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REVIEW ARTICLE

Radiation costing methods: a systematic review

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ABSTRACT

Objective Costs for radiation therapy (RT) and the methods used to cost RT are highly diverse across the literature. To date, no study has compared various costing methods in detail. Our objective was to perform a thorough review of the radiation costing literature to identify sources of costs and methods used.

Methods A systematic review of Ovid MEDLINE, Ovid OLDMEDLINE, EMBASE, Ovid HealthStar, and EconLit from 2005 to 23 March 2015 used search terms such as "radiation," "radiotherapy," "neoplasm," "cost," " cost analysis," and "cost benefit analysis" to locate relevant articles. Original papers were reviewed for detailed costing methods. Cost sources and methods were extracted for papers investigating RT modalities, including three-dimensional conformal RT (3D-CRT), intensity-modulated RT (IMRT), stereotactic body RT (SBRT), and brachytherapy (BT). All costs were translated into 2014 U.S. dollars.

Results Most of the studies (91%) reported in the 33 articles retrieved provided RT costs from the health system perspective. The cost of RT ranged from US$2,687.87 to US$111,900.60 per treatment for IMRT, followed by US$5,583.28 to US$90,055 for 3D-CRT, US$10,544.22 to US$78,667.40 for BT, and US$6,520.58 to US$19,602.68 for SBRT. Cost drivers were professional or personnel costs and the cost of RT treatment. Most studies did not address the cost of RT equipment (85%) and institutional or facility costs (66%).

Conclusions Costing methods and sources were widely variable across studies, highlighting the need for consistency in the reporting of RT costs. More work to promote comparability and consistency across studies is needed.

Key Words Radiation therapy, costs, cost analyses, cost-effectiveness analyses, cost–benefit analyses

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INTRODUCTION

Based on the World Health Organization's *World Cancer Report 2014*, the burden of cancer rose to approximately 14 million incident cases per year in 2012 and is expected to rise to 22 million annually by the mid-2030s[1]. Given this striking increase in incident cancer cases, it becomes imperative to properly manage finances and resources for timely and appropriate patient care.

An integral part of cancer treatment is radiation therapy (RT). Approximately 50% of all cancer patients will receive RT at some point during the course of their treatment[2]. Using ionizing and non-ionizing radiation, RT kills cells or damages DNA to prevent cancerous cell growth[3]. Delivery of RT can be achieved using various clinical procedures: three-dimensional conformal RT (3D-CRT), intensity-modulated RT (IMRT), stereotactic body RT (SBRT), brachytherapy (BT), and so on. The end goal of RT is to cure or shrink early-stage cancer, to prevent cancer recurrence, and to treat symptoms caused by advanced cancer[3].

Radiation therapy requires high capital expenditure and is staff- and resource-intensive[2]. Because the costs associated with health systems have to be economically sustainable, cost becomes an important factor to take into consideration[4,5]. Given that health care costs are consuming a rising share of government budgets, understanding the true costs of RT, a procedure so common and so necessary in cancer treatment, is important for managing drivers related to cancer costs. Internationally, the operationalization, definition, and costs of RT show large variation, which emphasizes the importance of using rigorous evidence-based methods to develop an accurate

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representation of the cost of RT[2]. Methods for costing RT are inconsistent, making it difficult to compare and contrast RT costs and to determine their accuracy.

The objective of the present study was to conduct a systematic review of the literature to critically assess various RT costing methods for various cancer types. Specific costs and sources of costs were identified for each study, as were the costing methods used.

METHODS

Database Search

A systematic review of the published literature identified studies assessing the costs of RT in any type of cancer (Figure 1). A number of electronic databases were used: MEDLINE (resources from 1946 onward) and Ovid OLDMEDLINE (resources from 1946 to 1965) were searched for the combined terms "radiation," "neoplasm," "cost," and "cost analysis"; EMBASE (resources from 1974 onward) was searched for the combined terms "radiotherapy," "neoplasm," and "cost effectiveness analysis" or "cost benefit analysis"; Ovid HealthStar (resources from 1966 onward) was searched for the combined terms "radiation," "neoplasm," "cost," and "cost analysis"; and a basic search of the EconLit database for "cost of radiotherapy" was also performed. All searches (excluding EconLit) were limited to studies with human subjects and were searched for the years from 2005 to 23 March 2015. Searches of Ovid MEDLINE, EMBASE, EconLit, and Ovid HealthStar were limited to the English language.

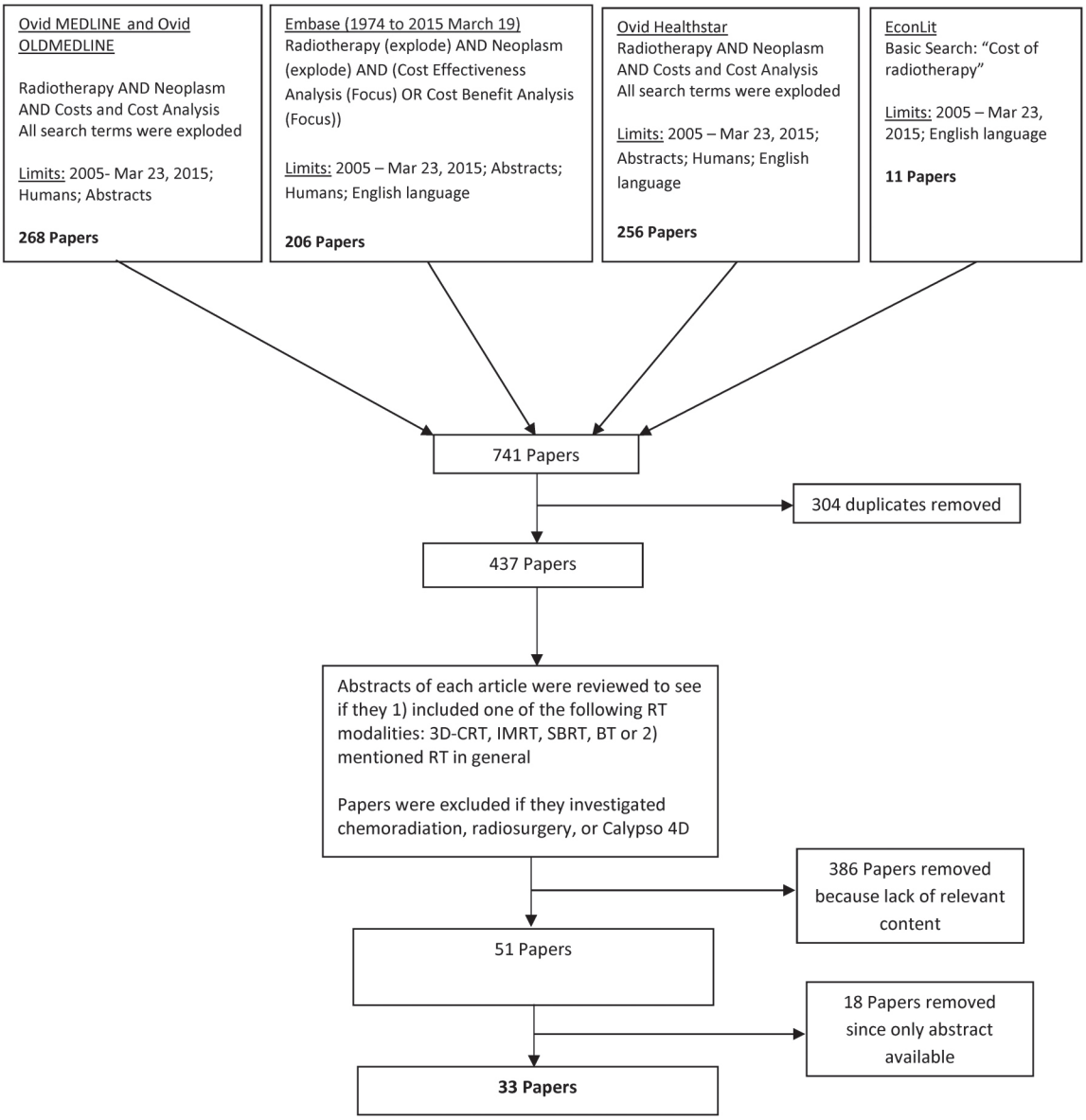

FIGURE 1 Flowchart of study selection process. RT = radiation therapy; 3D-CRT = 3-dimensional conformal RT; IMRT = intensity-modulated RT; SBRT = stereotactic body RT; BT = brachytherapy; 4D = 4-dimensional.

Study Selection

Studies selected for inclusion had to have provided the cost of RT for any type of cancer. No geographic restrictions were used. The method used for determining costs had to be documented in enough detail to outline the resources for or the sources of the costs (or both) used to cost RT and could come from burden-of-illness studies or comparative analyses. Abstracts were further reviewed, and the studies were included if they investigated at least one of 3D-CRT, IMRT, SBRT, BT, or if they mentioned RT in general; studies were excluded if they assessed chemoradiation, radiosurgery, or Calypso 4D (Varian Medical Systems, Palo Alto, CA, U.S.A.). To remain current, studies published before 2005 were excluded. Review articles were also excluded, but were checked for relevant articles within the reference sections. Duplicates and studies that lacked relevant content were also excluded.

Data Extraction

The selected articles were thoroughly reviewed (FR, SJS, SYC), and any study-relevant methods—such as patient population, modality, costing method, cost of the various modalities of RT, costing source or sources, costing outcome measures, and year of costs—were extracted. The extracted information was amalgamated into a comprehensive table and critically analyzed for the purposes of the present study. Using the Consumer Price Index[6], the cost per treatment for each RT modality was inflated to 2014 U.S. dollars for comparison purposes.

RESULTS

Study Characteristics

Ovid MEDLINE and Ovid OLDMEDLINE generated 268 results, EMBASE produced 206 results, Ovid HealthStar produced 256 results, and EconLit generated 11 results. Of the 741 studies located, 304 were duplicates and were removed. Of the 437 remaining studies, 386 were removed because of lack of relevant content, and another 18 were removed because only abstracts were available (Figure 1). Of the thirty-three original articles included in the analysis, twenty-seven had been conducted in the United States[7–33] (one of which used international data[26]), four were from Canada[34–37], and two were from the Netherlands[38,39].

Methods in the Included Studies

The costing methods varied widely in the articles reviewed, largely because of the perspective from which the costs were reported (that is, reimbursed costs, charged costs, billed costs, and so on) and also because of the data sources and components included in determining the overall cost of RT.

Of the thirty-three studies considered, thirty (91%) used costing methods that took a health care perspective (that is, Medicare for U.S. studies, and provincial ministry of health for Canadian studies); the remaining three[9,25,26] took a societal perspective.

A detailed review of the costing components for RT can be found in Tables I and II. Approximately 94% of the studies ($n = 31$) stated RT costs for a course of treatment. Two others were reported at more granular levels: one reported at a per-fraction level[12] and one was based on radiation episodes of care[30]. The disease site most often evaluated in RT costing studies was prostate cancer (39%)[7,9,10,15–18,24,27,29,31,32,34], followed by breast cancer (18%)[8,19,22,25,26,28], non-small-cell lung cancer (12%)[20,23,37,39], head-and-neck cancer (9%)[14,33,38], cervical cancer (6%)[13,21], and other sites [bone metastases (6%)[12,30], metastatic epidural spinal cord (3%)[36], oropharyngeal cancer (3%)[35], and squamous cell cancer of the anus (3%)[11]]. Thirteen studies used original costing data to conduct the costing analysis[8,19,20,24–26,28,29–33,37]; the remaining twenty studies modelled outcomes using hypothetical patient cohorts[7,9,10–18,21–23,27,34–36,38,39].

In the determination of RT costs, almost all studies ($n = 32$, 97%) included professional or physician fees in their cost analyses, which consisted of personnel such as physicians, radiation oncologists, physicists, and nurses. All studies included treatment and planning costs, per the objective of the studies. Only 33% of the studies incorporated institution or facility costs into their costing model, which most often included inpatient, outpatient, and technical costs of the hospital[7,16,18,22,24,26,33–37]. Only five studies (15%) included equipment costs in their cost analyses (that is, computed tomography scanner and planning system, capital cost, specialized construction cost, and maintenance and operating costs of the radiation equipment)[22,24,34,35,37]. Most studies (70%) accounted for other costs (overhead, administration, and so on), which included minor equipment such as port films, immobilization devices, multileaf collimator, and other complex treatment devices; however, ten studies did not account for such items in their costing method[13,16,18,21,23,26,28,30,34,37].

As shown in Figure 2, twenty-two studies provided costs for IMRT[7,9–11,14,16–24,27,28,29,31–35]; sixteen, for 3D-CRT[11,14,15,17,19,20,22,23,28,31–35,37,39]; six, for BT[9,13,22,24,31,32]; and six, for SBRT[7,10,20,23,27,37]. A number of studies also costed other modalities of RT (RT in general, whole-breast radiation, external-beam partial-breast irradiation, etc.), which are excluded from Figure 2 because they do not fall under the main RT modalities.

Based on modality type, cancer type, and costing components used, costs showed large variability between the studies. The cost for IMRT ranged from US$2,687.87 to US$111,900.60 per treatment, followed by 3D-CRT at US$5,583.28 to US$90,055, BT at US$10,544.22 to US$78,667.40, and SBRT at US$6,520.58 to US$19,602.68. Studies by Lanni *et al.*[20] and Shah *et al.*[24] included institutional costs in addition to the hospital-specific reimbursement for RT treatment.

DISCUSSION

This literature review was able to retrieve thirty-three papers representing studies conducted over 10 years with the objective of costing RT in a number of cancer types. The results show that costing methods are vastly different across studies and countries, resulting in wide variations in cost estimates for similar treatments. Our findings demonstrate the need for consistent agreed-on costing methods for future economic studies of RT.

A study by Paravati *et al.*[40] identified sources of variation in RT costing for Medicare beneficiaries with

cancer. Another study by Amin *et al.*[41] systematically reviewed the literature to identify articles that performed cost-effectiveness analysis of RT options for prostate cancer to identify the main cost drivers. Both studies also found large variations in the cost of RT between studies because of factors unrelated to the patient and the

TABLE I Radiation costing components for each study

Disease site	Reference	Professional fees	Equipment	Treatment or planning	Facility or institutional	Other[a]
Prostate cancer						
	Konski, 2005[16]	X		X	X	
	Konski *et al.*, 2005[15]	X		X		X
	Konski *et al.*, 2006[17]	X		X		X
	Konski *et al.*, 2007[18]	X		X	X	
	Perlroth *et al.*, 2010[31]	X		X		X
	Hodges *et al.*, 2012[10]	X		X		X
	Perlroth *et al.*, 2012[32]	X		X		X
	Shah *et al.*, 2012[24]	X	X	X	X	X
	Yong *et al.*, 2012[34]	X	X	X	X	X
	Eldefrawy *et al.*, 2013[7]	X		X	X	X
	Hayes *et al.*, 2013[9]	X		X		X
	Yu *et al.*, 2013[29]	X		X		
	Sher *et al.*, 2014[27]	X		X		X
Breast cancer						
	Smith *et al.*, 2011[28]	X		X		
	Greenup *et al.*, 2012[8]	X		X		X
	Lanni *et al.*, 2013[19]	X		X		X
	Shah *et al.*, 2013[25]	X		X		X
	Sen *et al.*, 2014[22]	X	X	X	X	X
	Shah *et al.*, 2014[26]	X		X	X	
Non-small-cell lung cancer						
	Lanni *et al.*, 2011[20]	X		X		X
	Ramaekers *et al.*, 2013[39]			X		X
	Shah *et al.*, 2013[23]	X		X		
	Mitera *et al.*, 2014[37]	X	X	X	X	X
Head-and-neck cancer						
	Kohler *et al.*, 2013[14]	X		X		X
	Ramaekers *et al.*, 2013[38]	X		X		X
	Sheets *et al.*, 2014[33]	X		X	X	
Cervical cancer						
	Lesnock *et al.*, 2013[21]	X		X		
	Kim *et al.*, 2015[13]	X		X		
Others						
	Furlan *et al.*, 2012[36] (neoplastic metastatic epidural spinal cord compression)	X		X	X	
	Hess *et al.*, 2012[30] (bone metastases secondary to breast or prostate cancer)	X		X		X
	Yong *et al.*, 2012[35] (oropharyngeal cancer)	X	X	X	X	X
	Hodges *et al.*, 2014[11] (squamous cell cancer of the anus)	X		X		X
	Kim *et al.*, 2015[12] (painful vertebral bone metastases)	X		X		X

[a] Refers to overhead costs, administrative costs, and so on.

TABLE II Radiation therapy (RT) costing component details by study

Reference and disease site	Professional fees	Equipment	Treatment and planning	Facility and institutional	Other[a]	RT cost details
Prostate cancer						
Konski, 2005[16]	Medicare reimbursement (professional or physician treatments)	Not available	Assumed treatment[b] (Medicare reimbursement for technical or hospital treatments)	Medicare reimbursement (technical or hospital treatments)	Not available	Mean Medicare reimbursement (2004 US dollars) IMRT: $24,953 per treatment 3D-CRT: $13,900 per treatment
Konski *et al.*, 2005[15]	2003 Medicare reimbursements ■ Physicist ■ Physician	Not available	2003 Medicare reimbursements [accounted for technical (hospital fees) and professional components (physician fees)] RT: ■ Planning ■ Treatment ■ Simulation ■ Procedure	Not available	2003 Medicare reimbursements: ■ Immobilization device ■ Beam-modifying device ■ Port films	2003 US dollars RT only: $8117 per treatment RT hormones: $11,219 per treatment
Konski *et al.*, 2006[17]	Medicare reimbursement ■ Consultation	Not available	Medicare reimbursement IMRT and 3D-CRT: ■ Planning ■ Simulation ■ Treatment	Not available	Medicare reimbursement ■ Port films ■ Devices	Using 2004 Medicare conversion factor Treatment costs— IMRT: $38,000 per treatment 3D-CRT: $9,900 per treatment Hospital-based Medicare reimbursement— IMRT: $27,000 per treatment 3D-CRT: $12,800 per treatment
Konski *et al.*, 2007[18]	2005 resource-based relative value conversion factor ■ Physician	Not available	Assumed treatment[b] Ambulatory payment classification payment rates (2005)	Ambulatory payment classification payment rates (2005) for technical (hospital) component of the treatment	Not available	2005 US dollars IMRT: $25,846 Proton-beam therapy: $58,610 per treatment

TABLE II Continued

Reference and disease site	Professional fees	Equipment	Treatment and planning	Facility and institutional	Other[a]	RT cost details
Prostate cancer						
Perlroth *et al.*, 2010[31]	Ingenix (private insurance database) ■ Physician costs	Not available	Assumed treatment[b]	Not available	Ingenix (private insurance database) ■ Prescription drug costs ■ Ancillary costs (lab and diagnostic testing) ■ Inpatient or outpatient hospitalization	2-Year unadjusted mean health expenditures (2004 US dollars) Brachytherapy: $67,700 per treatment EBRT: $77,500 per treatment IMRT: $96,300 per treatment
Hodges *et al.*, 2012[10]	University of Texas Southwestern Medical Center data and CPT codes ■ Physician ■ Physicist	Not available	University of Texas Southwestern Medical Center data and CPT codes IMRT: ■ Planning ■ Simulation ■ Treatment ■ Procedure SBRT costs: University of Texas Southwestern Medical Center data (assume same treatment and planning as for IMRT)	Not available	University of Texas Southwestern Medical Center data and CPT codes ■ Immobilization device ■ Beam-modifying device ■ Port films	2010 US dollars SBRT: $14,315 per treatment IMRT: $29,530 per treatment
Perlroth *et al.*, 2012[32]	Ingenix (private insurance database) ■ Physician costs	Not available	Assumed treatment[b]	Not available	Ingenix ■ Prescription drug costs ■ Ancillary costs (lab and diagnostic testing) ■ Inpatient/outpatient hospitalization	US dollars Brachytherapy: $28,600 per treatment EBRT: $18,900 per treatment IMRT: $48,550 per treatment [costs based on first year and assuming base case (conservative management) is $0]

TABLE II Continued

Reference and disease site	Professional fees	Equipment	Treatment and planning	Facility and institutional	Other[a]	RT cost details
Prostate cancer						
Shah *et al.*, 2012[24]	2010 Medicare CPT codes using the hospital-based 2010 Medicare Ambulatory Payment Classification					2010 US dollar Medicare reimbursement: Total institutional cost plus reimbursement (facility + professional) LDR brachytherapy: $2,395+$9,938= $10,582 per treatment HDR brachytherapy: $5,467+$17,514= $21,951 per treatment IMRT: $23,665+29,356= $52,635 per treatment
	Physician fee screen reimbursement rates, staffing requirements, service contracts	Equipment requirements	Treatment	Space required to deliver treatment	Technical services	
Yong *et al.*, 2012[34]	Personnel: radiation oncologist, radiation therapist, physicist and nurse (activity-based costing via expert opinion)	Equipment (CCO Capital Planning Dept., PMH, CVH): ■ Capital cost ■ Specialized construction cost ■ Maintenance and operating	IMRT and 3D-CRT (based on CVH) ■ CT simulation ■ Dosimetry ■ Planning ■ Treatment preparation and delivery ■ Physics quality assurance ■ Linear accelerator	Assumed centre with 3 linear accelerators, performing 1260 cases per year	PMH and CVH: ■ Supplies such as immobilizer and gold seeds ■ Overhead such as department and hospital	2009 Canadian dollar IMRT: $14,520 per treatment 3D-CRT: $13,501 per treatment
Eldefrawy *et al.*, 2013[7]	2010 Medicare reimbursement EBRT: ■ Medical physicist ■ Radiation oncologist Brachytherapy: ■ Medical physicist ■ Radiation oncologist ■ Anesthesiologist	Not available	2010 mean inpatient cost at institution EBRT: ■ Simulation ■ Planning ■ IMRT ■ Procedure Brachytherapy: ■ Simulation ■ Planning ■ Treatment ■ Dosing	2010 mean inpatient cost at institution Brachytherapy: ■ Inpatient facility	2010 mean inpatient cost at institution	2010 US dollars EBRT: $20,730 per treatment Brachytherapy: $14,061 per treatment

TABLE II Continued

Reference and disease site	Professional fees	Equipment	Treatment and planning	Facility and institutional	Other[a]	RT cost details
Prostate cancer						
Hayes *et al.*, 2013[9]	Centers for Medicare and Medicaid Services, CPT codes, and ASA units ■ Physician fees	Not available	Centers for Medicare and Medicaid Services, CPT codes, and ASA units ■ Procedure	Not available	Centers for Medicare and Medicaid Services, CPT codes, and ASA units ■ Inpatient and outpatient direct/indirect costs	2012 US dollars 65-Year-old patients— Brachytherapy: $35,374 per treatment IMRT: $48,699 per treatment 75-Year-old patients— Brachytherapy: $28,810 per treatment IMRT: $42,286 per treatment
Yu *et al.*, 2013[29]	Physician claims (Medicare)	Not available	PRT and IMRT (Medicare): ■ Outpatient treatment planning ■ Management and delivery 3 months after radiation initiation	Not available	Not available	2008/2009 US costs Proton RT: $32,428 per treatment IMRT: $18,575 per treatment
Sher *et al.*, 2014[27]	Physician visit, physics consult (Medicare)	Not available	For all modalities (Medicare): ■ Simulation ■ Planning ■ Treatment ■ Dosing	Not available	Medicare ■ Treatment devices ■ Port films ■ CT radiation guidance	2012 US costs IMRT: $27,564 per treatment Non-robotic SBRT: $10,109 per treatment Robotic SBRT: $19,275 per treatment
Breast cancer						
Smith *et al.*, 2011[28]	Physician (Medicare)	Not available	Outpatient treatment (Medicare)	Not available	Not available	Mean total costs in 2005 US dollars Non-IMRT: $7,179 per treatment IMRT: $15,230 per treatment
Greenup *et al.*, 2012[8]	2011 Medicare CPT codes ■ Consultations	Not available	2011 Medicare CPT codes APBI, C-RT, WBRT: ■ Simulation ■ Planning ■ Treatment ■ Dosing ■ Procedure	Not available	2011 Medicare CPT codes ■ Immobilization devices ■ Port verification films	2011 US dollars APBI: $5,342 per treatment C-RT: $9,122 per treatment WBRT: $13,358 per treatment

TABLE II Continued

Reference and disease site	Professional fees	Equipment	Treatment and planning	Facility and institutional	Other[a]	RT cost details
Breast cancer						
Lanni *et al.*, 2013[19]	HOPPS 2011 Medicare and Physician Fee Schedule reimbursement rates for professional components ■ Physicist ■ Physician	Not available	HOPPS 2011 Medicare and Physician Fee Schedule reimbursement rates for technical ■ Planning ■ Dosimetry ■ Simulation ■ Treatment	Not available	Medicare reimbursement ■ Port films ■ Devices	Expected 2011 Medicare reimbursement Whole-breast: $11,725 per treatment Whole-breast IMRT: $20,637 per treatment Whole-breast RT-B: $13,829 per treatment Whole-breast RT-B IMRT: $22,130 per treatment CDN 3D-CRT: $7,826 per treatment CDN IMRT: $13,656 per treatment APBI 3D-CRT: $6,578 per treatment APBI IMRT: $10,547 per treatment APBI-IC single: $12,602 per treatment APBI-IC multiple: $13,506 per treatment
Shah *et al.*, 2013[25]	Physics consult and professional reimbursements (Medicare)	Not available	For all RT modalities (Medicare): ■ Simulation ■ Planning ■ Treatment ■ Dosing	Not available	Medicare: ■ Treatment ■ Devices ■ Port films ■ CT radiation guidance	2011 US costs WBI IMRT: $20,637 per treatment WBI 3D-CRT: $11,726 per treatment APBI IMRT: $10,547 per treatment APBI 3D-CRT: $6,578 per treatment APBI single: $12,602 per treatment APBI multi: $16,438 per treatment APBI interstitial: $11,766 per treatment

TABLE II Continued

Reference and disease site	Professional fees	Equipment	Treatment and planning	Facility and institutional	Other[a]	RT cost details
Breast cancer						
Sen *et al.*, 2014[22]	Physician (Medicare)	Durable medical equipment claims (Medicare)	Treatment (Medicare)	Inpatient plus outpatient facility (Medicare)	Home health, hospice (Medicare)	2012 US costs EBRT: $15,396 per treatment IMRT: $23,605 per treatment Brachytherapy: $23,628 per treatment
Shah *et al.*, 2014[26]	Professional (Medicare)	Not available	Assumed treatment[b] (Medicare)	Facility (Medicare)	Not available	Assume 2010–2012 US costs IORT: $3,094 per treatment Next 6 costs are referenced from Shah *et al.*,[25] WBI 3D-CRT: $11,726 per treatment APBI IMRT: $10,547 per treatment APBI 3D-CRT: $6,578 per treatment APBI single: $12,602 per treatment APBI multi: $16,438 per treatment APBI interstitial: $11,766 per treatment
Non-small-cell lung cancer						
Lanni *et al.*, 2011[20]	Medicare reimbursement ■ Consultation	Not available	Medicare reimbursement ■ Planning ■ Simulation ■ Treatment	Not available	Medicare reimbursement ■ Port films ■ Devices	2010 US dollars Based on average number of fractions Treatment cost— 3D-CRT (35 fractions): $55,705 IMRT (35 fractions): $146,570 SBRT (3 fractions): $48,783

TABLE II Continued

Reference and disease site	Professional fees	Equipment	Treatment and planning	Facility and institutional	Other[a]	RT cost details
Non-small-cell lung cancer						
Lanni *et al.*, 2011[20] (continued)						2010 Hospital-based Medicare reimbursement 3D-CRT (35 fractions): $13,639 IMRT (35 fractions): $22,747 SBRT (3 fractions): $9,645
Ramaekers *et al.*, 2013[39]	Not available	Not available	Treatment costs for CRT, VART, MART, HRT-I, and HRT-H: Statistics Netherlands	Not available	Toxicity costs (includes hospital admission and medications): Manual for Costing Research, Statistics Netherlands, Dutch Healthcare Authority, Health Care Insurance Board, literature and market price Cancer and non-cancer mortality costs: Council for Public Health and Health Care Health state costs: Statistics Netherlands, Manual for Costing Research	2011 price level, based on price indices from Statistics Netherlands Number of fractions from meta-analysis CRT: €6,940 per treatment VART: €8,290 per treatment MART: €8,940 per treatment HRT-I: €8,940 per treatment HRT-H: €12,237 per treatment
Shah *et al.*, 2013[23]	Physician planning and management, physics planning (Medicare physician fees)	Not available	SBRT (Medicare outpatient payments): ■ Simulation ■ Planning ■ Treatment	Not available	Not available	2012 US costs SBRT: $14,821 per treatment
Mitera *et al.*, 2014[37]	Physician billing codes from Ontario Schedule of Benefits for Physician Services Direct labour costs determined using Ontario standardized staffing model for radiotherapy (1 radiation oncologist, 1 nurse, 1 physicist, 7 radiation therapists)	2010 provincial costs ■ CT scanner ■ Planning system	Assumed treatment[b]	OCCI hospitalization cost	Manufacturer ■ Carbon fibre lung board 2010 provincial costs ■ Abdominal compression board CRT and SBRT (2010 provincial costs): ■ LINAC plus multileaf collimator	2010 CAD CRT: $6886 per treatment SBRT: $8042 per treatment

TABLE II Continued

Reference and disease site	Professional fees	Equipment	Treatment and planning	Facility and institutional	Other[a]	RT cost details
Head-and-neck cancer						
Kohler *et al.*, 2013[14]	2012 Medicare reimbursement payments ■ Nurse ■ MD	Not available	2012 Medicare reimbursement payments IMRT: ■ Simulation ■ Planning ■ Treatment 3D-CRT: ■ Simulation ■ Planning ■ Treatment	Not available	2012 Medicare reimbursement payments ■ Port film ■ Casting-tape head ■ Multileaf collimator	2012 US dollars IMRT: $20,606 per treatment 3D-CRT: $11,336 per treatment
Ramaekers *et al.*, 2013[38]	Dutch Manual for Costing Research and Dutch list of tariffs ■ Examination and consultation by speech therapist, radiotherapist, and dentist	Not available	IMRT treatment: Dutch Manual for Costing Research	Not available	Market price, Dutch Manual for Costing Research, and Dutch list of tariffs: medications, fillings, crowns, dentures, root canal, dental implant, dental plate Salvage therapy (based on literature) Cost of cancer and non-cancer mortality: Council for Public Health and Health Care	Not available
Sheets *et al.*, 2014[33]	Professional [University of North Carolina (UNC) hospital billing]	Not available	Assumed treatment[b] (UNC hospital billing)	Inpatient, outpatient (UNC hospital billing)	Not available	1999–2009 hospital billing charges for the on-treatment phase IMRT: $29,659 per treatment CRT: $23,083 per treatment
Cervical cancer						
Lesnock *et al.*, 2013[21]	Medicare CPT codes maintained by AMA ■ Provider costs	Not available	Medicare CPT codes maintained by AMA Radiation planning and delivery of treatment	Not available	Not available	2009 US dollars BOX RT: Planning—$564.69 ($282 to $847)

TABLE II Continued

Reference and disease site	Professional fees	Equipment	Treatment and planning	Facility and institutional	Other[a]	RT cost details
Cervical cancer						
Lesnock *et al.*, 2013[21] (continued)						Treatment— $262.30 per treatment ($131 to $393) × 28 treatments IMRT: Planning—$2088.19 ($1044 to $3132) Treatment— $519.84 per treatment ($260 to $780)
Kim *et al.*, 2015[13]	CPT codes for 2013 Medicare reimbursement accounted for professional (physician) fees ■ Physicist ■ Physician	Not available	CPT codes for 2013 Medicare reimbursement accounted for technical (hospital) Brachytherapy: ■ Simulation ■ Planning ■ Treatment	Not available	Not available	2013 US dollars IG brachytherapy: $21,374 or $22,847 per 5 fractions (CT or MRI plan, respectively) 2D brachytherapy: $17,177 per 5 fractions
Others						
Furlan *et al.*, 2012[36] (neoplastic metastatic epidural spinal cord compression)	OHIP ■ Physician fees for direct decompression surgery (surgeon, anesthesiologist, surgical assistant) ■ Physician fees for inpatient RT (radiation oncologist)	Not available	Assumed treatment[b] from OCCI	OCCI ■ Inpatient palliative care ■ Hospital admission ■ Fixed hospital costs	Not available	2010 US dollars Surgery + RT: $13,995 per treatment RT only: $2,440 per treatment
Hess *et al.*, 2012[30] (bone metastases secondary to breast or prostate cancer)	■ Medical physicist (claims-linked EMR CPT codes) ■ Medical radiation physicist ■ Physician	Not available	Claims-linked EMR CPT codes ■ Simulation ■ Dosing	Not available	Claims-linked EMR CPT codes ■ Treatment devices	2008–2009 US dollars Medicare reimbursement Breast cancer: $7457 Prostate cancer: $7553 per REOC

TABLE II Continued

Reference and disease site	Professional fees	Equipment	Treatment and planning	Facility and institutional	Other[a]	RT cost details
Others						
Yong *et al.*, 2012[35] (oropharyngeal cancer)	Personnel: radiation oncologist, radiation therapist, physicist and nurse (activity-based costing via expert opinion)	Equipment (CCO Capital Planning Dept., PMH, CVH): ■ Capital cost ■ Specialized construction cost ■ Maintenance and operating	IMRT and 3D-CRT (based on CVH): ■ CT simulation ■ Dosimetry ■ Planning ■ Treatment preparation and delivery ■ Physics quality assurance ■ Linear accelerator	Assumed centre with 3 linear accelerators, performing 1260 cases per year	PMH and CVH ■ Supplies such as immobilizer and gold seeds ■ Overhead such as department and hospital	2009 Canadian dollars IMRT: $16,085 per treatment 3D-CRT: $13,638 per treatment
Hodges et al., 2014[11] (squamous cell cancer of the anus)	Local Coverage Determination of 2014 Medicare (CPT codes) ■ Physicist ■ Physician	Not available	Local Coverage Determination of 2014 Medicare (CPT codes) 3D-CRT and IMRT: ■ Simulation ■ Planning ■ Treatment ■ Procedure	Not available	Local Coverage Determination of 2014 Medicare (CPT codes) 3D-CRT and IMRT: ■ Complex treatment device ■ Multileaf collimator ■ Port films	2014 US dollars IMRT: $17,671 per treatment 3D-CRT: $11,835 per treatment
Kim *et al.*, 2015[12] (painful vertebral bone metastases)	CPT codes for 2014 Medicare reimbursement Billing accounted for professional (physician) fees	Not available	EBRT and SBRT: ■ Planning ■ Simulation ■ Treatment	Not available	CPT codes for 2014 Medicare reimbursement Billing accounted for technical (hospital) EBRT and SBRT: ■ Treatment device	2014 US dollars SBRT: $9000 per fraction EBRT: $1087 per fraction

[a] Refers to overhead costs, administrative costs, and so on.
[b] Study lacked sufficient detail to determine what constituted the cost of radiation treatment; the assumption was therefore that authors costed for treatment and planning (that being one of the main objectives of the paper).

IMRT = intensity-modulated RT; 3D-CRT = 3-dimensional conformational RT; EBRT = external-beam RT; SBRT = stereotactic body RT; OHIP = Ontario Health Insurance Plan; OCCI = Ontario Case Costing Initiative; CPT = Current Procedural Terminology; APBI = external-beam partial-breast irradiation; C-RT = Canadian RT fractionation; WBRT = whole-breast RT; EMR = electronic medical record; REOC = radiation episode of care; LDR = low-dose-rate; HDR = high-dose-rate; CCO = Cancer Care Ontario; PMH = Princess Margaret Hospital; CVH = Credit Valley Hospital; ASA = American Standards Association; HOPPS = Hospital Outpatient Prospective Payment System; RT-B = RT with boost; CDN = Canadian fractionation schedule; IC = intracavitary; AMA = American Medical Association; BOX RT = 4-field box RT; CRT = conventionally fractionated RT; VART = very accelerated RT; MART = moderately accelerated RT; HRT-I = hypofractionated RT identical (dose); HRT-H = hypofractionated RT higher (dose); WBI = whole-breast irradiation; CT = computed tomography; IORT = intraoperative RT; IGBT=image-guided; MRI = magnetic resonance imaging.

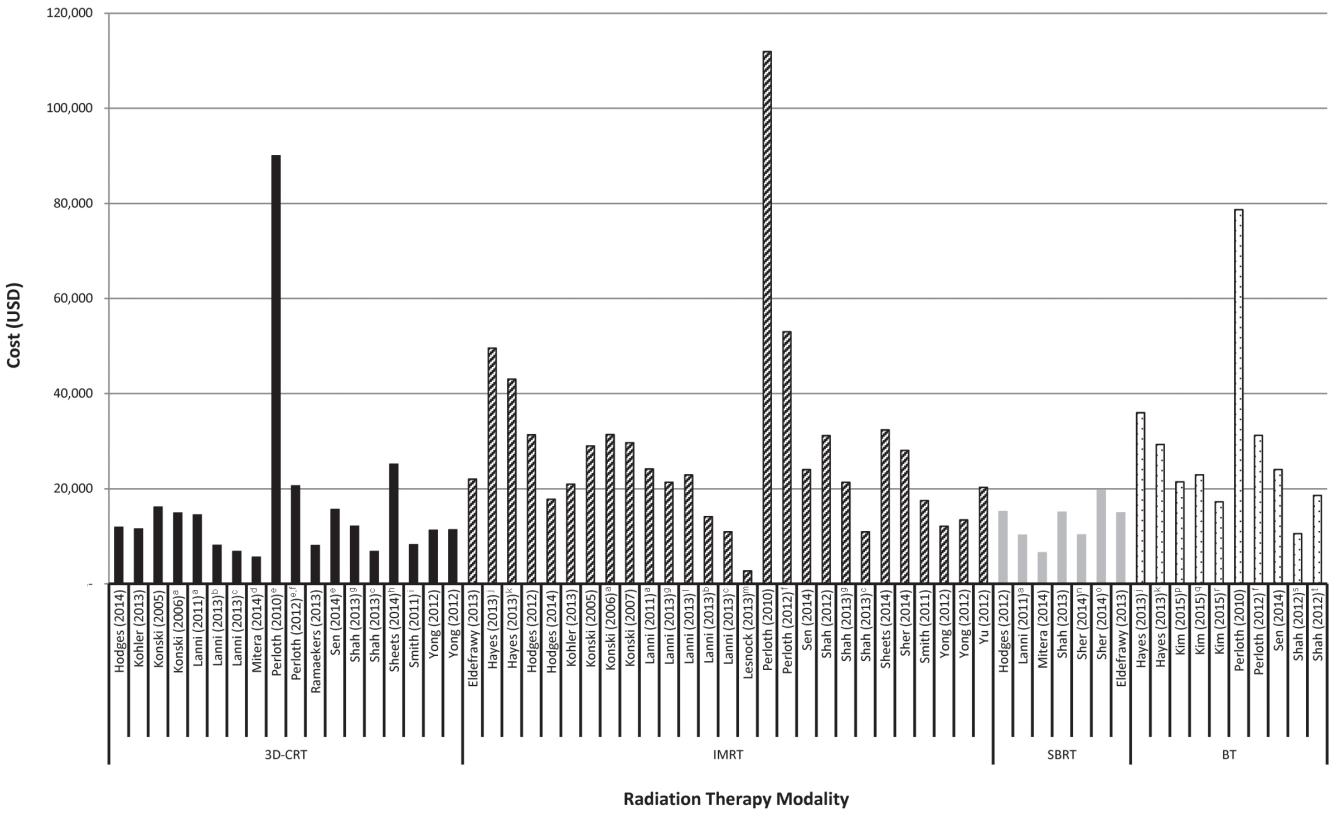

FIGURE 2 Per-treatment costs of radiation therapy (RT) modalities across studies, 2014 U.S. dollars. [a]Hospital-based Medicare reimbursement. [b]Canadian fractionation. [c]Accelerated partial-breast irradiation. [d]Conventionally fractionated RT. [e]External-beam RT. [f]Costs based on first year and assuming base case (conservative management) is $0. [g]Whole-breast irradiation. [h]Conventional RT. [i]Non-intensity-modulated RT. [j]65-Year-old patients. [k]75-Year-old patients. [l]Whole breast with boost. [m]Sum of average planning $2088.19 and average treatment $519.84. [n]Non-robotic. [o]Robotic. [p]Computed tomography plan. [q]Magnetic resonance imaging plan. [r]2-Dimensional. [s]Low dose. [t]High dose. 3D-CRT = 3-dimensional conformal RT; IMRT = intensity-modulated RT; SBRT = stereotactic body RT; BT = brachytherapy.

various treatment-related morbidities; however, neither study performed a thorough investigation of differences in costing components and sources in RT.

To our knowledge, the present study is the first to review RT costing components and sources across all cancer types. It shows that most costing was based on inputs into hypothetical models from pre-existing original costing studies. Original data would allow for a more accurate representation of cost outcomes based on the cohort of interest and the cancer type, which might otherwise be subject to unreliable statistics when model inputs are used. Such inputs might differ based on institution, geography, and adopted care or clinical pathways, and thus original patient-level data would provide the most unbiased costing results.

In addition, although some societal costing was found, most studies were conducted from the health system perspective. The most consistent variables used in the costing analyses were the costs associated with treatment and planning, followed by professional or personnel and other fees. Costing studies rarely considered the costs of equipment and facility or institutional fees. Such omissions caused the final cost of RT treatment to appear inconsistent across studies, with large variability in costs being observed within and between RT modalities. The cost drivers therefore included the costs of the various personnel required during the course of RT and the actual costs of the delivery and planning of RT.

Notably, RT often requires the delivery of services by a variety of personnel (the physician, radiation therapist, medical oncologist, nurse, etc.) that were more often reflected in the Canadian than in the Dutch and U.S. studies. In addition, although all studies included treatment and planning costs, many did not identify the components that fell within the treatment and planning phase of RT; the reader is therefore unable to identify what the costs truly encompass. Both of the foregoing costing components are cost drivers in the overall cost of RT and thus should be considered for inclusion in future RT costing studies.

All in all, the inconsistencies identified here can lead to the drawing of incorrect and inappropriate conclusions about the cost of RT when the largest variability in costs can be attributed to the differences in RT components between studies. Our study's Figure 2 provides evidence of the wide variability in costs between studies, which might become more comparable if RT costing components were to be more inclusive, complete, and consistent from study to study.

We recommend that RT costing studies aim to be as inclusive as possible in their costing methods. At a minimum, components should include detailed treatment costs, capital costs, operational costs (that is, equipment and overhead), detailed personnel costs, institutional or facility costs, and other costs (administration, etc.). To promote comparability between studies and an understanding of the cost drivers of RT, costing studies should be as transparent and comprehensive as possible.

Our study uncovered vast differences in RT costing components across studies, which draws attention to the fact that RT costing studies have room to improve and to be more inclusive in their costing components and methods. The limitations discussed and the variation in costing components between studies creates difficulty in comparing, contrasting, and understanding the true costs associated with RT. Even within countries, the heterogeneity between studies using the same health care perspective does not allow for ease of interpretation and application, oftentimes involving underestimations and overestimations in costs. Future research requires a more comprehensive costing analysis that encompasses as many elements of RT costing as possible for thorough inclusion and standardization. Such inclusivity will allow for efficient comparisons and informed evidence-based public health changes. More comprehensive costing is important for producing the good inputs required for policy decision-making and economic analyses.

CONCLUSIONS

The literature review presented here demonstrates that RT costing is diverse and complex between studies and especially between countries, which results in differing costing units and wide ranges in RT costs. The summarized findings provide insight into the costing frameworks and methods used by such studies and the accuracy and usefulness of those methods of RT costing. Based on the perspective used, the data available, the components used, and the aims of the study, RT can be costed in a variety of ways. Such variation makes understanding the true cost of RT at a per-patient or per-visit level quite difficult. Future research has to focus on using patient-level data and including as many of the cost drivers of RT as possible to arrive at a true cost. Given the increasing cost of health care delivery, it is necessary to understand the current financial burden and to pinpoint areas that require improvement to prevent negative effects on health care delivery and to support good management of the health care system.

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CONFLICT OF INTEREST DISCLOSURES

We have read and understood *Current Oncology*'s policy on disclosing conflicts of interest, and we declare that we have none.

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