The changing costs of radiation treatment for early prostate cancer in Ontario: a comparison between conventional and conformal external beam radiotherapy

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Purpose: *Prostate cancer represents a large part of the workload for radiation oncology departments in Canada. Recent evidence suggests that conformal external beam radiotherapy improves results. The planning and treatment process for conformal patients requires a greater amount of resources that are in short supply in Ontario. An understanding of these differences is important to provide an accurate estimate of future radiation needs of the province. These differences can be quantified in a cost model that portrays the direct costs of delivering external beam radiotherapy in Ontario. With a developed cost model, a prospective direct cost comparison between standard four field external beam radiotherapy versus conformal radiotherapy in early stage prostate carcinoma was designed.*
Methods: *Activity based costing has been used to create a model of radiotherapy related costs for prostate cancer. A process map was developed which separated the process in five activities for conventional radiotherapy and six activities for dose escalated conformal radiotherapy. Time was recognized as the important cost driver within each activity. The time required for pre-treatment preparation (CT planning, dosimetry, simulation, and other preparatory work) and actual treatment times were collected prospectively. Treatment times were collected in 414 patients. The annual costs of capital equipment purchase costs and specialized construction of hospital space for radiotherapy equipment were amortized using a 6% discount rate plus the cost of annual maintenance. Indirect costs were not included in this cost analysis.*
Results: *An activity based costing model using time as the primary cost driver reflects the additional costs of conformal over conventional external beam radiotherapy. The costs of single phase and double phase six field conformal therapy with 42 fractions delivered was $7867 and $8227 per patient. Four field single phase conformal therapy with 28 fractions costs $5723. The cost of conventional radiotherapy over 33 fractions was $3068. The majority of the cost differences arose from the cost of the additional time needed for treatment per day as well as the extra fractions per patient when compared to conventionally treated patients. The average treatment times per fraction for six field conformal, four field conformal and four field conventional have the median times of 22.72, 20.63 and 11.07 minutes respectively. Planning costs for conformal radiotherapy were up to three times the cost of conventional therapy.*
Conclusions: *The direct costs of dose escalated conformal external beam radiotherapy are over 2.5 times that of conventional external beam radiotherapy for early stage prostate cancer. These direct costs are a reflection of the additional capital and human resources needed to provide state-of-the-art radiation therapy in the province of Ontario. Planning for radiation oncology needs should consider the additional costs of conformal external beam radiotherapy.*

Key Words: cost analysis, prostate cancer, conformal radiotherapy

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Introduction

Radiation oncology departments in Ontario have been troubled with long patient waiting lists for radiation treatment.[1] In a specialty that requires large pieces of

treatment equipment that are both expensive and have lengthy installation procedures, the clinical availability today is predicated on earlier estimates of future radiotherapy demands. The estimation of provincial radiotherapy demands is difficult because considerations include many social, demographic and clinical factors[1] such as approximations of cancer incidence, indications for radiotherapy in cancer patients and the number of fractions per treatment for a range of clinical scenarios. An additional variable should be considered – the emergence of conformal external beam radiotherapy that is the new standard of care in radiation oncology.

Conformal radiation therapy brings a new level of accuracy and sophistication to radiation treatments. Computed Tomography (CT) based radiation planning systems allows for precise axial delineation of tumor volumes and the surrounding sensitive structures, accurate dose calculations and the creation of complex multi-beam plans to conform the high dose to the treatment volume. The translation of this planning precision to the linear accelerator requires additional quality assurance measures of varying degree depending on the institution. At Princess Margaret Hospital (PMH), immobilization devices[2] and daily portal imaging are used to minimize organ motion and set-up errors. As well, conformal therapy allows for dose escalation that increases the number of fractions per treatment course. A failure to consider these factors may contribute to inadequate resource allocation.

Early stage prostate cancer is a very common diagnosis in today's population and represents approximately a quarter of all patients treated in radiotherapy departments. Although the relative value of the different modalities of curative treatment for prostate cancer continue to be debated, many studies[3-5] show the benefit of dose escalated conformal radiotherapy.

Conformal techniques clearly require extra resources beyond conventional radiotherapy, but the extent of which is not well known. An understanding of the relative and/or absolute differences between conventional and conformal radiotherapy costs is necessary to aid government-directed radiotherapy planning. Previous Canadian cost analyses did not have to consider conformal therapy because it is a relatively new phenomenon.[6-8] American studies may not be relevant because of the inherent differences in health delivery structure.[9,10] However, Kobeissi et al[11] performed a cost analysis using activity based costing methods and calculated the cost of delivering radiotherapy by dividing radiation treatments into low, intermediate and high difficulty. Activity based costing (ABC) is a commonly utilized method for managerial decision-making. Large multinational corporations now use ABC for decision-making purposes because traditional based accounting methods inappropriately allocate overhead costs as a result of a fundamental failure to understand the basis of the costs drivers needed to deliver a product.[12] ABC is ideally suited to capture these cost differences. Traditional accounting methods allocate costs without tracing them to the specific product/customer. Traditional cost accounting systems were designed for a prior era when direct labor and materials were the predominant factors of production and were fairly accurate when overhead activity was consumed in relation to production volume. Estimated costs become inaccurate when overhead activities that are not related to production volume increase in magnitude. The traditional approach to cost accounting is to break down an enterprise into specialized units with rigid division of responsibility while ABC assigns costs associated with each work unit. Activity based costing methods breaks an organization or a department into activities; an activity describes what an enterprise does, the way time is spent and the outputs of the process.[13]

As an example, the cost of radiotherapy was estimated in a Canadian institution using traditional costing methods that divided the calculated annual cost of a linear accelerator by the number of patients treated per year to create a treatment cost per patient.[6] This methodology is flawed simply because all patients do not receive an equal number of fractions. Available linear accelerator time is finite and one can reason that fractions that require greater time or patients who require a greater number of fractions should cost a greater amount.

We sought to prospectively quantify and compare the costs of escalated conformal dose external beam techniques versus conventional low dose external beam radiotherapy at the PMH. To describe a relatively large and homogenously treated population, we selected early stage non-randomized prostate cancer patients for evaluation that were treated with either conventional four field external beam radiation or conformal six field/four field external beam radiation.

Materials and methods

Treatment protocol

During the period of September 1997- September 1999, the conventional dose treatment is 6600 cGy in 33 fractions in 6.6 weeks using a four field pelvic box

without pelvic immobilization. Planning was done with a CT based plan with two lateral fields and an anterior and posterior field. Portal films were done on the 1st day of treatment and only repeated if clinically indicated. Conformal patients were irradiated to definitive radiotherapy to a dose of 7560 cGy in 42 fractions over 8.4 weeks with a six-field technique. Other patients were treated with 5400 cGy in 28 fractions in 5.6 weeks (as part of a neoadjuvant hormones and RT protocol) using four oblique fields. Prior to the start of radiotherapy, conformal patients will have three small gold seeds inserted into the prostate. These seeds are visualized with portal films to allow for adjustments in field positioning.[14] Individual pelvic immobilization was used for all conformal patients. Six field conformal patients were planned initially with two phases with an initial larger margin around the target volume. The planning was later simplified to a single phase. All four field conformal patients were planned only with a single phase. Daily portal images were performed for set-up verification with small set-up deviations corrected autonomously by therapists. Portal films were also taken every 2 days initially to evaluate prostate motion because the marker seeds could not be visualized on electronic portal images. This policy was revised July 2 1999 on one of two linear accelerators to weekly portal films. More recently, portal films have been discontinued entirely with the use of high-resolution portal images that are performed daily. Four hundred fourteen consecutive prostate carcinoma patients were evaluated. A total of 260, 13 and 141 patients with conventional four field, four field conformal and six field conformal treatments times respectively were available.

Statistics

The mean of the pre-treatment preparation times was used for the cost calculations. A mixed linear model was fitted to the treatment times data. The dependent variable (time required for each fraction) was – log transformed in order to normalize the data. There were two variables of interest, the number of the fraction (ie.1st 2nd 3rd fraction etc.) and the type of treatment (6 field conformal versus 4 field conformal versus 4 field conventional). The mean treatment time was used to calculate the treatment costs.

Costs

Only the direct costs were considered in this study. A direct cost is a cost item that can be identified specifically to a product in an economically feasible manner. As such, all costs not directly associated to the delivery of radiotherapy to these two groups of patients and/or not believed to be significantly different between the study groups were not included such as nursing, social work, nutrition, administrative support, general maintenance of the hospital and research activities. No pre-radiotherapy costs of consultation or tests were included nor were professional (MD) fees. The current purchase price for any operating costs was used. Capital costs were based on Cancer Care Ontario (CCO) estimates of the acquisition of equipment at the completion of this study. The cost of film and film developed was calculated previously.[15] Salaries for physicists and radiation therapists were based on current wages in 1999 at PMH.

Calculation of annual costs of capital equipment

The cost of acquisition and specialized construction for radiotherapy equipment is a one-time cost that is listed in Table 1. Included are the expected lifetimes of equipment based on Cancer Care Ontario (CCO) estimates. An annual cost for each piece of equipment can then be calculated using an amortization rate of 6%, the one-time costs of specialized construction and acquisition and the estimates of expected lifetimes of the equipment

TABLE 1. **Capital equipment costs**

Capital Equipment	Specialized Construction costs	Acquisition Costs	Maintenance Costs	Estimated Lifespan
Linac+MLC	$924 000	$2 500 000	$199 700	10
CT scanner	$308 000	$1 400 000	$90 000	10
Oldelift simulator	$308 000	$900 000	$20 000	10
Planning system	0	$299 970*	$140 000	5

*Reflects an estimation of the cost of a portion of a planning system required to support only two linear accelerators

TABLE 2. **Cost of use of equipment/time**

Capital Equipment	Annual Construction Costs	Annual Acquisition Costs	Annual Maintenance Costs*	Total Annual Cost	Total Cost ($/min)**
CT planner	$27 603.27	$205 830.90	$90 000	$323 434.17	$5.78
Planning system	0	$86 568.93	$140 000	$226 568.93	$2.76
Simulator	$45 282.80	$132 319.90	$20 000	$197 602.70	$1.69
Linac	$109 329.10	$367 555.20	$199 700	$676 584.30	$1.93

*Estimation of salary and equipment of physics and technical support
**Total cost includes radiotherapists' salary

Table 2. The CCO guidelines for available worktime per year is 250 days/year, with 8 hour workdays. Assuming full utilization of equipment, an average cost per minute use of capital equipment can be calculated to appropriately allocate the cost of capital equipment (which may be shared by different activities) to an activity Table 2.

Cost analysis

Our prospective study reflects only the direct costs. Prostate cancer patients who underwent definitive radiotherapy between February 1997 to September 1999 at the PMH using two linear accelerators with multi-leaf collimator capability were evaluated. The cost of shielding was not calculated because of the multi-leaf collimator capability of the linear accelerators in this study.

A process map Figure 1 was created that outlines the necessary activities required to deliver radiotherapy to a prostate cancer patient. The same five activities are necessary for both conventional and conformal prostate cancer patients that include: CT planning, dosimetry, simulation, set-up work and treatment. Fiducial marker seeds were placed via trans-rectal ultrasound in the conformal patients. Within each activity are multiple steps that comprise each activity. (The creation of a pelvic immobilizer at PMH is done in the CT room during the same appointment just before CT images are acquired.) Within each activity, the operating, capital costs and cost drivers within an activity are documented Figure 2. The time required to complete an activity (cost driver) was collected prospectively from February 1997 to September 1999 in conjunction with the initiation of a conformal high dose program at the PMH. Pre-treatment preparation times were collected manually with a hand-held timer by radiation therapists. All manually recorded times began when a patient entered the room of the simulator, bunker etc and end when the patient exits that room. The treatment times include all time in which the linear accelerator is occupied by that patient (including any set-up/immobilization/ and portal imaging). The treatment times were collected as follows: as one therapist calls the patient from the waiting room, a 2nd therapist records the start of the treatment using the

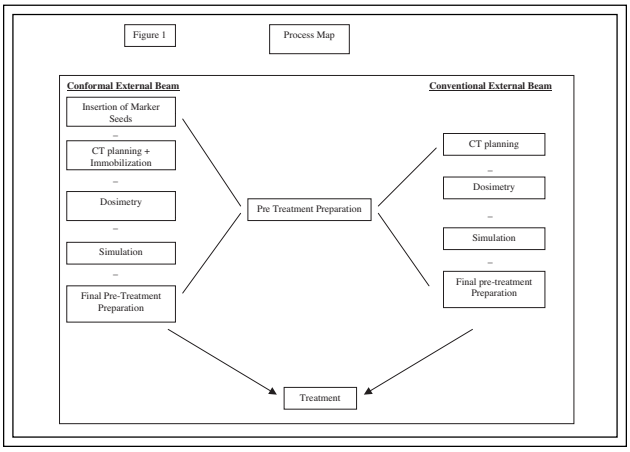

Figure 1. Process map

	Capital cost	Operating cost	Cost Driver: Time	Cost Driver: # of pts		Capital cost	Operating cost	Cost Driver: Time	Cost Driver: # of pts
CT Plan					**Simulation**				
CT scanner	•		1		Simulator	•		1	
Cradle		•	1	2	Film		•		1
Film		•		1	RTT salary		•	1	
Dosimetry					R.O. salary		•		1
Planning sys.	•		1		**Treatment**				
RTT/phys.sal		•	1		Linac	•		1	
R.O. salary		•		1	Film		•		1
Set-up work					RTT salary		•	1	
Linac	•		1		R.O. fee		•		1
RTT salary		•	1						

Figure 2. Direct cost contributors and cost drivers

IMPAC Medical System. At the termination of the last field, the system automatically prompts the therapists to 'capture' the procedure, thus ending the treatment time.

Results

Cost analysis

A process map was devised to separate the process of delivering radiotherapy into two categories with five activities for conventional EBRT and six activities for conformal EBRT Figure 1. The direct cost contributors and their cost drivers for each activity are listed in Figure 2. Indirect costs were not included. Time was the most significant cost driver for all activities. Allocation of the capital costs to each patient's treatment was proportional to the time needed to perform an activity using that piece of equipment.

Pre-treatment preparation

Pre-treatment preparation is comprised of four separate activities for conventional radiotherapy and five activities for conformal radiotherapy. The time to complete the followings tasks, CT ± immobilization, dosimetry, simulation and pre-treatment paperwork was measured manually by radiation therapists. The mean times were used in calculations with a standard deviation calculation Table 3. Insertion of marker seeds for conformal therapy was done outside of the department of radiation oncology and the Ontario Health Insurance Plan (OHIP) fee schedule was used.

Treatment

In total, the daily fractions of 414 consecutively treated prostate patients were evaluated. A total of 260, 13 and 141 patients were available for conventional four field, four field conformal and six field conformal treatments times respectively. Statistical analysis showed significantly shorter treatment times ($p<0.0001$) when four field conventional radiotherapy was compared to either four field conformal or six field conformal radiotherapy. The time for six field conformal radiotherapy was also statistically significantly larger as compared with the four field conformal radiotherapy ($p=0.001$) Figure 3. Treatment times were found to be longest for the first fraction and diminished in length to a plateau time by the 3rd fraction. Based on the fitted model, the decrease in time between the 1st and 2nd fraction is 6, 8 and 5 minutes respectively for the 4-conventional, 4-conformal and 6 conformal, but the differences between the 3rd and 4th fraction within each group were one minute or less. Alternate day portal films were reduced to weekly portal films on Linac #14 only after July 1, 1999. However, an analysis of conformal

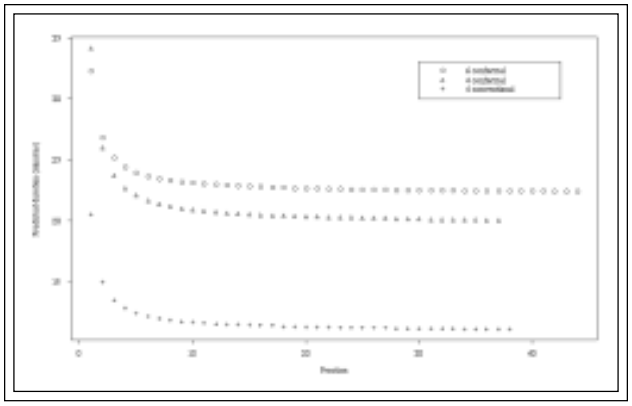

Figure 3. Treatment times for 4 conventional

TABLE 3. **Pre-treatment preparation**

	Conformal treatment Four field single phase Time (minutes)	**n**	**Six field single phase Time (minutes)**	**n**
CT scan+/- Pelvic immobilization	53 ± 16*	34	53 ± 16	27
Dosimetry	157†	25	235†	25
Simulation	34‡	15	34 ± 9	15
Pre-treatment set-up/paperwork	80 ± 57	10	130 ± 29	26

*CT protocol for six (single of double phase) and four field conformal was identical
†Based on all conformal plans performed using an observed average of 39.3 min/field
(includes time needed for beam placement, MLC production, dose calculation, assessment of plan quality, plotting/
‡Estimation of simulation times based on six field conformal times and that the time required for the simulation process

TABLE 4. **Pre-treatment cost and treatment costs/patient**

	Pre-treatment costs	Treatment costs	Cost/fraction	Total cost*
Conventional				
Four field	$646	$2422	$73	$3068†
Conformal				
Single phase, four field	$1210	$4513	$136	$5723‡
Single phase, six field	$1541	$6326	$150	$7867§
Two Phase, six field	$1901	$6326	$150	$8227§

*Operating and capital cost
† 33 fractions delivered
‡ 28 fractions delivered
§ 42 fractions delivered

treatment times before and after July 1 1999 for *both* linear accelerators did show a statistically significant reduction (#14 - p<0.0001, Unit #15 - p=0.006) in treatment length after July . This suggests that treatment efficiencies were developed and learned independent of portal filming. Using the calculated cost/min for each piece of equipment plus the salary of radiation therapists, a cost and time required for all radiotherapy-related pre-treatment preparation work activities and treatment times per fraction were calculated Table 4.

Total treatment costs

The total treatment costs include all direct capital and operating costs. The total average direct costs and its' components are summarized in Table 5. The total costs of four field single phase conventional, four field single phase conformal, six field single phase conformal, 6f two phase conformal treatments are $3068 (33 fr), $5723 (28 fr), $7867 (42 fr) and $8227 (42 fr) in 1999 Canadian dollars respectively. The differences in treatment costs between conventional and conformal patients and different conformal regimens reflect the statistically significant differences in time required per fraction between these regimens as well as the different number of fractions delivered. The costs of treatment were calculated using the average treatment time multiplied by the previously calculated cost of linear accelerator time/minute multiplied by the number of fractions/ patient Table 4. Pre-treatment preparation times vary by a factor of 3 between conventional four field, single phase treatment four field and six field conformal and 6f two phase conformal treatment with a cost ranging between $646 for conventional four field treatment and $1901 for 6f two phase conformal treatment.

Six field single phase Time (minutes)	n	Conventional treatment Four field single phase Time (minutes)
53 ± 16		27 ± 8
352 ± 90	11	50 ± 13
36 ± 10	9	30 ± 14
210 ± 65	16	58 ± 5

write-up,digitization of sim films)
is linearly associated with the number of fields in the plan

Discussion

This cost study compares the direct costs of conformal versus conventional radiotherapy in prostate cancer patients. A cost-effectiveness study of dose escalated conformal beam therapy to reduce both disease failures and associated treatment toxicity has been reported.16 However, the basis of cost-effectiveness studies is efficacy and toxicity rates that can vary significantly (due to patient selection, radiation dose/ techniques, methods of evaluation etc.), thereby leading to dubious conclusions. A review of conformal radiotherapy for early stage prostate cancer17 corroborates the individual study results of decreased toxicity and improved biochemical control and solidifies the view that conformal radiotherapy is the standard of care for early stage prostate cancer. Our study outlines a direct cost model using activity based costing for radiotherapy treatment that reflects the resource burden of external beam conformal

TABLE 5. **Costs divided by activity**

	Conventional four field single phase	Conformal four field field single phase	Conformal six field single phase	Conformal six field double phase
Pre-treatment costs				
Marker seed insertion	N/A	$276	$276	$276
CT scan/immobilization + alpha cradle + films	$292	$299	$299	$299
Simulation + films	$92	$82	$82	$82
Dosimetry	$110	$371	$649	$877
Pre-Treatment Preparation	$152	$182	$235	$367
Total pre-treatment costs	$646	$1210	$1,541	$1,901
Treatment costs	2422 (33 fr)	4513 (28 fr)	6326 (42 fr)	6326 (42 fr)
Total costs	$3068	$5723	$7867	$8227

radiotherapy in prostate cancer. This cost model defines the major cost driver as time in the different activities needed to deliver radiotherapy and for that reason, time is used to allocate expensive capital equipment that represents a large proportion of the cost of delivering radiation treatments. The cost figures are particular to one institution with certain assumptions during that period of time, but this study outlines the simple steps that can be adjusted to fit the specifics of other institutions.

Our results show that the overall direct costs of conformal patients are roughly 2.5 times that of conventional patients. Pre-treatment preparation costs are also up to three times more expensive than those of conventional patients but represent a small absolute increase in comparison to the higher conformal treatment costs Table 5. The majority of the extra cost in conformal patients derives from treatment delivery because the cost of the each radiation fraction includes any time that the treatment machine is occupied by the patient (which includes set-up and quality assurance checks).

Several factors contribute to the greater cost/fraction of the conformal patient. As part of the PMH protocol, conformal patients used pelvic immobilization (that tended to require greater set-up time) and daily portal imaging with isocenter adjustment as needed. The higher treatment costs reflect two inescapable consequences of dose-escalated conformal therapy; immobilization errors/organ motion must be minimized and escalated dose requires a greater number of fractions per course. Dose escalation with standard fractionation beyond 75.6 Gy is being researched and will probably widen the cost differences because of the greater number of fractions and the impetus to minimize set-up uncertainties. The resurgence of interest in hypofractionation for prostate cancer[18] could radically change treatment cost estimates, but this is currently limited to research investigation.

Furthermore, familiarity with the conformal program has reduced treatment times during the course of our study (22 minutes versus 18 minutes) although still significantly greater than conventional treatments (11 minutes) because of the extra quality assurance checks. Perez et al[10] reported a similar average treatment time per fraction for conformal 3D treatment to the treatment times reported in our study for conformal prostate radiotherapy. Since the conclusion of this study, PMH has reduced daily conformal treatment times to approximately 15 minutes. Using an average treatment time of 15 minutes/fraction (as compared to the observed average times of 20.6 minutes for four field conformal and 22.7 minutes for six field conformal), 42 fractions/patient and the average cost of a single phase, six field pre-treatment preparation cost, we calculated a hypothetical treatment cost that is still considerably higher than that of conventional four field treatment, $5700 (42 fractions) and $3068 (33 fractions) respectively. Finally, our analysis also shows a statistically significant difference between four field and six field conformal treatments times that suggests increasing treatment plan complexity is a contributor to treatment times length.

Interest in conformal techniques in many tumor sites is increasing, both as a means to dose escalate and to minimize the radiation toxicity. This study helps to document the additional resources required to treat patients in a conformal manner. Our cost study was limited to a single tumor site in a single institution treated in a homogenous protocol as a means of

accurately first defining important cost aspects of radiotherapy delivery. This cost analysis can be adjusted to consider specific cost situations within other centers and can also be applied to a more general radiotherapy population. These results should help guide appropriate allocation of radiotherapy resources in the future.

Conclusions

Conformal external beam radiotherapy is a new standard of care for many patients receiving definitive radiation doses in prostate cancer. We have developed an activity based cost model that uses time as the primary cost driver in that the time required to complete an activity was used to allocate the costs (acquisition and maintenance) of expensive equipment. One would expect that the cost of conformal radiotherapy versus conventional treatment would be significantly greater because of the extra level of sophistication that requires time-consuming (costly) quality assurance measures. Our study shows that the direct cost of dose escalated conformal external beam radiotherapy for prostate carcinoma is approximately 2.5 times that of conventional radiotherapy, which reflects the extra capital and human resources needed for conformal external beam radiotherapy. Estimations of radiotherapy needs for a population should incorporate these extra resources needed to deliver conformal external beam radiotherapy. □

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