Dutch nuclear medicine and radiology residency

exploring challenges and opportunities

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Dutch nuclear medicine and radiology residency: exploring challenges and opportunities

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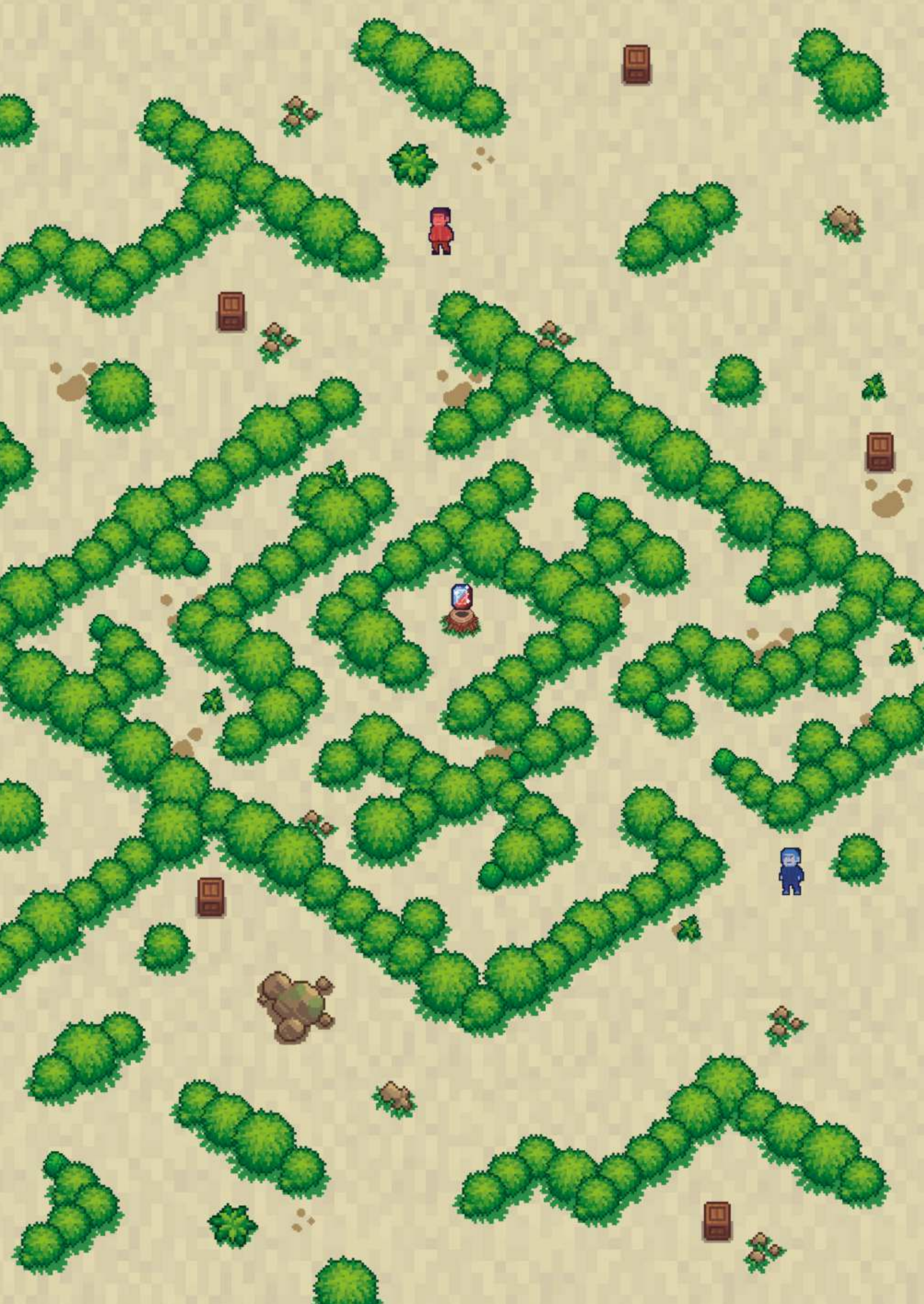


Chapter 1

General introduction

BACKGROUND

Global advancements in medicine can, in part, be attributed to the rapid developments in medical imaging, particularly in nuclear medicine and radiology. In the current state-of-the-art work-up of patients, both nuclear medicine and radiology offer a vast array of tools for early diagnosis, monitoring treatment response, and performing image-guided therapies, which are available for the diagnosis and treatment of a wide spectrum of diseases. Numerous techniques, some developed decades ago or even earlier, have been established in the field of radiology, including conventional imaging (X-ray), ultrasonography (US), computed tomography (CT), and magnetic resonance imaging (MRI). Similarly, in nuclear medicine, techniques such as single-photon emission computed tomography (SPECT) and positron emission tomography (PET) have been developed. In more recent years, the strengths of both specialties have been combined in clinical practice, particularly through the integration of both imaging modalities in hybrid systems such as SPECT-CT, PET-CT, and PET-MRI [1,2,3]. These advancements in medical imaging present both opportunities and challenges. While the ability to diagnose, monitor, and treat patients using the diverse multimodality tools available today offers significant benefits, it also introduces challenges related to managing workload, maintaining quality, preventing burnout, and training imaging specialists in multimodality imaging [4,5,6,7,8].

In general, medical imaging specialists are divided into nuclear medicine physicians and radiologists, which largely reflects the preponderant current training structure for residents worldwide. There is some overlap in training, as nuclear medicine physicians are trained to review CT images and radiologists are trained to review (FDG)-PET scans, at least in the Netherlands. From an efficiency standpoint, having a single specialist responsible for reviewing both functional and anatomic images is optimal, not only for reporting efficiency, but also for multidisciplinary meetings and supervising residents. However, the training curricula for nuclear medicine and radiology remain largely separate in most countries, with varying degrees of overlap between the two specialties. The curricula differ significantly across Europe, the United States, and Asia in terms of duration, levels of expertise to be acquired, and the structure of training [9]. In order to improve efficiency and quality, the Netherlands decided in 2015 to integrate nuclear medicine and radiology specialties into a single resident training curriculum [10]. This approach aimed to prepare future nuclear medicine physicians and radiologists to manage the increasing complexity of imaging and enhance efficiency in both reporting and multidisciplinary meetings. Residents who complete the nuclear medicine subspecialty in this combined training pathway ought to become proficient both in nuclear medicine and radiology and are referred to as nuclear radiologist. As the integrated training program is the first of its kind in the Netherlands, the proposed benefits have not been previously evaluated independently, and potential areas for improvement have yet to be identified in the setting of the Check and Act of the classical PDCA cycle (Plan, Do, Check, Act). Nuclear medicine physicians and radiologists have gained firsthand experience with the program as supervisors or residents and can provide valuable feedback on its success and potential areas of improvement. **Chapter 2** presents the results of a survey conducted among nuclear medicine physicians and radiologists participating in the Dutch integrated nuclear medicine and radiology residency, aimed at reviewing the assumed benefits and identifying potential areas for improvement.

The Dutch integrated training program spans five years, with the first 2.5 years focused on general training in both nuclear medicine and radiology, followed by an additional 2.5 years that includes a maximum of 1.5 years of training in a subspecialty of the residents' choice, and at least 1 year of rotations between the different radiology subspecialities[1]. The program offers eight subspecialties: one in nuclear medicine and seven in radiology, including abdominal, breast, cardiothoracic, interventional, musculoskeletal, neuro- and head and neck, and pediatric radiology. Only residents who choose the nuclear medicine subspecialty would be able to practice nuclear medicine in the Netherlands at the same level as the nuclear medicine residents who completed the previous, dedicated nuclear medicine curriculum. The integration of the two residency programs primarily led to less time for nuclear medicine training compared to what was provided in the previous dedicated 5-year nuclear medicine curriculum. In contrast, residents choosing a radiology subspecialty experienced fewer changes to their previous dedicated 5-year training program, as relatively more time was still available for the radiology subspecialties. Concerns were raised regarding the number of residents who would pursue nuclear medicine training and regarding their level of expertise, given the mandatory radiology training, which includes on-call shifts and emphasizes a significant volume of radiology-based imaging, as well as concerns about the international, and particularly European, recognition of the training program [11]. These concerns were supported by the number of residents who chose the nuclear medicine pathway in the new integrated training program compared to the previous program: 14 in 2020 versus 50 in 2015, and a steady increase again up to 26 residents in March 2024. This initial decline could substantially impact the future nuclear medicine workforce, particularly with the anticipated increase in hybrid imaging and theranostics. Identifying the factors that influence residents' decisions to pursue, or refrain from, the nuclear medicine pathway may provide valuable insights

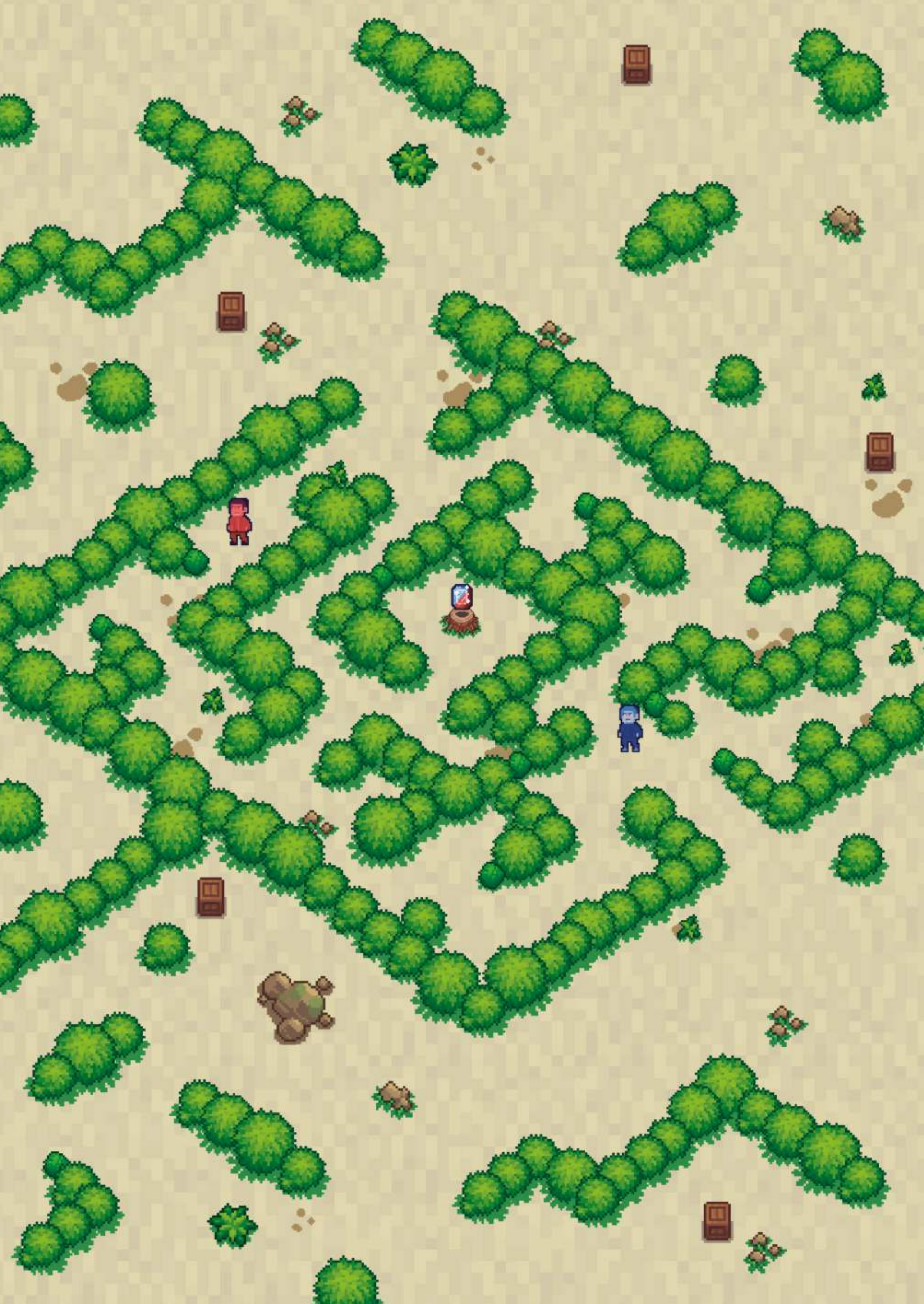
1 Effective from 2023, the revised combined training program has increased the duration of the nuclear medicine subspecialty training from 1.5 years to 2 years.

into how to address this issue, encouraging more residents to choose nuclear radiology, and ensure the sustainability of an adequate workforce. **Chapter 3** presents the results of a survey conducted among residents in the integrated training program, aiming to evaluate their opinions on the strengths and weaknesses of the integrated curriculum and to understand the factors influencing their decision to subspecialize in nuclear medicine.

Following the recent implementation of the integrated training program in the Netherlands, the first cohort of residents who selected either a nuclear medicine or radiology pathway completed their training and were expected to enter the workforce in 2021. With a relatively small number of residents trained as nuclear radiologists, it remains uncertain whether the proposed benefits —such as the ability to review and report on both anatomical and functional imaging, as well as their contribution to multidisciplinary meetings—are noticeable in clinical practice. Furthermore, it remains unclear whether nuclear radiologists reduce the overall workload compared with the current model, in which nuclear medicine physicians and radiologists largely work and report separately, combining their findings into a single report for hybrid imaging studies. Next to this, one of the challenges for the newly trained nuclear radiologist is securing employment. Key factors in this process are the needs of the workforce and how employers perceive the role of nuclear radiologists. However, there are no current insights into the job market demands for (nuclear) radiologists. **Chapter 4** provides an evaluation of the job market demands in the Netherlands in 2021, approximately five years after the implementation of the integrated residency program, when the first nuclear radiologists were expected to search for employment.

While the new developments in medical imaging and therapies are promising and exciting, they also pose a financial risk, as most imaging techniques are costly and may contribute to the already rapidly rising medical costs. Preventing further growth in healthcare expenditures is a major concern for maintaining the affordability and accessibility of healthcare services [12]. Medical imaging specialists play a crucial role in advising clinicians on which imaging tests are the most appropriate and cost-effective for each clinical question and individual patient. However, general knowledge of imaging costs is not included in the training of residents in specialties that frequently request medical imaging, nor is it included in the training of radiology residents. It is hypothesized that financial literacy regarding medical imaging costs among residents is therefore limited [13,14]. **Chapter 5** presents a survey conducted among internal medicine, surgery, and radiology residents to evaluate their financial (il)literacy regarding medical imaging costs.

The increasing availability and reliance of clinicians on multimodal and complex imaging techniques is leading to a more complex and growing workload, necessitating a high level of expertise and efforts from nuclear medicine physicians and radiologists. Research has shown that the workload has significantly increased over the past decade, and the anticipated continued rise will place even greater demands on medical imaging specialists [15]. This increased workload presents new challenges in managing the burden on each specialist, while also necessitating measures to prevent burnouts and ensure that quality of care is maintained [5,6,7]. One potential solution to address this challenge is artificial intelligence (AI). Promising results have been reported, indicating that AI can assist medical imaging specialists by enabling faster and more accurate lesion detection, as well as assisting with basic interpretation tasks [17]. And future advancements in AI are expected to provide even more support. However, the current state of AI, coupled with its generally limited implementation in clinical practice thus far, does not yet provide sufficient support to counterbalance the exponential rise in workload faced by imaging specialists. AI is currently implemented in specific areas of imaging interpretation task (IITs), such as fracture detection during on-call hours in some hospitals and may potentially alleviate some workload [18]. Non-image interpretation tasks (NITs) also contribute to the increased workload of medical imaging specialists. Importantly, NITs are not the exclusive domain of medical specialists and can be performed by other qualified and trained personnel, who are typically less expensive. One potential strategy to support medical imaging specialists with NITs is through the employment of "reading room assistants". These individuals undergo brief, targeted training to assume responsibility for NITs, thereby relieving medical specialists. This approach has been shown to significantly reduce the burden of NITs and reduce interruptions by managing tasks such as answering telephone calls, handling administrative duties, and organizing patient logistics for medical imaging specialists [15]. However, the impact of incorporating reading room assistants into the radiology specialty has not yet been fully investigated. Introducing reading room assistants during radiology on-call shifts may reduce the workload and potentially provide more time for IITs, which, compared to NITs, are far more educationally valuable for residents. **Chapter 6** examines the possible time savings and interruption reduction that reading room assistants can provide by assuming responsibility for NITs from radiology residents during on-call hours.



Chapter 2

The integrated nuclear medicine and radiology residency program in the Netherlands: Strengths and potential areas for improvement according to nuclear medicine physicians and radiologists

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ABSTRACT

Purpose
To evaluate the Dutch integrated nuclear medicine and radiology residency program from the perspective of nuclear medicine physicians and radiologists.

Methods
A survey was distributed among nuclear medicine physicians and radiologists in hospitals that participate in the Dutch integrated nuclear medicine and radiology training program.

Results
A total of 139 completed questionnaires were included. Nuclear medicine physicians (n = 36) assigned a mean score of 5.7 ± 2.0, and radiologists (n = 103) assigned a mean score of 6.5 ± 2.8 (on a 1–10 scale) to the success of the integrated training program in their hospital. On multiple regression, female gender of the survey participant (B = 2.22, P = 0.034), musculoskeletal radiology as subspecialty of the survey participant (B = 3.36, P = 0.032), and the survey participant's expectancy of resident's ability to handle workload after completion of residency were significantly associated with perceived success of the integrated training program (B = 1.16, P = 0.023). Perceived strengths of the integrated training program included broadening of expertise, a better preparation of future imaging specialists for hybrid imaging, increased efficiency in training residents, and increased efficiency in multidisciplinary meetings. Perceived weaknesses of the integrated training program included reduced exposure to nuclear medicine, less time for research and innovation, and concerns about its international recognition.

Conclusion
This study provided insights into the experiences of nuclear medicine physicians and radiologists with the Dutch integrated nuclear medicine and radiology residency program, which may be helpful to improve the program and similar residency programs in other countries.

INTRODUCTION

Nuclear medicine uses an ever increasing arsenal of radiolabeled compounds for various diagnostic and therapeutic indications [1]. Hybrid imaging, which is the combination of single photon or positron emission tomography (PET) with computed tomography (CT) or magnetic resonance imaging (MRI), has facilitated the correlation between metabolic processes and anatomy. One of many other important areas of nuclear medicine is the rapidly developing field of thera(g) nostics, which combines diagnostic and therapeutic applications [2]. With new, complex developments in imaging techniques and in diagnostic and therapeutic radiotracers, new challenges arise in daily practice in the communication with clinicians, in multidisciplinary consultation, and also in the way residents are trained.

Several nuclear medicine residency training programs have integrated (parts of) nuclear medicine with radiology training programs [3]. This was also the case for the Netherlands, where the separate residency programs for nuclear medicine and radiology have been replaced by a completely integrated residency training in 2015 [4]. This Dutch integrated training program consists of 2.5 years of general nuclear medicine and radiology, followed by another 2.5 years of training of which 1.5 years in a subspecialty of the resident's choice. There are eight subspecialties for the residents to choose from, of which seven radiology-based and one nuclear medicine. The latter subspecialty is named "nuclear medicine and molecular radiology" (NMMR). A resident that successfully completes the integrated training and the NMMR subspecialty will bear the title "nuclear radiologist." The societies of radiology and nuclear medicine in the Netherlands implemented the integrated training program in 2015, with the aim to ensure quality and efficiency of reporting medical imaging and communication with colleagues from other medical specialties [4].

More than 5 years have elapsed since its implementation, which provides the opportunity to evaluate firsthand, and independently from the organizing professional societies, the experiences from nuclear medicine physicians and radiologists who work in hospitals that offer this integrated training program. Previous research has identified factors that influence a resident's choice to start the NMMR subspecialty of the integrated training, but experiences from nuclear medicine physicians and radiologists about the integrated training are still lacking [5]. This information may be useful to identify strengths of the program that may be emulated by other national societies who consider developing a similar program, and on the other hand, identify potential areas for improvement. Hence, the purpose of this study was to evaluate the Dutch integrated nuclear medicine and radiology residency program from the perspective of nuclear medicine physicians and radiologists.

MATERIALS AND METHODS

Medical ethics review board

The local medical ethics review board approved this prospective survey study (IRB number: 202000862).

Participants

All nuclear medicine physicians and radiologists who work in hospitals that participate in the integrated nuclear medicine and radiology training program in the Netherlands were eligible to participate in this survey. Note that there are eight academic training hospitals and 28 non-academic training hospitals, in eight geographically designated residency training regions in the Netherlands. The curriculum of the integrated training program has been established by the nuclear medicine and radiology societies of the Netherlands and is therefore the same in all of these hospitals; the Dutch integrated training curriculum is summarized in Supplemental Table 1 [4].Eligible nuclear medicine physicians and radiologists were contacted by e-mail. This e-mail contained a brief explanation of the study purpose and a request to participate. Participation in this survey was voluntary. Access to the survey was made possible via a digital link which was provided in the email. The initial request to participate was sent by email on the 23rd of December 2020, and a reminder was sent on the 6th of January 2021. Inclusion took place between the 23rd of December and the 15th of February. Partially completed questionnaires were excluded from the analysis as well as the group of participants who practice both nuclear medicine and radiology (dual practitioners) due to the small size of this group.

Survey

The questionnaire was developed and analyzed by radiologists (T.V. and T.C.K.), a nuclear medicine physician (W.N.) and a survey specialist (Y.O.), and was in part based on previous literature [6]. The survey was digitalized using the Qualtrics Core XM survey software (Qualtrics, LLC an SAP America Inc. Company). The questionnaire contained 20 closed-ended questions and 6 open-ended questions. The closed-ended questions captured basic characteristics of the participants, including age, gender, type of training curriculum followed, specialty (nuclear medicine or radiology) and subspecialty, the type of center were they followed their own training, (academic, non-academic or a combination of both), the national region they were trained in and are currently practicing in, the type of hospital where they currently practice (academic, nonacademic or both), and years of post-residency experience (as nuclear medicine physician or radiologist); the closed-ended questions are summarized in Supplemental Table 2. The closed-ended questions also addressed the participants' perceived rate of integration of the nuclear medicine and radiology departments in their hospital (on a 10-point scale), and if there have been residents in training for the NMMR subspecialty in their hospital, the possibility for residents to write combined clinical reports for hybrid imaging (e.g., PET-CT) and the supervisor of these combined reports (nuclear medicine physician, radiologist or both) in their hospital, time allocated to residents to perform research in their hospital (yes/no), the perceived distribution of allocated time between nuclear medicine and radiology in the first 2.5 years of training (balanced, unbalanced and in favor of nuclear medicine, or unbalanced and in favor of radiology) in their hospital, estimated chance of future employment of residents after completion of training (5-point scale from 1 slim to 5 excellent), expected chance of recognition of the training program by other European countries (5-point scale from 1 unlikely to 5 very likely), expectancy of resident's ability to handle workload in clinical practice after completion of residency (5-point scale from 1 unlikely to 5 very likely), and level of independence of senior residents (5-point scale from 1 minimal to 5 complete). The open-ended questions evaluated the perceived success of the integrated training program in their hospital (on a scale from 0 to 10), their general opinion on the integrated training program, and the opportunity to give additional comments on the closed-ended questions. The data collected from the open-ended questions were analyzed to find common categories of strengths and weaknesses of the integrated training program perceived by nuclear medicine physicians and radiologists. The answers on the closed-ended and openended questions are summarized in Table 1 and Table 2.

Data analysis

The data collected from the closed-ended questions were compared and analyzed via a multiple regression analysis. We used the participants' answer to the question "what is your opinion about the success of the integrated training?" (ranging from failure to a complete success on a scale from 0–10) as the dependent variable. The remaining closed-ended questions were entered as independent variables. Multiple regression analysis was used to explore a link between all predictors and their additive effects on the dependent variable. *P*-values less than 0.05 were considered statistically significant. The data collected from the open-ended questions were descriptively analyzed. Statistical analyses were performed using R Studio, Version 1.2.5033.

Table 1. Characteristics of nuclear medicine physicians (NM) and radiologists (RAD) who participated in the survey

Variable	NM (*n* = 36)	RAD (*n* = 103)
Age (years) 31–40/41–50/51–60/60 + /NI	9/13/8/6/0	33/35/25/9/1
Gender Male/female/NI*	21/15/0	72/30/1
Training curriculum followed by participants Integrated/old style nuclear medicine*/old style radiology*/older/NI*	0/34/1/0/1	6/1/58/38/0
Type of center where survey participant's residency training was done Academic/non-academic/combination/other	24/7/5/0	34/22/47/0
Postresidency experience (years) 0–10/11–20/21–30/30 + /NI*	15/14/5/2/0	51/26/20/3/3
Current hospital of practice Academic/non-academic/combination/other	15/19/1/1	41/58/4/0
Resident's currently or previous in training with NMMR subspecialty Yes/no/do not know/NI*	20/7/2/7	58/21/4/20
Perceived rate of integration of nuclear medicine and radiology departments None/low/mid/high/fully/NI*	2/4/9/11/9/1	1/13/24/31/30/4
Perceived rate of success of the integrated training*** Failure/low/mid/high/success/NI*	0/5/12/9/1/9	0/14/17/34/13/25
Multidisciplinary meeting attendance by Only radiologist/only nuclear medicine physician/both/otherwise/NI*	0/0/18/17/1	8/1/54/39/1
Sufficient time for residents to do research Yes/no/NI*	16/18/2	91/12/0

* *NI*, not indicated; *NMMR*, nuclear medicine and molecular radiology

** Old style refers to previous nuclear medicine and radiology training programs which were largely separated

*** The 10 point scale that was used is summarized in steps of 2 grades, ranging from failure as the lowest, up until success for the highest, for easier overview

Table 2. Association between different variables (characteristics of nuclear medicine physicians and radiologists, their hospitals, and their opinion on different aspects the integrated training) with the perceived success of the integrated training on multiple regression

Variable	Beta-coefficient	95% *CI*	*P*-value
Age (years)	− 0.038	[− 0.39–0.32]	.794
Gender (male or female)	2.22	[0.25–4.19]	.034[3]
Received type of training (integrated vs. previous)	0.25	[− 1.23–1.73]	.683
Hospital of training (academic vs. non-academic)	− 2.46	[− 5.25–0.34]	.074
Region of training[1]	0.14	[− 0.38–0.65]	.523
Years of post-residency experience	− 0.03	[− 0.41–0.35]	.841
Specialty (nuclear medicine or radiology)	2.02	[− 1.11–5.15]	.158
Subspecialty[2]	3.36	[0.43–6.30]	.032[4]
Region of practice[1]	− 2.6	[− 7.12–1.93]	.201
Hospital of practice (academic vs. non-academic)	1.75	[− 2.25–5.75]	.313
Rate of integration of departments (scale 0–10)	0.42	[− 0.33–1.16]	.208
NMMR residents in training in hospital (yes/no)	− 1.83	[− 4.98–1.33]	.198
Combined reporting by resident (yes/no)	0.52	[− 3.68–4.72]	.763
Combined reporting supervision (nuclear medicine physician, radiologist or both)	− 0.42	[− 2.69–1.85]	.653
Multidisciplinary meeting attendance (nuclear medicine physician, radiologist, or both)	0.55	[− 2.15–3.25]	.624
Sufficient time for research (yes/no)	1.36	[− 1.79–4.51]	.318
Distribution of allocated time between nuclear medicine and radiology in the first 2.5 years of training (balanced vs. unbalanced)	− 0.41	[− 2.51–1.69]	.636
Future employment chances for residents (scale 0–5)	0.63	[− 0.80–2.05]	.310
Recognition of the training in the European Union (scale 0–5)	0.10	[− 1.06–1.26]	.831
Ability of residents to handle workload after completion of residency (scale 0–5)	1.16	[0.24–2.09]	.023
Independence of senior residents (scale 0–5)	− 0.71	[− 2.55–1.14]	.370

Eight different geographical training and practice regions in the Netherlands
Nuclear medicine and molecular radiology and seven radiology subspecialties
Females were significantly more positive regarding the perceived success of the integrated training program
Participants in the musculoskeletal subspecialty were significantly more positive regarding the perceived success of the integrated training program compared to those in the abdominal subspecialty (reference category)

RESULTS

Survey

A total of 759 potentially eligible participants were contacted by email (54 nuclear medicine physicians and 714 radiologists). A total of 184 questionnaires were digitally returned (response rate of 24%). Forty partially completed questionnaires and 5 questionnaires of participants with a dual certification in nuclear medicine and radiology were excluded. A total of 139 fully completed surveys remained for inclusion. No nuclear medicine physician and only 6 radiologists participating in this survey had undergone the integrated training themselves.

Participants and training center characteristics

The 139 included questionnaires were completed by 36 nuclear medicine physicians and 103 radiologists. Each of the eight residency training regions in the Netherlands was represented among the participants. The nuclear medicine physicians assigned a mean score of 5.7 ± 2.0, and the radiologists assigned a mean score of 6.5 ± 2.8 (on a 1–10 scale) to the success of the integrated training in their hospital. The basic characteristics of the participating nuclear medicine physicians and radiologists are summarized in Table 1, and median values of the continuous variables in Supplemental Table 3.

Association between variables and perceived success of the integrated training program

On multiple regression, female gender of the survey participant (B = 2.22, P = 0.034), musculoskeletal radiology as subspecialty of the survey participant (B = 3.36, P = 0.032), and the survey participant’s expectancy of resident’s ability to handle workload after completion of residency (B = 1.16, P = 0.023) were significantly associated with perceived success of the integrated training program (Table 2).

Strengths and weaknesses of the integrated training program according to nuclear medicine physicians

Nuclear medicine physicians described varying degrees of integration (ranging from “complete” to “just on paper”) of management, staff, resident training, and research between nuclear medicine and radiology departments.

Nuclear medicine physicians made 31 comments about the value of the integrated training program (9 strengths, 5 neutral comments, and 17 weaknesses). Advantages of the integrated training program that were mentioned were increased expertise in hybrid imaging reporting, broadening of competencies and expertise for nuclear medicine and radiology residents, and increased efficiency for multidisciplinary meetings (i.e., only one staff member required who can interpret both modalities). Weaknesses of the integrated training program that were mentioned were concerns about its international recognition, the expected mandatory fellowship after the integrated training, the lack of internal medicine training for NMMR subspecialty residents (note that 1 year of internal medicine training was included in the previous training program), whether or not the Dutch society of nuclear medicine can remain a member of the EANM, the lack of exposure to nuclear medicine, reduced time for innovation and research related to nuclear medicine due to the integration of two training programs into one, and the added radiology "workload" compared to the previous training programs. Some participants worried that the aforementioned factors might turn NMMR training less attractive for new residents.

Strengths and weaknesses of the integrated training program according to radiologists

Radiologists described varying degrees of integration between nuclear medicine and radiology departments in their hospitals regarding finance, management, staff, resident training and research, and work activities.

Radiologists made 71 comments about the value of the integrated training program (40 strengths, 8 neutral comments, and 23 weaknesses). Strengths of the integrated training program that were mentioned were integration leads to better preparation of future medical imaging specialists with the expected increase in hybrid imaging and imaging directed on pathology/organs and therapies, increased efficiency with combined reporting and in multidisciplinary meetings, better patient care, broadening of expertise for both nuclear medicine physicians and radiologists, and an opportunity to learn from each other. Weaknesses of the integrated training program that were mentioned were less time for residents to reach the same level of quality, decreased exposure and knowledge of nuclear medicine and radiology compared to the previous training programs, not all competencies can be acquired to an independent level for residents due to the sheer number of available competencies, integration of departments goes slow which leads to less success of the integrated training, less time to do research and delve into new developments of nuclear medicine and radiology (thera(g)nostics/big data/artificial intelligence), possible depreciation of Dutch nuclear medicine and radiology on a European level, and concerns that the completed training is not necessarily equal to the previous training programs.

Suggested points for improvement

The nuclear medicine physicians and radiologists made several suggestions for improvement of the integrated training program. These included more time for exposure to nuclear medicine (both nuclear medicine physicians and radiologists), especially during the first 2.5 years of training and for residents who choose the NMMR pathway to comply with European standards (nuclear medicine physicians), increased time for innovation and research in nuclear medicine for residents during their training (nuclear medicine physicians), improved workflow integration of both departments (both nuclear medicine physicians and radiologists), and fusion of the nuclear medicine and radiology societies (radiologists). Some suggested increasing the duration of the training from 5 to 6 years (both nuclear medicine physicians and radiologists).

DISCUSSION

In 2015, the Netherlands started with a unique integrated nuclear medicine and radiology residency training program. Now, 5 years later, this study for the first time looks at its strengths and weaknesses. All nuclear medicine physicians and radiologists that participate in the integrated training program in the Netherlands were contacted via email to complete this study survey. Eventually, we included 36 nuclear medicine physicians and 103 radiologists. The survey participants assigned average marks of 5.7 (nuclear medicine physicians) and 6.5 (radiologists) on a 10-point scale to the success of the integrated training program, suggesting both that the program is feasible and that there is still room for improvement. Our data also showed that nuclear medicine physicians and radiologists were significantly more positive about the integrated training program when they were female, musculoskeletal radiologists, and when they deemed residents in their hospital capable to handle workload after completion of residency. The reason why women and musculoskeletal radiologists were significantly more positive about the integrated training program than their male and other subspecialty counterparts remains unclear. Further in-depth interviews with these populations are necessary to understand their more positive attitude towards the integrated training program. On the other hand, It seems plausible that nuclear medicine physicians and radiologists were significantly more positive about the integrated training program when they considered their residents able to handle workload after completion of residency, because one of the main goals of any residency program should be to deliver specialists who are directly deployable in busy clinical practice. Clinical productivity of residents may be monitored with metrics such as relative value units. Of interest, previous research has shown that clinical productivity is independently associated with medical knowledge relevant to radiology practice during radiology residency [7]. Further research is necessary to understand how residents can be best selected and trained to reach a level of clinical productivity that prepares them well for post-residency work life. None of the other variables that were investigated were significantly independently associated with the perceived success of the integrated training program.

Of interest, around three-quarters of participants additionally expressed their opinion about the success of the integrated training in the open-ended question. This is in line with the attention this topic has received in the respective professional societies in the Netherlands. Both nuclear medicine physicians and radiologists agreed that positive aspects of the integrated training were broadening of expertise, a better preparation of future imaging specialists for the expected increase in hybrid imaging, increased efficiency in training residents, and increased efficiency in multidisciplinary meetings. Weaknesses of the integrated training program mentioned by participants in this survey included reduced exposure to nuclear medicine, less time for research and innovation compared to the previous training programs, and concerns about its international recognition.

Several nuclear medicine physicians and radiologists who participated in this survey provided suggestions to improve the training, which included allocating more time during the first 2.5 years of training to nuclear medicine and for residents who chose the NMMR pathway to comply with European standards, allocating more time for innovation and research, and increasing integration of departments and workflows.

A previous survey study, in which 114 residents participated, investigated reasons that influence a resident's choice for the nuclear medicine subspecialty in the Dutch integrated training program [5]. The results of that previous study and those of the current study show that both residents, nuclear medicine physicians and radiologists, consider increased expertise, efficiency of training, broadening of competencies, and a better preparation for the expected increase in hybrid imaging in the future, as strengths of the integrated training program. Furthermore, both residents, nuclear medicine physicians and radiologists, generally indicated poor integration of nuclear medicine and radiology departments, imbalance in exposure to the detriment of nuclear medicine, and concerns about its international recognition, as weaknesses of the integrated training program. However, unlike residents, nuclear medicine physicians and radiologists generally expressed concerns about reduced time for research and loss of quality of the trained residents. Meanwhile, unlike nuclear medicine physicians and radiologists, residents were generally concerned about their future employment prospects. This difference in concerns might be due to differences in interests between future employment and quality of trained residents.

Above-mentioned factors may be taken into account by policy makers and other stakeholders who are developing and aiming to improve integrated nuclear medicine and radiology residency programs.

This study had some limitations. First, the ratio of nuclear medicine physicians to radiologists who participated in this survey (36:103) was relatively high compared to the ratio of nuclear medicine physicians to radiologists comprising the entire workforce in all training hospitals in the Netherlands (54:714). This relatively higher participation rate by nuclear medicine physicians might potentially be explained by the possibility that the integrated training affects nuclear medicine more than radiology. Relatively less time is available for nuclear medicine compared to radiology during the integrated training and also compared to the previous largely separate nuclear medicine training program, which might raise increased concerns from nuclear medicine physicians and in turn have led to a better response rate. In other countries where different forms of integrated training programs are running, similar concerns among nuclear medicine physicians exist [8]. Second, the integrated training was implemented in 2015 and only a few participants have followed the integrated training as residents themselves. Not all participants may be completely used to this form of training and time may be needed to fine-tune implementation, to build experience and gain more widespread acceptance. Third, with promising developments in both fields, such as artificial intelligence and thera(g)nostics, a change in clinical practice may be expected which might also lead to a change in how the integrated training is evaluated. Further research is needed to investigate the impact of the integrated training on the vast number of diagnostic and therapeutic nuclear medicine procedures in daily practice. Fourth, the response rate was slightly on the lower normal end of what can be expected from survey results in healthcare [9]. Fifth, the response rate of the radiologists was relatively low compared to the nuclear medicine physicians. It remains unclear if this was caused by differences in interest to participate in this survey or due to other differences inherent to both specialties. And last, the training curriculum defines that only nuclear radiologists will be trained in radionuclide therapies, and will be fully certified for therapeutic applications after finishing their residency. Nuclear diagnostic procedures are carried out by any (nuclear) radiologist with the required level of entrustable professional activity. The radionuclide therapies were not specifically addressed in this survey, since there are yet only small numbers of fully trained nuclear radiologists. Further research might provide more insights on how this will impact the distribution of nuclear medicine activities.

In conclusion, this study provided insights into the experiences of nuclear medicine physicians and radiologists with the Dutch integrated nuclear medicine and radiology residency program, which may be helpful to improve the program and similar residency programs in other countries.

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SUPPLEMENTAL DATA

Supplemental table 1. The Dutch integrated nuclear medicine and radiology training curriculum as established in 2015. Time allocated for each subspecialty in different phases of the training in months.

	Common trunk phase	Subspecialty phase[1,2]
Cardiothoracic	5	18
Abdominal	5	18
Intervention	2	18
Nuclear medicine and molecular radiology	2	18
Neuro- and head & neck	4	12
Musculoskeletal	4	12
Breast	2	6
Pediatric	2	6
Time for education, congress, catch-up, holiday, elective training, courses, etc.	4	
	2,5 year	2.5 year[3]

[1] The total length of the training is 5 years.

[2] Residents can either choose a subspecialty that requires 18 months or two different subspecialties that require 12 months and 6 months, respectively.

[3] During the subspecialty phase a resident spends 18 months on the chosen subspecialty or subspecialties and 12 months on further general radiology training.

Supplemental table 2. Closed- ended question from the questionnaire.

Date of birth
Gender (male or female)
Received type of training (integrated vs. previous)
Hospital of training (academic, non-academic or both)
Region of training
Years of post-residency experience as nuclear medicine physician or radiologist
Specialty (nuclear medicine, radiology or both)
Radiology subspecialty (abdominal, cardiothoracic, intervention, neuro- and head & neck, musculoskeletal, breast, pediatric, other)
Region of practice
Hospital of practice (academic, non-academic or both)
Possibility for residents to do NMMR subspecialty in their hospital (yes/no/other)
Rate of integration of departments (scale 0-10)*
Opinion on the success of the integrated training (scale 0-10)**
Residents currently or previous in training with NMMR subspecialty
Possibility for common trunk residents to do the complete NMMR subspecialty in their hospital
Possibility for NMMR subspecialty residents to do the complete NMMR subspecialty in their hospital
Combined reporting by resident (yes/no)
Combined reporting supervision (nuclear medicine physician, radiologist or both)
Multidisciplinary meeting attendance (nuclear medicine physician, radiologist or both)
Sufficient time for research (yes/no)
Distribution of allocated time between nuclear medicine and radiology in the first 2.5 years of training (balanced vs. unbalanced favoring either nuclear medicine or radiology)
Future employment chances for residents (scale 0-5)***
Recognition of the training in the European Union (scale 0-5)***
Ability of residents to handle workload after completion of residency (scale 0-5)***
Independence of senior residents (scale 0-5)***

* Ranging from 0 as no integration at all, until 10 completely integrated.
** Ranging from 0 as complete failure to 10 as great success.
*** Ranging from 0 as very low, until 5 great.

Supplemental table 3. Continuous variables with median values.

Variable	Median	
	Nuclear medicine physicians	Radiologists
Age (years)	48	45
Years of post-residency experience	13	10
Rate of integration of departments (scale 0-10)*	7	8
Future employment chances for residents (scale 0-5)**	4	4
Recognition of the training in the European Union (scale 0-5)**	1	3
Ability of residents to handle workload after completion of residency (scale 0-5)**	4	4
Independence of senior residents (scale 0-5)**	4	4
Success of the integrated training (scale 0-10)*	6	7

* Ranging from 0 as no integration at all, until 10 completely integrated.
** Ranging from 0 as very low, until 5 great.

2

Chapter 3

The new integrated nuclear medicine and radiology residency program in the Netherlands: Why do residents choose to subspecialize in nuclear medicine and why not?

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ABSTRACT

Purpose

To explore the reasons that a resident chooses to enter the nuclear medicine subspecialty in the integrated nuclear medicine and radiology residency program in The Netherlands.

Methods

A web questionnaire was developed and distributed among residents in the Dutch integrated nuclear medicine and radiology training program.

Results

In total, 114 residents were included. The survey results revealed 4 categories of incentives to choose the nuclear medicine subspecialty: the expertise of nuclear medicine physicians and their quality of supervision in the training hospital; opportunities to do scientific research during and after residency; the diversity of pathologic conditions, radiotracers, examinations, and therapies in the training hospital; and the expectation that the role of hybrid imaging will increase in the future. The results also revealed 4 groups of disincentives to choose the nuclear medicine subspecialty: lack of collaboration and integration between nuclear medicine and radiology in some training hospitals; imbalance between nuclear medicine and radiology during the first 2.5 y of basic training during residency at the expense of nuclear medicine; uncertainty regarding the international recognition of nuclear medicine subspecialty training; and the uncertain future of nuclear medicine regarding the chances for employment and the ratio of nuclear medicine to radiology work activities.

Conclusion

This study provided insight into residents' motives in pursuing or refraining from nuclear medicine subspecialization in an integrated nuclear medicine and radiology residency program. Medical imaging specialists in training hospitals and developers of curricula for nuclear medicine and radiology training should take these motives into account to ensure a sufficient outflow of newly graduated nuclear medicine specialists.

INTRODUCTION

Nuclear medicine keeps evolving thanks to the ever-expanding armament of diagnostic and therapeutic radiotracers and to continuing advances in photon detection technology. The hybrid imaging techniques that combine SPECT or PET with CT or MRI make the synergy between diagnostic nuclear medicine and radiology apparent [1]. This synergy is also reflected in the structure of most nuclear medicine and radiology residency programs in the United States and Europe, in which crossover training between the 2 specialties is common [2–5].

A completely separate residency program for nuclear medicine (with a crossover internship in radiology) existed in The Netherlands until 2015 and secured a constant outflow of newly graduated nuclear medicine physicians. In 2015, an integrated residency for nuclear medicine and radiology was implemented in The Netherlands [6]. A complete integration of radiology and nuclear medicine was thought to provide the best opportunities for optimal and comprehensive medical imaging, collaboration with clinical colleagues, and quality patient care, as communicated by representatives from the Dutch societies of radiology and nuclear medicine [6]. At the same time, the completely separate residency program for nuclear medicine ceased to exist. The newly integrated nuclear medicine and radiology residency program offers residents a completely free choice between 1 or 2 of 8 subspecialties to pursue after the first 2.5 y of general integrated nuclear medicine and radiology residency [6]. Nuclear medicine, in the Dutch curriculum named "Nuclear Medicine and Molecular Radiology," is among these subspecialties and includes training in both diagnostic and therapeutic nuclear medicine [6]. The other 7 radiology-based subspecialties are cardiothoracic radiology, abdominal radiology, interventional radiology, musculoskeletal radiology, neuroradiology and head and neck radiology, breast radiology, and pediatric radiology [6]. Residents who choose the nuclear medicine subspecialty cannot subspecialize in any other field during their residency in the current program, because this would be at the expense of the time that is considered necessary to master the required nuclear medicine skills [6]. Residents who successfully complete the nuclear medicine subspecialty training bear the title "nuclear radiologist."

The number of residents who choose the nuclear medicine specialty has been declining in many countries in the past few years [7–9]. Importantly, a few years after the implementation of the integrated nuclear medicine and radiology residency program in The Netherlands, it appeared that only 14 residents had chosen the nuclear medicine specialty [7]. This number was considerably lower than anticipated and can be considered a threat to the future nuclear medicine workforce.

Eventually, this decline may negatively affect patient care and the future development of the specialty. The reason for this lagging interest is currently unclear and requires investigation. Such information may potentially be useful to increase recruitment of residents for the nuclear medicine subspecialty and to maintain the future nuclear medicine workforce. It may also reveal targets for improvement in other countries' integrated nuclear medicine and radiology residency programs that are similar to the program in The Netherlands.

Therefore, the purpose of this study was to explore reasons that influence a resident's decision to choose the nuclear medicine subspecialty in the integrated nuclear medicine and radiology residency program in The Netherlands.

MATERIALS AND METHODS

Study Design

The local medical ethics review board approved this prospective study (approval 202000290), which was based on a questionnaire. On voluntary participation in this study, informed consent was given.

Participants

The Netherlands has 8 teaching and training regions for nuclear medicine and radiology, with a total of 28 training hospitals. Each region consists of 1 academic and several nonacademic hospitals. All residents spend at least 1 y of their residency in an academic hospital and at least 1 y in a nonacademic hospital. Each region offers the same integrated nuclear medicine and radiology residency program according to the guidelines set by the Radiologic Society of The Netherlands [10].

A web questionnaire was developed and e-mailed to the residency program directors of the training hospitals, with a request that they distribute it to their residents. No reminder to return the questionnaires was sent after the initial e-mail. Both the program directors and the participating residents were informed about the purpose of the questionnaire, that is, to investigate why residents choose or do not choose the nuclear medicine subspecialty in the integrated nuclear medicine and radiology residency program. The questionnaire was accessible to the residents via an anonymous web link. Anonymous registration via Internet protocol addresses ensured unique respondents. Any personal data, including Internet protocol addresses, were not available to the investigators.

Any residents participating in the integrated nuclear medicine and radiology program in The Netherlands, regardless of their year of training, were included. Residents who were participating in the previous curriculum, in which nuclear medicine and radiology had not yet been integrated, were excluded. Partially completed questionnaires were also excluded.

Completed questionnaires digitally returned between May 27 and July 12, 2020, were included in the study.

Questionnaire

The questionnaire was developed by 2 radiologists, 1 nuclear medicine physician, and 1 survey specialist and contained 14 closed-ended questions and 9 open-ended questions that were further analyzed.

The closed-ended questions aimed to capture the following variables from each resident: their age, sex, and teaching and training region; whether they had received any nuclear medicine education before residency (yes or no); whether they had completed or were working on a PhD thesis (yes or no); their level of interest in scientific research (expressed on a 10-point grading scale); whether they had worked in a clinic before residency (yes or no); whether they had chosen or begun nuclear medicine or subspecialty radiology subspecialty training; whether they had been inspired by someone to choose a certain subspecialty (yes or no); whether there are any circumstances that made the nuclear medicine subspecialty program in their region attractive or unattractive (yes or no); whether these circumstances had influenced the subspecialty choice (yes or no); whether future employment chances influenced the subspecialty choice (yes or no); and where they would prefer to work in the future (academic hospital, nonacademic hospital, or elsewhere).

The open-ended questions aimed to explore the answers to some of the closed-ended questions in greater depth, that is, what kind of nuclear medicine education did they receive before residency, which person inspired them to enter the integrated nuclear medicine and radiology residency program, what was their specialty during their clinical work before residency, which person inspired them to choose a certain subspecialty, which circumstances make the nuclear medicine subspecialty program in their region attractive or unattractive, how these circumstances influenced the subspecialty choice, what their opinion is on the integration of the nuclear medicine and radiology training programs, and whether they wished to share any other comments on the residency training program.

The questionnaire was digitized with Qualtrics Core XM survey software (Qualtrics, LLC, an SAP America Inc. company).

Data Analysis

Survey participants were divided into 3 groups: undecided residents (residents who were still in their first 2.5 y of general integrated nuclear medicine and radiology residency and had not yet chosen their subspecialty), nuclear medicine residents (residents who had already begun or decided to choose nuclear medicine training), and radiology residents (residents who had already begun or decided to choose radiology training).

Answers to the closed-ended questions were compared between nuclear medicine residents and radiology residents, using the Mann–Whitney test for ordinal variables and the x^2 test for dichotomous and nominal variables.

Answers to the open-ended questions were qualitatively analyzed by 2 radiologists, 1 nuclear medicine physician, and 1 survey specialist to identify common categories that shape a resident's decision to choose nuclear medicine training.

P values of less than 0.05 were considered statistically significant. Statistical analyses were executed using MedCalc software, version 17.2.

RESULTS

Respondents

At the time of the survey, approximately 350 residents were in the integrated nuclear medicine and radiology residency program in The Netherlands [7]. All 28 program directors distributed the questionnaire to their residents. The number of questionnaires returned was 129 (estimated response rate, 36.9%), 15 of which were excluded because they were only partially completed. Fifty-two (46%) of the respondents were men, 60 (53%) were women (2 did not indicate their sex), and most (89%) were between 26 and 35 y old. Their characteristics are shown in Table 1. There were 35 (31%) undecided residents, 9 (8%) nuclear medicine residents, and 70 (61%) radiology residents. Residents from each of the 8 regions were represented (Amsterdam Academic Medical Center, 6%; Vrije Universiteit Amsterdam Medical Center, 20%; Leiden, 5%; Nijmegen, 9%; Northeast Netherlands, 18%; Southeast Netherlands, 18%; Southwest Netherlands, 14%; and Utrecht, 10%).

Comparison of Characteristics Between Subspecialties

The proportion of nuclear medicine residents who had completed or were working on a PhD thesis (79%) was higher than that of radiology residents (57%). High interest in scientific research was also more frequent among nuclear medicine residents (67%) than among radiology residents (26%). In choosing their subspecialty, nuclear medicine residents were more frequently influenced by circumstances that make the nuclear medicine program in their region attractive or unattractive (33%) than were radiology residents (9%). In deciding on their specialty, nuclear medicine residents were also more frequently influenced by future employment chances (44%) than were radiology residents (19%). On the other hand, nuclear medicine residents were less likely to have received nuclear medicine education before residency (11%) than were radiology residents (33%). There were no other substantial differences between the nuclear medicine and radiology residents, and there were no statistically significant differences in any of the variables that were analyzed between the 2 groups (P values ranging from 0.100 to 0.981) (Table 1).

Incentives to Choose the Nuclear Medicine Subspecialty

In their answers to the open-ended questions, almost a third of the residents (9 undecided, 5 nuclear medicine, and 28 radiology) indicated reasons that they favored pursuing the nuclear medicine subspecialty. These could be grouped into 4 categories: the expertise of nuclear medicine physicians and their quality of supervision in the training hospital; opportunities to do scientific research during and after residency; the diversity of pathologic conditions, radiotracers, examinations, and therapies in the training hospital; and an expectation that the role of hybrid imaging will increase. Representative responses are listed in Supplemental Table 1 (supplemental materials are available at http://jnm.snmjournals.org).

Disincentives to Choose the Nuclear Medicine Subspecialty

In their answers to the open-ended questions, a fifth of the residents (4 undecided, 2 nuclear medicine, and 19 radiology) indicated reasons that they did not favor pursuing the nuclear medicine subspecialty. These could be grouped into 4 categories: lack of collaboration and integration between nuclear medicine and radiology in some training hospitals; imbalance between nuclear medicine and radiology during the first 2.5 y of basic training during residency at the expense of nuclear medicine; uncertainty regarding the international recognition of nuclear medicine subspecialty training; and uncertainty about the future of nuclear medicine, regarding the chances of employment and the ratio of nuclear medicine to radiology work activities. Representative responses are listed in Supplemental Table 2.

Table 1. Characteristics of Residents

	Resident's subspecialty			
Variable	**Undecided (*n* = 35)**	**NM (*n* = 9)**	**Radiology (*n* = 70)**	***P****
Age (y)				0.259†
20–25	0	0	0	
26–30	21	2	24	
31–35	10	4	41	
36–40	0	1	3	
41+	4	1	1	
Not indicated		1	1	
Sex				0.981‡
Male	18	3	31	
Female	17	5	38	
Not indicated	0	1	1	
Exposure to NM education before residency	13	1	23	0.342‡
Completed or ongoing work on PhD thesis	16	7	40	0.409‡
Interest in scientific research				0.135†
Low	6	2	11	
Mid	16	0	27	
High	10	6	18	
Not indicated	3	1	14	
Clinical working experience before residency	27	5	38	0.777‡
Inspired by someone to choose subspecialty	NA	3	32	0.728‡
Attractive circumstances for NM subspecialty	9	5	28	0.595‡
Unattractive NM subspecialty circumstances	4	2	19	0.931‡
Influence of attractive or unattractive circumstances	NA	3	6	0.100‡
Influence of future employment chances	NA	4	13	0.178‡
Preference of future working place				0.361‡
Academic	11	3	29	
Nonacademic	19	3	30	
Elsewhere	5	3	10	
No choice	0	0	1	

*Differences between NM and radiology residents.
†According to Mann–Whitney test.
‡According to χ^2 test.
NM = nuclear medicine; NA = not applicable.
Of the 9 NM residents, 7 had already started NM training and 2 had decided to choose it. Of the 70 radiology residents, 47 had already started radiology training and 23 had decided to choose it.

DISCUSSION

Of the approximately 350 residents who were in the Dutch integrated nuclear medicine and radiology residency program in May–July 2020, 114 were included in this study. The estimated response rate (36.9%) was in line with previously reported response rates for surveys in health care [11]. Furthermore, because the respondents included residents from all 8 teaching and training regions in The Netherlands, the survey can be considered representative of the entire country.

The fact that no statistically significant differences in characteristics were found between nuclear medicine and radiology residents is likely due to the relatively low number of the former (n = 9) in comparison with the latter (n = 70). In March 2020, the total number of residents in the nuclear medicine subspecialty program in The Netherlands was 14 [12]. Assuming that 175 of the 350 residents were in the subspecialty phase of their training in March 2020, 8% (14/175) of residents had chosen the nuclear medicine subspecialty. In addition, the number of residents in the nuclear medicine subspecialty program in March 2020 was substantially lower than the approximately 50 nuclear medicine residents who were in training in the dedicated nuclear medicine residency program before 2015 [7], when the nuclear medicine and radiology programs were still separate. These data underline the relevance of the present study.

Although the differences in characteristics between nuclear medicine and radiology residents were not statistically significant, some interesting observations could be made. First, our data suggest that nuclear medicine residents generally have a greater affinity for scientific research than do radiology residents, as reflected by higher proportions of completed or ongoing PhD theses (79% vs. 57%) and higher interest in scientific research (67% vs. 26%). This difference is perhaps related to the reputation of nuclear medicine as a highly innovative field, particularly in Europe, where new imaging biomarkers and nuclear theranostics have been developed in the past few years [5]. In The Netherlands, theranostics currently comprises only a fraction of the daily nuclear medicine workload. Second, regional circumstances regarding nuclear medicine training (such as the availability of a wide or unique arsenal of nuclear medicine procedures or nuclear medicine staff expertise) more frequently influenced nuclear medicine residents than radiology residents in their subspecialty choice (33% vs. 9%). This finding suggests that attractive circumstances may persuade some individuals to pursue the nuclear medicine subspecialty but that unattractive circumstances do not necessarily deter residents from choosing it. Third, expected postresidency employment opportunities more frequently influenced nuclear medicine residents than radiology residents (44% vs. 13%). This finding seems plausible because the nuclear medicine workforce is currently decreasing in The Netherlands whereas the job market for radiologists is saturated. Fifth, nuclear medicine residents were less likely than radiology residents to have received nuclear medicine education before residency (11% vs. 33%). This observation is somewhat surprising but feeds the hypothesis that the overall quality of undergraduate nuclear medicine education in The Netherlands needs to be improved to inspire future residents to subspecialize in nuclear medicine.

The observed differences between nuclear medicine and radiology residents resonate with the results of our qualitative analysis of the open-ended questions. Among the 4 categories of reasons that residents favored pursuing the nuclear medicine subspecialty, 3 share the common denominator of showing that residents are attracted to being at the forefront of educational, scientific, and clinical expertise and innovation (expertise of nuclear medicine physicians and their quality of supervision in the training hospital; opportunities to do scientific research during and after residency; and diversity of pathologic conditions, radiotracers, examinations and therapies in the training hospital). Although it can be argued that leadership in these areas is primarily an academic task, the study suggests that any hospital accredited to offer the nuclear medicine subspecialty should fulfill and maintain a certain standard in this respect. The fourth category that motivates residents to choose the nuclear medicine subspecialty is the expectation that the role of hybrid imaging will increase in the future, which is also one of the reasons why a national taskforce decided to implement an integrated nuclear medicine and radiology residency program in The Netherlands in 2015 [6]. Future studies are necessary to confirm and monitor the expected rise in hybrid imaging examinations.

Regarding the 4 categories of reasons that residents did not favor pursuing the nuclear medicine subspecialty, one potential obstacle is the lack of collaboration and integration between nuclear medicine and radiology in some training hospitals. It can be speculated that historical differences in clinical workloads, workflows, and reimbursement between the 2 departments may play a role. If and how general collaboration can be improved, and whether the 2 subspecialties should operate as a single department or as 2 different ones, are complicated issues that require further investigation. Another potential obstacle is the imbalance between nuclear medicine and radiology—at the expense of nuclear medicine—during the first 2.5 y of basic training during residency. However, dedicating more time to nuclear medicine would then be at the expense of radiology training or would require prolonging the total duration of the residency. The remaining obstacles to choosing subspecialty training in nuclear medicine relate to uncertainty about whether such training will be internationally recognized, whether there will be sufficient future chances of employment, and whether there will be a sufficient ratio of nuclear medicine to radiology work activities. These knowledge gaps need to be urgently addressed because they hinder recruitment of residents for the nuclear medicine subspecialty.

Previous studies surveying radiology residents in the United States [13], the United Kingdom [14], and Saudi Arabia [15] found that among the most popular factors influencing subspecialty choice were strong personal interest, intellectual challenge, a successful or enjoyable rotation during training, the availability of advanced or multimodality imaging, the ability to have a direct impact on patient care, favorable working hours and on-call commitments, and good job prospects. Likewise, in the present study, the role of multimodality imaging and job opportunities were influential. However, other motivating factors largely differed between the present study and the 3 previous studies [13–15], most likely because the latter did not specifically investigate why residents choose or refrain from subspecialization in nuclear medicine.

The present study had some limitations. First, the results should be considered a snapshot in time. New insights may arise from future developments such as adjustments to the Dutch integrated nuclear medicine and radiology curriculum, scientific developments that lead to clinical paradigm shifts (e.g., the expansion of theranostics and the clinical implementation of artificial intelligence), and employment opportunities. Nevertheless, our results provide a baseline framework that can be useful to all stakeholders who wish to increase the recruitment of nuclear medicine residents. This recruitment needs further monitoring before a definitive conclusion can be made on the viability of the integrated curriculum. Second, this study did not investigate the role of postresidency fellowships, which, in combination with the training received during residency, may allow a resident to become an accredited subspecialist in both nuclear medicine and a radiology-based field. Third, because the questionnaire was returned anonymously, it was not possible to ask for specific feedback from residency program directors and other medical imaging specialists in the training hospitals.

CONCLUSION

This study provided insight into what motivates residents to pursue or refrain from nuclear medicine subspecialization in an integrated nuclear medicine and radiology program. Medical imaging specialists in training hospitals and developers of training curricula should consider these motives to ensure a sufficient outflow of newly graduated nuclear medicine specialists.

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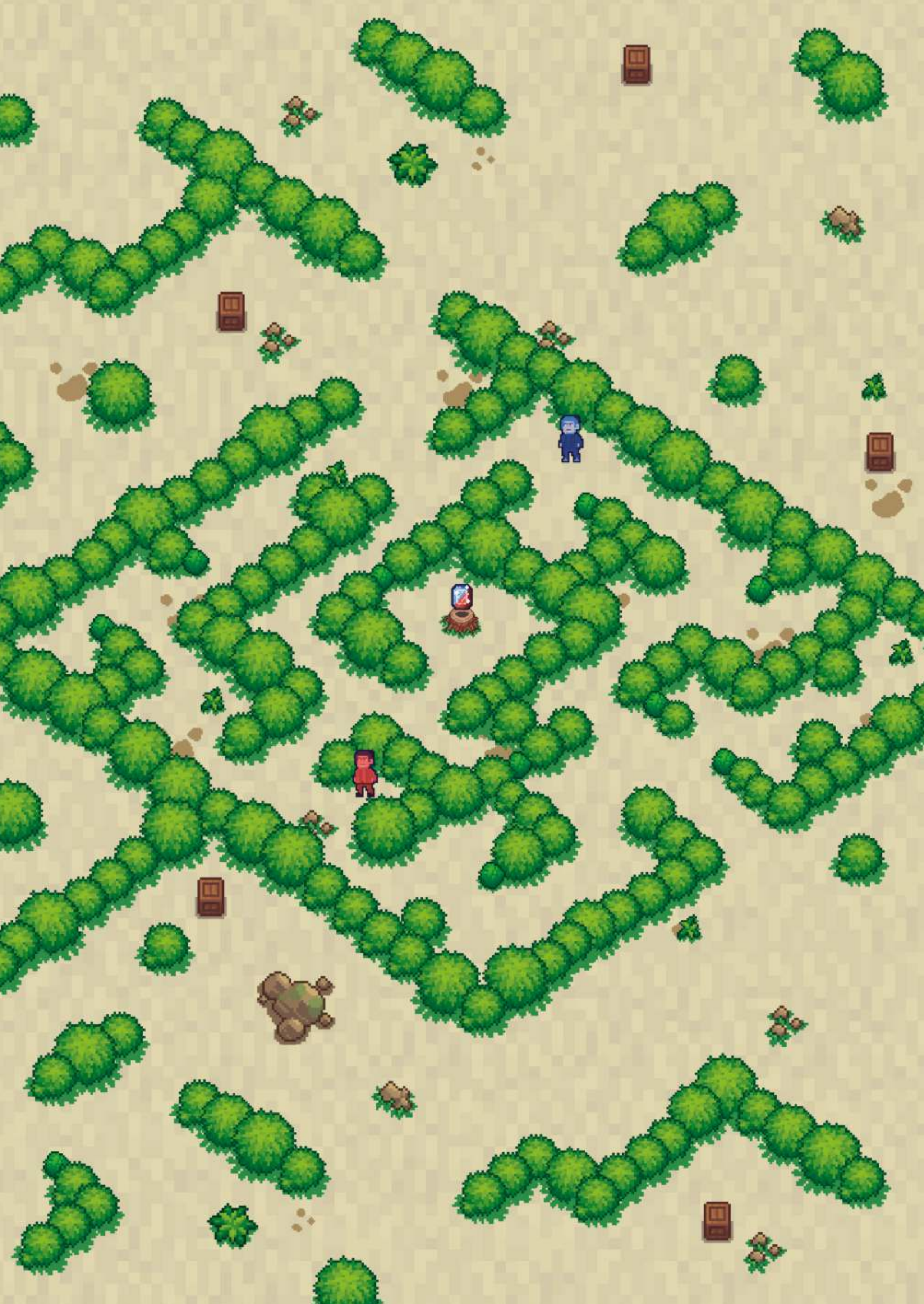
SUPPLEMENTAL DATA

Supplemental table 1. Examples of quotes given by residents in the survey that favor a choice for the nuclear medicine (NM) subspecialty according to four categories.

Category	Open-ended questions and quoted answers given by the residents
1. Expertise of NM physicians and their quality of supervision in the training hospital	Are there any circumstances that make the NM subspecialty program in your teaching and training region attractive? *"Expertise and a great team. Good integration with radiologists."*
2. Opportunities to do scientific research during and after residency	Are there any circumstances that make the NM subspecialty program in your teaching and training region attractive? *"There are lots of opportunities to do research. Treatments (in research setting) and (a lot of) scientific research is done by NM staff"*
3. Diversity of pathology, radiotracers, examinations and therapies in the training hospital	Are there any circumstances that make the NM subspecialty program in your teaching and training region attractive? *"Nuclear medicine in the broad sense of the word, a wide range of examinations and an interesting patient population."*
4. The expectation that the role of hybrid imaging will increase in the future	What is your opinion on the integration of the NM and RAD training? *"This is a good development in my opinion, since they are both imaging specialties and in the upcoming future overlap in both specialties will increase (for instance with PET-MRI)."*

Supplemental table 2. Examples of quotes given by residents in the survey that disfavor a choice for the nuclear medicine (NM) subspecialty according to four categories.

Category	**Open-ended questions and quoted answers given by the residents**
1. Lack of collaboration and integration between NM and RAD in some training hospitals	Are there any circumstances that make the NM subspecialty program in your teaching and training region unattractive? *"Mediocre collaboration between NM and RAD and bad reputation regarding NM; some of the old NM staff is not positive about the new integrated program"*
2. Imbalance between NM and RAD during the first 2.5 years of basic training during residency at the expense of NM	What is your opinion on the integration of the NM and RAD training? *"Prior to the start of residency, I did not have a good understanding of NM. During residency, information and exposure regarding NM is lacking"*
3. Uncertainty regarding the international recognition of the NM subspecialty training	What is your opinion on the integration of the NM and RAD training? *"I am worried about international recognition. I'm hoping to be able to register as a NM physician"*
4. Uncertain future of NM regarding the chances of employment and the ratio of work activities of NM to RAD	Do you have any remarks regarding the integrated NM and RAD program? *"An important reason to not choose the NM subspecialty is the unclear future. It feels like a waste to be deployed solely in NM and not being able to do any acute or other RAD tasks. Choosing a RAD subspecialty with NM expertise in the same field would better prepare me for the future"*



Chapter 4

The radiology job market in the Netherlands: Which subspecialties and other skills are in demand?

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ABSTRACT

Purpose

To evaluate the current job market for medical specialists in radiology and nuclear medicine (NM) in the Netherlands.

Methods

Vacancies posted for radiologists and nuclear medicine physicians in the Netherlands between December 2020 and February 2022 were collected and analyzed.

Results

A total of 157 vacancies (146 for radiologist and 11 for nuclear medicine physicians) were included. The most sought-after subspecialties were all-round (22%), abdominal (19%), and interventional radiology (14%), and 30% of vacancies preferred applicants with additional non-clinical skills (research, teaching, management, information and communications technology (ICT)/artificial intelligence (AI)). Non-academic hospitals significantly more frequently requested all-round radiologists (n = 31) than academic hospitals (n = 1) (p = 0.001), while the distribution of other requested subspecialties was not significantly different between non-academic and academic vacancies. Non-academic hospitals also significantly more frequently requested additional research tasks in their vacancies (n = 35) compared to academic hospitals (n = 4) (p = 0.011). There were non-significant trends for non-academic hospitals more frequently requesting teaching tasks in their vacancies (n =18) than academic hospitals (n = 1) (p = 0.051), and for non-academic hospitals more frequently asking for management skills (n = 11) than academic hospitals (n = 0) (p = 0.075).

Conclusion

All-round, abdominal, and interventional radiologists are most in demand on the job market in the Netherlands. All-round radiologists are particularly sought after by non-academic hospitals, whereas nuclear radiologists who completed the Dutch integrated NM and radiology residency seem to be welcomed by hospitals searching for a nuclear medicine specialist. Finally, non-clinical skills (research, teaching, management, ICT/AI) are commonly requested. These data can be useful for residents and developers of training curricula.

Clinical relevance statement

An overview of the radiology job market and the requested skills is important for residents, for those who seek work as a radiologist, and for those who are involved in the design and revision of residency programs.

INTRODUCTION

Job opportunities for radiologists and nuclear medicine physicians continue to be a point of concern and discussion in Europe and the USA [1, 2]. The general perception is that the job market is overflooded and that vacancies are scarce [1, 2]. Factors that bring additional uncertainty for the job market in Europe and the USA are ongoing cuts in healthcare reimbursement, the continuing increase in workload for radiologists, and uncertainties regarding the effect of developments in artificial intelligence (AI) on daily practice [3–7]. Furthermore, with the increased focus on inclusion and diversity, the number of female radiologists is expected to increase [8]. Female radiologists more often work part-time than male radiologists, which might lead to an even higher demand for radiologists in the future [8].

In the Netherlands, another factor to take into account regarding the job market is the relatively recent revision of the previously separate NM and radiology training curricula that have been combined into one integrated training in 2014 [9]. The Netherlands has been a frontrunner with this integrated training while in other European countries separate residencies for radiology and NM (with some attention to radiology) still exist. Residents who complete this integrated training can be deployed for radiology as well as NM, depending on the (sub) specialty they chose during the training [9]. In this new Dutch curriculum, a resident has to choose at least one (sub)specialty and a maximum of two subspecialties. There are seven radiology subspecialties, i.e., abdominal (ABDOM), breast, cardiothoracic (CTH), interventional (INT), musculoskeletal (MSK), neuro- head and neck (NHN), and pediatric radiology (PED), and one specialty dedicated to NM. A major change compared to previous curricula is that the residents who finish the NM pathway are called nuclear radiologists [9]. The first (nuclear) radiologists who were enrolled in this new curriculum graduated in 2019 [9]. Based on this change in the way residents are trained, some departments of radiology and NM in the Netherlands have decided to merge. This new curriculum could affect the employability and thus the job opportunities of new (nuclear) radiologists [10].

There are no recent data on vacancies for radiologists and nuclear medicine physicians in European countries such as the Netherlands, in terms of number of vacancies and the distribution of these vacancies between academic and non-academic hospitals, the most sought-after subspecialties, types of employment offered (locum or permanent employment), and requested tasks besides direct patient care (such as research, teaching, management, and ICT (information and communications technology)/AI assignments). This information is potentially useful to those who are considering or preparing to work as a medical specialist in radiology or NM in the future. Such data could also provide valuable feedback to all stakeholders who determine the contents and learning objectives of residency programs.

The purpose of this study was therefore to evaluate the current job market for medical specialists in radiology and NM in the Netherlands.

MATERIALS AND METHODS

Study design

This research used publicly available data and did not concern investigations on human subjects. Therefore, ethical review board approval and informed consent were not applicable.

Data collection

Data collection took place between December 2020 and February 2022 via the websites of the Dutch radiology and NM societies, where all formal vacancies in these disciplines are generally listed [11, 12]. All vacancies for radiologists and nuclear medicine physicians that were posted on these websites in the aforementioned 14-month period were recorded. Vacancies for jobs outside the Netherlands and vacancies that were posted for a second time (due to not being filled in initially) were excluded. All other non-medical specialist vacancies related to radiology and NM, e.g., PhD studentships, post-doc positions, or other research-related vacancies, were excluded.

The following variables were recorded for each vacancy: the type of hospital (academic or non-academic), the type of (sub)specialty (radiology subspecialty or NM), the type of employment (fellow, locum, or permanent employment), required additional non-clinical tasks (research, teaching, management, ICT/AI, or other), the amount of full-time equivalent (FTE) for this position, and the reason for the vacancy listing.

Data analysis

Vacancy characteristics were descriptively analyzed. Differences between non-academic and academic job postings in terms of requested subspecialisation and requests for additional research, teaching, management, or ICT/AI tasks were analyzed with a chi-square test. p-values < 0.05 were considered statistically significant.

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 23 (IBM Corp).

RESULTS

Eligible vacancies

A total of 189 vacancies were posted on the websites of the Dutch radiology and NM societies between December 2020 and February 2022. We excluded 26 vacancies for jobs abroad and 6 vacancies that were posted for a second time. The reposted vacancies were all from non-academic hospitals, concerned 4 permanent and 2 locum vacancies, and requested 3 all-round radiologists and 3 radiologists with a subspecialty (ABDOM, CTH, and INT).

Characteristics of included vacancies

The 157 vacancies that were included concerned 119 (76%) vacancies for non-academic hospitals, 34 (22%) vacancies for academic hospitals, and 4 (2%) vacancies for a combination of academic and non-academic hospitals. There were 146 medical specialist vacancies for radiology and 11 medical specialist vacancies for NM. There were 104 locum vacancies (of which 52 for a fellowship position) and 50 permanent vacancies, while 3 vacancies did not report the type of contract. The amount of FTE per vacancy ranged from 0.2 to 1.0 with a median of 0.9 FTE. Thirty-four vacancies (22%) listed the reason for the job posting, which included the following: (temporary) replacement of a radiologist or nuclear medicine physician (n = 10), retirement replacement (n = 6), expansion of work activities or replacement (n = 12), or a combination of the aforementioned (n = 6).

The majority of vacancies did not disclose if their radiology and NM departments were fused as one department.

Requested qualifications

The most frequently requested (sub)specialties for the 157 vacancies were as follows: all-round radiology (n = 35; 22%), ABDOM radiology (n = 30; 19%), and INT radiology (n = 22; 14%) (Fig. 1). Table 1 displays the distribution of subspecialty vacancies between academic and non-academic hospitals. Eight out of 11 (73%) NM vacancies specifically mentioned the search for a nuclear radiologist (i.e., residents who specialized in NM during their integrated training). Forty-eight vacancies (31%) mentioned a preference for applicants who were skilled in one or more additional nonclinical tasks. These non-clinical tasks concerned research (n = 39), teaching (n = 19), management (n = 11), and skills or interests in ICT/AI (n = 2). Note that 23 vacancies asked for more than one of the aforementioned non-clinical tasks.

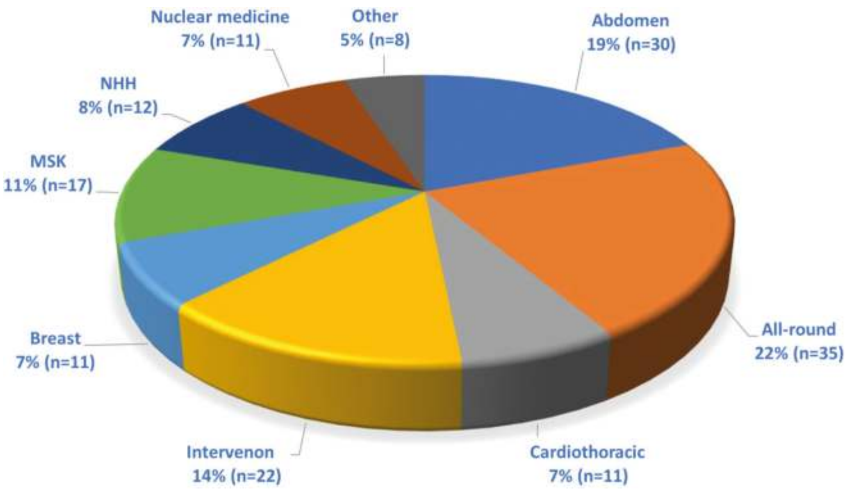

Fig. 1. Pie chart showing the (sub)specialties requested by the 157 vacancies that were included in this study. Percentages are given with absolute numbers between parentheses. Due to the small size of the subspecialties of acute radiology, "none specified," and pediatric radiology, these groups were combined and collectively named "other." MSK, musculoskeletal; NHH, neuro- head and neck radiology

Table 1. Requested subspecialties in non-academic vs. academic vacancies

Subspecialty		Hospital	
		Non-academic (n = 119)	Academic (n = 34)
Radiology (n = 146)	Abdomen	21 (18%)	9 (26%)
	All-round	34 (29%)	1 (3%)
	Breast	11 (9%)	0
	Cardiothoracic	6 (5%)	5 (15%)
	Intervention	17 (14%)	5 (15%)
	MSK[1]	11 (9%)	4 (12%)
	NHH[2]	6 (5%)	5 (15%)
	Other[3]	3 (3%)	4 (12%)
Nuclear medicine (n = 11)	Nuclear medicine	10 (8%)	1 (3%)

The combined academic and non-academic vacancies were not included in this table

[1] *MSK*, musculoskeletal

[2] *NHN*, neuro- head and neck radiology

[3] Due to the small size of the subspecialties of acute radiology, "none specified," and pediatric radiology, these groups were combined and collectively named "other"

Differences between academic and non-academic vacancies

Non-academic hospitals significantly more frequently requested all-round radiologists (*n* = 34) than academic hospitals (*n* = 1) (*p* = 0.001), while the distribution of other requested subspecialties was not significantly different between non-academic and academic vacancies. Non-academic hospitals also significantly more frequently requested additional research tasks in their vacancies (*n* = 35) compared to academic hospitals (*n* = 4) (*p* = 0.011). There were non-significant trends for non-academic hospitals more frequently requesting teaching tasks in their vacancies (*n* = 18) than academic hospitals (*n* = 1) (*p* = 0.051), and for non-academic hospitals more frequently asking for management skills (*n* = 11) than academic hospitals (*n* = 0) (*p* = 0.075).

Distribution of subspecialties between locum and permanent vacancies

All 157 vacancies mentioned the duration of the contract, of which 51 (32%) were permanent vacancies and 106 (68%) locum vacancies (Table 2). There were 52 fellowships among the locum vacancies. The most soughtafter subspecialty was all-round radiology for both the permanent vacancies (*n* = 23, 22%) and locum vacancies (*n* = 12, 24%).

Table 2. Distribution of requested subspecialties between permanent and locum vacancies

Subspecialty		Locum vacancies (*n* = 106)	Permanent vacancies (*n* = 51)
Radiology (*n* = 146)	Abdomen	20 (19%)	10 (20%)
	All-round	23 (22%)	12 (23%)
	Breast	9 (9%)	2 (4%)
	Cardiothoracic	9 (9%)	2 (4%)
	Intervention	11 (10%)	11 (21%)
	MSK[1]	15 (14%)	2 (4%)
	NHH[2]	8 (8%)	4 (8%)
	Other[3]	5 (5%)	3 (6%)
Nuclear medicine (*n* = 11)	Nuclear medicine	6 (4%)	5 (10%)

The combined academic and non-academic vacancies were not included in this table

MSK, musculoskeletal

[2] *NHH*, neuro- head and neck radiology

[3] Due to the small size of the subspecialties of acute radiology, “none specified,” and pediatric radiology, these groups were combined and collectively named “other”

DISCUSSION

This study, which included 157 vacancies for medical specialists in radiology or NM that were published on the websites of the Dutch radiology and NM societies between December 2020 and February 2022, shows that in more than half of job postings either all-round radiologists, ABDOM radiologists, or INT radiologists were requested while the other four radiology subspecialties together with NM comprised the minority. This disbalance raises the question whether quota should be imposed to prevent unnecessary training in some subspecialties and to train sufficient residents in others. However, this speculation requires further longitudinal studies matching the qualifications of recently graduated radiologists with the demands in the job market that are probably dynamic in time. For example, further expansion of INT radiology services in the future is likely [13], and radiology departments that enlarge due to hospital mergers may aim to provide more subspecialty service. Nevertheless, the present data on subspecialty demands may already be helpful to current residents in choosing their subspecialisation.

Although the number of vacancies for nuclear medicine physicians in this study was relatively low, the majority of them specifically asked for a nuclear radiologist. This is most likely due to the versatility of a nuclear radiologist compared to a specialist trained in NM only, because the former can be deployed for both NM and radiology tasks (including on-call duties) [10]. The acceptation of and apparent preference for nuclear radiologists in the job market can be considered a potential success of the new integrated radiology and NM training and/or a reflection of the ongoing fusion of the radiology and NM departments in the Netherlands.

The far majority of vacancies in this study (approximately three-fourths) concerned jobs in non-academic hospitals. This distribution matches the number of non-academic hospitals (*n* = 74) and academic hospitals (*n* = 8) in the Netherlands [14]. Our results indicate that non-academic hospitals more frequently require all-round radiologists than academic hospitals, which seems

logical because nonacademic hospitals have a smaller pool of radiologists to fulfil all clinical tasks, and all-round skills increase flexibility and efficiency. Both permanent and locum vacancies in non-academic hospitals most frequently requested allround radiologists, reflecting the high demand of all-round radiologists outside the academia. However, in the current Dutch curriculum, residents have to choose either NM or at least one radiology subspecialty, which somewhat conflicts with the time that can be evenly spent on all radiology subspecialties to become an all-rounder. This issue may be addressed in future revisions of the curriculum. On the other hand, only one out of 34 academic vacancies asked for an all-round radiologist. This indicates that, when choosing to become an all-round radiologist without subspecialisation, a career as an academic radiologist can almost be excluded in the Netherlands. Except for the all-round radiology profile, other subspecialty requests were not significantly different between non-academic and academic hospitals, indicating that radiologists with a subspecialty can find employment both non-academically and academically.

Nearly one-third of vacancies in this study asked for additional non-clinical tasks. Interestingly, non-academic hospitals also more frequently requested radiologists with research skills and tended to more frequently request teaching tasks and management skills in their vacancies than academic hospitals. Next to clinical excellence, research and teaching are important pillars in the mission statement of the non-academic top hospitals in the Netherlands [15], which is apparently reflected by the contents of the job vacancies for radiologists. It remains unclear why academic hospitals less frequently asked applicants to perform research tasks in their job postings. However, it can be postulated that performing research and teaching are considered matters of course in an academic institution. Overall, our findings highlight the necessity for all residents to acquire skills in both research and teaching, regardless of their future working place as a radiologist. The fact that management skills are more in demand by non-academic hospitals than their academic counterparts is probably related to their often more profit-driven nature and their smaller group of radiologists in which management positions frequently rotate. Importantly, although research and teaching are part of the Dutch curriculum, just like in other European and American radiology training programs, management is only trained in basics, if addressed at all [16, 17]. This issue is a potential point for improvement in these curricula. Of interest, management tasks were only requested in non-academic vacancies and not in any of the academic vacancies. This suggests that trainees who aspire a non-academic appointment should consider bolstering their management skills, while residents who pursue an academic career can perhaps better focus on research and teaching as additional non-clinical skills. In this study, only a few vacancies specifically mentioned a search for applicants who were skilled in AI or ICT tasks, while developments in this field suggest their role to rise in the near future [18]. Residents who want to best prepare for this could benefit from courses which focus on the role of AI in radiology, e.g., as provided by the ESR [19]. Finally, communication and empathy skills (so-called soft skills) were not explicitly asked for in any of the vacancies, although these aspects may also become more important in radiology practice [20]. The lack of requests for soft skills could also be due to the fact that in the Netherlands residents are trained according to CANMEDS criteria and these skills might also be tested during the application procedure [11].

Previous literature on which radiology subspecialties and skills are in demand is rather limited. Several previous studies in the USA focused on the supply and demand of radiologists on the job market. These studies reported that too many residents were trained compared to the number of available jobs in the years 2013 [21] and 2015 [1]. However, these data do not provide information on what qualifications are requested from radiologists looking for employment. In another study in which an anonymous survey was sent to Belgian radiologists (who graduated between 2013 and 2018) and to the heads of all Belgian radiology departments, it was reported that the most desired subspecialties were MSK imaging, INT radiology, and breast imaging [2]. However, these data may be less reliable because they are based on survey results and not on actual job postings. One recent study with a similar design as ours evaluated American College of Radiology (ACR) job postings in 2018, but limited their analysis to jobs labelled as MSK subspecialty [22]. In the 456 vacancies that were included in that study by Nellamattathil et al [22], approximately 19% were for a dedicated MSK radiologist, 25% sought a combination of MSK and a general skill set, and 56% were specifically for a general radiologist position. These data are somewhat in line with our findings, in that all-round radiology skills remain important. Otherwise, however, it is difficult to make a comparison with the present study, because Nellamattathil et al [22] limited their analysis to MSK job postings and did not perform any further analyses on required non-clinical skills and non-academic vs. academic vacancies.

The present study had some limitations. First, this study analyzed all vacancies posted on the radiology and NM society websites. Vacancies outside these media that were filled via non-official channels were not included. This probably means there were more vacancies available than included in this study. Second, whether or not the Dutch job market for radiologists is oversupplied or not cannot be determined in this study, because exact data regarding number of unemployed radiologists and their subspecialties vs. available vacancies were lacking. Third, the findings of this study are primarily applicable to the Netherlands. Nevertheless, some results are probably generalizable, such as the need for curricula to maintain the possibility for residents to be trained as all-round radiologists, the apparent interest of imaging departments in nuclear radiologists over nuclear medicine physicians from the previous curriculum who have no integrated radiology skills, and the need to train residents in important non-clinical skills (research and teaching, but also management), and to consider adding new elements to curricula such as ICT/AI and "soft skills" [20]. Our study also showed that a review of job vacancies over an extended period of time provides valuable information to residents and feedback to potentially improve radiology and NM residency programs. Fourth, data collection took place during the COVID pandemic which caused drastic changes in radiology practices. The periodic decline in imaging requests but also a decrease in available staff during lockdown periods might have been of influence on the job market in the Netherlands as well [23].

In conclusion, this study provided an overview of the current state of the job market for radiologists and nuclear medicine physicians in the Netherlands. All-round, ABDOM, and INT radiologists are most in demand on the job market. All-round radiologists are particularly sought after by nonacademic hospitals, whereas nuclear radiologists who completed the Dutch integrated NM and radiology residency seem to be welcomed by hospitals searching for a nuclear medicine specialist. Finally, non-clinical skills (research, teaching, management, ICT/AI) are commonly requested. These data can be useful for residents and developers of training curricula.

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Chapter 5

Financial illiteracy among internal medicine, surgery, and radiology residents regarding medical imaging costs in the Netherlands

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ABSTRACT

Purpose

To assess the knowledge of internal medicine, surgery, and radiology residents of medical imaging costs at a university hospital in the Netherlands.

Methods

A survey was conducted among internal medicine, surgery, and radiology residents at a tertiary care university hospital to determine their knowledge and view on medical imaging costs. Participants were asked to estimate the costs of a two-view chest X-ray, unenhanced CT of the brain, unenhanced MRI of the brain, contrastenhanced CT of the chest and abdomen, ultrasound of the complete abdomen, and FDG-PET and PSMA-PET torso. Estimates within ± 25% of the available published costs were considered accurate.

Results

A total of 44 participants (18 in internal medicine, 15 in surgery, and 11 in radiology) were included. No resident accurately estimated all imaging costs, with accuracies ranging from 18% for contrast-enhanced CT of the chest and abdomen to 39% for two-view chest X-rays. Cost estimation accuracy did not significantly vary by specialty or training duration. Most participants were concerned about the affordability of medical care within or beyond the next five years (80%, 95%), 66% of residents felt that doctors bear responsibility for limiting healthcare costs, and 89% agreed that education about the financial aspects of medical imaging is useful.

Conclusion

This study showed that residents are financially illiterate regarding medical imaging costs, and neither the duration of training nor specialty influences their knowledge levels. Nevertheless, residents share common concerns and responsibilities about rising healthcare costs and express a desire for additional education regarding the finance of medical imaging.

INTRODUCTION

Rising healthcare costs pose a significant challenge to maintaining the affordability and accessibility of healthcare in the Western world. However, financial education within the medical curriculum for physicians in training appears to be insufficiently addressed [1–4]. Medical imaging constitutes a substantial and continuously growing portion of healthcare expenditures [5]. The demand for medical imaging has surged exponentially over the past decades and is projected to continue to grow in the foreseeable future [6, 7].

Radiologists, as key advisors to clinicians, must be knowledgeable in order to recommend the most appropriate and cost-effective imaging tests. Internal medicine physicians and surgeons, being frequent users of these imaging services, should also possess a fundamental understanding of imaging costs. This could potentially reduce unnecessary and costly testing and mitigate the risk of overdiagnosis—defined as a process where the risk of harm of an intervention outweighs its benefits [8, 9].

However, it remains unclear whether residents in internal medicine, surgery, and radiology are adequately informed about the costs associated with medical imaging and what their attitudes are toward healthcare costs related to medical imaging. Previous studies investigating residents' knowledge of medical imaging costs have primarily been conducted in the United States, with a notable lack of studies in Europe. Should financial literacy be found lacking, this may prompt policymakers to consider integrating this topic into residency curricula.

Therefore, the purpose of this study was to assess the knowledge levels of internal medicine, surgery, and radiology residents regarding the costs of medical imaging at a university hospital in the Netherlands.

MATERIALS AND METHODS

Medical Ethics Review Board

Approval from the local medical ethics review board was obtained for this prospective survey (IRB number: 19198).

Settings and participants

Residents and doctors-not-in-training from the internal medicine and surgery departments of a tertiary care university hospital in the Netherlands (serving a population of over 2.5

million people) were invited to participate in an online questionnaire on medical imaging costs during a group meeting held between April 4th and May 18th, 2024. They were not informed about the contents of the meeting in advance and completed the questionnaire without access to online or other resources, under the supervision of one of the authors (T.V.). Radiology residents were approached individually to participate and completed the questionnaire without access to online or other resources, under the supervision of one of the authors (T.V.).

Residents from departments other than internal medicine, surgery, and radiology were excluded from the analysis to maintain group homogeneity. No other exclusion criteria were applied.

The questionnaire was accessed via a QR code provided during the meeting, which participants scanned using their smartphones, after which the questionnaire became available for completion on their devices. Participation was voluntary, and informed consent was automatically obtained upon participation. Registration was conducted via IP addresses to ensure unique participants were included.

Questionnaire

The questionnaire was developed in Qualtrics by the authors, including two radiologists, a nuclear medicine physician, and a survey specialist. To ensure the quality of reporting, the "Checklist For Reporting Results of Internet E-surveys" has been used as a reporting standard guideline specific to survey results. The questionnaire comprised a total of thirteen questions: twelve closed-ended questions, one open-ended question, and two conditional open-ended questions.

The questionnaire collected data on the following variables: residents' age, gender, department (internal medicine, surgery, radiology, or other), years of residency training, and prior experience with medical imaging costs (an optional open-ended question was included to allow for further clarification). Participants were also asked how frequently they requested various imaging examinations (plain radiograph, ultrasound, CT, MRI, and FDG-PET), with response options ranging from "never" to very often".

Additionally, the questionnaire included six Likert-type statement items with five levels of agreement (ranging from "strongly disagree" to "strongly agree"). These statements addressed concerns about the affordability of medical care within and/or after the next five years, whether residents consider costs when requesting medical imaging, the perceived responsibility of doctors to limit healthcare costs, the consideration of cost-saving possibilities when requesting medical imaging (e.g., preventing other unnecessary costly tests or reducing/preventing morbidity and mortality with appropriate imaging), and the usefulness of financial education on imaging costs prior to residency. Responses of "agree" or "strongly agree" were grouped to determine the highest level of agreement among residents.

Participants were also asked to estimate the costs of several of the most frequently requested imaging tests at our institution, with options ranging from €0 to €5000. The imaging tests included a two-view chest X-ray (€110), unenhanced CT of the brain (€314), unenhanced MRI of the brain (€477), contrast-enhanced CT of the chest and abdomen (€878), ultrasound of the complete abdomen (€198), FDG-PET (€1695), and PSMA PET torso (€2034). The used imaging costs are based on mutual medical service costs in the Netherlands, which are accessible through the hospital's intranet [10]. Note that the costs for FDG PET and PSMA PET did not include a diagnostic CT. To exclude any question-order effects, the abovementioned diagnostic tests were presented in random order. Supplementary File A contains the complete list of questions and answer options.

Data analysis

Residents' survey responses, including demographic data (age, gender, years of residency training, department) were collected and analyzed. The duration of residency training was categorized into four groups for analytical purposes; 1. Not in training, 2. Short training experience (< 1–3 years), 3. Medium training experience (4–7 years), and 4. Long training experience (7 years or more), which could result from part-time work schedules, pregnancy, illness, or other factors extending the training beyond the typical 5–6 years.

The residents' estimated costs for the seven different medical imaging tests were extracted from the published costs available in the Netherlands, resulting in 'cost estimation differences' (in Euros). For example, the cost of an unenhanced CT of the brain (€314) minus a resident's estimate of €250 results in a cost estimation difference of €64. This allowed us to calculate error percentages and identify residents whose estimates were within ± 25% of the published cost for each of the seven imaging tests, consistent with previous research on cost estimation accuracy [11–13]. Estimates outside of this ± 25% range were considered incorrect. The proportion of residents whose estimates fell within ± 25% of the published costs was calculated for the entire group and per department (internal medicine, surgery, and radiology).

A multiple linear regression analysis was conducted to explore associations between the independent variables (duration of residency training and department) and the dependent variable (cost estimation difference). p-values of less than 0.05 were considered statistically significant.

All data were analyzed using IBM SPSS Statistics for Windows, version 23.

RESULTS

Residents' characteristics

From the initial group of participants, approximately 30 internal medicine residents, 20 surgery residents, and 16 radiology residents were in training in their respective departments during the survey period. Out of these, 46 residents completed the questionnaire. Two residents employed in other departments were excluded from the analysis, leaving 44 completed questionnaires for further evaluation, resulting in a response rate of 67%. Of the included residents (18 in internal medicine, 15 in surgery, and 11 in radiology), 21 were male, and 23 were female, with a mean age of 32 years (range: 25–38 years). All questionnaires were fully completed.

Among the respondents, 35 were currently in training, while 9 were doctors not in training. The average duration of residency training was 4.6 years (range: 0–9 years). Four residents (9%) reported having prior knowledge of medical imaging costs, which they had acquired through previous studies, internships, scientific research, projects related to the finance of medical imaging, or personal interest.

The imaging modalities most frequently requested by residents were conventional X-ray studies and CT scans (requested by 33 residents, 75%) and ultrasound imaging (requested by 28 residents, 64%) (Table 1).

Table 1. Frequency of the different imaging modalities that are requested by the 44 residents

Modality	Often*	Sometimes	Never
X-ray	33 (75%)	6 (14%)	5 (11%)**
Ultrasound	28 (64%)	12 (27%)	4 (9%)
CT	33 (75%)	7 (16%)	4 (9%)
MRI	16 (36%)	22 (50%)	6 (14%)
PET	18 (41%)	18 (41%)	8 (18%)

* "Often" is defined as an examination that is requested weekly or even daily, "sometimes" is defined as an examination that is requested only sporadically

** Among the five residents who have never requested plain radiographs; four are radiology residents

Cost estimation error and associated variables

The percentage of residents who estimated costs within ± 25% of the published costs for the seven medical imaging tests ranged between 18% for contrast-enhanced CT of the chest and abdomen to 39% for two-view chest X-rays. Table 2 and Fig. 1 provide detailed values and their distributions.

Table 2. The cost estimation differences (the difference between the published examination cost and the resident's estimates) in Euros

Imaging test	Published cost**	Mean estimate	SD	Median estimate	Min–Max (€)	Within ± 25% of the published costs (%)
Two-view chest X-ray	€ 110,-	€ 89,-	76	€ 78,-	20–516	39%
Unenhanced CT of the brain	€ 314,-	€ 318,-	331	€ 230,-	83–2020	32%
Unenhanced MRI of the brain	€ 477,-	€ 846,-	669	€ 692,-	101–3883	27%
Contrast-enhanced CT of the chest and abdomen	€ 878,-	€ 541,-	356	€ 490,-	152–2120	18%
Ultrasound of the complete abdomen	€ 198,-	€ 189,-	120	€ 159,-	45–595	27%
FDG-PET torso*	€ 1695,-	€ 1351,-	829	€ 1209,-	335–5000	27%
PSMA (prostate-specific membrane antigen)-PET torso	€ 2034,-	€ 1309,-	716	€ 1211,-	0–3505	23%

* FDG- PET and PSMA PET scans without diagnostic CT
** Publicly available cost in the Netherlands [10]

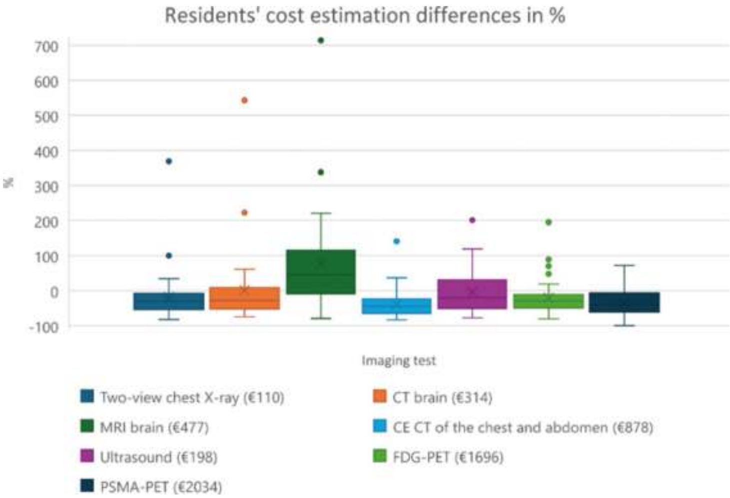

Fig. 1. Residents' cost estimation differences in %
Residents' cost estimation differences are in % relative to the published costs of several imaging tests.
* Shown are the actual prices per modality and their corresponding resident cost estimation differences in ±%. **Publicly available cost in the Netherlands [10]

For internal medicine residents, the percentage of accurate cost estimations within ±25% of the published cost for the seven medical imaging tests ranged from 17% for unenhanced MRI of the brain, contrast-enhanced CT of the chest and abdomen, and ultrasound of the complete abdomen, to 33% for two-view chest X-ray, unenhanced CT of the brain, and FDG-PET torso. Surgery residents demonstrated accuracies ranging from 27% for unenhanced MRI of the brain and contrast-enhanced CT of the chest and abdomen, to 53% for two-view chest X-ray and ultrasound of the complete abdomen. Among radiology residents, the accuracies ranged from 9% for contrastenhanced CT of the chest and abdomen and ultrasound of the complete abdomen, to 46% for unenhanced MRI of the brain (Table 3).

Table 3. Number of residents with cost estimates within ± 25% of the published cost per examination and department

Imaging test	Internal medicine	Radiology	Surgery
Two-view chest X-ray	6 (33%)	2 (18%)	8 (53%)
Unenhanced CT of the brain	6 (33%)	2 (18%)	6 (40%)
Unenhanced MRI of the brain	3 (17%)	5 (46%)	4 (27%)
Contrast-enhanced CT of the chest and abdomen	3 (17%)	1 (9%)	4 (27%)
Ultrasound of the complete abdomen	3 (17%)	1 (9%)	8 (53%)
FDG-PET torso*	6 (33%)	1 (33%)	5 (33%)
PSMA (prostate-specific membrane antigen)-PET torso	4 (22%)	2 (18%)	5 (33%)

* FDG- PET and PSMA PET scans without diagnostic CT

No significant correlation was found between the cost estimation differences for the various imaging tests (twoview chest X-ray, unenhanced CT of the brain, unenhanced MRI of the brain, contrast-enhanced CT of the chest and abdomen, ultrasound of the complete abdomen, FDG PET torso, PSMA PET torso) and the duration of training or department type. Similarly, no significant correlation was identified between residents who had prior knowledge of medical imaging costs and their cost estimation accuracy.

None of the 44 residents accurately estimated the costs of all seven medical imaging tests, and 4 residents (9%) incorrectly estimated the costs of all tests.

Residents’ attitudes towards medical imaging costs

Strong agreement among residents was observed regarding concerns about the affordability of medical care within the next five years (35 residents, 80%) and beyond five years (42 residents, 95%). Additionally, 11 residents (25%) reported considering the costs of medical imaging when requesting imaging, 29 residents (66%) felt that doctors bear responsibility for limiting healthcare costs, 17 residents (39%) considered cost-saving opportunities when requesting imaging, and 39 residents (89%) agreed that educating medical students about the financial aspects of medical imaging before residency would be beneficial.

DISCUSSION

This study demonstrated that residents in internal medicine, surgery, and radiology lack accurate knowledge of medical imaging costs. None of the residents accurately estimated all imaging costs (i.e., within the 25% error margin), and 9% incorrectly estimated the cost of all imaging tests. The financial (il)literacy of residents regarding medical imaging is not influenced by their years of training or specialty. Additionally, the few residents who reported prior knowledge of medical imaging finance did not perform better in estimating the costs of different modalities.

Despite their general illiteracy regarding medical imaging costs, the majority of residents expressed concerns about the affordability of healthcare both in the near and distant future. Notably, radiology residents had the least accurate estimates, although the reasons for this remain unclear. Approximately two-thirds of the participants agreed that doctors play a vital role in controlling the rise in healthcare costs, and nearly 90% of the residents expressed a desire to receive education on medical imaging costs prior to starting their residency. This suggests a clear need for financial education related to medical imaging costs during residency, or possibly even earlier in medical school, to enhance cost awareness and contribute to reducing healthcare costs through the efficient use of limited resources [14, 15].

Previous studies investigating knowledge of medical imaging costs have primarily focused on medical specialists or were conducted a considerable time ago, in the United States or South Africa, where medical costs and training curricula differ from those in Europe [12, 13, 16]. For instance, online survey studies conducted by Vijayasarathi et al in 2015 and 2016 among 381 postgraduate physician trainees and 1066 radiology trainees revealed that only 6% of the postgraduate physician trainees and 17% of the radiology trainees provided cost estimates within the correct range (defined as within ± 25% of published Medicare allowable amounts) [12, 13].

Integrating financial education early in residency training or even during medical school could potentially reduce costs by increasing knowledge, as demonstrated by previous studies involving minor educational interventions, such as lectures on abdominal imaging charges and 15-minute educational modules focused on costeffective ordering [17]. By enhancing cost awareness among residents, they can make more informed decisions and reduce unnecessary imaging studies, as shown in a study by Kanzaria et al, where 50% of emergency physicians identified increased education as one of the most effective solutions for reducing unnecessary imaging requests [18]. Increased cost awareness regarding medical imaging through resident education may lead to more efficient use of diagnostic tests. Further research is needed to determine the most effective way to integrate financial education about medical imaging into the medical curriculum.

The study has several limitations. First, the sample size was relatively small; however, the high response rate suggests that the results accurately reflect the current level of knowledge and general opinions of internal medicine, surgery, and radiology residents in a large academic hospital. Second, only a selection of available imaging tests was presented to the participants to maintain survey conciseness, which limits the scope of the available imaging tests evaluated. Third, the questionnaire only addressed the direct costs of imaging, and not the potential long-term cost savings that imaging could provide by preventing or reducing mortality and morbidity, shortening hospital stays, and reducing the need for additional diagnostics and therapies. Fourth, this was a single-center study conducted in an academic hospital, and the results may differ in other hospitals or countries with different curricula and imaging costs. However, in the Netherlands, the training curricula are standardized nationwide, so similar results might be expected in other institutions.

In conclusion, this study demonstrated that residents are financially illiterate regarding medical imaging costs, and neither the duration of training nor the specialty appears to influence their level of knowledge. Nonetheless, residents share common concerns and responsibilities regarding rising healthcare costs and express a strong desire for additional education on the financial aspects of medical imaging.

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SUPPLEMENTAL DATA

Supplemental file 1. The complete list of the questions and answer options.
Q1. What is your age?
Yes/No
Q2. What is your gender?
Male/Female/Other
Q3. Within which specialty are you working?
Internal medicine/Radiology/Surgery/Other, namely
Q4. How many years have you been in training within your specialty?
Scale from <1 year to > 10 years, or I am not in training
Q5. Have you acquired knowledge regarding the costs of radiological and/or nuclear imaging prior to beginning your specialty training?
Yes/No or I don't know
Q5a. If you answered 'yes' on the previous question, please clarify how you gained knowledge of the costs of radiological and/or nuclear imaging.
Q6. Please indicate for the following imaging tests (conventional X-ray. Ultrasound, CT, MRI, FDG-PET) what applies to you.
I request regularly/ I sometimes request/ I have never requested this imaging test

Introduction to the next questions:
Radiological and nuclear imaging (medical imaging) incurs costs. However, it can also save costs, for example, by enabling faster diagnoses that can limit or prevent morbidity and mortality, avoid unnecessary interventions, or shorten hospital stays.

The following are several statements for which you can indicate the extent to which you agree or disagree. Please rate your agreement on a five-point scale, ranging from 'strongly disagree' to 'strongly agree'.

Q7. I am concerned about the short-term affordability of healthcare over the next five years.
Q8. I am concerned about the long-term affordability of healthcare (beyond the next five years).
Q9. When requesting medical imaging, I also take the costs into consideration.
Q10. Limiting healthcare costs is key responsibility for doctors.
Q11. When requesting medical imaging, I also considering cost-saving possibilities.
Q12. It is beneficial to educate medical students about the costs of medical imaging.

Introduction to the next questions:

The following questions pertain to the costs (in euros) of the most commonly requested radiological and nuclear medicine imaging studies at our institution. Using a slider (€0 - €5000), please indicate what you believe the costs per study are. Our goal is to assess your knowledge of the current costs of medical imaging. Please provide your best estimate at this time.

Q13. What is your cost estimate for the following imaging studies at our institution: two-view chest Xray, unenhanced CT of the brain, unenhanced MRI of the brain, contrast-enhanced CT of the chest and abdomen, ultrasound of the complete abdomen, FDG-PET, and PSMA-PET torso?

Supplemental table 1. Checklist for Reporting Results of Internet E-Surveys (CHERRIES)

	Checklist for Reporting Results of Internet E-Surveys (CHERRIES)		
Item Category	***Checklist Item***	***Explanation***	
Design	Describe survey design	Describe target population, sample frame. Is the sample a convenience sample? (In "open" surveys this is most likely.)	Materials & Methods Page 1-2
IRB (Institutional Review Board) approval and informed consent process	IRB approval	Mention whether the study has been approved by an IRB.	Materials & Methods Page 1
	Informed consent	Describe the informed consent process. Where were the participants told the length of time of the survey, which data were stored and where and for how long, who the investigator was, and the purpose of the study?	Materials & Methods Page 1
	Data protection	If any personal information was collected or stored, describe what mechanisms were used to protect unauthorized access.	N/A
Development and pretesting	Development and testing	State how the survey was developed, including whether the usability and technical functionality of the electronic questionnaire had been tested before fielding the questionnaire.	Materials & Methods Page 1
Recruitment process and description of the sample having access to the questionnaire	Open survey versus closed survey	An "open survey" is a survey open for each visitor of a site, while a closed survey is only open to a sample which the investigator knows (passwordprotected survey).	Materials & Methods Page 1-2
	Contact mode	Indicate whether or not the initial contact with the potential participants was made on the Internet. (Investigators may also send out questionnaires by mail and allow for Web-based data entry.)	Materials & Methods Page 1

Supplemental table 1. Continued

	Checklist for Reporting Results of Internet E-Surveys (CHERRIES)		
Item Category	***Checklist Item***	***Explanation***	
	Advertising the survey	How/where was the survey announced or advertised? Some examples are offline media (newspapers), or online (mailing lists – If yes, which ones?) or banner ads (Where were these banner ads posted and what did they look like?). It is important to know the wording of the announcement as it will heavily influence who chooses to participate. Ideally the survey announcement should be published as an appendix.	N/A
Survey administration	Web/E-mail	State the type of e-survey (eg, one posted on a Web site, or one sent out through e-mail). If it is an e-mail survey, were the responses entered manually into a database, or was there an automatic method for capturing responses?	Materials & Methods Page 1
	Context	Describe the Web site (for mailing list/newsgroup) in which the survey was posted. What is the Web site about, who is visiting it, what are visitors normally looking for? Discuss to what degree the content of the Web site could pre-select the sample or influence the results. For example, a survey about vaccination on a anti-immunization Web site will have different results from a Web survey conducted on a government Web site	N/A
	Mandatory/voluntary	Was it a mandatory survey to be filled in by every visitor who wanted to enter the Web site, or was it a voluntary survey?	Materials & Methods Page 1
	Incentives	Were any incentives offered (eg, monetary, prizes, or non-monetary incentives such as an offer to provide the survey results)?	Materials & Methods Page 1
	Time/Date	In what timeframe were the data collected?	Materials & Methods Page 1
	Randomization of items or questionnaires	To prevent biases items can be randomized or alternated.	N/A

Supplemental table 1. Continued

	Checklist for Reporting Results of Internet E-Surveys (CHERRIES)		
Item Category	***Checklist Item***	***Explanation***	
	Adaptive questioning	Use adaptive questioning (certain items, or only conditionally displayed based on responses to other items) to reduce number and complexity of the questions.	Materials & Methods Page 1-2
	Number of Items	What was the number of questionnaire items per page? The number of items is an important factor for the completion rate.	Materials & Methods Page 1
	Number of screens (pages)	Over how many pages was the questionnaire distributed? The number of items is an important factor for the completion rate.	N/A
	Completeness check	It is technically possible to do consistency or completeness checks before the questionnaire is submitted. Was this done, and if "yes", how (usually JAVAScript)? An alternative is to check for completeness after the questionnaire has been submitted (and highlight mandatory items). If this has been done, it should be reported. All items should provide a non-response option such as "not applicable" or "rather not say", and selection of one response option should be enforced.	N/A
	Review step	State whether respondents were able to review and change their answers (eg, through a Back button or a Review step which displays a summary of the responses and asks the respondents if they are correct).	N/A
Response rates	Unique site visitor	If you provide view rates or participation rates, you need to define how you determined a unique visitor. There are different techniques available, based on IP addresses or cookies or both.	Materials & Methods Page 1
	View rate (Ratio of unique survey visitors/unique site visitors)	Requires counting unique visitors to the first page of the survey, divided by the number of unique site visitors (not page views!). It is not unusual to have view rates of less than 0.1 % if the survey is voluntary.	N/A

Supplemental table 1. Continued

	Checklist for Reporting Results of Internet E-Surveys (CHERRIES)		
Item Category	***Checklist Item***	***Explanation***	
	Participation rate (Ratio of unique visitors who agreed to participate/unique first survey page visitors)	Count the unique number of people who filled in the first survey page (or agreed to participate, for example by checking a checkbox), divided by visitors who visit the first page of the survey (or the informed consents page, if present). This can also be called "recruitment" rate.	Materials & Methods Page 1 N/A
	Completion rate (Ratio of users who finished the survey/users who agreed to participate)	The number of people submitting the last questionnaire page, divided by the number of people who agreed to participate (or submitted the first survey page). This is only relevant if there is a separate "informed consent" page or if the survey goes over several pages. This is a measure for attrition. Note that "completion" can involve leaving questionnaire items blank. This is not a measure for how completely questionnaires were filled in. (If you need a measure for this, use the word "completeness rate".)	Results Page 1
Preventing multiple entries from the same individual	Cookies used	Indicate whether cookies were used to assign a unique user identifier to each client computer. If so, mention the page on which the cookie was set and read, and how long the cookie was valid. Were duplicate entries avoided by preventing users access to the survey twice; or were duplicate database entries having the same user ID eliminated before analysis? In the latter case, which entries were kept for analysis (eg, the first entry or the most recent)?	N/A
	IP check	Indicate whether the IP address of the client computer was used to identify potential duplicate entries from the same user. If so, mention the period of time for which no two entries from the same IP address were allowed (eg, 24 hours). Were duplicate entries avoided by preventing users with the same IP address access to the survey twice; or were duplicate database entries having the same IP address within a given period of time eliminated before analysis? If the latter, which entries were kept for analysis (eg, the first entry or the most recent)?	Materials & Methods Page 1

Supplemental table 1. Continued

	Checklist for Reporting Results of Internet E-Surveys (CHERRIES)		
Item Category	***Checklist Item***	***Explanation***	
	Log file analysis	Indicate whether other techniques to analyze the log file for identification of multiple entries were used. If so, please describe.	Via Qualtrics during data analysis
	Registration	In "closed" (non-open) surveys, users need to login first and it is easier to prevent duplicate entries from the same user. Describe how this was done. For example, was the survey never displayed a second time once the user had filled it in, or was the username stored together with the survey results and later eliminated? If the latter, which entries were kept for analysis (eg, the first entry or the most recent)?	User was identified via IP address to ensure unique participants.
Analysis	Handling of incomplete questionnaires	Were only completed questionnaires analyzed? Were questionnaires which terminated early (where, for example, users did not go through all questionnaire pages) also analyzed?	Results Page 1. Incomplete questionnaires were not included.
	Questionnaires submitted with an atypical timestamp	Some investigators may measure the time people needed to fill in a questionnaire and exclude questionnaires that were submitted too soon. Specify the timeframe that was used as a cut-off point, and describe how this point was determined.	N/A
	Statistical correction	Indicate whether any methods such as weighting of items or propensity scores have been used to adjust for the non-representative sample; if so, please describe the methods.	N/A

Chapter 6

Reading room assistants to reduce workload and interruptions of radiology residents during on-call hours: Initial evaluation

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ABSTRACT

Purpose
To determine how much timesaving and reduction of interruptions reading room assistants can provide by taking over non-image interpretation tasks (NITs) from radiology residents during on-call hours.

Methods
Reading room assistants are medical students who were trained to take over NITs from radiology residents (e.g. answering telephone calls, administrative tasks and logistics) to reduce residents' workload during on-call hours. Reading room assistants' and residents' activities were tracked during 6 weekend dayshifts in a tertiary care academic center (with more than 2.5 million inhabitants in its catchment area) between 10 a.m. and 5p.m. (7-hour shift, 420 min), and time spent on each activity was recorded.

Results
Reading room assistants spent the most time on the following timesaving activities for residents: answering incoming (41 min, 19%) and outgoing telephone calls (35 min, 16%), ultrasound machine related activities (19 min, 9%) and paramedical assistance such as supporting residents during ultrasound guided procedures and with patients (17 min, 8%). Reading room assistants saved 132 min of residents' time by taking over NITs while also spending circa 31 min consulting the resident, resulting in a net timesaving of 101 min (24%) during a 7-hour shift. The reading room assistants also prevented residents from being interrupted, at a mean of 18 times during the 7-hour shift.

Conclusion
This study shows that the implementation of reading room assistants to radiology on-call hours could provide a timesaving for residents and also reduce the number of times residents are being interrupted during their work.

INTRODUCTION

The general workload in clinical radiology practice has increased considerably over the past decades [1,2,3]. Residents experience a greater workload, increased levels of stress, and burnout has a relatively high prevalence among radiology residents when compared to other specialties [4,5,6]. In many (academic) hospitals, residents act as the primary point of contact for referring physicians to discuss and execute imaging requests, and to review and communicate pertinent imaging findings during on-call hours. On-call duties are generally found to be more demanding and stressful than work during office hours because of the combination of an increased workload and the responsibility for patients' health [7].

The core work of residents during on-call hours consists of image interpretation tasks (IITs), but another part concerns non-image interpretation tasks (NITs) such as answering telephone calls, administrative tasks, and arranging logistics for patients to undergo imaging [8,9]. NITs frequently interrupt residents during IITs and these interruptions may potentially lead to diagnostic errors, disruption of workflow efficiency and increased psychological stress [10]. Call triage assistants can take over a large part of these NITs, such as answering telephone calls and administrative tasks, and this has been proven to increase residents' image interpretation time and efficiency, decrease task-switching events, and potentially decrease interpretative errors [11,12,13]. However, the call triage assistants' tasks are mostly limited to answering telephone calls and administrative tasks, and other NITs such as assisting residents with patients, procedures and materials (e.g. for ultrasound or CT guide abscess drainage, ascites or joint fluid puncture), were not included in previous studies. These additional NITs could be performed by a reading room assistant. Of interest, the study by Horowitz et al. suggested that implementing reading room assistants to take over NITs may contribute to the well-being of radiologists (in training) [14].

The purpose of this study was therefore to determine the effects of reading room assistants on timesaving and reduction of interruptions for radiology residents during on-call hours.

MATERIALS AND METHODS

Study design

This study was carried out with anonymously collected observational data for quality improvement purposes. The involved residents all gave written informed consent prior to data collection and the observer and residents were given unique identifier codes to store the data anonymously. No patient-related information was used. Approval was obtained from the local ethical review board.

Hospital setting

This research was performed at a tertiary care academic center in the Netherlands with more than 2.5 million inhabitants in its catchment area. Weekend day shifts (i.e. Saturdays and Sundays from 8:30 a.m. to 8:30p.m.) were selected for this pilot study because they are generally the busiest shifts in our hospital, and the deployment of reading room assistants was thought to be most useful on these days. In our hospital the reading room assistants have supported residents on Saturday and Sunday shifts from 10 a.m. till 5p.m. since the end of 2018. The radiology residency takes 5 years in the Netherlands, and residents are scheduled to be on call after 9 to 12 months of general radiology training. During on-call hours in our hospital, the radiology resident is contacted by the referring physician for all ultrasonography, CT, and MRI) requests (except for conventional radiography requests, which are coordinated by one of the radiology technicians). The radiology resident is also contacted by referring physicians for all other questions related to the imaging during on-call hours. Reading room assistants act as the primary point of contact and take over all of these phone calls from the radiology residents. Reading room assistants have been trained to triage between urgent imaging requests (e.g. trauma, aortic dissection, suspected hemorrhage, pulmonary embolism) and less urgent imaging requests, and direct all urgent imaging requests immediately towards the radiology resident to prevent delays. One resident is on call during each weekend dayshift, with different residents on Saturday and Sunday. The residents are supervised by a general radiologist, a neuroradiologist, and an interventional radiologist during on-call hours. Residents interpret all emergency CT and MRI scans and communicate the results to the referring physicians, both verbally and with (preliminary) written radiology reports. They also perform and interpret ultrasonography examinations (except cardiac, gynecologic, and point-of-care (POCUS) examinations). Ultrasonography machines are available at the radiology department and emergency room. For admitted patients who cannot be transported to the radiology department, an ultrasonography machine has to be moved from the radiology department to the ward and back, by the resident. Conventional radiographs are only interpreted during on- call hours if acquired in trauma patients or upon request. Interventions are generally performed by or under direct supervision of the general or interventional radiologist.

The specialties with most imaging requests during on-call hours (i.e. surgery, internal medicine, neurology, intensive care, emergency medicine, and pediatrics) are also staffed by residents with a similar supervising system. Note that there are no reading room assistants in any of the other departments in our hospital.

Reading room assistants

Reading room assistants were recruited from a pool of medical students affiliated to our university. To be able to enroll in this pool, students were required to have successfully completed their first year of medical study and to be available for at least one year for 16 h per week. In our study reading room assistants were medical students in their 2nd to 5th year (note that the general medicine study, including clinical internships, takes 6 years in the Netherlands). There were no other predefined selection criteria from the radiology department. The number of reading room assistants in our radiology department has been around 6–7 over the past years, and the group of reading room assistants consisted of 7 members during data collection for this study. All students who apply for a reading room assistant position have an introductory interview with one resident and a staff radiologist. The students then accompany and observe an experienced reading room assistant during 4 complete shifts as a training. The very first reading room assistants were trained by residents in a similar manner. During these training shifts, the reading room assistants learn to gather relevant information when receiving imaging requests (patient name, hospital patient number and the department the patient is admitted to, requesting physicians telephone number, requested examination, potential (contrast) allergies, renal function (eGFR), if the patient has an intravenous access, any prior or planned future surgeries, urgency of the examination, main clinical history, physical examination and laboratory test results and if there is a request for an additional intervention (e.g. abscess drainage) and if so, if anticoagulants are used. During these training shifts the reading room assistants also learn how to work with basic features of the electronic patient file. In our institution we use EPIC Electronic Health Record software (EPIC Corporation, Madison, WI). During their training the reading room assistants also learn the locations of important departments, e.g. the intensive care unit (ICU), emergency room (ER), and the reporting room. Reading room assistants receive feedback on their functioning by the residents with whom they attend the training shifts to improve their functioning. The reading room assistants are financially compensated for the hours they work.

Data collection

Three medical students, who were not part of the pool of reading room assistants, collected data on 6 randomly selected weekend day shifts including Saturday March 23rd, Saturday March 30th, Sunday March 31st, Saturday April 6th, Saturday April 13th, and Sunday April 21st, 2019, from 10 a.m. to 5p.m. Data collection was designated to 6 weekends due to the limited time assigned to the students to perform data collection. These 3 students recorded all activities performed by the residents and the reading room assistants attending these 6 shifts, using a stopwatch, which was not visible to the residents and reading room assistants. During each shift two students attended to collect the data without interrupting the residents and reading room assistants, one student was assigned to collect data from the resident and the other from the reading room assistant. The reading room assistants and residents were unaware of the purpose of this study and the type of data that were collected.

The time spent by residents on the following activities were recorded: making a report, performing ultrasonography, reviewing cross- sectional imaging (note that residents are sometimes only able to review the images and discuss the key findings with the clinician first, and make a report later during the shift), face to face or telephone consultation with clinicians, supervising radiologists, radiology technicians, or reading room assistants, walking (to ICU, ER, or reporting room), (toilet) break, assisting (during procedures performed by staff radiologist, radiology technician, or other healthcare professionals for non- radiology tasks), answering or sending work-related e-mails, resolving technical errors and administrative tasks (such as assigning protocols, reviewing patient laboratory results or previous imaging) and non- active time (social talks).

The time spent by the reading room assistants on the following activities were recorded: incoming and outgoing telephone calls or face to face consultations with clinicians, radiology residents, and radiology technicians, ultrasound machine related activities (moving the ultrasonography machine, booting the system, supplying materials such as ultrasound gel, towels, biopsy materials), walking (to ICU, ER or reporting room), paramedical assistance (e.g. assisting residents with procedures, materials, and patients), administrative tasks (such as starting or finishing ultrasound examinations in the electronic patient file, checking laboratory results and available previous imaging), (toilet) breaks. The activities performed by the reading room assistants that were considered timesaving for the residents were: incoming and outgoing telephone calls, ultrasound machine related activities, paramedical assistance, administrative tasks, and consulting referring clinician and radiology technician face to face. The reading room assistants also had non-active time during the shifts, these were excluded from analysis.

Data analysis

The time spent by residents and reading room assistants on the aforementioned various activities during their 6 weekend day shifts between 10 a.m. and 5p.m. (7-hour shift, 420 min) were descriptively analyzed. The amount of time that was saved for the residents by the reading room assistants was calculated as: time spent by the reading room assistants on all activities (except walking, (toilet) breaks, and non-active time) - time spent by the reading room assistants on consulting the radiology resident. The number of interruptions that were prevented for the residents by the reading room assistants was calculated as:

number of incoming phone calls that were answered by the reading room assistants at times the radiology resident was busy with other activities - number of times the reading room assistants consulted the radiology resident.

Statistical analysis

The mean time spent on each activity by the residents and reading room assistants was calculated, along with standard deviations (SDs) and ranges, using IBM SPSS Statistics for Windows, version 23.

RESULTS

Resident characteristics

The 6 residents that were followed on the 6 weekend day shifts had a mean of 40 months training (range: 18–54 months) in their 5-year radiology residency program. The included residents had a mean radiology shift experience of 31 months (range: 6–48 months) before this study. Table 1 shows the time spent on different activities during weekend day shifts by the residents (Fig. 1).

Table 1. Performed activities by the residents during weekend day shifts from 10 a.m. − 5p.m.

Activities	Mean time spent in min (SD)	Range in min	Percentage of total
Reporting	94 ± 25	73–125	27 %
Performing ultrasonography	74 ± 47	8–144	21 %
Reviewing scan	44 ± 29	3–100	13 %
Consulting reading room assistant	31 ± 13	14–47	9 %
Consulting clinician	30 ± 12	19–49	9 %
Consulting supervising radiologist	30 ± 12	18–54	9 %
Telephone: outgoing	23 ± 14	6–40	6 %
Miscellaneous*	12 ± 12	0–45	3 %
Telephone: incoming	10 ± 4	7–17	3 %

*Waiting for scans, walking (to ICU, ER or reporting room), (toilet)breaks, resolving technical errors, assigning protocols, assisting staff during procedures and sending.
**The residents also spent 11 min on non-active time (social talks) which was excluded from the analysis.

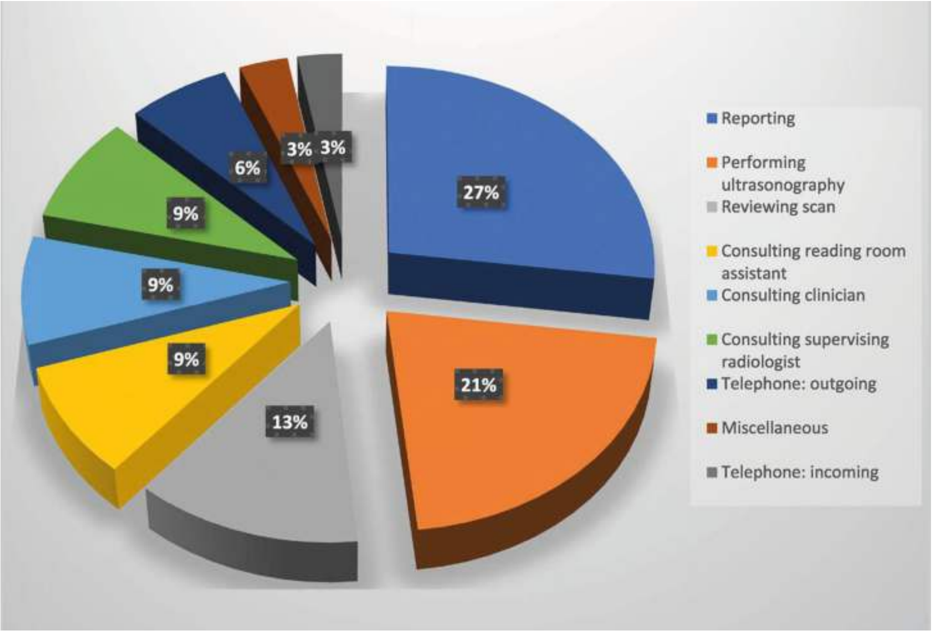

Fig. 1. Mean time spent on different activities by residents during weekend day shifts between 10 a.m. and 5p.m.

* All activities that took less than 30 mins or less per shift were summarized as miscellaneous in this figure (e.g. waiting for scans, walking, (toilet) breaks, resolving technical errors, assigning protocols, assisting and mailing), except for incoming and outgoing telephone calls.

** The percentages are based on the 7 h per shift when data were collected with exclusion of 11 min spent on non-active time (social talks).

Residents' activities

Residents on average spent the most time on the following activities during their weekend day shifts between 10 a.m. and 5p.m.; making reports (94 min, 27 %), performing ultrasonography (74 min, 21 %), reviewing scans (44 min, 13 %), consulting reading room assistant (31 min, 9 %), referring clinicians (30 min, 9 %), and supervising radiologist (30 min, 9 %), outgoing and incoming telephone calls (23 min, 6 % and 10 min, 3 %) and miscellaneous (e.g. waiting for scans, walking, (toilet) breaks, resolving technical errors, protocols, assisting staff during procedures and answering or sending e-mails) (12 min, 3 %). The residents also spent 11 min on non-active time (social talks) which were excluded from the analysis. Table 1 provides an overview of the time spent on the different activities.

Reading room assistants' activities

The 6 reading room assistants spent 214 min on these various activities: incoming (41 min, 19 %) and outgoing (35 min, 16 %) telephone calls, consulting radiology resident (31 min, 15 %), walking (27 min, 13 %), (toilet) break (24 min, 11 %), ultrasound machine related activities (19 min, 9 %), paramedical assistance (17 min, 8 %), administrative tasks (16 min, 8 %), consulting clinician face to face (3 min, 1 %), face to face contact with radiology technician (1 min, 0 %). The reading room assistants also had 173 min of non-active time, during which they were waiting for tasks to perform. The remaining 33 min during the 7 h shift were spent on non-work related activities (social talks or personal activities). The reading room assistants spent 132 min (31 %) in total on activities that were timesaving for residents. Table 2 provides an overview of the time spent on the different (timesaving) activities by the reading room assistants (Fig. 2.).

Table 2. Performed activities by the reading room assistant and mean time spent/ saved during weekend dayshifts from 10 a.m. – 5p.m.

Activities	Mean time spent in min (SD)	Range in hours:min	Percentage of total
Consulting resident	31 ± 13	14–47	15 %
Walking**	27 ± 13	12–42	13 %
(Toilet) break	24 ± 10	0–32	11 %
Timesaving activities Telephone call: incoming	41 ± 12	0–39	19 %
Telephone call: outgoing	35 ± 13	2–45	16 %
Ultrasound machine related activities***	19 ± 8	0–24	9 %
Paramedical assistance	17 ± 12	1–31	8 %
Administrative tasks	16 ± 16	0–40	8 %
Consulting referring clinician face to face	3 ± 3	0–7	1 %
Contact with radiology technician face to face	1 ± 2	0–4	0 %

*Reading room assistants also spent 173 min (41%) on non-active time and 33 min (8%) on non-work related activities (social talks or personal activities), these were excluded from analysis.
**Walking to ICU, ER or reporting room. ***Including transportation of the ultrasound machine.

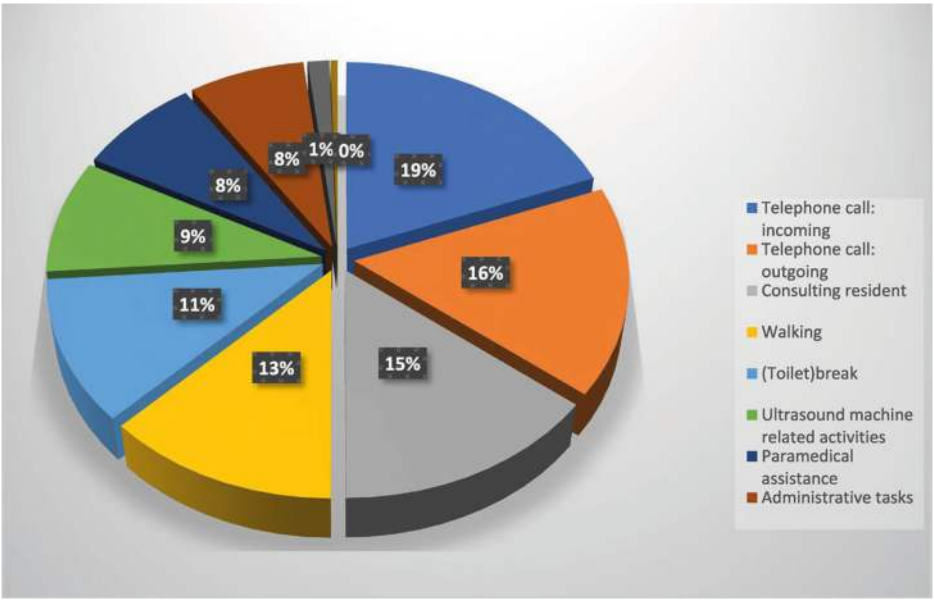

Fig. 2. Mean time spent on different activities by reading room assistants during weekend day shifts between 10 a.m. and 5p.m.
* Walking to ICU, ER or reporting room
** Non-active time and social talks were excluded from analysis.

Implementing reading room assistants to save time and reduce interruptions for residents

The reading room assistants saved the residents 101 min (132 min timesaving – 31 min consulting resident) of time by taking over NITs. Reading room assistants took over a mean of 44 (36–56) telephone calls during each 7-hour shift while also consulting the resident at a mean of 26 times (12–44) during each 7-hour shift. Resulting in a mean reduction of 18 (44–26) interruptions per 7-hour shift by implementing reading room assistants.

DISCUSSION

The introduction of reading room assistants as an aid to radiology residents in our hospital during weekend day shifts has led to a reduction in workload by taking over NITs from residents, resulting in a net timesaving of 24 % (101 min out of 7 h). The most timesaving NITs that were taken over by the reading room assistants were incoming and outgoing telephone calls, moving and preparing the ultrasound machine for use by the resident, and paramedical assistance. These NITs could be done by reading room assistants that were medical students in their second or higher year of their study and after receiving a limited training. Furthermore, reading room assistants frequently prevented residents from being interrupted due to incoming phone calls, at a mean of 44 times during a 7-hour shift (10 a.m.to 5p.m.). Note that the time the reading room assistants takes up from the resident for consultation is done during set times or when the resident is not making reports, reviewing scans or occupied by more urgent activities. As such, residents' workflow disruptions could be minimized.

Implementing reading room assistants to on-call hours has financial implications. However, the study by Miksanek et al. showed that the workload reduction achieved by implementing reading room assistants can lead to an increase in productivity and in turn lead to more income to compensate for reading room assistant costs in all major surgical, medical and mixed disciplines [15]. During radiology on-call hours, the benefit of adding reading room assistants might not lead to more revenue in the form of increased productivity, since on-call hour productivity is mostly driven by the number of acute cases that are presented. The added benefit of adding reading room assistants during radiology on-call hours lies in reducing workload and interruptions. This could lead to less emotional exhaustion, depersonalization, and loss of personal accomplishment, and could reduce the number of resident burnouts, attrition and associated costs [5,7,10]. Additionally, less interruptions may also reduce the number of medical errors [16,17].

Some limitations apply to this study. First, the way the on-call hours for radiology are arranged in our hospital in terms of staffing, diagnostic services offered, and patient supply, might differ from other hospitals. Consequently, if and how the implementation of reading room assistants will be beneficial, needs to be adapted to local circumstances. In our hospital we recently changed the working hours for reading room assistants on weekend day shits from 10 a.m. to 5p.m. into 12p.m. to 7p.m., because residents experienced the latter time slot to be generally busier. Whether or not it is useful to deploy reading room assistants in our hospital during other shifts (e.g. evening shifts during week days) still needs to be investigated. Another relevant issue to consider is that radiology residents in our hospital perform and interpret all ultrasonography examinations (except cardiac, gynecologic, POCUS examinations), which proved to be relatively time consuming (including moving and preparing the ultrasound machine), while in other hospitals radiology technicians or clinicians themselves perform all ultrasonography examinations. Second, we have recruited medical students who have successfully completed their first year of their medical study as reading room assistants, but otherwise did not use any specific selection criteria. Further research may be required to improve the selection procedure and to assess whether personnel without medical experience could also be used. Third, we did not take into account the experience of the reading room assistants and residents, while the time spent on the various activities are likely to differ between reading room assistants and residents with different levels of experience. Fourth, we have not investigated the expected reduction in residents' physiological stress and risk of diagnostic errors by implementing reading room assistants; further research regarding these potential beneficial factors is necessary. Fifth, although the residents and reading room assistants were unaware of the purpose of and type of data that were collected, it could have altered or influenced their behavior, which is known as the Hawthorne effect [18].

In conclusion, this study shows that the implementation of reading room assistants to radiology on-call hours could provide a timesaving for residents and also reduce the number of times residents are being interrupted during their work.

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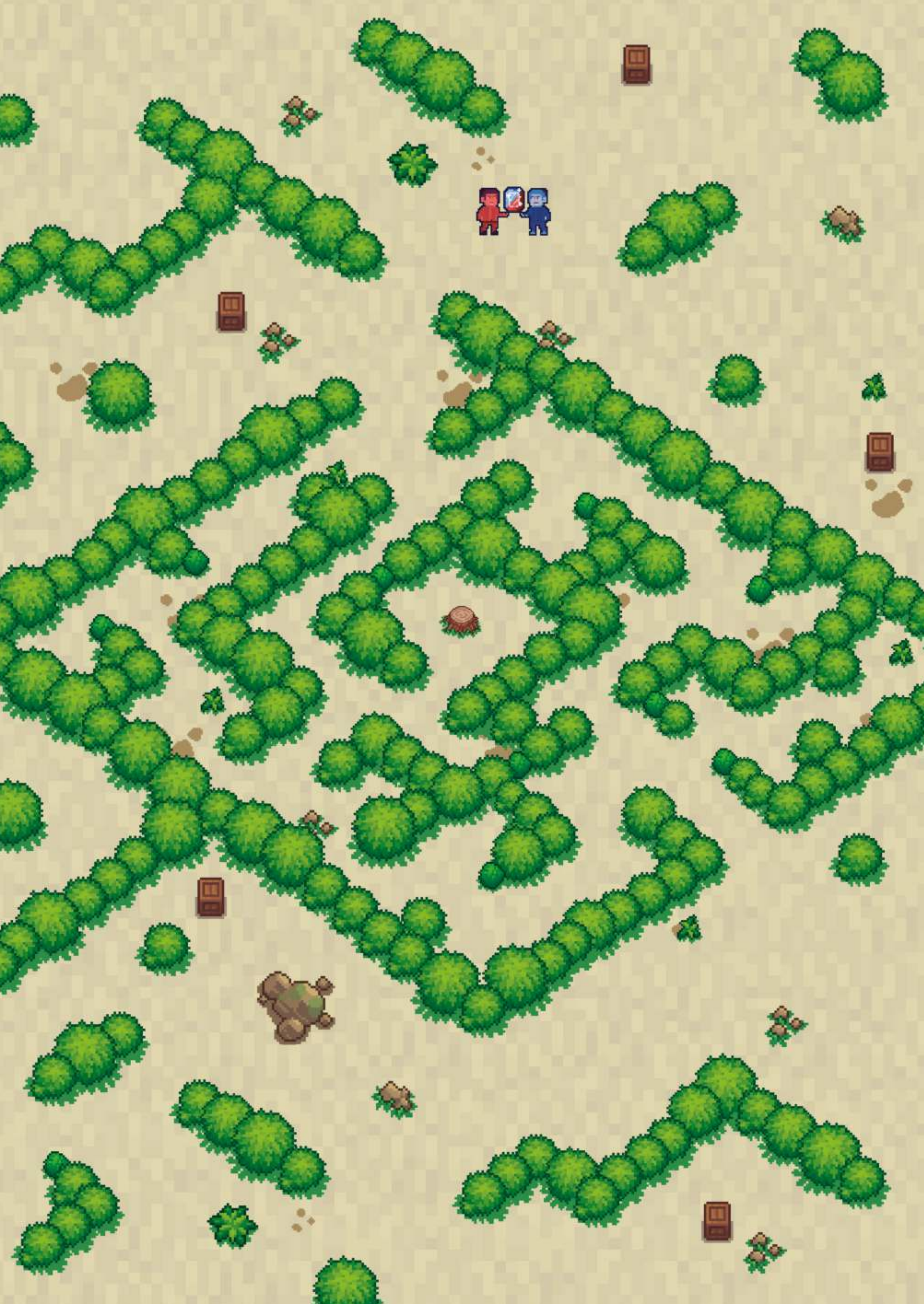

Appendices

SUMMARY

The rapid advancements in medical imaging over the past few decades hold great promise for future diagnostic and treatment options, with hybrid imaging techniques such as PET-CT, PET-MRI, and theranostics among the most recent developments. However, challenges have also emerged, including the high costs associated with medical imaging and the increased workload for imaging specialists, which is not matched by a proportional increase in the workforce. To maintain healthcare costs at a manageable level and prevent burnout, attrition, and a decline in image interpretation quality, various strategies have been implemented to address the growing workload. While AI shows promise for assisting with IITs and NITs, some of the NITs primarily consist of labor-intensive manual activities, such as answering telephone calls, administrative duties, and logistics. In this regard, reading room assistants have been deployed to varying extents to support staff and residents.

And although the integration of imaging specialties in clinical practice continues to enhance efficiency, the training programs and workforces of nuclear medicine and radiology remain largely separate in most countries.

A key distinction between the Netherlands and other countries in the training of medical imaging specialists is the 2015 integration of the nuclear medicine and radiology residency programs, which aims to enhance expertise in hybrid imaging and improve efficiency in both diagnostic and therapeutic applications. **Chapter 2** presents the results of a survey conducted among 139 nuclear medicine physicians and radiologists across eight training regions in the Netherlands to assess the strengths and potentials areas of improvement of the integrated training program. As an indication of its success, participating staff members gave an average score of 5.7 on a 10-point scale.

The positive aspects of the training included increased expertise in hybrid imaging, better preparation for future imaging needs, and enhanced efficiency in training residents and in multidisciplinary meetings. However, concerns were raised about reduced exposure to nuclear medicine, limited time for research and innovation, and potential challenges with international recognition. The concerns regarding the limited time for nuclear medicine, research, and innovation stemmed from the fact that nuclear medicine and radiology were previously separate five-year training programs but were integrated into a single-five year program. In this new structure, the first 2.5 years were dedicated to general radiology training, while the remaining 2.5 years included 1.5 years of nuclear medicine subspecialty training, should residents choose this pathway. Participants suggested several

improvements, such as increasing exposure to nuclear medicine, enhancing research opportunities, and better integrating nuclear medicine and radiology workflows.

In conclusion, the integration of nuclear medicine and radiology shows promise in terms of efficiency, but particular attention should be paid to finding a balance between exposure to nuclear medicine and radiology, as well as addressing the international recognition of the program.

While monitoring the effects of the integrated nuclear medicine and radiology training program, we observed a decline in the number of residents choosing the nuclear medicine pathway. Therefore, we decided to conduct a survey among residents in the integrated training program to investigate the factors influencing their decisions to pursue or refrain from the nuclear medicine pathway. The results of this survey, which included responses from 114 residents, are discussed in **chapter 3**. The survey identified several favorable conditions influencing residents' choice of the nuclear medicine pathway, including expert supervision, opportunities for scientific research, diversity in procedures, and the expanding role of hybrid imaging. In contrast, unfavorable conditions included insufficient integration of nuclear medicine and radiology in some hospitals, imbalances in training that favored time for radiology at the expense of nuclear medicine, uncertainty regarding the international recognition of the specialty, and concerns about future job opportunities. Nuclear medicine residents also demonstrated a stronger interest in scientific research and innovation.

These findings highlight the need for improved collaboration between nuclear medicine and radiology departments, as well as addressing uncertainties regarding employment and international recognition, in order to attract more residents to the nuclear medicine pathway.

Although future employment opportunities were noted by the residents as an uncertainty, our previous research among nuclear medicine physicians and radiologist indicated that future employment opportunities were considered a positive factor. In **chapter 4,** we present our findings from an exploration of the job market in the Netherlands in 2021, the year following the entry of the first cohort of nuclear radiologists into the job market. We examined 157 vacancies during this period, and positions for all-round, abdominal, and interventional radiologists were in the highest demand. Nuclear medicine positions were comparatively fewer in number, but the vast majority specifically requested nuclear radiologists, indicating the rapid adaptation of the job market to the changes in training.

As nuclear radiologists are trained to perform both diagnostic and therapeutic tasks across both specialties, they may also apply for radiology vacancies in non-academic hospitals, which predominantly request all-round specialists. Notably, around 30% of the vacancies also sought candidates for non-clinical tasks such as research, teaching, management, and ICT/AI skills. This could benefit nuclear radiologists, as they have expressed a stronger interest in research and innovation compared to their radiology-focused counterparts in our previous research.

Overall, this study highlights the demand for imaging specialists with broad clinical expertise and the growing need for non-clinical skills in both academic and non-academic hospitals. It also underscores the impact of the integrated training program in the Netherlands, which produces nuclear radiologists skilled in both nuclear medicine and radiology, including diagnostic and therapeutic procedures.

Until now, our focus has primarily been on strategies to manage the increased medical imaging workload by improving efficiency on the supply side; however, the primary contributor to workload increase is the rising demand. Clinicians base their imaging requests primarily on medical considerations, and given the constraints of limited financial resources, both the referring clinicians and imaging specialists share the responsibility of efficiently distributing these resources across the population. **Chapter 5** presents the results of our survey among residents from internal medicine, radiology, and surgery to assess the impact of financial knowledge regarding medical imaging on decision-making when requesting imaging tests. We selected internal medicine and surgery residents, as these specialties are among the highest users of medical imaging in nuclear medicine and radiology.

Our study revealed that most residents lack accurate knowledge of imaging costs, with no residents correctly estimating the costs of all the imaging tests in nuclear medicine or radiology. Additionally, 9% of residents incorrectly estimated the costs of all imaging tests. It is evident that financial literacy regarding medical imaging among residents is insufficient, and the study showed that neither the residents' specialty nor their years of training influenced their level of knowledge. Despite this lack of knowledge, residents generally expressed concerns about rising healthcare costs, acknowledged the importance of managing these costs, and showed a strong desire for financial education on imaging costs. Nearly 90% of participants agreed that financial education should be integrated into medical training curricula to improve cost awareness and reduce unnecessary imaging tests, which could help mitigate imaging costs.

However, this study did not investigate the long-term benefits of imaging and only addressed knowledge of direct imaging costs. Despite these limitations, the findings suggest that improving cost awareness among residents could contribute to more efficient use of medical resources and reduce unnecessary healthcare expenses.

In **chapter 6**, we present the results of our analysis regarding the introduction of reading room assistants during radiology on-call hours. Reading room assistants are individuals who undergo brief training to assume NITs from residents, such as answering telephone calls, handling administrative duties, and assisting with procedures and logistics, thereby alleviating the workload of residents. Our key findings indicate that reading room assistants resulted in a net time saving of 24% and a mean reduction of 18 interruptions during a 7-hour shift (answering 44 telephone calls and consulting with residents an average of 26 times). This led to a significant reduction in workload and interruptions, which may contribute to lower stress levels and potentially fewer medical errors, while also creating more time for residents to focus on IITs which have high educational value. These findings also have the potential to reduce burnout and attrition among radiology residents.

GENERAL DISCUSSION AND FUTURE PERSPECTIVES

Finding the optimal balance between nuclear medicine and radiology in an integrated training program

Five years after the integration of the nuclear medicine and radiology residency training program in the Netherlands in 2015, strengths and weaknesses were identified based on feedback from both nuclear medicine and radiology staff. Identified benefits of the program were increased expertise in hybrid imaging and greater efficiency in training residents and in daily clinical practice. Areas for improvement were reduced exposure to nuclear medicine, limitations in research and innovation opportunities, and challenges regarding international recognition.

Future research on the integration of nuclear radiologist into daily practice should focus on evaluating long-term outcomes, the role of nuclear radiologists in theranostics, and the challenges of achieving international recognition. Long-term outcomes can be assessed through efficiency measures in medical imaging, satisfaction surveys from physicians, patients and colleagues, and comparisons with other imaging specialists. The evolving role of nuclear radiologists in theranostics can be evaluated by comparing the effectiveness of hybrid imaging procedures and clinical outcomes.

The integrated training program for nuclear radiologists has shown efficiency, but adjustments in time allocation and increased post-residency prospects are needed to increase resident interest for the nuclear medicine pathway. Future research should focus on optimizing resident training and strengthening the integration of nuclear medicine and radiology in daily practice. Key areas of study include evaluating the impact of reduced time for nuclear medicine training on clinical competence, comparing nuclear radiologists' skills in theranostics, clinical decision-making, image interpretation and reporting, knowledge of innovative techniques and research protocols, and their communication skills with referring specialists compared to those trained via previous curricula. Additionally, it should address uncertainties regarding international recognition, job vacancies, and post-residency work distribution between nuclear medicine and radiology. Finally, international recognition of nuclear radiologists should be examined through surveys of medical imaging professionals and policymakers in Europe, and preferably worldwide, to identify barriers and promote greater cooperation across countries.

Currently there is no fellowship for nuclear medicine available for radiologists in the Netherlands. This will probably be implemented in 2025 and following the implementation of this fellowship, a longitudinal study should be conducted among nuclear radiologists and radiologists who have followed the nuclear medicine fellowship to evaluate their experiences, to find potential strengths and points of improvement, and to compare the two training pathways.

With ongoing developments in the integrated training program, a new version—including an extension of the nuclear medicine subspecialty training from 1.5 to 2 years—was implemented in 2023. The additional training duration dedicated to the nuclear medicine subspecialty warrants evaluation in the coming year to assess its potential impact on addressing the raised concerns related to limited clinical exposure and the overall competency of trained nuclear radiologists.

Advancing the optimization of medical imaging training programs to effectively balance workload demands while maintaining high-quality standards

As medical imaging specialists face increasing workloads, aligning supply and demand in this field is essential. Preventing unnecessary imaging studies is a key responsibility of both medical and medical imaging specialists. Our study revealed that residents have no financial knowledge regarding medical imaging, suggesting this factor plays a minimal role in decision-making for imaging requests. Integrating financial knowledge into resident training programs could help control rising healthcare costs [19,20]. Further research should focus on educational interventions to improve financial literacy and assess their impact on reducing unnecessary imaging requests and enhancing cost-efficiency.

Additionally, strategies related to AI (which falls beyond the scope of this thesis) and reading room assistants have been explored to manage the growing workload of medical imaging specialists. Reading room assistants can reduce interruptions, save time, and decrease the risk of diagnostic errors, potentially alleviating burnout and reducing costs. However, their financial impact needs to be considered related to their potential benefits in comparison to residents working without reading room assistants. Expanding this research to a multicenter study could provide insights into the role of cheaper non-medical personnel and assess the varying local benefits across institutions nationwide.

To achieve a consistent standard of medical imaging education across the European Union, improve healthcare professional mobility, and identify barriers to establishing a unified medical imaging training framework, further studies should focus on evaluating the degree of convergence between the curricula of nuclear medicine and radiology training across different European nations. These studies should consider not only the content, but also the teaching methodologies, competencies, the employed assessment techniques, and differences arising from cultural, regulatory, and healthcare systems [21]. Ultimately, such research will provide valuable insights into the feasibility and capacity of an integrated training program which is applicable through the whole of Europe, offering a comprehensive understanding of the needs and challenges from the perspective of policymakers, medical imaging staff, and residents.

In addition to changes in the patient population, imaging techniques, and a significant increase in workload, it would be valuable to investigate the evolving characteristics of the upcoming resident cohorts, commonly referred to as Generation Z and Alpha. These groups of future residents are expected to have distinct learning needs compared to the previous generations, particularly in terms of learning styles, self-care strategies, demands for safe learning environments, technological integration, and quality of life. Addressing these needs is crucial to ensure they are well-equipped to thrive in the rapidly evolving field of medical imaging [22].

Initial investigations should focus on how future residents approach medical imaging education and how medical imaging curricula can be adapted to meet these evolving needs. This includes understanding their preferences regarding learning formats, digital tools, and teaching methods, and comparing these emerging generations with their predecessors. Eventually observational studies can then assess the differences in impact of workload on the well-being, stress levels, work-life balance, and the quality of work of these residents, comparing these outcomes to the effects of implementing flexible learning schedules, mindfulness practices, and support systems within residency programs.

While our primary focus has been on the physicians specializing in medical imaging, the implementation of a combined nuclear medicine and radiology training program is likely to affect the dynamics of all personnel both within and beyond the nuclear medicine and radiology departments. For instance, prior to the integration of the nuclear medicine and radiology residency programs in the Netherlands, technicians in both disciplines were already cross-trained, possessing extensive knowledge of and practical experience with hybrid imaging systems. An emerging domain within nuclear medicine is theranostics, particularly radioligand therapy, which is experiencing rapid growth and it would be valuable to investigate the training requirements and roles of other personnel involved in hybrid imaging—such as laboratory technicians, nurses, physician assistants and technical medicine specialists—to ensure adequate preparation for these advances. Following the convergence of medical imaging training programs in the Netherlands, medical physicists have likewise adapted their curricula. Similar considerations regarding training needs and program adjustments should be applied to this group to maintain alignment with evolving clinical practices.

Furthermore, it is important to assess the potential impact of integrated medical imaging training on interdisciplinary collaboration with other medical specialties. For example, clinical fields such as radiation oncology and cardiology rely heavily on the imaging expertise and training provided by nuclear medicine and radiology imaging departments.

Additionally, the implications of integrated training on the expanding collaborative efforts toward integrated diagnostics and multi-omics —encompassing pathology, microbiology, laboratory medicine, and other diagnostic specialties—warrant careful evaluation.

Finally, beyond patient care, medical imaging training and research collaboration, the education of medical students, and other related disciplines should be considered. Notably, in several places like Groningen, there is a promising trend towards integrated imaging research that leverages both nuclear medicine and radiological modalities to address clinical research questions. A similar integrated approach is evident in medical student education through coordinated programs involving nuclear medicine, radiology, and anatomy.

The research opportunities outlined above aim to provide insights into the requirements for a future-proof medical imaging residency training program that aligns with the evolving needs of future residents, the growing patient population, the increasing medical imaging workload and diversification of imaging techniques, as well as the standards and expectations established by national and European frameworks.

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SAMENVATTING (SUMMARY IN DUTCH)

De snelle ontwikkelingen in medische beeldvorming in de afgelopen decennia is veelbelovend voor toekomstige diagnostische en behandelingsopties, waarbij hybride beeldvormingstechnieken zoals PET-CT, MRI-PET en theranostics tot de meest recente ontwikkelingen behoren. Er zijn echter ook uitdagingen ontstaan, waaronder de hoge kosten die gepaard gaan met medische beeldvorming en de toegenomen werkdruk, die niet gepaard gaat met een evenredige toename van beeldvormingsspecialisten. Om de zorgkosten beheersbaar te houden en burn-out, personeelsverloop en een afname van de beeldinterpretatiekwaliteit te voorkomen, zijn verschillende strategieën geïmplementeerd om de toenemende werkdruk te verminderen. Hoewel AI veelbelovend is voor het ondersteunen bij IIT's en NIT's, bestaan sommige NIT's voornamelijk uit arbeidsintensieve, handmatige activiteiten, zoals telefoneren, administratieve werkzaamheden en logistieke taken. Om deze reden zijn in verschillende mate scribes ingezet om de medische staf en de arts-assistenten te ondersteunen. En hoewel de integratie van beeldvormingsspecialismen in de klinische praktijk de efficiëntie zou moeten verbeteren, blijven de opleidingsprogramma's en het personeelsbestand van nucleaire geneeskunde en radiologie in de meeste landen grotendeels gescheiden. Nederland is het eerste land dat een geïntegreerd opleidingsprogramma voor arts-assistenten nucleaire geneeskunde en radiologie introduceert. Dit programma bereidt arts-assistenten voor op het uitvoeren van diagnostische en therapeutische taken binnen beide disciplines; deze arts-assistenten worden nucleaire radiologen genoemd.

De integratie van de opleidingsprogramma's voor nucleaire geneeskunde en radiologie in Nederland in 2015 onderscheid zich van andere landen en is gericht op het versterken van de expertise op het gebied van hybride beeldvorming, evenals het verbeteren van de efficiëntie in zowel diagnostische als therapeutische toepassingen. **Hoofdstuk 2** presenteert de resultaten van een enquête die is gehouden onder 139 nucleair geneeskundigen en radiologen in acht opleidingsregio's in Nederland om de sterke en potentiële verbeterpunten van het geïntegreerde opleidingsprogramma te beoordelen. Als indicatie van het succes gaven de deelnemende medewerkers een gemiddelde score van 5,7 op een 10 puntsschaal.

De positieve aspecten van de opleiding waren onder meer een grotere expertise op het gebied van hybride beeldvorming, een betere voorbereiding op toekomstige beeldvormingsbehoeften en een grotere efficiëntie bij het trainen van arts-assistenten en in multidisciplinaire vergaderingen. Er werd echter bezorgdheid geuit over de verminderde blootstelling aan nucleaire geneeskunde, de beperkte tijd voor onderzoek en innovatie

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en mogelijke uitdagingen met betrekking tot de internationale erkenning. De zorgen over de beperkte tijd voor nucleaire geneeskunde, onderzoek en innovatie kwamen voort uit het feit dat nucleaire geneeskunde en radiologie voorheen afzonderlijke vijfjarige opleidingsprogramma's waren, maar werden geïntegreerd in een enkel vijfjarig programma. In deze nieuwe structuur is de eerste 2,5 jaar gewijd aan de algemene radiologieopleiding, terwijl de resterende 2,5 jaar, indien gekozen door arts-assistenten, 1,5 jaar subspecialisatieopleiding nucleaire geneeskunde omvatte. De deelnemers stelden verschillende verbeteringen voor, zoals het vergroten van de blootstelling aan nucleaire geneeskunde, het verbeteren van onderzoeksmogelijkheden en het beter integreren van de werkprocessen van nucleaire geneeskunde en radiologie.

Concluderend is de integratie van nucleaire geneeskunde en radiologie veelbelovend in termen van efficiëntie, maar er moet bijzondere aandacht worden besteed aan het vinden van een evenwicht tussen nucleaire geneeskunde en radiologie, evenals aan de internationale erkenning van het programma.

Tijdens het monitoren van de effecten van het geïntegreerde opleidingsprogramma voor nucleaire geneeskunde en radiologie, zagen we een afname van het aantal arts-assistenten dat voor het traject nucleaire geneeskunde koos. Daarom hebben wij besloten om een enquête uit te voeren onder arts-assistenten in het geïntegreerde opleidingsprogramma om de factoren te onderzoeken die hun beslissing beïnvloeden om al dan niet het subspecialisatietraject nucleaire geneeskunde te kiezen. De resultaten van deze enquête, met reacties van 114 arts-assistenten, worden besproken in **hoofdstuk 3**. In maart 2020 hadden 14 (8%) van de arts-assisteten in het geïntegreerde opleidingsprogramma gekozen voor het traject nucleaire geneeskunde. Ter vergelijking: in 2015 waren ongeveer 50 arts-assisteten van nucleaire geneeskunde ingeschreven in het oude gescheiden curriculum.

De enquête identificeerde verschillende gunstige voorwaarden voor arts-assistenten om te kiezen voor het traject nucleaire geneeskunde, waaronder deskundige supervisie, mogelijkheden voor wetenschappelijk onderzoek, diversiteit in procedures en de groeiende rol van hybride beeldvorming. Daarentegen waren ongunstige omstandigheden onder meer onvoldoende integratie van nucleaire geneeskunde en radiologie in sommige ziekenhuizen, onevenwichtigheden in de opleiding die de tijd voor radiologie begunstigden ten koste van nucleaire geneeskunde, onzekerheid over de internationale erkenning van het specialisme en zorgen over toekomstige werkgelegenheid. Arts-assistenten nucleaire geneeskunde toonden ook een sterkere interesse in wetenschappelijk onderzoek en innovatie.

Deze bevindingen benadrukken de noodzaak van een betere samenwerking tussen de afdelingen nucleaire geneeskunde en radiologie, en van het aanpakken van onzekerheden met betrekking tot werkgelegenheid en internationale herkenning, om meer arts-assistenten aan te trekken voor het subspecialisatietraject nucleaire geneeskunde.

Toekomstige werkgelegenheid werd door de arts-assistenten als een onzekerheid opgemerkt. Uit ons eerdere onderzoek onder nucleair geneeskundigen en radiologen bleek echter dat de toekomstige werkgelegenheid juist als een positieve factor werd beschouwd. In **hoofdstuk 4** presenteren we onze bevindingen uit een verkenning van de arbeidsmarkt in Nederland in 2021, het jaar na de intrede van het eerste cohort nucleaire radiologen op de arbeidsmarkt. We onderzochten in deze periode 157 vacatures, de meeste vraag was naar functies voor allround-, abdominale- en interventieradiologen. De beschikbare posities in de nucleaire geneeskunde waren relatief beperkt, maar de overgrote meerderheid van de vacatures richtte zich specifiek op nucleaire radiologen, wat duidt op een snelle aanpassing van de arbeidsmarkt aan de veranderingen in het opleidingsprogramma.

Aangezien nucleaire radiologen zijn opgeleid om zowel diagnostische als therapeutische taken uit te voeren binnen beide specialismen, kunnen zij ook solliciteren naar radiologievacatures in niet-academische ziekenhuizen, die voornamelijk op zoek zijn naar allround specialisten. In ongeveer 30% van de vacatures werd ook gevraagd naar niet-klinische taken zoals onderzoek, onderwijs, management en ICT/AI-vaardigheden. Dit zou nucleaire radiologen ook ten goede kunnen komen, aangezien zij een sterkere interesse hebben getoond in onderzoek en innovatie in vergelijking met hun op radiologie gerichte tegenhangers.

Over het algemeen bevestigd deze studie de vraag naar beeldvormingsspecialisten met brede klinische expertise en de groeiende behoefte aan niet-klinische vaardigheden in zowel academische als niet-academische ziekenhuizen. Het benadrukt ook de impact van het geïntegreerde opleidingsprogramma in Nederland, dat nucleaire radiologen voortbrengt die bedreven zijn in zowel nucleaire geneeskunde als radiologie, inclusief diagnostische en therapeutische procedures.

Tot nu toe hebben we ons voornamelijk gericht op strategieën om de toegenomen werklast voor medische beeldvorming aan de aanbodzijde te beheersen, terwijl de primaire factor die bijdraagt aan de toename van de werklast in de toegenomen klinische vraag ligt. Clinici baseren hun beeldvormingsverzoeken voornamelijk op medische overwegingen; gezien de beperkte financiële middelen delen zowel clinici als beeldvormingsspecialisten de verantwoordelijkheid om deze middelen efficiënt over de bevolking te verdelen.

Hoofdstuk 5 presenteert de resultaten van onze enquête onder arts-assistenten van de interne geneeskunde, radiologie en chirurgie, met als doel de invloed van hun financiële kennis van medische beeldvorming op de besluitvorming bij het aanvragen van beeldvormende onderzoeken te evalueren. We hebben gekozen voor arts-assistenten interne geneeskunde en chirurgie, omdat deze specialismen tot de hoogste gebruikers van medische beeldvorming in nucleaire geneeskunde en radiologie behoren.

Uit ons onderzoek bleek dat de meeste arts-assistenten geen nauwkeurige kennis bezitten van de kosten van beeldvormende onderzoeken, en dat geen enkele arts-assistent de kosten van alle beeldvormende onderzoeken binnen nucleaire geneeskunde of radiologie correct inschatte. Bovendien werd door 9% van de arts-assistenten de kosten van alle beeldvormende onderzoeken verkeerd ingeschat. Uit het onderzoek blijkt duidelijk dat de financiële kennis met betrekking tot medische beeldvorming onder arts-assistenten onvoldoende is, en dat noch de specialisatie van de arts-assistenten, noch de duur van hun opleiding invloed heeft op hun kennisniveau. Ondanks dit gebrek aan kennis uitten arts-assistenten over het algemeen hun bezorgdheid over de stijgende zorgkosten, erkenden zij het belang van het beheersen van deze kosten en toonden zij een sterk verlangen naar financiële educatie over beeldvormingskosten. Bijna 90% van de deelnemers was het ermee eens dat financiële educatie moet worden geïntegreerd in medische opleidingscurricula om het kostenbewustzijn te verbeteren om onnodige beeldvormende onderzoeken te verminderen, wat zou kunnen helpen de kosten te beperken.

Deze studie onderzocht echter niet de lange termijn voordelen van beeldvorming en ging alleen in op kennis van de directe beeldvormingskosten. Ondanks deze beperkingen suggereren de bevindingen dat het verbeteren van het kostenbewustzijn onder arts-assistenten zou kunnen bijdragen aan een efficiënter gebruik van medische middelen en het verminderen van onnodige zorgkosten.

In **hoofdstuk 6** presenteren we de resultaten van onze analyse met betrekking tot de introductie van scribes tijdens radiologiediensten. Scribes zijn personen die een korte opleiding volgen om NIT's van arts-assistenten over te nemen, zoals het beantwoorden van de telefoon, het afhandelen van administratieve taken en het assisteren bij procedures en logistiek, waardoor de werkdruk van de arts-assistenten wordt verlicht. Onze belangrijkste bevindingen geven aan dat het inzetten van scribes resulteerde in een netto tijdsbesparing van 24% en een gemiddelde vermindering van 18 onderbrekingen tijdens een dienst van 7 uur (gemiddeld 44 telefoontjes beantwoorden en 26 keer overleggen met arts-assistenten). Dit leidde tot een aanzienlijke vermindering van de werkdruk en onderbrekingen, wat kan bijdragen aan lagere stressniveaus en mogelijk minder medische fouten, terwijl er ook meer tijd wordt gecreëerd voor arts-assistenten om zich te concentreren op IIT's die een hoge educatieve waarde hebben. Deze bevindingen hebben ook het potentieel om burn-out en uitval onder arts-assistenten van de radiologie te verminderen.

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