WHAT IS THE DEGREE OF INNOVATION ROUTINELY IMPLEMENTED IN DUTCH RADIOThERAPY CENTRES? A MULTICENTRE CROSS-SECTIONAL STUDY

INTRODUCTION
Radiotherapy (RT) centres have the complex task of simultaneously improving patient outcomes (tumour control, survival and toxicity), safety, patient service (such as taking into account patients’ preferences for the time to come for RT, shared decision making for treatment selection etc.) and efficiency. It is generally agreed that innovation implementation helps to tackle this many-faceted challenge. This is despite the fact that data from randomized trials are often lacking, for instance, due to the experienced ethical difficulties or acceptance for patients and physicians to investigate innovations in a clinical controlled randomized trial, e.g. if it is clear that the innovation leads to less radiation dose in the normal tissue. Consequently, the outcome of innovation strategies is often merely based on retrospective series. In this study, innovation is defined as “the intentional introduction and application within a role, group or organization of ideas, processes, products or procedures new to the relevant unit of adoption, designed to significantly benefit the individual, group or wider society”. This definition is largely accepted among researchers in the field. In the current study, we take into account four types of innovations: product innovation, technological innovation, market innovation and organizational innovation (Table 1).

Innovative technology plays a vital role in improving the quality of care for patients receiving radiation therapy, provided that new clinical treatments enabled by the new technology are not only theoretically better but also lead to

FULL PAPER
What is the degree of innovation routinely implemented in Dutch radiotherapy centres? A multicentre cross-sectional study

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Objective: To study the implementation of innovation activities in Dutch radiotherapy (RT) centres in a broad sense (product, technological, market and organizational innovations).

Methods: A descriptive cross-sectional study was conducted in 15 Dutch RT centres. A list of innovations implemented from 2011 to 2013 was drawn up for each centre using semi-structured interviews. These innovations were classified into innovation categories according to previously defined innovation indicators. Where applicable, each innovation was rated by each centre on the effort required to implement it and on its expected effects, to get an impression of how far reaching and radical the innovations were and to be able to compare the number of innovations between centres.

Results: The participating RT centres in the Netherlands implemented 12 innovations per year on average (range 5-25); this number was not significantly different for academic (n = 13) or non-academic centres (n = 10). Several centres were dealing with the same innovations at the same time. The average required effort and expected output did not differ significantly between product, technological and organizational innovation or between academic and non-academic centres.

Conclusion: The number of innovations observed per centre varied across a large range, with a large overlap in terms of the type of innovations that were implemented. Registering innovations using the innovation indicators applied in our study would make it possible to improve collaboration between centres, e.g. with common training modules, to avoid duplication of work.

Advances in knowledge: This study is the first of its kind investigating innovation implementation in RT in a broad sense.
improved patient outcomes.\textsuperscript{4,5} Technological advances allow radiation oncologists to deliver radiation more precisely, increasing the dose to tumour targets and reducing the dose to normal tissues and critical structures.\textsuperscript{1,2} Successful examples include stereotactic RT of intracranial and extracranial primary tumours and metastases and the incorporation of molecular imaging in treatment planning.\textsuperscript{4,8,9} Organizational innovations, such as adopting the lean philosophy and introducing lean tools, can also help to decrease waiting times and increase safety and cost-effectiveness.\textsuperscript{10–12} Both lower doses to normal tissues and shorter waiting times or fewer interruptions of the treatment are clearly desirable outcomes.

To improve their quality of care as well as cost-effectiveness, RT centres in the Netherlands are currently developing and implementing a range of the innovations mentioned above. The Dutch, European and American Societies for Radiotherapy and Oncology take a very active part in sharing knowledge and experience. However, as is the case with nearly all guidelines and recommendations, at present the focus is on the scientific basis of the innovation, much less on its practical implementation. The failure rates for implementing complex innovations in healthcare are high.\textsuperscript{13} The failure rate for RT is unknown. Previously, we conducted a Delphi study to determine indicators for innovation for the four types of innovations described (Table 1).\textsuperscript{3} The general objective of our study is, first, to gather information on the annual number and type of innovation activities in a broad sense in Dutch RT centres, according to the previously determined innovation indicators. Furthermore, we aim to obtain more insight into how far-reaching and radical innovations are and to take into account the effort required to implement them and their expected output, e.g., their effect on outcome, illustrating a better treatment quality, or their effect on service, illustrating process optimizations. Subsequently, we want to explore the effect of two potential variables on the amount and types of innovations: academic vs non-academic centres, and the impact of innovative work behaviour (IWB). IWB refers to the behaviour of individuals aiming to achieve innovation as defined above.\textsuperscript{14} We investigate this correlation because IWB is important in creating innovative solutions, but it is not known if this is also the case for innovation implementation.

The broader motivation for this study is the belief that gaining more information about innovation activities in RT in a broad sense could help accelerate the implementation of innovations and save costs by preventing different organizations from struggling with the same problems.\textsuperscript{15}

### Table 1. Definitions of the various innovation types used in our study

| Type of innovation | Definition |
|--------------------|------------|
| Product (treatment) innovation | The introduction of treatments that are new or which constitute a significant improvement in terms of their characteristics or intended use |
| Technological innovation | The introduction of new or significantly improved technological processes or methods that have no noticeable consequences for the patient. This also includes new equipment or devices |
| Market innovation | The entry into a hospital area in which the clinic has not operated before |
| Organizational innovation | The introduction of new or significantly improved forms of organizational structure, management methods and systems aimed at improving the use of knowledge, the quality of services or the efficiency of the workflow |

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### METHODS AND MATERIALS

#### Design

A descriptive cross-sectional study was conducted to list and categorize the innovations implemented in Dutch RT centres from 2011 to 2013.

#### Procedure

We asked all Dutch RT centres\textsuperscript{16} to participate in our study. Centres were classified as academic (affiliated with a university) and non-academic. Semi-structured interviews were conducted by two researchers, followed by a request for additional information by email. The following issues were addressed:

- **Number and type of implemented innovations per centre from 2011 to 2013**

To address this point, the centres (mostly the head of medical physics and/or head of department, and/or a manager) usually used their annual policy plans from 2011 to 2013. If a centre did not have a detailed policy plan, we asked them to provide us with an inventory of all the innovations they implemented. In a final step, all participating centres received a list with all innovations mentioned by other centres with the request to check if their own list was complete.

The researchers subsequently classified the innovations on these lists according to the previously identified innovation indicators into three innovation categories (product, technology and organizational innovation; Figure 1).\textsuperscript{4} Since some indicators were quite broad, a further subclassification was conducted according to the treatment phase of the care path.

Since the annual policy plans did not provide information on the product innovation indicator “number of patients in trials” and on the market innovation indicators, we subsequently asked the centres for information on these issues by email regarding the period 2011–13. We excluded the patent, royalty and Conformité Européenne (CE)-marking indicators, as included in Figure 1, because our study investigates clinical practice. The excluded indicators refer respectively to granted rights to inventors or assignees, payments to licensors and to a manufacturers’ declaration that the product complies with the...
essential requirements of the relevant European health, safety and environmental protection legislations.17

Effort required and impact on output for each innovation, and innovative working behaviour
Since we expected a large variation across the innovations with respect to the required effort and expected output and also aimed to obtain more insight into how far-reaching and radical innovations are, we looked for a method to take into account these aspects when comparing, for instance, academic with non-academic centres. Therefore, we provided each centre with the complete overview of all product, technology and organizational innovations (Tables 2–4) and asked them to rate each innovation on a scale of 1–5 (1 = no impact at all, 5 = very large impact) regarding the effort required from the organization and employees (effort) and also regarding the effect on output (outcomes, service, safety and efficiency) (output). Subsequently, we calculated the number of innovations per centre, weighted for effort and output by multiplying the frequency of the innovation with the average "impact score". In addition, we used these average impact scores to investigate whether different types of innovations required more or less effort or had more or less output.

We asked the medical chairpersons to rate the innovative behaviour of their medical staff according to a nine-item questionnaire measuring innovative work behaviour.18 This scale has a Cronbach’s α of 0.95 for the self-rated and 0.96 for the leader-rated scale and a strong correlation between both scales (r = 0.35).14

Finally in the spring of 2016, we asked all centres again if there were any important innovations (impact on effort from organization/employee or an impact on outcome ≥3) implemented in their clinic since 2014.

Statistical analysis
A Mann–Whitney U test was used to analyse differences between academic and non-academic centres. We assumed a significance level of 0.05. A one-way analysis of variance was used to analyse differences between impact-scores of product, and technological and organizational innovations. Because of the small size of the sample (n = 15), a Spearman’s rho test was used to analyse the correlation between perceived innovative behaviour of the medical staff and innovation.

RESULTS
Response rate
Of the 20 RT centres invited to participate in our study, 15 responded (75%). One organization declined because they could not generate the necessary data and another one declined because they were in the middle of a large transition project. Three organizations declined without mentioning a reason.

Number and type of implemented innovations
Tables 2–4 list all product, technological and organizational innovations in the period 2011–13 reported by the centres, according to the innovation indicators and subdivided according to treatment phase of the care path, including the frequency with which it was mentioned. Several centres were implementing the same innovations. The majority of the innovations can be classified as organizational innovations (n = 209). Most of these organizational innovations can be classified as an IT project (n = 83). In addition, 168 product innovations and 148 technological innovations were reported. Most product innovations relate to extending existing techniques to other patient groups (n = 87), whereas most technological innovations relate to treatment technique and treatment planning software optimization (n = 49). In the period 2011–13, most centres
Table 2. All product innovations and frequencies in the period 2011-13

| Indicator | Product innovations | Total |
|-----------|---------------------|-------|
| 1. Number of introductions of new or significantly improved treatments | Treatment preparation: imaging, positioning and delineation | |
| | CT—technique optimization | 3 |
| | Simulation—technique optimization | 1 |
| | Upgrade positioning devices | 8 |
| | New imaging modalities for target delineation | 11 |
| | Brachytherapy—MRI guided | 3 |
| | Introducing spacer between the prostate and rectum | 1 |
| | Frameless radiosurgery | 4 |
| | Orthovolt therapy—changing technique | 1 |
| | Subtotal | 32 |
| | Treatment delivery, including setup and adaptive RT | |
| | Implementing 6 degree of freedom couch | 1 |
| | SBRT/SRS—technique optimization | 17 |
| | IGRT—kV CBCT | 19 |
| | IGRT—software upgrade | 2 |
| | Adaptive radiotherapy | 4 |
| | Subtotal | 43 |
| | Extending techniques to other patient groups | |
| | VMAT—extending indications | 25 |
| | Brachytherapy—implementation for other indications | 8 |
| | IORT | 2 |
| | IMRT | 37 |
| | SBRT/SRS—extending indications | 15 |
| | Subtotal | 87 |
| | Adjust fractionation scheme’s | |
| | From normofractionation to hypofractionation | 3 |
| | Subtotal | 3 |
| | Improved follow-up | |
| | Standardized medical protocols | 1 |
| | Subtotal | 1 |
| 2. Number of new positioning devices for patient treatment | Treatment delivery, including setup and adaptive RT | |
| | Patient positioning—technique optimization | 2 |
| | Subtotal | 168 |
| 3. Number of approved patents | | Not applicable |
| 4. Percentage of patients in Phase III randomized controlled trials approved by an IRB | | Range 0–1% |
| 5. Percentage of patients in Phases I–II trials approved by an IRB | | Range 0–6.6% |

CBCT, cone beam CT; IGRT, image-guided radiation therapy; IMRT, intensity-modulated radiation therapy; IORT, Intraoperative radiation therapy; IRB, institutional review board; kV, kilovoltage; RT, radiotherapy; SBRT/SRS, stereotactic body radiation therapy/stereotactic radiosurgery; VMAT, volumetric arc therapy.
Table 3. All technological innovations and frequencies in the period 2011–13

| Indicator | Technological innovations | Total |
|-----------|--------------------------|-------|
|           | Treatment preparation: imaging, positioning and delineation |       |
| Imaging—new hardware | 8 |     |
| Imaging—software upgrade | 2 |     |
| Imaging—protocol optimization | 12 |     |
| **Subtotal** | **22** |     |
|           | Treatment technique and TPS optimization |       |
| TPS—new software | 6 |     |
| TPS—software upgrade | 7 |     |
| TPS—optimization | 1 |     |
| TPS—protocol optimization | 27 |     |
| Brachytherapy—technique optimization | 7 |     |
| PDT—technique optimization | 1 |     |
| **Subtotal** | **49** |     |
|           | Treatment delivery, including patient setup |       |
| Linac—new equipment | 12 |     |
| Brachytherapy—new hardware | 1 |     |
| Linac—new software/upgrade | 7 |     |
| Linac—protocol optimization | 1 |     |
| Patient positioning | 4 |     |
| Upgrade positioning devices | 1 |     |
| **Subtotal** | **26** |     |
|           | IGRT |       |
| IGRT—introduction kV imaging | 2 |     |
| IGRT—software upgrade | 2 |     |
| DGRT—implementation | 8 |     |
| IGRT—new modality | 2 |     |
| IGRT—protocol optimization | 12 |     |
| IGRT—technique optimization | 2 |     |
| **Subtotal** | **28** |     |
|           | QA and connectivity |       |
| QA—new hardware 3 | 4 |     |
| Connectivity software | 1 |     |
| OIS—upgrade | 18 |     |
| **Subtotal** | **23** |     |
| **Total** | **148** |     |

1. Frequency of implementation of new medical devices

CE, Conformité Européenne; DGRT, dose-guided radiotherapy; IGRT, image-guided radiation therapy; kV, kilovoltage; Linac, linear accelerator; OIS, Oncology information system; PDT, Photodynamic therapy; QA, quality assurance; TPS, treatment planning system.
implemented intensity-modulated RT (IMRT) and volumetric arc therapy (VMAT) in clinical routine (Table 5). The other top five innovations were stereotactic body radiation therapy/stereotactic radiosurgery technique optimization, treatment planning system (TPS) protocol optimization, oncology information system upgrade and software for patient care. The top

Table 4. All organizational innovations and frequencies in the period 2011–13

| Indicator | Organizational innovations | Total |
|-----------|-----------------------------|-------|
| IT projects | Software for patient care | 19 |
| Implementation of EHR | Completely | 4 |
| | Just some specific parts | 6 |
| Introduction of new patient service/reachability projects | Completely | 1 |
| | Just some specific parts | 19 |
| Software for telecommuting/communication | 12 |
| Software for clinical data/imaging exchange | 8 |
| Software for operational management | 14 |
| Subtotal | 83 |
| Projects to improve patient flow/reduce waiting time/LEAN projects | Improve time referral—intake | 5 |
| | Improve time intake—start RT | 34 |
| | Improve efficiency work at the linear accelerator | 3 |
| Subtotal | 42 |
| Safety and quality management/ERM/information security management | Safety/risk system | 10 |
| | Quality systems | 8 |
| Subtotal | 18 |
| Broad organizational innovations | HRM + culture projects | 10 |
| | Reorganization | 11 |
| Subtotal | 21 |
| Employee development | Introduction of new jobs | 5 |
| | Staff—redefining tasks and responsibilities of staff members | 11 |
| | Educational projects | 6 |
| Subtotal | 22 |
| Growth—external relations | New alliances/external collaborations | 8 |
| | New outpatient clinic/annexe for department | 15 |
| Subtotal | 23 |
| Total | 209 |

ERM, enterprise risk management; HRM, human resource management; IT, information technology; LEAN, lean management; RT, radiotherapy.
five innovations cover 295/525 innovations (56%). A wide variation was seen in the number of centres that implemented each innovation; for example, 61 innovations were implemented by 1–3 centres, and 103 innovations were implemented by 4–6 centres (Figure 2). The majority of the innovations (n = 361) was implemented by 7 or more centres.

For the product innovation indicator “percentage of patients in trials”, six participating centres could not generate data and one centre had no patients in trials. Nevertheless, for the centres that could, we obtained the percentage of patients in Phase I–II trials and in Phase III trials (Table 2 and Figure 3). During the time of the study, there were 10 RT trials open for recruitment in the Netherlands according to the information on http://www.trialregister.nl and http://www.clinicaltrials.gov. These trials included innovations such as image- and dose-guided RT, multimodality and molecular imaging, and VMAT techniques. The included innovations were mandatory for these trials. However, in only in three trials, the innovation as such was tested against the standard treatment. Three of the innovations in our study could be related to these trials.

Concerning market innovation, we asked for their activities on two indicators: (1) percentage of patients from outside the market area referred by physicians from hospitals which do not regularly refer their patients to this centre and (2) number and percentage of new general hospitals that refer the desired patient population. Concerning the first market innovation indicator, one participating centre considered their figures too confidential to hand over, whereas five centres did not register this information. The results from the remaining nine centres that did provide data on this indicator are listed in Figure 4.

Regarding the second market innovation indicator, we found that 10 out of 15 participating RT centres opened one or two new satellites/outpatient clinics. In total, 12 new satellites/outpatient clinics (which are not counted as a separate centre in this study) were opened in the period 2011–13. Most of them treat patients who would also be referred to the original RT centre if there were no satellite/outpatient clinic. In two cases, the newly opened satellites/outpatient clinics treat patients who would not have been referred before the opening.

Effort required and impact on output for each innovation, and innovative working behaviour

Table 6 shows that product, technological and organizational innovations are scored almost equally regarding average effort required and impact on output. For the average effort score, there is no significant difference between the different kinds of innovations (p = 0.249). However, for the average output, there is a significant difference (p = 0.000). This difference can be found between product innovations and technological innovations.

| Type of innovation | Innovation | Frequency | Number of centres | Score effort | Score output |
|--------------------|------------|-----------|-------------------|--------------|--------------|
| **Product innovation** | IMRT | 37 | 12 | 3 | 4 |
| | VMAT—extending indications | 25 | 8 | 4 | 4 |
| | IGRT—kV CBCT 2 | 19 | 8 | 3 | 4 |
| | SBRT/SRS—technique optimization | 15 | 9 | 4 | 4 |
| | SBRT/SRS—extending indications | 17 | 11 | 4 | 4 |
| **Technological innovation** | TPS—protocol optimization | 27 | 11 | 3 | 4 |
| | Oncology information system—upgrade | 18 | 11 | 4 | 3 |
| | Imaging—protocol optimization | 12 | 4 | 3 | 3 |
| | Linac—new equipment | 12 | 8 | 5 | 4 |
| | IGRT—protocol optimization | 10 | 8 | 3 | 3 |
| **Organizational innovation** | Improve time intake—start RT | 19 | 12 | 3 | 3 |
| | Software for patient care | 19 | 12 | 3 | 3 |
| | Introduction of new patient service/reachability projects, just some specific parts | 19 | 10 | 3 | 3 |
| | New outpatient clinic/annexe for department | 15 | 10 | 4 | 4 |
| | Software for operational management | 14 | 9 | 3 | 3 |

CBCT, cone beam CT; IGRT, image-guided radiation therapy; IMRT, intensity-modulated radiation therapy; kV, kilovoltage; Linac, linear accelerator; RT, radiotherapy; SBRT/SRS, stereotactic body radiation therapy/stereotactic radiosurgery; TPS, treatment planning system; VMAT, volumetric arc therapy.
(p = 0.000) and between product innovations and organizational innovations (p = 0.000). There is no significant difference between technological and organizational innovations (p = 0.327).

Innovative work behaviour varied between 3.3 and 4.9 (Table 7).

**Short repeat survey**

In the inquiry in 2016, two completely new innovations were reported which entered into clinical routine after 2013: three-dimensional printing of the bolus for electrons and the implementation of MR-guided RT with online adaptation. The introduction of protons and of MR-linear accelerator that was also mentioned was not counted, because it was not yet integrated into clinical routine.

**Academic vs non-academic centres, and influence of innovative work behaviour**

The number of innovations in academic centres was higher but not significantly different from non-academic centres (p = 0.325) (Table 8). This also holds for every innovation type separately. On average, academic centres implemented 39 (range 14–75) innovations in the period 2011–13, whereas non-academic centres implemented 30 (range 17–38). In academic centres, a larger range in number of innovations was observed than in non-academic centres. As is shown in Table 7, also when weighted for required effort and expected output, we did not find any significant difference between academic and non-academic centres for any of the types of innovation. We found that the innovation categories with the fewest implemented innovations and also those that were implemented in the fewest centres are more often implemented in academic centres. 22 out of these 29 innovations are implemented in academic centres.

No significant differences in IWB were seen between academic and non-academic centres (Table 7). In addition, no significant correlation was found between the number of innovations and innovative work behaviour (p = 0.972). This also holds for the weighted total of innovations and innovative work behaviour (effort p = 0.939, output p = 0.992).

**DISCUSSION**

This study shows that RT centres in the Netherlands innovate a great deal: for the product, technological and organizational
innovation categories, academic centres count 13 innovations a year and non-academic centres count 10 innovations a year. However, the range between centres is large: in 3 years, this range was 14–75 for academic centres and 17–38 for non-academic centres. There are no significant differences between academic and non-academic centres. Even when weighting for the effort required by organizations/employees or for perceived impact on output, no significant differences were found between academic and non-academic centres.

The product innovation indicators “patients in trials Phase I–II or III” were not registered in 6/15 centres (3 academic). During the period of the study, 3 trials out of the 10 trials open for recruitment were randomizing or evaluating an innovation against standard RT. Three of the innovations in our study could be related to these trials.

Regarding market innovation, no registration on market performance outside the normal market area was available in 5/15 centres (2 academic). Starting new outpatient clinics/departments was only aimed at entering new markets in 2/12 cases. Innovative work behaviour of the medical staff (physicians and physicists) was not correlated with the degree of innovation.

Differences between centres: academic vs non-academic and the wide range

The literature shows that the implementation of health innovations is affected by many factors, including leadership, slack time (the positive difference between the available resources of an organization/department of the employee and the combination of demands made on that resource),\(^{19}\) shared vision, communication, team responsibility and innovation capacity (the organizational potential to innovate, which is determined by the skills and strengths in basic research and development and technology). Basic research and development refers to experimental or theoretical work undertaken primarily to acquire new knowledge without any particular application or use in view of RT, for example, some research in the area of radiobiology and physics.\(^{14,16,20–26}\) In a systematic review, 62 measures were identified in a multilevel framework predicting implementation outcomes.\(^{27}\) These factors can differ between different centres, which is a possible explanation for the large range in innovation performance in our study. In addition, these factors are not by definition more common in academic centres, which we think partly explains why we did not find differences between academic and non-academic centres. Furthermore, academic centres are, based on their function, more focused on research than non-academic centres. Research can be seen as innovation generation. In the literature, this is described as an innovation competence and distinguished from innovation adoption.\(^{28}\)

Generating innovation is a creative process, which is characterized by variation, search, experimentation and discovery and which produces new knowledge and information. Innovation adoption, on the other hand, is a problem-solving process, which is planned more tightly and can be characterized by selection, refinement, choice and execution. An academic centre should have more innovation-generating capacity but not per definition more employees with innovation-adoption competences. The fact that the innovation categories with the fewest implemented innovations and those that were implemented in the fewest centres are more often implemented in academic centres is probably also related to innovation-generating competences. More specifically,
Table 7. Weighted innovations (frequency × score) for the period 2011–13, academic centres (ACs) vs non-academic centres (NACs)

| Clinic | Effort | Output | Mean innovative work behaviour |
|--------|--------|--------|--------------------------------|
|        | Product innovations | Technological innovations | Organizational innovations | Product innovations | Technological innovations | Organizational innovations |                                |
| Academic | | | | | | | | 3.7 |
| AC 1  | 54  | 49  | 104  | 60  | 47  | 102  | 3.7 |
| AC 2  | 46  | 45  | 51  | 47  | 45  | 46  | 4.9 |
| AC 3  | 24  | 0  | 32  | 24  | 0  | 30  | 4.2 |
| AC 4  | 11  | 4  | 51  | 12  | 3  | 49  | 4  |
| AC 5  | 65  | 128 | 71  | 66  | 126 | 70  | 4  |
| AC 6  | 56  | 14  | 11  | 63  | 15  | 10  | 3.4 |
| AC 7  | 21  | 66  | 54  | 23  | 61  | 50  | 4.8 |
| AC 8  | 59  | 20  | 76  | 63  | 15  | 80  | 3.7 |
| Mean AC | 42  | 41  | 56  | 45  | 39  | 55  | 4.1 |
| Range AC | 11–65 | 0–128 | 11–104 | 12–66 | 0–126 | 10–102 | 3.4–4.9 |
| Non academic | | | | | | | | 3.3 |
| NAC 1  | 55  | 35  | 28  | 66  | 34  | 28  | 3.3 |
| NAC 2  | 31  | 25  | 57  | 40  | 22  | 52  | 4.2 |
| NAC 3  | 24  | 23  | 11  | 28  | 23  | 10  | 4.4 |
| NAC 4  | 33  | 29  | 50  | 35  | 24  | 47  | 3.6 |
| NAC 5  | 36  | 29  | 56  | 39  | 25  | 54  | 3.6 |
| NAC 6  | 38  | 42  | 57  | 44  | 38  | 56  | 4.4 |
| NAC 7  | 39  | 17  | 38  | 44  | 20  | 38  | 4.2 |
| Mean NAC | 37  | 29  | 42  | 42  | 27  | 41  | 4.0 |
| Range NAC | 24–55 | 17–42 | 11–57 | 28–66 | 20–38 | 10–56 | 3.3–4.4 |
| Total weighted innovations | 592 | 526 | 747 | 654 | 498 | 722 |
| p-value | 0.524 | 0.008 | 0.384 | 0.722 | 1.000 | 0.452 | 0.727 |
the five fewest implemented innovations in each innovation category (product, technological and organizational) count a total of 29 different innovations. 22 out of these 29 innovations are implemented in academic centres, probably as a continuation of research, such as the introduction of the spacer prostate–rectum and the introduction of the six-dimensional couch.

It is not clear whether the degree and nature of the types of innovation in Dutch RT centres is comparable with centres abroad. In research, new developments are described as a continuation of research, such as the introduction of the spacer prostate–rectum and the introduction of the six-dimensional couch.

Table 8. Innovations per centre and per innovation type from 2011 to 2013, academic centres (ACs) vs non-academic centres (NACs)

| Clinic | Innovations | | | Total innovations per clinic |
|--------|-------------|---|---|-----------------------------|
|        | Product innovations | Technological innovations | Organizational innovations |
| Academic | | | | |
| AC 1  | 16 | 13 | 30 | 59 |
| AC 2  | 12 | 14 | 14 | 40 |
| AC 3  | 6  | 0  | 8  | 14 |
| AC 4  | 3  | 1  | 14 | 18 |
| AC 5  | 17 | 38 | 20 | 75 |
| AC 6  | 16 | 4  | 3  | 23 |
| AC 7  | 6  | 18 | 14 | 38 |
| AC 8  | 17 | 5  | 23 | 45 |
| Mean AC | 12 | 12 | 16 | 39 |
| Range AC | 3–17 | 0–38 | 3–50 | 14–75 |
| Non academic | | | | |
| NAC 1  | 17 | 10 | 8  | 35 |
| NAC 2  | 10 | 7  | 16 | 33 |
| NAC 3  | 7  | 7  | 3  | 17 |
| NAC 4  | 9  | 7  | 13 | 29 |
| NAC 5  | 10 | 8  | 16 | 34 |
| NAC 6  | 11 | 11 | 16 | 38 |
| NAC 7  | 11 | 5  | 11 | 27 |
| Mean NAC | 11 | 8  | 12 | 30 |
| Range NAC | 7–17 | 5–11 | 3–16 | 17–38 |
| Total innovations | 168 | 148 | 209 | 525 |

More recently, expert clinicians and scientists in the field of RT discussed how innovative technology in radiation oncology is being developed and translated into clinical practice in the face of current and future challenges and opportunities. The workshop focused on the challenges posed by new technologies, addressed the state of the science for several disease sites, discussed clinical trials for advanced technology and reviewed the future promise and potential pitfalls of emerging, innovative technologies. Themes to help guide innovative technology-based research for radiation oncology included: (a) innovative treatment-delivery technology, (b) advances in imaging for quantitative and validated treatment design, (c) oncology informatics and (d) evidence building. The description of the workshop results contains important information about the field of future innovation, but it cannot serve as a benchmark for implemented innovations in clinical routine.

As mentioned earlier, there were 10 trials open for recruitment in the period of our investigation, 3 of which were randomizing or evaluating innovations against standard RT. It could be helpful to perform a trial to implement an innovation. The implementation
of complex techniques may vary per country. In the UK, advanced treatment techniques will continue to be introduced nationally via well-designed clinical trials. However, in the Netherlands, we also allow model-based approaches, as we are currently using for the introduction of proton therapy. Sometimes, complemented cost-effectiveness studies are used.

The degree of innovations in radiotherapy: radical or incremental innovations

Radical innovations include those treatments, technologies, and markets and organizational changes that are completely new to the clinic. Such major innovations require skills, abilities and knowledge different from those required to master the old technologies. Incremental innovation, by contrast, introduces alterations to existing treatments, technologies, methods or systems that lead to improvements in content or efficiency. The factors affecting the implementation of incremental innovations are different from those affecting radical innovations. Therefore, it is important for organizations that have the ambition to improve their innovation implementation to consider how radical the intended innovations are.

As shown in Figure 5, on required effort by organization/employees and on expected output, the vast majority of innovations score a 3 (moderate impact, 46% and 42%, respectively) or 4 (large impact, 50% and 58%, respectively). Only 4.2% of all innovations are considered to have a very large impact on the effort required from organization and employees, for example, the introduction of a completely new electronic health records system, or a TPS or new linear accelerators. It is debatable whether these innovations with a score of 5 can be seen as radical. Some innovations in some academic centres such as the introduction of protons, MRI-linear accelerators, trials with RT and immunotherapy or decision support systems are in our opinion more in line with the characteristics of radical innovations as defined above but are not scored as such due to the fact that they are still in preparation. Clinical introduction of radical innovations requires a long period of preparation.

Nevertheless in our study, product innovations, with a high potential to improve treatment quality, scored a significantly higher impact on expected output than the other two categories of innovations and are especially beneficial from a patient’s perspective.

Product innovation indicators regarding patients in trials

The lack of registration of patients in trials is surprising, especially for academic centres. In addition, 8 out of 10 of the registered percentages are <5%, which is relatively low than found in the literature. To improve the quality of innovation, we consider it valuable to systematically measure these indicators and to provide the centres with feedback on their results compared with the other centres. Therefore, it is important to set up an adequate registration system, since this may help to identify barriers and facilitators. Such a system may therefore help to develop strategies that will increase trial participation.

Market innovations

With regard to market innovation, too, a comprehensive registration system is lacking in several centres. Geographically, it seems that there are only a few possible avenues for market innovations.
Most of the time, new outpatient clinics/satellites treat patients from already connected market areas. Often, this reduces travel time for patients. It is generally known that new satellites are also established to protect the existing market area. With new RT indications, new markets can be entered (for example, RT combined with immunotherapy); the introduction of, for example, hypofractionation may also be able to attract new patients.

Correlation innovative work behaviour and innovations
We investigated the correlation of IWB with innovation implementation because IWB is important for innovation generation.\(^\text{14}\) We found no correlation. Apparently, for innovation implementation, IWB alone is not a determining factor.

Limitations
One limitation of this study concerns the sample size. Data from only a limited number of 15 treatment centres (8 academic and 7 non-academic) were available for analysis. Because of the limited number of RT treatment centres in the Netherlands, it was not possible to markedly increase the sample size. This severely limits the power of the statistical tests to detect a statistically significant difference and a statistically significant correlation. Therefore, all relevant descriptive statistics are also presented to get an indication of the estimated size of an effect and the accompanying uncertainty of these estimates.

Another limitation is that we used a cross-sectional design; therefore, we measured the innovation performance of centres in a specific period but not the innovation performance in an absolute sense. For example, the three centres which implemented no IMRT innovations in the period of our study had already introduced IMRT before 2011.

Finally, our study does not offer insight into the question whether innovations are sufficiently evaluated and actually improve treatment quality before their introduction in clinical routine. For example, does VMAT with full Arc possibly increase toxicity compared with three-dimensional conformal radiation therapy?\(^\text{25}\) Investigating this research question would be very meaningful. We are convinced, however, that a systematic collaboration between centres, e.g. through joint training, either face to face or with e-learning modules, or through the exchange of standard operating procedures could avoid duplication of work and increase the efficiency of innovation implementation at the national level.

CONCLUSION
RT centres in the Netherlands implement on average 12 innovations per year in their department (range: 5–25); this number is not significantly different for academic \((n = 13)\) or non-academic centres \((n = 10)\). This study has shown that several centres are dealing with the same innovations in a certain period. The numbers confirm that RT centres quickly adopt innovations within their discipline and are very dynamic and innovative. However, there is a large range with regard to innovation implementation performance. There is room for improvement for centres with low numbers and centres can definitely help each other more to reduce this range. Further research is necessary to get more insight into the innovation performance degree in an absolute sense. We conclude it is important that all centres use an adequate, preferably uniform, registration system on innovation indicators and propose to select the system we used because it has been developed and approved by the sector itself. Furthermore, we suggest promoting systematic collaboration between centres not only for the scientific basis of innovations but also for innovation implementation, because this could avoid duplication of work. This can best be carried out by the national RT societies. Although the framework of our study can be used worldwide, communication across countries can be complicated because every country has its own context, systems, rules etc. National recommendations on the implementation of innovations can be helpful. On the other hand, European Society for Radiotherapy and Oncology/American Society for Radiation Oncology could also play a role in particular in training.

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