives. However, safety literature suggests that additional ways to improve radiation safety in the angiosuite do exist. The safety climate reflects the way team members perceive various key characteristics of their work environment and is closely related to relevant safety outcomes. A specific 'radiation safety climate' has not been described nor studied in the hybrid angiosuite. This study explores the radiation safety climate in the hybrid angiosuite and its relation to team members' radiation safety behavior, knowledge and motivation.

Materials and Methods: Vascular surgeons, fellows/trainees and operating room nurses active in the angiosuite at five hospitals were invited to complete an online self-report questionnaire assessing the radiation safety climate (28 items); radiation safety behavior; radiation safety knowledge and radiation safety motivation. Relations between climate scores and behavior were investigated using Pearson correlations. Mediation was analyzed using the Baron and Kenny analysis. P-Values < 0.05 were considered statistically significant.

Results: No major differences were identified in total radiation safety climate scores between centers or team member functions. Scale reliability for radiation safety climate was good to excellent ($\alpha > 0.663$). Total radiation safety climate scores were positively related to the radiation safety behavior score ($r=0.403$; $p=0.015$). This relation was partially mediated by radiation safety knowledge ($\beta=0.1730$; 95% CI: [0.0475; 0.3512]), while radiation safety motivation did not act as a mediator: ($\beta=0.010$; 95% CI: [-0.0561; 0.0998]).

Conclusion: A well-developed radiation safety climate in the hybrid angiosuite fosters positive radiation safety behaviors, which may partially be explained through improved radiation safety knowledge transfer. Further research on (radiation) safety climate and its impact on radiation safety-related outcome measures for patients is recommended.

Key words: Endovascular; Radiation safety climate; Radiation safety behavior; Radiation safety; Healthcare worker; Ionizing radiation

1. Introduction

In vascular surgery, rapid technological innovation has shifted the surgical landscape towards minimally invasive endovascular treatment of increasingly complex pathologies, often performed in a high-tech hybrid angiography suite (from here on referred as angiosuite). This has strongly increased the use of ionizing radiation [1], exposing patients and endovascular team members to important risks, such as skin damage, cataract and development of malignancies [2,3]. To adequately manage these risks and warrant patient and team safety, team members need to apply the 'as low as reasonably achievable' (ALARA) principles of radiation safety (Appendix A) and optimize radiation safety practices in the angiosuite[2,3].

1.1. Establishing a (radiation) safety culture

There are numerous interventions and management strategies through which (radiation) safety-related practices can be affected and improved. Following the safety literature, these can be categorized into two categories or 'routes', depending on the organizational level at which they take place:

The 'technological/managerial/engineering route' involves any technology-based interventions and managerial decisions regarding safety that take place at higher levels of the organization. Examples include perfecting radiation safety equipment to reduce radiation doses [4-11] and developing and implementing standard operating procedures to routinely measure (occupational) radiation doses and manage overexposed patients or team members.

Conversely, the 'human route' acknowledges and stresses the importance of non-technological, human-related factors taking place at the workers' level. Examples include employees' job satisfaction, their safety motivation and attitudes, but also encompasses educational initiatives to improve team members' safety knowledge and influence their safety behaviors [12-15].

Although both routes occur at different hierarchical levels within an organization and have distinct working mechanisms, they are not mutually exclusive, as they affect the same safety outcomes and can complement or even strengthen each other. In the food industry, De Boeck et al. [16] proposed and validated a conceptual framework which structures key components of both routes and their interplay into a single overarching concept called 'safety culture'.

In the context of radiation safety, several specialists and professional organizations have already expressed the urgent need for a well-developed 'radiation safety culture' [17-23], which combines characteristics of the ‘human’ and ‘technological/managerial/engineering’ routes to provide an all-encompassing outline of the habits and beliefs necessary for optimizing radiation safety practices. Examples include: ‘shared responsibility for radiation safety within the team, with possibility to speak up’, ‘frequent monitoring of doses and reflection on radiation safety performance’, ‘optimization of technical performance through qualitative education’, ‘Involvement and commitment of leaders in maintaining radiation safety’, etc. [21,23-25].

As safety culture is a very broad and inclusive higher-order construct, which tends to be quite stable over time, safety scholars, nowadays, propose to measure safety culture more precise and at the individual or group level, through assessment of safety climates at work [26].

1.2. Radiation safety climate in the angiosuite

Safety climate is defined as ‘*employees'* (shared) perception of leadership, communication, commitment, resources and risk awareness concerning the safety situation within their work organization’ [16]. It can be considered an expression of an organization’s safety culture at a specific moment in time, through the eyes of the employees, which makes it more tangible and suitable for evaluation (e.g. through questionnaires) compared to radiation safety culture.

Safety climates have already been described in 1980 by Zohar et al. [27] and their relevance have been demonstrated in various technology-based environments in healthcare [28,29] and non-healthcare sectors, such as aviation, food industry, and nuclear and radiation facilities [16,30,31]. Meta-analyses [32,33] have also confirmed that better safety climates improve safety-related behaviors, yielding better work outcomes (e.g. safety performance, employees' attendance and organizational commitment). Furthermore, previous research revealed a mediating role of safety knowledge and safety motivation (Table 1) in the relationship between safety climates and employees' behaviors [16,29,34].

Yet, despite this accumulating evidence, the radiation safety climate in the endovascular field remains unstudied. This study aims to investigate if a radiation safety climate can be evaluated in the angiosuite using self-assessment and whether previous findings in other fields regarding safety behavior and its relationship with safety knowledge and motivation can be replicated in a radiation safety context.

2. Material and methods

This multicenter observational cross-sectional study has been approved by the ethical committee (Registration number: B670201837824) and has been registered in the ‘Clinicaltrials.gov’ database (Unique Identifying Number: NCT04063969). This report is written following the 'Strengthening the reporting of cohort studies in surgery'(STROCSS) guideline [35].

2.1. Online questionnaires

An online questionnaire (SurveyMonkey, California, United States) was used to assess the perceived radiation safety climate, radiation safety behavior, radiation safety knowledge and radiation safety motivation of vascular surgeons, fellows, trainees and nurses in the angiosuite (Table 1). All questions were presented in participants' native language (i.e. Dutch).

Eligible participants were invited per e-mail and non-responders were sent reminders at a two-week interval. Participants provided informed consent and completed a demographics questionnaire about their current function and professional experience with endovascular procedures. All data were stored depersonalized.

To assess participants' perceived *radiation safety climate,* a validated (Dutch) safety climate questionnaire [36] was adapted to a radiation safety context by the research team, based on literature review and interviews with subject matter experts. The 28-item questionnaire assesses five components of the radiation safety climate (Appendix B). First, *'leadership'* (6 items) measures how team members perceive their leaders' engagement and ability to set and achieve radiation safety objectives. Secondly, *'communication'* (5 items) reflects the perceived quality of radiation safety communication within the team and with leaders. Thirdly, *'commitment'* (5 items) measures whether radiation safety is perceived as a priority in the angiosuite. Fourthly, *'resources'* (6 items), refers to the perceived availability of resources (time, equipment, education…) required for safe practice. Finally, *'risk awareness'* (6 items) reflects the perceived awareness of team members/peers and leaders of radiation-related risks within the angiosuite. All statements were rated on 5-point Likert scales (1: Completely disagree; 3: Neutral; 5: Completely agree). Sum scores were computed for each component and the total radiation safety climate (all 28 items).

Participants' self-assessed *radiation safety behavior* was measured using two items (Appendix B), adapted from the safety performance framework of Neal et al., who described the role of safety behavior in healthcare [29]. This measure encompasses both mandatory behaviors (i.e. radiation safety compliance; *'I follow the highest standards of* radiation safety*… e.g. wearing all required protective equipment…') and* voluntary actions to improve safety (i.e. radiation safety participation; *'I put in extra effort to improve* radiation safety… *e.g. voluntary tasks or activities…')*. Each item was rated using a 5-point Likert scale and a total radiation safety behavior score was computed by adding both ratings.

Finally, self-reported *radiation safety knowledge ('I possess the necessary knowledge…)* and *radiation safety motivation ('I consider it important to maintain radiation safety at all times…')* were assessed using two single items inspired by Neal et al. [29] (Appendix B).

2.2. Statistics

Data analysis was performed using SPSS software (version 25; IBM Corp, Armonk, NY). Linear variables were analyzed using t-tests or ANOVA with post-hoc Bonferroni analysis for variables with two or three categories respectively. Variable relationships were assessed using Pearson analysis. P-Values < 0.05 were considered statistically significant.

The mediation effect of radiation safety knowledge and motivation was investigated using the Baron and Kenny analysis (Figure 1A) [37]. This method explores the relationship between independent (radiation safety climate) and dependent variables (radiation safety behavior) to identify an indirect connection mediated through a 'mediator' (radiation safety knowledge / radiation safety motivation). To test mediation, there should be significant relations between the independent and the dependent variables and between the mediator and both independent and dependent variables, after controlling for confounding variables. Additionally, when controlling for the effect of the mediator variable, the relationship between the independent variable and the dependent variable should weaken (i.e. partial mediation) or disappear (i.e. complete mediation). All analyses were performed using the PROCESS macro (v3.3; Andrew F. Hayes). Effect sizes are reported as standardized β-values. All results were confirmed through bootstrapping and analysis of the 95% confidence intervals.

3. Results

3.1. Characteristics of participating centers

Between February and May 2019, 69 out of 89 team members (85%) from five centers completed the questionnaire. Centers 1 and 4 utilized a Philips C-arm equipped with AlluraClarity™ (Philips N.V., Amsterdam, Netherlands), centers 2 and 5 used a Siemens Zeego™ C-arm (Siemens, Munich, Germany) and center 3 used a GE healthcare Discovery™ IGS C-arm system (GE Healthcare, Chicago, Illinois, United States). Participant characteristics are shown in table 2.

3.2. Control variables

Significant differences between centers were noted for the radiation safety climate 'leadership' component, with the lowest scores in center 1 and the highest in center 5 (Table 3). Comparison of function groups revealed a significant difference in reported radiation safety knowledge, with staff surgeons scoring highest, followed by nurses and trainees/fellows scoring lowest (respective means (SD): 4.2 (1.0) vs. 3.5 (0.9) vs. 3.3 (1.0);

p=0.018). Other outcome variables did not differ significantly between function groups. Team members who had completed a radiation safety educational course scored significantly higher on self-reported radiation safety knowledge, compared to those who had not (respective means (SD): 4.0 (0.8) vs. 3.2 (1.0); $p=0.001$)

When investigating the correlations between control variables (work experience in current function and since radiation safety training) and study variables, a significant, weak correlation was identified between team members' work experience in their current function and their risk awareness ($r=0.388$; $p<0.001$).

Given these results, participants' center, their function within the team, attendance of a radiation safety educational course and work experience (in years) were used as control variables.

3.3. Radiation safety climate, behavior, knowledge and motivation

Overall, moderate to strong positive correlations were found between the five radiation safety climate components and the total radiation safety climate score, with Pearson's r values between 0.666 (risk awareness) and 0.899 (leadership). Scale reliability was excellent ($\alpha=0.880$).

Radiation safety climate correlated positively with radiation safety behavior ($r=0.403$; $p=0.015$).

Employees' radiation safety knowledge correlated moderately positive with total radiation safety climate ($r=0.454$; $p=0.005$) and three component scores: leadership ($r=0.468$; $p=0.004$), communication ($r=0.338$; $p=0.044$) and risk awareness ($r=0.523$; $p=0.001$).

There was no statistically significant correlation between radiation safety motivation and the radiation safety climate score. However, moderate positive correlations were identified between employees' radiation safety motivation and their radiation safety behavior ($r=0.463$; $p=0.004$) and knowledge scores ($r=0.378$; $p=0.023$).

3.4. Mediation analysis

The Baron and Kenny mediation analyses confirmed that radiation safety knowledge partially mediated the positive relationship between radiation safety climate and radiation safety behavior (Figure 1B). This was confirmed after bootstrapping, as the 95% confidence intervals estimating the indirect effects of radiation safety climate on radiation safety behavior did not contain zero ($\beta=0.1730$; 95% CI: [0.0475; 0.3512]; SE=0.0770). Radiation safety motivation did not mediate the relationship between radiation safety climate and radiation safety behavior (Indirect effect: $\beta=0.010$; 95% CI: [-0.0561; 0.0998]; SE=0.0381).

4. Discussion

To protect patients and team members from the harmful effects of ionizing radiation in the angiosuite, proper application of radiation safety principles is crucial.

4.1. Assessment of Radiation safety climate

This multi-centric study is the first to measure the radiation safety climate in (endo)vascular practice using a self-assessment tool. The use of this online survey, among vascular surgeons, trainees/fellows and nurses active in the angiosuite was feasible and resulted in good response rates and satisfactory internal consistency.

4.2. Radiation safety climate and employee behavior

The radiation safety climate was positively correlated to radiation safety behavior which seems to replicate previous findings in other technological environments [16,28,34].

4.3. Radiation safety climate and radiation safety knowledge

Various international scientific organizations such as the International Commission on Radiological Protection (ICRP) [38] have already highlighted the importance of adequate radiation safety knowledge and stressed the key role of universities, hospitals and scientific societies in establishing and promoting well-developed radiation safety education [12-15].

In the angiosuite, radiation safety knowledge acted as a partial mediator in the relationship between radiation safety climate and radiation safety behavior. This suggests that in addition to theoretic training courses, developing a strong radiation safety climate may also improve a team's radiation safety knowledge, which in turn fosters safe behaviors.

More specifically, radiation safety knowledge was most strongly related to the leadership, communication and risk awareness components of radiation safety climate. These factors may diminish the barriers to share/develop knowledge, thereby enhancing transfer of radiation safety knowledge among team members [39].

Indeed, it seems plausible that when leaders highlight the importance of radiation safety and put the ALARA principles into practice, team members will pay more attention and remember these better. Similarly, it's likely that dissemination of radiation safety knowledge is better in an environment with clear communication, where team members can freely speak up about radiation safety issues and are heard.

4.4. Radiation safety climate and radiation safety motivation

Previous research has emphasized the key psychological role of motivational processes in employees' work behavior and team functioning [39,40]. Although safety motivation has previously been shown to mediate the relationship between safety climate and safety-related behaviors [16,28,29], we were not able to replicate this in the hybrid angiography suite.

Nevertheless, this does not make radiation safety motivation irrelevant. Positive correlations were found between radiation safety motivation and radiation safety behavior, suggesting that radiation safety motivation may be part of a separate, unexplored pathway towards radiation safety behaviors. For example, motivation might be affected by other factors, such as employees' psycho-social well-being (e.g. burnout, job stress), work characteristics (e.g. job content; work conditions) or individual characteristics (e.g. conscientiousness). Future studies are required to investigate the potential influence of these alternative factors on one's radiation safety motivation and behaviors.

4.5. Study limitations

These study results need to be interpreted with caution. Firstly, self-report measures and single-item questions (radiation safety knowledge and radiation safety motivation) in this study might have caused common-method-variance and self-report bias which may limit construct validity as individuals tend to over-report socially desirable answers [41]. Since self-report bias depends on many factors (e.g. nature of the question, personal characteristics, fear for punishment, situational pressures,…), it cannot be eliminated. Nevertheless, the authors tried to limit this bias by guaranteeing confidentiality, using existing pilot-tested scales and selecting items with high factor loadings and high face validity.

Additionally, due to the explorative nature of this study, the sample size was small. Nevertheless, similar sample sizes have also been reported by several valuable studies on safety climate in various specialties [16,42]. Additionally, despite the limited sample size, high response rates were achieved (overall 85%), with only a single center below 70%. This is crucial, as survey-driven studies are often plagued by non-response bias. Although this bias cannot be totally excluded, it is unlikely that it played an important role, suggesting that, while the current sample is small, it may be representative of the radiation safety climate within hybrid angiosuites in the participating centers.

Furthermore, while five centers of varying sizes with both academic and non-academic backgrounds participated, all hospitals were located in the same region. However, these findings may differ in other countries, due to differences in national culture and habits, regulations regarding radiation safety education [43] or composition of the team and roles of the various team members. For example, in some countries a dedicated radiographer is responsible for operating the C-arm and optimizing radiation safety, whereas in the current study, this was done by vascular surgeons and/or scrub nurses. Future studies should evaluate if differences between countries exist and how these may affect the radiation safety climate and team members' behavior.

Finally, as our findings are based on a cross-sectional research design, no causal statements can be inferred. Further longitudinal studies are needed to investigate potential causal effects.

4.6. Future research

Previous studies described positive relationships between safety climates and safety outcomes [32,33]. However, this was not investigated in the current study. Future large-scale studies should focus on the potential relationship between radiation safety climate and radiation safety-related outcomes, using relevant and representative outcome measures.
In general healthcare settings, safety outcomes include measures such as the number of patient/worker injuries or adverse events. However, in context of radiation safety, this is challenging, since direct radiation-related injuries are scarce and difficult to identify. Indirect radiation dose parameters such as the Dose Area Product and the Cumulative Air Kerma could be used, given their established value in the scientific community, though they may strongly vary between (e.g. different imaging systems), and within centers (e.g. differences in patient anatomy, procedure difficulty, lead physicians, etc.), independent of the perceived radiation safety climate. Therefore, these confounding factors will also need to be captured in detail to allow comparison between teams and centers. Alternatively, it may be valuable to investigate measures, such as direct assessment of team members' actual radiation safety behaviors. This may provide an objective evaluation of radiation safety-related outcomes, independent of patient, team and center-based characteristics. A rating scale to assess video recordings of radiation safety behaviors is currently under development.

Additionally, these outcome measures may also strengthen the analysis of the local radiation safety climate, through method triangulation [42]. This generates insights about how team members' perceptions influence their radiation safety behaviors and may facilitate development of targeted interventions, based on the local needs and deficiencies.

Finally, future research may also study the joined or synergistic effects of the human route (e.g. human factors) and the technological/managerial route (e.g. safety control and assurance procedures) on radiation safety outcomes.

5. Conclusions

This multicenter study is the first to investigate the radiation safety climate in the angiosuite. The results have shown that there is a strong positive direct and indirect effect of radiation safety climate on radiation safety behaviors of team members.

The indirect effect seems to be primarily mediated through team members' knowledge about radiation safety, which emphasizes the importance of high-quality education, radiation safety training and knowledge sharing within endovascular teams.

This investigation of the human pathway towards radiation safety suggests that solely applying control systems, standards and procedures may not be sufficient to achieve an optimal radiation safety culture. We hope that these results might inspire medical industry, (endo)vascular scientists and staff to recognize the importance of the 'radiation safety climate' and value human factors in their work environment.

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8. Tables

Table 1: Definitions of frequently used constructs and study variables

Construct	Definition
Radiation safety culture	Combination of the technical, social and scientific dimensions of safety management which encompasses all ideas, beliefs and habits that affect how radiation safety is managed at different organizational levels. [18]
Radiation safety climate	Perceptions and beliefs of the (individual) team members at a specific moment in time regarding the various aspects of the radiation safety situation in the angiosuite. [16]
Radiation safety behavior	The entirety of individuals' voluntary and mandatory radiation safety behaviors, required to develop and maintain radiation safety.
Radiation safety knowledge	Individuals' knowledge about the different aspects of radiation safety which is required for proper safety performance.
Radiation safety motivation	Individuals' willingness to exert effort to enact radiation safety behaviors and the valence associated with those behaviors. [29]
Mediating variable	A variable which can be used to explain the reason or mechanism for an (observed) relationship between two other variables.

Table 2: Participant characteristics per center

		Center 1	Center 2	Center 3	Center 4	Center 5
Response rate *N, %*		36/38 *94.7*	9/12 *75.0*	11/12 *91.7*	6/8 *75.0*	7/11 *63.6*
Function within the team *N, %*	Staff surgeon	5 *13.9*	2 *22.2*	2 *18.2*	2 *33.3*	3 *42.9*
	Fellow surgeon	2 *5.6*	0	1 *9.1*	0	0
	Trainee surgeon	6 *16.7*	3 *33.3*	3 *27.3*	0	1 *14.3*
	Nurse	23 *63.9*	4 *44.4*	5 *45.5*	4 *66.7*	3 *42.9*
Years active in current function	Median *(IQR)*	6 *2-10*	5 *2.5-6*	5 *2.5-15*	17.5 *5-26*	11 *1-30*
Number of EVAR procedures attended in current function *N, %*	0	4 *11.1*	0	0	0	0
	<10	11 *30.6*	3 *33.3*	4 *36.4*	1 *16.7*	0
	10 - 50	14 *38.9*	4 *44.4*	5 *45.5*	3 *50.0*	3 *42.9*
	51 - 100	3 *8.3*	0	1 *9.1*	1 *16.7*	2 *28.6*
	> 100	4 *11.1*	2 *22.2*	1 *9.1*	1 *16.7*	2 *28.6*
Followed a radiation safety training course *N, %*	No	18 *50.0*	6 *66.7*	4 *36.4*	1 *16.7*	2 *28.6*
	Yes	18 *50.0*	3 *33.3*	7 *63.6*	5 *83.3*	5 *71.4*
Years since radiation safety training course	Median *(IQR)*	4 *4-11*	7 *6-14*	12 *5-17*	9 *5-17*	11.5 *5.5-17*

Table 3: Questionnaire results per center

	Mean *SD*					P-Value ANOVA*
	Center 1 (n=36)	Center 2 (n=9)	Center 3 (n=11)	Center 4 (n=6)	Center 5 (n=7)	
Radiation safety climate - Leadership	**19,94** ***4,41***	**22,33** ***1,32***	**22,09** ***2,12***	**21,17** ***2,32***	**24,43** ***1,90***	**.023**
Radiation safety climate - Communication	16,39 *2,96*	18,00 *2,45*	16,73 *2,15*	16,83 *3,06*	18,29 *3,09*	.374
Radiation safety climate - Commitment	19,83 *4,34*	21,00 *2,92*	20,64 *2,69*	22,00 *2,10*	23,14 *1,95*	.211
Radiation safety climate - Resources	19,11 *3,62*	19,33 *4,12*	19,82 *3,82*	20,83 *3,43*	22,57 *1,72*	.199
Radiation safety climate - Risk awareness	18,36 *3,60*	18,00 *3,24*	18,18 *2,23*	19,67 *1,03*	19,00 *2,71*	.844
Radiation safety climate - Total	93,64 *16,09*	98,67 *11,29*	97,45 *11,41*	100,50 *9,18*	107,43 *6,70*	.166
Radiation safety behavior	6,75 *1,50*	7,78 *1,48*	6,82 *1,25*	7,17 *1,72*	8,29 *,95*	.065
Radiation safety motivation	4,50 *,56*	4,56 *,53*	4,36 *,50*	4,83 *,41*	4,71 *,49*	.413
Radiation safety knowledge	3,47 *1,06*	3,44 *1,01*	3,73 *,79*	3,67 *,82*	4,29 *,76*	.344

* Post-hoc testing with Bonferroni correction for multiple analyses; statistically significant p-values are mentioned in bold

9. Figures

Figure 1: Baron and Kenny analysis of mediation. **(A)** Context and legend. **Total effect**: Relationship between independent and dependent variables without taking the effects of the mediating variable into account. **Direct effect**: Part of the relationship between independent and dependent variables, which is not caused by the mediating variable. **Indirect effect**: Part of the relationship between independent and dependent variables, which is caused by the mediating variable. **(B)** Mediating effect of radiation safety knowledge in the relation between radiation safety climate and radiation safety behavior; statistically significant values are highlighted in bold.

10. Appendices

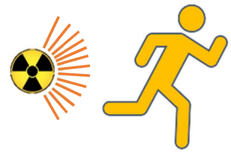
Appendix A: Poster-styled overview of radiation safety guidelines – 10 tips to keep your doses ALARA

Appendix B – Online questionnaire

Radiation safety in the hybrid angiography suite

10 tips to keep your doses ALARA (As Low As Reasonably Achievable)

1 Increase distance to the radiation source

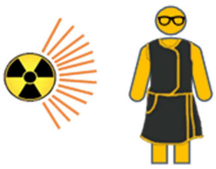


- √ **Step back** from the table during angiographies
- √ Stand on the side of the **image detector**

2 Manage your radiation usage

- √ Keep your **fluoroscopy time** as low as possible
- √ **Avoid** making **unnecessary angiographies**

3 Use personal protective equipment

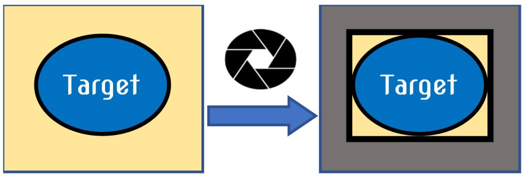


- √ Wear a **well-fitting lead apron** and **thyroid collar**
- √ Scrubbed in = **lead goggles**

4 Use additional shielding equipment

- √ Use **ceiling**- and **table-mounted lead shielding**
- √ Anaesthesiologists: use a **mobile lead screen**

5 Collimate the fluoroscopy image

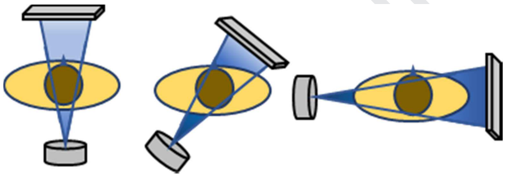


- √ **Collimate** the image as much as possible
- √ Only show the **area of interest**

6 Avoid using optical magnification

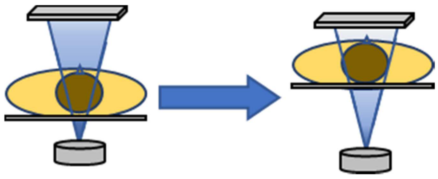
- χ Avoid optical magnification, use **digital zooming**
- √ Use a **large fluoroscopy screen**, close to operator

7 Avoid using steep angulations



- χ **Avoid** using **steep C-arm angulations** (>30°)
- √ **Avoid overexposure**: vary angulations if possible

8 Optimize patient and table positions



- √ **Use undercouch** system: X-ray tube **under** the table
- √ Position **detector** as **close to patient** as possible

9 Adjust image settings

- √ Use **low-dose imaging** mode whenever possible
- √ Use **pulsed fluoroscopy** with **low pulse rate**

10 Teamwork and communication

- √ Confirm safety: **'Is everyone protected?'**
- √ Concerned about radiation safety? **Speak up!**

Don't forget your dosimeters!

The following questionnaire assesses how you think about the radiation safety in your current workspace. Please read each of the following statements carefully and indicate how much you agree with each of these statements:

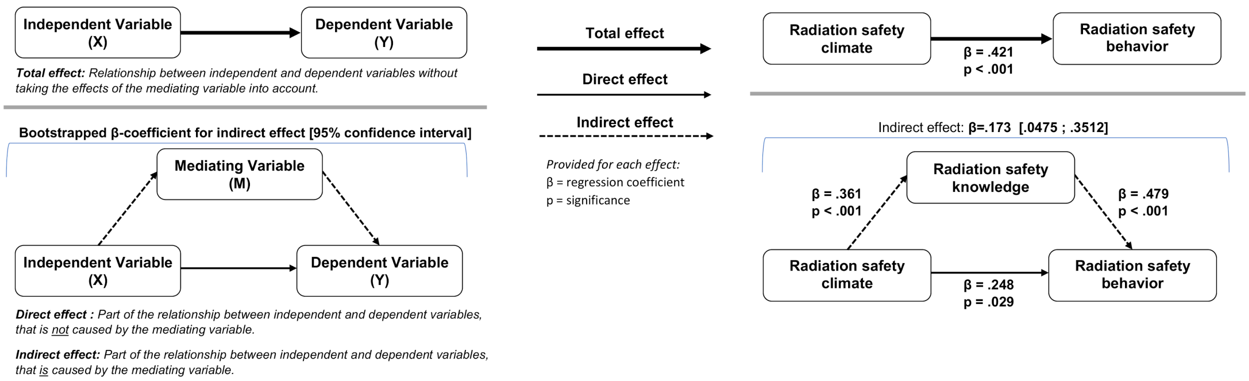
1 Completely disagree	2 Disagree	3 Neutral	4 Agree	5 Completely agree

Leadership concerning radiation safety in the hybrid angiography suite						
L1	In our hybrid angiography suite, the leaders set clear objectives concerning radiation safety.	1	2	3	4	5
L2	In our hybrid angiography suite, the leaders are clear about the expectations concerning radiation safety towards team members.	1	2	3	4	5
L3	In our hybrid angiography suite, the leaders are able to motivate their team members to work with ionizing radiation in a safe way.	1	2	3	4	5
L4	In our hybrid angiography suite, the leaders listen to team members, if they have remarks or comments concerning radiation safety.	1	2	3	4	5
L5	In our hybrid angiography suite, leaders address radiation safety issues in a constructive and respectful way.	1	2	3	4	5
L6	In our hybrid angiography suite, the leaders strive for a continuous improvement of radiation safety.	1	2	3	4	5
Communication concerning radiation safety in the hybrid angiography suite						
C1	In our hybrid angiography suite, the leaders communicate regularly with team members about radiation safety.	1	2	3	4	5
C2	In our hybrid angiography suite, the leaders communicate in a clear way with team members about radiation safety.	1	2	3	4	5
C3	In our hybrid angiography suite, it is possible for team members to communicate about radiation safety with the leaders.	1	2	3	4	5
C4	In our hybrid angiography suite, the importance of radiation safety is permanently present by means of, for example, posters, signs and/or icons related to radiation safety.	1	2	3	4	5
C5	I can discuss problems concerning radiation safety with colleagues in our hybrid angiography suite.	1	2	3	4	5
Commitment concerning radiation safety in the hybrid angiography suite						
Co1	In our hybrid angiography suite, the leaders clearly consider radiation safety to be of great importance.	1	2	3	4	5
Co2	My colleagues are convinced of the importance of radiation safety for the work within the hybrid angiography suite.	1	2	3	4	5
Co3	In our hybrid angiography suite, working in a radiation safe way is recognized and rewarded.	1	2	3	4	5
Co4	In our hybrid angiography suite, the leaders set a good example concerning radiation safety.	1	2	3	4	5
Co5	In our hybrid angiography suite, the leaders act quickly to correct problems/issues that affect radiation safety.	1	2	3	4	5
Co6	In our hybrid angiography suite, team members are actively involved by the leaders in radiation safety related matters.	1	2	3	4	5

1 Completely disagree	2 Disagree	3 Neutral	4 Agree	5 Completely agree

Resources concerning radiation safety in the hybrid angiography suite		
R1	In our hybrid angiography suite, team members get sufficient time to work with ionizing radiation in a safe way.	1 2 3 4 5
R2	In our hybrid angiography suite, sufficient staff is available to follow up radiation safety.	1 2 3 4 5
R3	In our hybrid angiography suite, the necessary infrastructure (e.g. good workspace, good equipment …) is available to be able to work with ionizing radiation in a safe way.	1 2 3 4 5
R4	In our hybrid angiography suite, sufficient financial resources are provided to support radiation safety (e.g. external support, maintenance, purchase of equipment…).	1 2 3 4 5
R5	In our hybrid angiography suite, sufficient education and training related to radiation safety is given.	1 2 3 4 5
R6	In our hybrid angiography suite, good procedures and instructions concerning radiation safety are in place.	1 2 3 4 5
Risk-awareness concerning radiation safety in the hybrid angiography suite		
Ra1	In our hybrid angiography suite, the risks related to radiation safety are known.	1 2 3 4 5
Ra2	In our hybrid angiography suite, the risks related to radiation safety are under control.	1 2 3 4 5
Ra3	My colleagues are alert and attentive to potential problems and risks related to radiation safety.	1 2 3 4 5
Ra4	In our hybrid angiography suite, the leaders have a realistic picture of the potential problems and risks related to radiation safety.	1 2 3 4 5
Ra5	In our hybrid angiography suite, the members of the endovascular team have a realistic picture of the potential problems and risks related to radiation safety.	1 2 3 4 5
Personal behavior, knowledge and motivation regarding radiation safety in the hybrid angiography suite.		
Mo1	I consider it important to maintain radiation safety at all times to prevent events and incidents in our hybrid angiography suite.	1 2 3 4 5
Kn1	I possess the necessary knowledge to maintain or improve the radiation safety in our hybrid angiography suite.	1 2 3 4 5
Com1	I follow the highest standards of radiation safety when I am active in the hybrid angiography suite (e.g. wearing all required protective equipment, applying the correct safety regulations…)	1 2 3 4 5
Pa1	I put in extra effort to improve radiation safety in our hybrid angiography suite (e.g. voluntary tasks or activities, promoting radiation safety…)	1 2 3 4 5

**Note: The currently presented (English) questionnaire was been adapted from the (Dutch) questionnaire used during the study through a translation-back-translation process.*



Independent Variable (X)
Dependent Variable (Y)
Total effect: Relationship between independent and dependent variables without taking the effects of the mediating variable into account.
Bootstrapped β-coefficient for indirect effect [95% confidence interval]
Mediating Variable (M)
Independent Variable (X)
Dependent Variable (Y)
Direct effect : Part of the relationship between independent and dependent variables, that is not caused by the mediating variable.
Indirect effect: Part of the relationship between independent and dependent variables, that is caused by the mediating variable.
Total effect
Direct effect
Indirect effect
Provided for each effect:
β = regression coefficient
p = significance
Radiation safety climate
Radiation safety behavior
β = .421
p < .001
Indirect effect: β=.173 [.0475 ; .3512]
Radiation safety knowledge
β = .361
p < .001
β = .479
p < .001
Radiation safety climate
Radiation safety behavior
β = .248
p = .029

Highlights

- Radiation safety climate can be reliably measured using self-report questionnaires
- In the hybrid angiosuite radiation safety climate is positively related to behavior
- Radiation safety knowledge partially mediates the relation of climate and behavior
- Well-developed radiation safety climates facilitate knowledge exchange
- Radiation safety climate does not seem to affect radiation safety motivation

International Journal of Surgery Author Disclosure Form

The following additional information is required for submission. Please note that failure to respond to these questions/statements will mean your submission will be returned. If you have nothing to declare in any of these categories, then this should be stated.

Please state any conflicts of interest

None to declare.

Please state any sources of funding for your research

Isabelle Van Herzeele received funding for research from the Fund for Scientific Research Flanders, Belgium

Please state whether Ethical Approval was given, by whom and the relevant Judgement's reference number

This multicenter observational study has been approved by the ethical committee of Ghent University Hospital (Registration number: B670201837824).

Research Registration Unique Identifying Number (UIN)

Please enter the name of the registry, the hyperlink to the registration and the unique identifying number of the study. You can register your research at http://www.researchregistry.com to obtain your UIN if you have not already registered your study. This is mandatory for human studies only.

1. Name of the registry:
   Clinicaltrials.gov

2. Unique Identifying number or registration ID:
   ClinicalTrials.gov Identifier: NCT04063969

3. Hyperlink to the registration (must be publicly accessible):
   https://www.clinicaltrials.gov/ct2/show/study/NCT04063969

Author contribution

Please specify the contribution of each author to the paper, e.g. study design, data collections, data analysis, writing. Others, who have contributed in other ways should be listed as contributors.

Bart Doyen: Conceptualization, Methodology, Investigation, Formal analysis, Writing - Original Draft
Peter Vlerick: Conceptualization, Methodology, Writing - Review & Editing, Supervision
Gilles Soenens: Conceptualization, Methodology, Writing - Review & Editing
Frank vermassen: Conceptualization, Writing - Review & Editing, Supervision
Isabelle Van Herzeele: Conceptualization, Methodology, Writing - Review & Editing, Supervision

Guarantor

The Guarantor is the one or more people who accept full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish. Please note that providing a guarantor is compulsory.

Bart Doyen
Isabelle Van Herzeele

Data statement

Given the sensitive nature of the items in the questionnaire, team members in each participating hospital were assured that raw data would remain confidential, therefore it is not possible to publicly share the raw data.