BJR http://dx.doi.org/10.1259/bjr.20160601

Received: 8 July 2016 | Revised: 20 September 2016 | Accepted: 22 September 2016

Cite this article as:
Jacobs M, Boersma L, Dekker A, Bosmans G, Van Merode F, Verhaegen F, et al. What is the degree of innovation routinely implemented in Dutch radiotherapy centres? A multicentre cross-sectional study. *Br J Radiol* 2016; **89**: 20160601.

FULL PAPER

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

[1,2]MARIA JACOBS, MSc, [1,3]LIESBETH BOERSMA, PhD, MD, [1,3]ANDRE DEKKER, PhD, [1,3]GEERT BOSMANS, PhD, [4]FRITS VAN MERODE, PhD, [1,3]FRANK VERHAEGEN, PhD, [1,3]DIRK DE RUYSSCHER, PhD, MD, [1,3]RACHELLE SWART, MSc, [1,3]CINDY KENGEN, MSc and [1,3]PHILIPPE LAMBIN, PhD, MD

[1]Department of Radiation Oncology, MAASTRO clinic, Maastricht, Netherlands
[2]CAPHRI School for Public Health and Primary Care, Maastricht University Medical Centre+, Maastricht, Netherlands
[3]GROW School for Oncology and Developmental Biology, Maastricht University, Medical Centre+, Maastricht, Netherlands
[4]Executive Board, Maastricht University Medical Centre+, Maastricht, Netherlands

Address correspondence to: Dr Maria Jacobs
E-mail: *maria.jacobs@maastro.nl*

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.

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".[1] This definition is largely accepted among researchers in the field.[2] In the current study, we take into account four types of innovations: product innovation, technological innovation, market innovation and organizational innovation (Table 1).[3]

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

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

improved patient outcomes.[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.[5–7] Successful examples include stereotactic RT of intracranial and extracranial primary tumours and metastases and the incorporation of molecular imaging in treatment planning.[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.[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.[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).[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.[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.[15]

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[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:

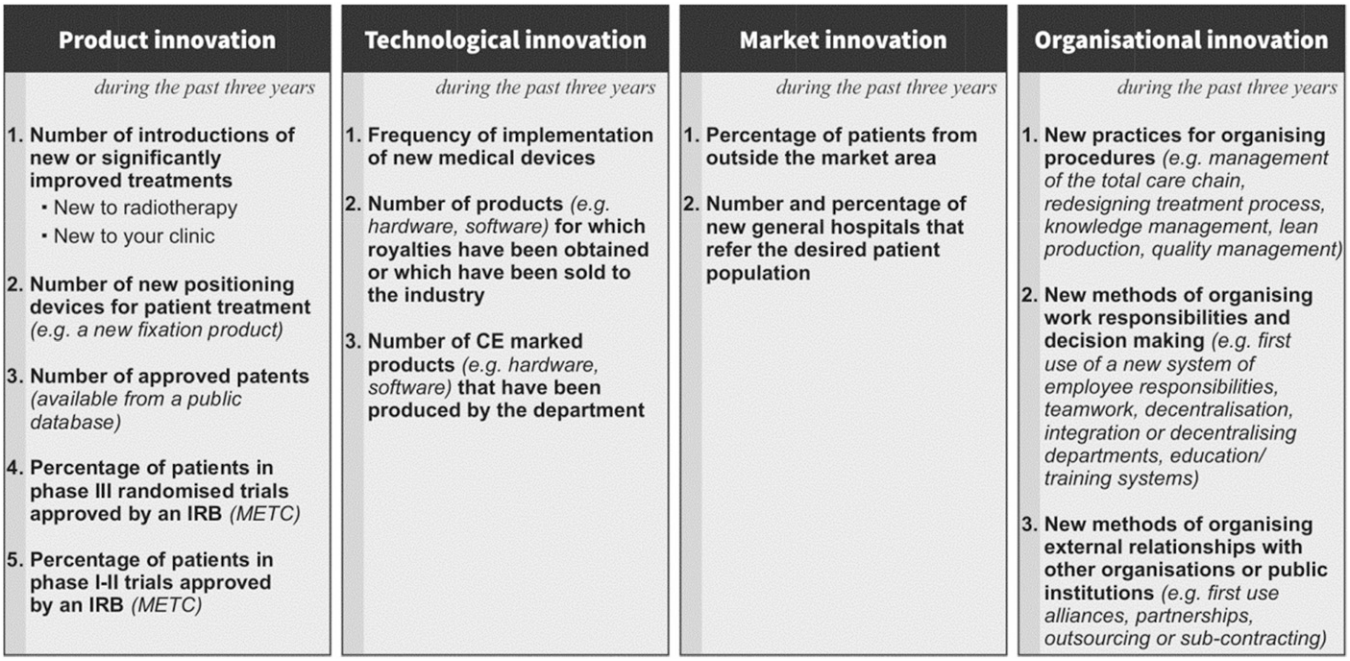
Number and type of implemented innovations per centre from 2011 to 2013

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).[3] 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

Figure 1. Overview of innovation indicators in radiotherapy on which consensus was reached between chairpersons of Dutch radiotherapy centres.



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 2	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	**2**
	Total	**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
1. Frequency of implementation of new medical devices	**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
	Brachytheraphy—technique optimization	7
	PDT—technique optimization	1
	Subtotal	**49**
	Treatment delivery, including patient setup	
	Linac—new equipment	12
	Brachytheraphy—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**
2. Number of products for which royalties have been obtained or which have been sold to the industry		Not applicable
3. Number of CE-marked products that have been produced by the department		Not applicable

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.

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

Indicator	Organizational innovations	Total
1. New practices for organizing procedures	**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**
2. New methods of organizing work responsibilities and decision making	**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**
3. New methods of organizing external relationships with other organizations or other institutions	**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.

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

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.[3] 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

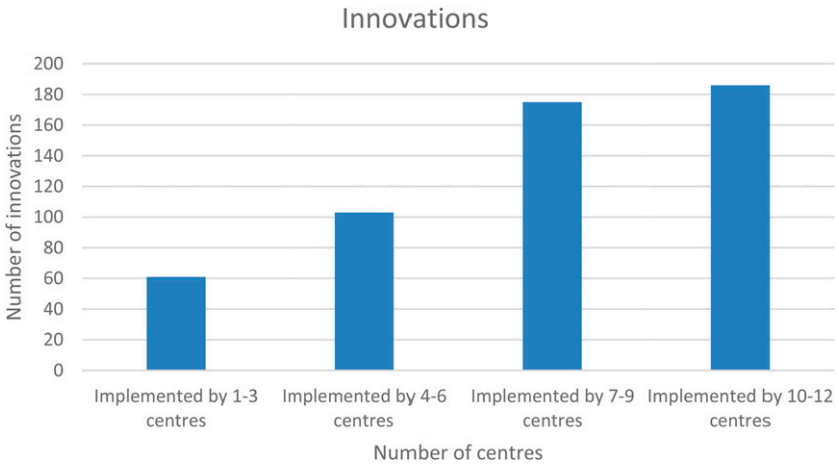
Table 6 shows that product, technological and organizational innovations are scored almost equally regarding average effort required and impact on output. For the average effort score, there is no significant difference between the different kinds of innovations ($p = 0.249$). However, for the average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

Table 5. Top five of each innovation category

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	17	11	4	4
	SBRT/SRS—extending indications	15	9	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	12	8	3	3
Organizational innovation	Improve time intake—start RT	34	10	4	4
	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.

Figure 2. Number of innovations implemented by number of centres.



($p = 0.000$) 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

Figure 3. Percentage of patients in Phase III and Phase I–II trials on a scale from 0% to 7%.

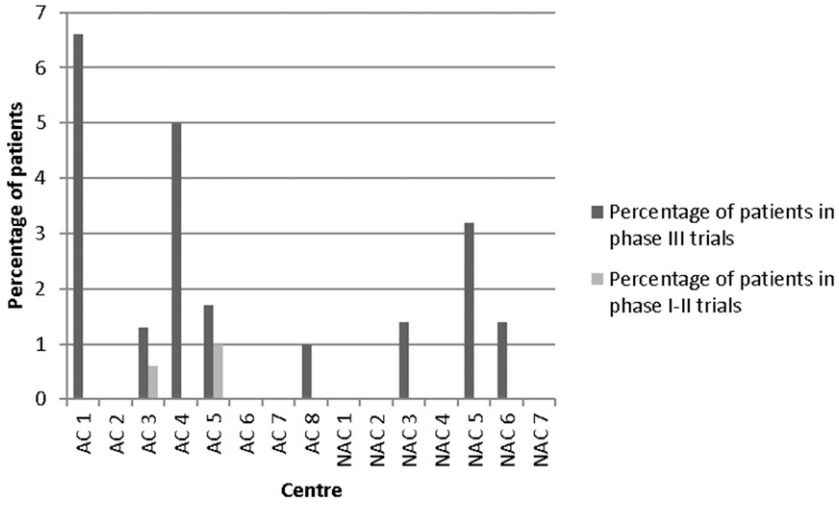
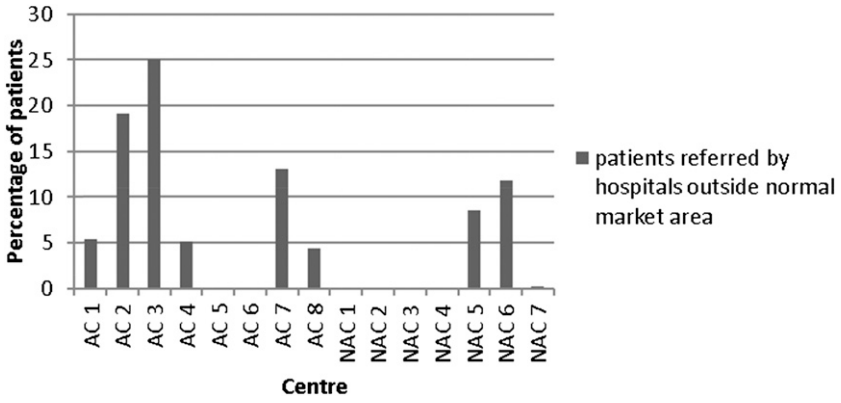


Figure 4. Percentage of patients referred by hospitals outside the normal market area on a scale from 0% to 30%.



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 6. Average score impact effort organization/employee and average score impact output

Type of innovation	Number of innovations	Total effort score	Average effort score (SD)	Total output score	Average output score (SD)
Product innovation	168	592	3.52 (0.538)	654	3.89 (0.329)
Technological innovation	148	526	3.55 (0.712)	498	3.39 (0.502)
Organizational innovation	209	747	3.62 (0.524)	722	3.45 (0.499)

SD, standard deviation.

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							
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							
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	0.908	0.384	0.722	1.000	0.452	0.727

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	3–30	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

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 but not the extent to which these developments are introduced in clinical practice. For example, in a worldwide literature review from 2010, new developments in arc-based RT techniques are described with attention given to VMAT, tomotherapy and the new approach to IMRT.[29] We showed that in the period 2011–13, most centres implemented IMRT and VMAT in clinical routine. The other top five innovations were stereotactic body radiation therapy/stereotactic radiosurgery technique optimization, TPS protocol optimization, oncology information system upgrade and software for patient care.

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.[4] 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.[30–33] 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.[34–37]

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.[38] The factors affecting the implementation of incremental innovations are different from those affecting radical innovations.[3] It is therefore 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.

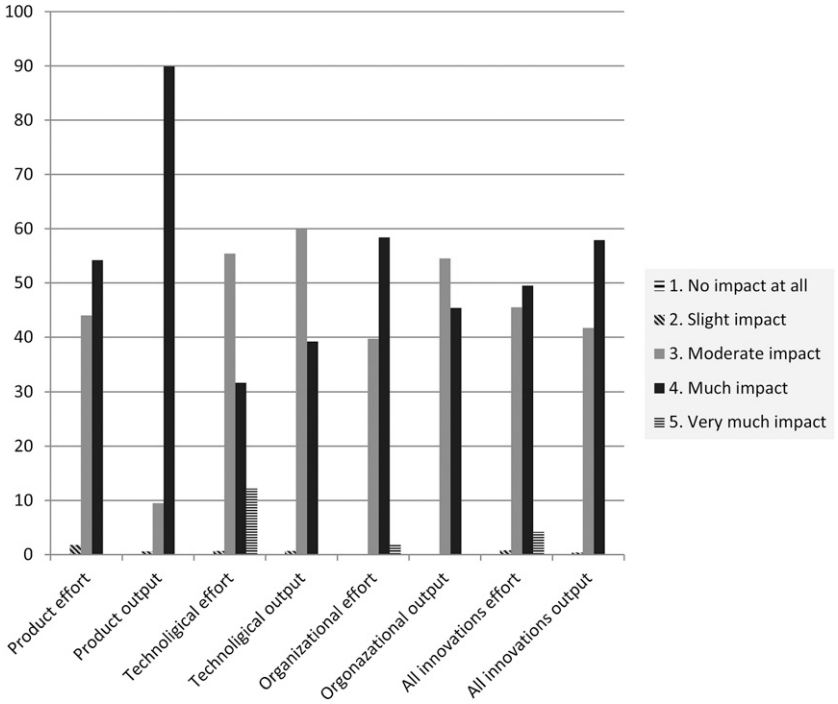
Product innovation indicators regarding patients in trials

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.[39,40] Clinical trials play a dominant role in clinical oncology.[41] 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.

Figure 5. Percentage of innovations per score category and distinguished by impact on effort required by organization/employees and expected output of the innovation.



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.[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?[42] 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.

ACKNOWLEDGMENTS

The authors thank the participants from all the centres for their willingness to share their information on innovation with them.

REFERENCES

1. Omachonu VK, Einspruch NG. Innovation in healthcare delivery systems: a conceptual framework. *Innov J* 2010; **15**: 1–20.
2. Anderson N, De Dreu CK, Nijstad BA. The routinization of innovation research: a constructively critical review of the state-of-the-science. *J Organiz Behav* 2004; **25**: 147–73. doi: http://dx.doi.org/10.1002/job.236
3. Jacobs M, Boersma L, Dekker A, Govers M, Lambin P, van Merode F. How to measure innovation in radiotherapy: an application of the Delphi method. *J Hosp Adm* 2015; **4**: 14. doi: http://dx.doi.org/10.5430/jha.v4n4p14
4. Chetty IJ, Martel MK, Jaffray DA, Benedict SH, Hahn SM, Berbeco R, et al. Technology for innovation in radiation oncology. *Int J Radiat Oncol Biol Phys* 2015; **93**: 485–92. doi: http://dx.doi.org/10.1016/j.ijrobp.2015.07.007
5. Winkler C, Duma MN, Popp W, Sack H, Budach V, Molls M, et al. Protection of quality and innovation in radiation oncology: the prospective multicenter trial QUIRO of DEGRO: evaluation of time, attendance of medical staff, and resources during radiotherapy with tomotherapy. *Strahlenther Onkol* 2014; **190**: 950–6. doi: http://dx.doi.org/10.1007/s00066-014-0615-3
6. Heron DE, Godette KD, Wynn RA, Arterbery VE, Streeter OA, Roach M 3rd, et al. Radiation medicine innovations for the new millenium. *J Natl Med Assoc* 2003; **95**: 55–63.
7. Bortfeld T, Jeraj R. The physical basis and future of radiation therapy. *Br J Radiol* 2011; **84**: 485–98. doi: http://dx.doi.org/10.1259/bjr/86221320
8. Van De Voorde L, Vanneste B, Houben R, Damen P, van den Bogaard J, Lammering G,

et al. Image-guided stereotactic ablative radiotherapy for the liver: a safe and effective treatment. *Eur J Surg Oncol* 2015; **41**: 249–56. doi: http://dx.doi.org/10.1016/j.ejso.2014.10.053

9. De Ruysscher D, Belderbos J, Reymen B, van Elmpt W, van Baardwijk A, Wanders R, et al. State of the art radiation therapy for lung cancer 2012: a glimpse of the future. *Clin Lung Cancer* 2013; **14**: 89–95. doi: http://dx.doi.org/10.1016/j.cllc.2012.06.006
10. Simons PA, Houben R, Vlayen A, Hellings J, Pijls-Johannesma M, Marneffe W, et al. Does lean management improve patient safety culture? An extensive evaluation of safety culture in a radiotherapy institute. *Eur J Oncol Nurs* 2015; **19**: 29–37. doi: http://dx.doi.org/10.1016/j.ejon.2014.08.001
11. Chera BS, Jackson M, Mazur LM, Adams R, Chang S, Deschesne K, et al. Improving quality of patient care by improving daily practice in radiation oncology. *Semin Radiat Oncol* 2012: **22**: 77–85. doi: http://dx.doi.org/10.1016/j.semradonc.2011.09.002
12. van Harten MC, Hoebers FJ, Kross KW, van Werkhoven ED, van den Brekel MW, van Dijk BA. Determinants of treatment waiting times for head and neck cancer in the Netherlands and their relation to survival. *Oral Oncol* 2015; **51**: 272–8. doi: http://dx.doi.org/10.1016/j.oraloncology.2014.12.003
13. Jacobs SR, Weiner BJ, Reeve BB, Hofmann DA, Christian M, Weinberger M. Determining the predictors of innovation implementation in healthcare: a quantitative analysis of implementation effectiveness. *BMC Health Serv Res* 2015; **15**: 6. doi: http://dx.doi.org/10.1186/s12913-014-0657-3
14. De Jong J, Den Hartog D. Measuring innovative work behavior. *Creativ Innovat Manag* 2010; **19**: 23–36. doi: http://dx.doi.org/10.1111/j.1467-8691.2010.00547.x
15. Thoma-Lürken T, Bleijlevens MH, Lexis MA, Hamers JP, de Witte LP. An overview of potential labor-saving and quality-improving innovations in long-term care for older people. *J Am Med Dir Assoc* 2015; **16**: 482–9. doi: http://dx.doi.org/10.1016/j.jamda.2014.12.017
16. Rosing K, Frese M, Bausch A. Explaining the heterogeneity of the leadership-innovation relationship: ambidextrous leadership. *Leadership Quart* 2011; **22**: 956–74. doi: http://dx.doi.org/10.1016/j.leaqua.2011.07.014
17. European Commission. Guidelines on the qualifictaion and classification of stand alone software used in healthcare within the regulatory framework of medical devices; 2016. Cited 9 September 2016. Available from: http://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjgqIaF1I7PAhUFORoKHTamC6UQFggoMAA&url=http%3A%2F%2Fec.europa.eu%2FDocsRoom%2Fdocuments%2F10362%2Fattachments%2F1%2Ftranslations%2Fen%2Frenditions%2Fnative&usg=AFQjCNEhbJftEVjWPWhvLGWe6NOm3yRVXA
18. Janssen O. Job demands, perceptions of effort-reward fairness and innovative work behaviour. *J Occup Organ Psychol* 2000; **73**: 287–302. doi: http://dx.doi.org/10.1348/096317900167038
19. Youn KI, Wan TT. Effects of environmental threats on the quality of care in acute care hospitals. *J Med Syst* 2001; **25**: 319–31. doi: http://dx.doi.org/10.1023/A:1010637324420
20. Zacher H, Rosing K. Ambidextrous leadership and team innovation. *Leader Organ Dev J* 2015; **36**: 54–68.
21. Zinn J, Flood AB. Commentary: slack resources in health care organizations—fat to be trimmed or muscle to be exercised? *Health Serv Res* 2009; **44**: 812–20. doi: http://dx.doi.org/10.1111/j.1475-6773.2009.00970.x
22. Pearce CL, Ensley MD. A reciprocal and longitudinal investigation of the innovation process: the central role of shared vision in product and process innovation teams (PPITs). *J Organiz Behav* 2004; **25**: 259–78. doi: http://dx.doi.org/10.1002/job.235
23. Ghosh K. Developing organizational creativity and innovation: toward a model of self-leadership, employee creativity, creativity climate and workplace innovative orientation. *Manage Res Rev* 2015; **38**: 1126–48.
24. Jong JPJ. *Individual innovation: the connection between leadership and employees' innovative work behavior.* EIM; 2007.
25. Thakur R, Hsu SH, Fontenot G. Innovation in healthcare: issues and future trends. *J Bus Res* 2012; **65**: 562–9. doi: http://dx.doi.org/10.1016/j.jbusres.2011.02.022
26. May C, Finch T, Mair F, Ballini L, Dowrick C, Eccles M, et al. Understanding the implementation of complex interventions in health care: the normalization process model. *BMC Health Serv Res* 2007; **7**: 148. doi: http://dx.doi.org/10.1186/1472-6963-7-148
27. Chaudoir SR, Dugan AG, Barr CH. Measuring factors affecting implementation of health innovations: a systematic review of structural, organizational, provider, patient, and innovation level measures. *Implement Sci* 2013; **8**: 22. doi: http://dx.doi.org/10.1186/1748-5908-8-22
28. Damanpour F, Wischnevsky JD. Research on innovation in organizations: distinguishing innovation-generating from innovation-adopting organizations. *J Eng Technol Manage* 2006; **23**: 269–91. doi: http://dx.doi.org/10.1016/j.jengtecman.2006.08.002
29. Palma DA, Verbakel WF, Otto K, Senan S. New developments in arc radiation therapy: a review. *Cancer Treat Rev* 2010; **36**: 393–9. doi: http://dx.doi.org/10.1016/j.ctrv.2010.01.004
30. Miles E, Venables K. Radiotherapy quality assurance: facilitation of radiotherapy research and implementation of technology. *Clin Oncol (R Coll Radiol)* 2012; **24**: 710–2. doi: http://dx.doi.org/10.1016/j.clon.2012.06.006
31. Nutting CM, Morden JP, Harrington KJ, Urbano TG, Bhide SA, Clark C, et al. Parotid-sparing intensity modulated *versus* conventional radiotherapy in head and neck cancer (PARSPORT): a phase 3 multicentre randomised controlled trial. *Lancet Oncol* 2011; **12**: 127–36. doi: http://dx.doi.org/10.1016/S1470-2045(10)70290-4
32. Donovan E, Bleakley N, Denholm E, Evans P, Gothard L, Hanson J, et al; Breast Technology Group. Randomised trial of standard 2D radiotherapy (RT) *versus* intensity modulated radiotherapy (IMRT) in patients prescribed breast radiotherapy. *Radiother Oncol* 2007; **82**: 254–64. doi: http://dx.doi.org/10.1016/j.radonc.2006.12.008
33. Bartlett FR, Colgan RM, Donovan EM, McNair HA, Carr K, Evans PM, et al. The UK HeartSpare Study (Stage IB): randomised comparison of a voluntary breath-hold technique and prone radiotherapy after breast conserving surgery. *Radiother Oncol* 2015; **114**: 66–72. doi: http://dx.doi.org/10.1016/j.radonc.2014.11.018
34. Langendijk JA, Lambin P, De Ruysscher D, Widder J, Bos M, Verheij M. Selection of patients for radiotherapy with protons aiming at reduction of side effects: the model-based approach. *Radiother Oncol* 2013; **107**: 267–73. doi: http://dx.doi.org/10.1016/j.radonc.2013.05.007
35. Bongers ML, Coupé VM, De Ruysscher D, Oberije C, Lambin P, Uyl-de Groot CA. Individualized positron emission tomography-based isotoxic accelerated radiation therapy is cost-effective compared with conventional radiation therapy: a model-based evaluation. *Int J Radiat Oncol Biol Phys* 2015; **91**: 857–65. doi: http://dx.doi.org/10.1016/j.ijrobp.2014.12.012
36. Cheng Q, Roelofs E, Ramaekers BL, Eekers D, van Soest J, Lustberg T, et al.

Development and evaluation of an online three-level proton *vs* photon decision support prototype for head and neck cancer—comparison of dose, toxicity and cost-effectiveness. *Radiother Oncol* 2016; **118**: 281–5. doi: http://dx.doi.org/10.1016/j.radonc.2015.12.029

37. Vanneste BG, Pijls-Johannesma M, Van De Voorde L, van Lin EN, van de Beek K, van Loon J, et al. Spacers in radiotherapy treatment of prostate cancer: is reduction of toxicity cost-effective? *Radiother Oncol* 2015; **114**: 276–81. doi: http://dx.doi.org/10.1016/j.radonc.2015.01.005
38. van Poucke A. *Towards radical innovation in knowledge-intensive service firms*; 2005.
39. Sinha G. United Kingdom becomes the cancer clinical trials recruitment capital of the world. *J Natl Cancer Inst* 2007; **99**: 420–2. doi: http://dx.doi.org/10.1093/jnci/djk140
40. Mathews C, Restivo A, Raker C, Weitzen S, Disilvestro P. Willingness of gynecologic cancer patients to participate in clinical trials. *Gynecol Oncol* 2009; **112**: 161–5. doi: http://dx.doi.org/10.1016/j.ygyno.2008.09.003
41. Roberson NL. Clinical trial participation. Viewpoints from racial/ethnic groups. *Cancer* 1994; **74**(Suppl. 9): 2687–91. doi: http://dx.doi.org/10.1002/1097-0142(19941101)74:9+<2687::AID-CNCR2820741817>3.0.CO;2-B
42. Chan C, Lang S, Rowbottom C, Guckenberger M, Faivre-Finn C; IASLC Advanced Radiation Technology Committee. Intensity-modulated radiotherapy for lung cancer: current status and future developments. *J Thorac Oncol* 2014; **9**: 1598–608. doi: http://dx.doi.org/10.1097/JTO.0000000000000346