Acta Oncologica, 2015; 54: 1282–1288

Taylor & Francis
Taylor & Francis Group

ORIGINAL ARTICLE

Can automation in radiotherapy reduce costs?

MARIANGELA MASSACCESI[1], MICHELE CORTI[2], LUIGI AZARIO[1], MARIO BALDUCCI[1], MILENA FERRO[1], GIOVANNA MANTINI[1], GIAN CARLO MATTIUCCI[1] & VINCENZO VALENTINI[1]

[1]*Radiation Oncology Department, Gemelli-ART, Università Cattolica S. Cuore, Rome and* [2]*Medipass Healthcare Consultant*

ABSTRACT

Background. Computerized automation is likely to play an increasingly important role in radiotherapy. The objective of this study was to report the results of the first part of a program to implement a model for economical evaluation based on micro-costing method. To test the efficacy of the model, the financial impact of the introduction of an automation tool was estimated. A single- and multi-center validation of the model by a prospective collection of data is planned as the second step of the program.
Material and methods. The model was implemented by using an interactive spreadsheet (Microsoft Excel, 2010). The variables to be included were identified across three components: productivity, staff, and equipment. To calculate staff requirements, the workflow of Gemelli ART center was mapped out and relevant workload measures were defined. Profit and loss, productivity and staffing were identified as significant outcomes. Results were presented in terms of earnings before interest and taxes (EBIT). Three different scenarios were hypothesized: baseline situation at Gemelli ART (scenario 1); reduction by 2 minutes of the average duration of treatment fractions (scenario 2); and increased incidence of advanced treatment modalities (scenario 3). By using the model, predicted EBIT values for each scenario were calculated across a period of eight years (from 2015 to 2022).
Results. For both scenarios 2 and 3 costs are expected to slightly increase as compared to baseline situation that is particularly due to a little increase in clinical personnel costs. However, in both cases EBIT values are more favorable than baseline situation (EBIT values: scenario 1, 27%, scenario 2, 30%, scenario 3, 28% of revenues).
Conclusion. A model based on a micro-costing method was able to estimate the financial consequences of the introduction of an automation tool in our radiotherapy department. A prospective collection of data at Gemelli ART and in a consortium of centers is currently under way to prospectively validate the model.

The term automation refers to the use of various control systems for operating equipment or processes with minimal or reduced human intervention. In many industries automation has been around for five decades due to its interconnected benefits that can be mainly felt in terms of labor saving and productivity gains. Over the past decade, due to an exponential increase in technological complexity, e.g. the introduction of highly sophisticated software-based treatment planning models and online imaging systems, radiotherapy has become more computerized than almost any other area of medicine.

In such context, computerized automation, which can encompass all aspects of the radiotherapy process (Electronic Medical Record, image transfer and storage, treatment simulation and planning, treatment administration and treatment dosage verification) is likely to play an increasingly important role. Indeed automation can help to counteract the higher resource demands related to more complex treatment strategies.

In a radiotherapy department computerized automation can be used with the aim of optimizing patient services (processing of patient data and care coordination) and individual practitioner (physician, dosimetrist, therapist, etc.) tasks.

In recent years the economics of health care has been a topic of increasingly interest due to competing

Correspondence: V. Valentini, Catholic University, Policlinico Universitario "A. Gemelli", Radiotherapy Department, Largo A Gemelli, 8, Roma, 00168 Italy. E-mail: vvalentini.it@gmail.com

(Received 8 June 2015; accepted 4 July 2015)

ISSN 0284-186X print/ISSN 1651-226X online © 2015 Informa Healthcare
DOI: 10.3109/0284186X.2015.1073353

demands on limited financial resources. Particularly the rapid diffusion of technological innovations has been identified as one of the most important factors driving the escalating health-care expenses [1,2], as it came inevitably with a higher workload and larger investments in infrastructure. Cost-effectiveness analysis (CEA) is presented in the research literature as a methodology to help decision-makers allocate scarce resources by comparing the relative costs and outcomes (effects) of two or more courses of action.

Typically the CEA is expressed in terms of a ratio where the denominator is a gain in health from a measure (years of life gained) and the numerator is the cost associated with the health gain. The most commonly used outcome measure is quality-adjusted life years (QALY) that is a measure of survival, including both the quality and the quantity of life lived, although it is not exempt from criticism as recently outlined by the European Consortium in Healthcare Outcomes and Cost-Benefit Research (ECHOUTCOME) [3].

Computerized automation can potentially have an impact on healthcare costs and clinical outcomes in many different ways. The most obvious one is by speeding up conventional tasks, meaning that more tasks could be completed in a typical work day. In the radiation oncology area, that allows to potentially increase the productivity for radiotherapy providers, decrease the waiting time for oncology patients, and reduce the need for investment in new radiotherapy units for payers. Computerized automation has also the potential to improve the quality and safety of patient treatments by enabling the delivery of advanced treatment modalities which traditionally could not have been performed through manual means (e.g. daily image-guided radiotherapy or real-time adaptation of the radiation treatment plan during the fractionated radiation treatment course) and by improving the reliability in performance of many tasks (namely those with a high propensity for variability or repetitive tasks with critical importance) [4].

A discussion about the potential impact of computerized automation on clinical outcomes is beyond the scope of this article. In this paper we report the results of the first part of a program to implement a model for estimating direct costs of radiotherapy, adopting the hospital's point of view. To test the efficacy of the model, it was used to estimate the financial impact of the introduction of an automation tool in the radiotherapy process. This manuscript focuses on the selection of the items to be included in the model and the method to calculate relevant endpoints. The validation of the model by a prospective collection of data both in a single center and in a consortium of centers with different technologies and activity volumes will be considered as the second step of the program and will be described in a separate manuscript.

Material and methods

The study was conducted at the Gemelli Advanced Radiation Therapy (ART) center in Rome (Italy) which is part of public healthcare system.

This study used earnings before interests and taxes (EBIT) as the reference output to evaluate economic impacts of different technology options. Therefore this assessment:

1) Included revenues (based on average Regional Healthcare System reimbursement) as well as relevant costs associated to treatment delivery (clinical staff, equipment maintenance, utilities, drugs and medications, immobilization systems, insurances, …) and capital expenditures depreciation (equipment and plants/buildworks when applicable);
2) Excluded both interests paid on debt and taxes since highly dependent from factor external from the radiotherapy department, such as the hospital's overall financial position or tax structure.

The first step of the program was aimed at selecting the variables to be included in the model. They were identified across three broad components each one highly interconnected with/dependent from the others: equipment plan, productivity targets and staffing requirements

Equipment plan

Treatment technology type of equipment were the key input of the study since they determined the center's productivity (in terms of total numbers of treatment delivered, mix of treatment techniques and Regional Healthcare System reimbursement for each technique), clinical staff requirements and most cost items. Relevant variables included, for each bunker:

1) Existing Linear Accelerators: type, residual useful life, expected decommissioning date, residual asset value, yearly maintenance costs, uptime guaranteed from the original equipment manufacturer.
2) New Linear Accelerators: type, useful life, acquisition cost, expected delivery date, expected installation and commissioning times, warranty period after technical acceptance, yearly maintenance cost after warranty expiry, uptime guaranteed from the Original Equipment Manufacturer (OEM)..

Productivity targets

For what concerns the center's productivity the following variables were identified: overall year-based treatment time schedule for each machine of the center, daily average treatment time by treatment technique, daily average treatment technique workload by machine, average number of treatments for patients by technique, the reimbursement foreseen per patient, per treatment type.

Staffing requirements

The individual workload for the staff was codified as follow: time spent for computerized tomography (CT) simulation, delineation, planning, treatment and quality assurance (QA) by each technique, duration and number of visits and reports by technique for radiation oncologists. Nurses and nursing assistants requirement was assumed to remain unchanged over time (3.6 and 3 full-time equivalent, FTE, respectively per shift). Three FTE radiotherapists per linac during each shift were deemed to be the fair requirement (independently from the number of fractions treated and treatment modality used). The assumption related to shifts time, number of shift, and holidays were considered as well the average salary of the staff. The Gemelli ART center is within a university hospital so a small part of radiation oncologist activities is done by specializing graduates (whose remuneration is not due by the Gemelli ART center provider). This aspect was considered in the simulation model. Staffing requirement was therefore estimated based on the assumptions of a 30-hours working week for all staff.

Other costs

Finally, in order to maximize the completeness of the economic assessment, standard costs were identified with the support of Gemelli's hospital Administration & Control Function with reference to the center's other relevant costs (direct/indirect) including: drugs, medical and non-medical consumables, other equipment (other than linear accelerators) maintenance, building and plants maintenance, utilities consumption, facility services (e.g. cleaning and laundry), insurances (capital assets insurance and liability insurance), and radio-protection.

As second step, to calculate radiation oncologists, medical physicists and radiotherapists requirements, the workflow of Gemelli ART center was mapped out and relevant workload measures were defined according to what routinely done as defined by departmental protocols (e.g. frequency and time slots dedicated to QA controls and medical visits) or personnel interviews. Following items were considered and categorized according to the involved staff and treatment modality: average working time required for general QA checks; average working time required for each simulation and treatment plan; number of QA check per patient and average working time required; number of visits per patient and average working time required.

The third and final step was to identify the significant outcome in terms of economic sustainability, productivity and staffing. The selection of EBIT as reference output for economic sustainability evaluation has been already described in this paper. For productivity the total number of fractions, patients and the revenues per year and by treatment modality were selected. Finally the number of headcounts and related costs for all staff components were also reported.

The model was implemented by using a simple interactive spreadsheet (Microsoft Excel 2010) divided in three sections:

1) Input section where all relevant inputs summarized above (equipment plan, productivity and staff requirement) were included with clear indication of the reference calculation driver (e.g. with reference to clinical staff workloads: "per fraction delivered", "per patient", "per linear accelerator", "per clinical shift", …) and, when applicable, of their evolution across the years (e.g. progressive reduction of fractions per patient as a result of hypo-fractionation);
2) Calculation sections (productivity and clinical staff) where the abovementioned drivers were collected and the calculation of relevant outputs were performed; the calculation spreadsheet were expressed on monthly basis to ensure model's reliability also in the years of equipment replacement (e.g. fractional impact on productivity, revenues, costs, …);
3) Summary sections (profit and losses, productivity and clinical staff) where the monthly results were aggregated on yearly basis and "easy-to-use" support ratios calculated (e.g. average tariff per patient, average number fractions per patient, …) to facilitate the interpretation of the model's results.

The basic excel file is available for free at the website http://www.gemelli-art.it/ricerca.html. To download of the file, an identification of the applicant and a disclosure signature is required.

The Gemelli ART center is currently equipped with three linear accelerators (linacs): one Trilogy, one TrueBeam and one Edge linac manufactured by Varian (Palo Alto, CA, USA) which can be used for all forms of advanced radiotherapy modalities including image-guided radiotherapy (IGRT), intensity-modulated radiotherapy (IMRT), volumetric intensity modulated arc therapy (VMAT) and stereotactic body radiotherapy (SBRT) along with conventional and three-dimensional conformal radiotherapy (3D-CRT).

For the test phase of the program, three different scenarios were hypothesized to assess the potential impact on costs of computerized automation and the predicted productivity (expected number of patients treated per year) was calculated across a period of eight years (from 2015 to 2022) for each scenario.

The installed Record and Verified system at Gemelli ART center is the ARIA® Oncology Information System (Varian) which tracks activities and records patient data throughout the course of treatment and makes this information available for review and evaluation. Workload measures (fraction duration, number of fractions per day, number of fractions per patient by treatment modality and linac type) were collected over a period of 6 months (from 1 March to 31 August 2014). Average values were calculated and used as input variables to estimate the expected productivity in the forthcoming eight years assuming a 52-working-week year (5 working days week) with an average equipment down time of 6% (average unavailability of the equipment during the center's normal functioning hours for planned and/or unplanned maintenance activities) in the following three scenarios:

Scenario 1 (baseline situation)

We hypothesize that the current situation at Gemelli ART center will remain substantially unchanged over time except for a little variation of IGRT incidence on the total amount of IMRT treatments (100% in the first year, 80% in the second, 85% in the third, and 90% in the fourth year) and a slight increase of the use of hypofractionated treatment schedules for IMRT, VMAT and stereotactic modalities (decrease of the average number of fractions per patient from 35, 28 and 4 to 33, 25 and 3, respectively starting from 2016). It was also assumed that the average duration of treatment fractions over time will remain unchanged. It was hypothesized the disposal of the Trilogy linac starting from the 1 January 2018 and its replacement with another TrueBeam Linear Accelerator (starting activity on 1 June 2018).

Scenario 2 (reduction of the average duration of treatment fractions)

This situation differs from baseline because we hypothesized an average reduction by two minutes of the time needed to complete a radiotherapy fraction with treatment modalities requiring IGRT due, e.g. to the introduction of a computerized automation tool that speeds up the treatment image verification process.

Scenario 3 (increased incidence of advanced treatment modalities)

This situation differs from the baseline because we assumed a more intensive prescription and delivery of advanced treatment modalities and consequently relatively less 3D-CRT treatments on the Trilogy linac due, e.g. to the introduction of a computerized automation tool that speeds up the planning process for IMRT.

Once the expected number of fractions and patients treated per year was calculated for each scenario, a micro-costing analysis was performed aiming at identify, measure and value each input that may lead to cost differences between hypothesized scenarios [5]. Using this technique we calculated the provisional total direct costs across a period of eight years (from 2015 to 2022). Costs are reported from the perspective of the radiotherapy department in 2015 euros.

Results

Productivity and revenues

Table I shows the expected number of fractions and patients treated per year in the three different scenarios across a period of eight years (from 2015 to 2022).

In all scenarios the expected number of fractions and patients has a fall off in 2018 that is certainly imputable to the replacement of the Trilogy with another TrueBeam linac (five months inactivity of one of three linacs).

Table I. Productivity summary.

	Year	2015	2016	2017	2018	2019	2020	2021	2022	Total
Expected no. of fractions delivered per year	Scenario 1	27 723	27 830	27 723	21 035	24 779	24 874	24 779	24 779	203 523
	Scenario 2	28 214	28 322	28 214	21 814	25 761	25 859	25 761	25 761	209 706
	Scenario 3	25 761	25 859	25 761	21 035	24 779	24 874	24 779	24 779	197 628
Expected no. of patients treated per year	Scenario 1	1756	1988	1974	1544	1745	1750	1745	1745	14 247
	Scenario 2	1816	2084	2069	1692	1930	1937	1930	1930	15 388
	Scenario 3	1760	2059	2045	1544	1745	1750	1745	1745	14 393

In all scenarios, in the period from 2015 to 2016, although the expected number of fractions remains almost unchanged, the expected number of patients increases over time (absolute increase: 13.2% in scenario 1, 15.2% in scenario 2, and 17.0% in scenario 3) that is because of a more intensive use of hypofractionated schedules of treatment.

As compared to baseline situation, in scenario 2 (reduction by two minutes of the time needed to complete a session for treatment modalities requiring IGRT) the expected number of fractions increases (absolute increase 1.7–3.5% per year). The expected number of patients also increases (absolute increase from 3.4% in 2015 to 10.5% in 2020).

As compared to baseline situation, in scenario 3 (reduction of the frequency of 3D-CRT and relative increase of IMRT treatment on Trilogy linac) the expected number of fractions decreases during the period 2015–2017 (absolute decrease per year: 7.0–7.1%) while the number of patients slightly increases (absolute increase 0.2–4.0%) in the same period. There are no differences starting from 2018 (disposal of Trilogy linac).

In all three scenarios, expected revenues increase from 2015 to 2022 (absolute increase 12.0% in scenario 1, 18.6% in scenario 2, and 7.0% in scenario 3). As compared to baseline situation, expected revenues increase in both alternative scenario (absolute increase: 7.2% in scenario 2 and 2.4% in scenario 3).

Costs and EBIT

The expected staff requirement across the eight-year simulation period is illustrated in Table II. Staff requirements in different scenarios slightly differ only for the number of radiation oncologists and medical physicists.

Table III provides a detailed description of costs and EBIT. For both scenarios 2 and 3 costs are expected to slightly increase as compared to baseline situation that is particularly due to a little increase in clinical personnel costs. However, in both cases EBIT values are more favorable than baseline situation (EBIT values: scenario 1, 27%, scenario 2, 30%, scenario 3, 28% of revenues).

Discussion

Economic evaluations are important to inform funding decisions but are only as good as the data upon which they are based. There is a range of methods available to use when undertaking a cost study. To assess the impact on costs of computerized automation we use a micro-costing method (also referring to as bottom-up costing). As micro-costing involves detailed identification and measurement of all intervention inputs before quantify them into monetary units it is likely to be a very precise method [6]. Furthermore, this approach provided a clear framework for presenting results.

Table II. Staff requirements.

		Year	2015	2016	2017	2018	2019	2020	2021	2022
Scenario 1	Clinical staff									
		Radiation oncologists	10.0	8.5	8.0	8.0	8.0	8.0	8.0	8.0
		Medical physicists	4.5	4.5	4.0	4.0	4.0	4.0	4.0	4.0
		Radiotherapists	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5
		Nurses	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
		Nursing assistants	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
	Subtotal		51.0	49.5	48.5	48.5	48.5	48.5	48.5	48.5
	TOTAL		53.0	51.5	50.5	50.5	50.5	50.5	50.5	50.5
Scenario 2	Clinical staff									
		Radiation oncologists	10.5	8.5	8.0	9.0	9.0	9.0	9.0	9.0
		Medical physicists	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		Radiotherapists	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5
		Nurses	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
		Nursing assistants	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
	Subtotal		52.0	49.5	49.0	50.0	50.0	50.0	50.0	50.0
	TOTAL		54.0	51.5	51.0	52.0	52.0	52.0	52.0	52.0
Scenario 3	Clinical staff									
		Radiation oncologists	11.0	9.0	8.5	8.0	8.0	8.0	8.0	8.0
		Medical physicists	5.0	5.0	4.5	4.0	4.0	4.0	4.0	4.0
		Radiotherapists	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5
		Nurses	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
		Nursing assistants	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
	Subtotal		52.5	50.5	49.5	48.5	48.5	48.5	48.5	48.5
	TOTAL		54.5	52.5	51.5	50.5	50.5	50.5	50.5	50.5

Table III. Profit and loss.

Costs		Scenario 1		Scenario 2		Scenario 3	
		Euro (.000)	% of total costs	Euro (.000)	% of total cost	Euro (.000)	% of total cost
Purchases	Pharma	35	0.1	37	0.1	36	0.1
	Medical consumables	908	2.3	973	2.4	930	2.4
	Other consumables	279	0.7	299	0.7	286	0.7
	Subtotal	1222	3.1	1309	3.3	1252	3.2
Services	Linac maintenance	6915	17.8	6915	17.3	6915	17.6
	Other equipment maintenance	672	1.7	672	1.7	672	1.7
	Building & plants maintenance	1160	3.0	1160	2.9	1160	2.9
	Laundry and other services	279	0.7	299	0.7	286	0.7
	Utilities	768	2.0	823	2.1	787	2.0
	Subtotal	9794	25.2	9869	24.6	9820	25.0
Personnel	Radiation oncologists	7328	18.8	7945	19.8	7576	19.2
	Other clinical personnel	17 409	44.8	17 673	44.1	17 522	44.5
	Non-clinical personnel	523	1.3	523	1.3	523	1.3
	Incentives	1515	3.9	1603	4.0	1548	3.9
	Subtotal	26 775	68.8	27 744	69.2	27 169	69.0
Overheads	Radioprotection	400	1.0	400	1.0	400	1.0
	Insurance	698	1.8	749	1.9	716	1.8
	Subtotal	1098	2.8	1149	2.9	1116	2.8
	Total	38 889	100.0	40 071	100.0	39 357	100.0
Revenues		69 825		74 857		71 565	
EBITDA[a]		30 935	44.3%	34 783	46.5%	32 206	45.0%
Depreciation - linac		8465		8465		8465	
Depreciation - other equipment		1037		1037		1037	
Depreciation - plants and building		2900		2900		2900	
	Total	12 402		12 402		12 402	
EBIT[a]		18 534	26.5%	22 382	29.9%	19 805	27.7%

EBIT, earnings before interests and taxes; EBITDA, earnings before interests taxes depreciation and amortization. [a] Values are expressed as percentage of revenues.

Three hypothetical scenarios were simulated and predicted costs and revenues across a period of eight years were calculated.

In the first scenario the prediction was made starting from current situation at Gemelli ART center and assuming some variation over time (replacement of a linac, different use of IGRT, more intensive use of hypofractionated schedules). In such situation, it was hypothesized the acquisition of a computerized automation tool that either speeds up the image verification process thus allowing an average reduction by two minutes of the time needed to complete a radiotherapy session with IGRT (scenario 2) or speeds up the planning process for IMRT thus leading to a more intensive prescription and delivery of advanced treatment modalities (scenario 3).

As expected, in scenario 2 the predicted productivity is higher than baseline because of a greater number of fractions completed within the time unit. A slight increase in costs is expected, that is mainly due to an increase in clinical staff costs thus reflecting the adaptation of manpower to the volume of patients.

However, the expected EBIT value is more favorable, that is due at least in part to the relative increase in incidence of treatment modalities which reimbursements are higher than 3D-CRT.

Conversely in scenario 3 the predicted number of treated fractions is lower than baseline because of an average longer duration of the radiotherapy session with more advanced treatment modalities, however, the number of patients treated remains almost unchanged because of the more intense use of hypofractionated schedules with these modalities than with 3D-CRT. As observed in scenario 2 a slight increase in costs is expected, however again with a more favorable EBIT value.

Therefore computerized automation can have different impacts on costs which are mainly depending on which task the computerized tool can automate, the effect of such automation on the workload related to that specific task, and the consequence of such effect on global productivity. The latter aspect largely depends on the particular workflow and workload features of each radiotherapy center. Therefore the results of this study only apply to Gemelli ART center and cannot be generalized.

Another major limitation of the study is that the resource use was estimated for an 'average' radiotherapy patient. This aspect necessarily limits the detail in the results compared to, e.g. a review of individual patient records or costs derived from the direct observation of actual resource utilization during treatment for individual patients.

In this study the introduction of computerized automation resulted in improved EBIT values over baseline situation in both the simulated scenarios. However, it cannot be excluded that another automation tool conversely would lead to decreased EBIT values. In such situation the model could also help radiotherapy providers to re-negotiate the reimbursement terms with healthcare payers whenever a cost-effectiveness benefit of the new technology is proven.

This is not the first time a micro-costing approach has been used for cost analysis in radiotherapy. Recently, Hanly and coworkers from Ireland used micro-costing methods to estimate total direct radiotherapy costs for long- and short-courses radiotherapy in rectal cancer [7]. By using the same method a group of French authors from the University of Lyon performed an economic evaluation of pulsed dose-rate brachytherapy with optimized dose distribution for cervix carcinoma in 2011 [8], and IGRT for prostate cancer in 2012 [9].

Although the results of this study may not directly apply to other radiotherapy centers, we have confirmed the feasibility of micro-costing method to estimate the financial consequences of the introduction of a new technology in a radiotherapy department.

A prospective collection of data at Gemelli ART and in a consortium of centers with different technologies and volumes of activities is currently under way to prospectively validate the model.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

[1] Bodenheimer T. High and rising health care costs. Part 2: Technologic innovation. Ann Intern Med 2005;142:932–7.

[2] Ploquin N, Dunscombe P. The cost of radiation therapy. Radiother Oncol 2008;86:217–23.

[3] European Guidelines for Cost-Effectiveness Assessments of Health Technologies presented during the Final conference of the ECHOUTCOME project held in Brussels on January 25th, 2013. Available from: http://www.echoutcome.eu/images/Echoutcome__Leaflet_Guidelines___final.pdf

[4] Moore KL, Kagadis GC, McNutt TR, Moiseenko V, Mutic S. Vision 20/20: Automation and advanced computing in clinical radiation oncology. Med Phys 2014;41:010901.

[5] Gray AM, Clarke PM, Wolstenholme JL, Wordsworth S. Chapter 6: defining, measuring and valuing costs in applied methods of cost-effectiveness analysis in health care. Handbooks in health economics series. Oxford: Oxford University Press; 2011.

[6] Sach TH, Desborough J, Houghton J, Holland R; CAREMED study team. Applying micro-costing methods to estimate the costs of pharmacy interventions: An illustration using multi-professional clinical medication reviews in care homes for older people. Int J Pharm Pract Epub 2014 Nov 6.

[7] Hanly P, Céilleachair AÓ, Skally M, O'Neill C, Sharp L. Direct costs of radiotherapy for rectal cancer: A microcosting study. BMC Health Serv Res 2015;15:184.

[8] Remonnay R, Morelle M, Pommier P, Haie-Meder C, Quetin P, Kerr C, et al. Economic assessment of pulsed dose-rate (PDR) brachytherapy with optimized dose distribution for cervix carcinoma. Cancer Radiother 2010;14:161–8.

[9] Pommier P, Morelle M, Perrier L, de Crevoisier R, Laplanche A, Dudouet P, et al. Prospective economic evaluation of image-guided radiation therapy for prostate cancer in the framework of the national programme for innovative and costly therapies assessment. Cancer Radiother 2012;16:444–51.