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Original article

Cost evaluation to optimise radiation therapy implementation in different income settings: A time-driven activity-based analysis

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ABSTRACT

Background: With increasing recognition of growing cancer incidence globally, efficient means of expanding radiotherapy capacity is imperative, and understanding the factors impacting human and financial needs is valuable.

Materials and methods: A time-driven activity-based costing analysis was performed, using a base case of 2-machine departments, with defined cost inputs and operating parameters. Four income groups were analysed, ranging from low to high income. Scenario analyses included department size, operating hours, fractionation, treatment complexity, efficiency, and centralised versus decentralised care.

Results: The base case cost/course is US$5,368 in HICs, US$2,028 in LICs; the annual operating cost is US $4,595,000 and US$1,736,000, respectively. Economies of scale show cost/course decreasing with increasing department size, mainly related to the equipment cost and most prominent up to 3 linacs. The cost in HICs is two or three times as high as in U-MICs or LICs, respectively. Decreasing operating hours below 8 h/day has a dramatic impact on the cost/course. IMRT increases the cost/course by 22%. Centralising preparatory activities has a moderate impact on the costs.

Conclusions: The results indicate trends that are useful for optimising local and regional circumstances. This methodology can provide input into a uniform and accepted approach to evaluating the cost of radiotherapy.

Radiation therapy is an essential component for cancer treatment worldwide. Depending on the local incidence rate, between 40 and 60% of all cancer patients need radiotherapy as part of their clinical management [1,2]. The availability of radiotherapy capacity varies enormously around the world, largely related to the gross national income (GNI) as well as the health services infrastructure. The projection of radiotherapy needs has been performed by several groups with the most recent and most comprehensive projections being provided by a Lancet Oncology Commission report [1] that was developed by the Union for International Cancer Control's (UICC) Global Task Force on Radiotherapy for Cancer Control (GTFRCC). This report concluded that "... investment in radiation therapy not only enables the treatment of a large number of cancer cases to save lives; it also brings positive economic benefits."

The data generated in the report were divided into three major components. The first component addressed the *burden and demand*, i.e., the incidence and population mix of cancer by country and the number of radiotherapy fractions, on average, that is required for that country. The second component addressed the *core investments* required, by income group, to treat the number of fractions projected by the first component. The core investments were subdivided into capital investment and professional training according to countries in four income groups as defined by the World Bank using 2015 gross national income (GNI) per capita classifications. High income countries (HIC) have a GNI/capita of ≥US$12,736, upper middle income countries (U-MIC) between US$4,126-US$12,735, lower middle income countries (L-MIC) between US$1,046-US$4,125 and low income countries (LIC) ≤ US$1,045 [3]. Activity-based costing (ABC) calculations (described in more detail later), based on models developed by the International Atomic Energy Agency (IAEA) [4,5] but modified to fit the needs of this analysis, were used to compute the facility and staffing costs. Both present conditions and future needs with projections to 2035 were determined. The third component addressed the *health (survival) and economic benefits* related to investment in radiotherapy. The results indicated that radiation therapy is

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"affordable and feasible, and can be safely and consistently deployed in low-income and middle-income countries." Furthermore, investment in radiotherapy can generate positive economic returns.

In this report, we expand on the cost calculations with a specific analysis of scenarios that can provide optimum benefit for different income settings. The intent is to understand what factors have the greatest influence on the costing of radiation therapy and to analyse the relative impact of various component costs in view of optimising the investments required. The resulting information can be of benefit for anyone involved in planning new radiotherapy facilities, especially in environments where there is a significant shortage of radiotherapy.

Materials and methods

Time-driven activity-based costing model (TD-ABC)

Activity-based costing (ABC) is a costing method originally developed in the 1980s in response to the shortcomings of traditional cost accounting methods in an era of rapidly increasing product complexity, product size and volume diversification. ABC calculates the cost of a "product", for example a course of intensity-modulated radiotherapy (IMRT), as the summated cost of the care process activities (such as treatment planning, delivery verification or dose delivery) and related resources involved in generating that product [6,7]. Time-driven ABC (TD-ABC) further evolved from these ABC principles in the sense that time is used as the unique cost driver. As such, for each resource group (e.g., radiation therapists, RTTs), estimates are required regarding the cost per time unit of supplying resource capacity (e.g., cost per minute of RTT time) and the time that these resources are committed to specific activities (e.g., minutes of RTT time needed to deliver one radiotherapy fraction). This optimised activity-based approach allows for higher flexibility and is less complex to maintain than the original ABC methodology [8].

The practical scheme that underlies a given TD-ABC model, i.e., the constituting components (costs, process activities and products), is unique for each specific situation [6]. This cost-accounting model was developed for the GTFRCC project, with the aim of defining resource needs and estimating the cost of radiotherapy fractions and courses, in terms of capital investment and of operation, across different GNI settings. It was developed starting from two former IAEA activity-based models: a costing model initially developed to support member states in setting up or expanding radiotherapy capacity [4] and a staffing estimator, developed to assess human resource needs for different infrastructural and treatment complexity scenarios [5]. Expanding on this expertise, the actual model allows the testing of cost implications of various input scenarios based on regional radiotherapy needs, infrastructural capabilities, operational models, expected level of complexity and economic determinants.

Base case model input parameters

In the base case scenario, the number of courses delivered per year is modelled towards a 100% utilisation of the linear accelerators (linacs), in existing departments operating two multi-energy linacs in HICs and LMICs. The other resources (full time equivalents (FTE) of personnel and equipment other than linacs) are scaled linearly as a function of the needs, in line with the defined activity times and complexity estimates. The resource costs, operational parameters, activity times and complexity and fractionation estimates, are shown in Table 1. All data apply for HICs and LMICs, except for the costs and products data, where only the extremes of HICs and LICs are presented. A short description follows.

Resources

Human resources consist of radiation oncologists, medical physicists, radiation therapists (RTTs), dosimetrists, nurses as well as information-technology, mechanical and electrical engineering support. For each of these, full training costs and monthly salaries are defined in US dollars (US$) and obtained by the GTFRCC through questionnaires using a Delphi process and public databases (e.g., International Labour Organization at www.ilo.org). Operational parameters include percentage of time devoted to activities performed by radiotherapy personnel, yet not directed to the radiotherapy care pathway as such (e.g., follow-up consultations, indirect patient care, research and development, teaching, continuing education, administration/management, radiation safety), working hours, RTTs per machine and shift, annual leaves. All personnel parameters are the same as those used in the GTFRCC report [1].

Capital resources consist of equipment and buildings. *Equipment* includes multiple-energy linacs, all equipped with an electronic portal imaging device (EPID) and multi-leaf collimators (MLC) and 50% with on-board imaging using cone-beam CT (OBI-CBCT). All departments are assumed to have a CT simulator, a treatment planning system (TPS) capable of performing 3D-conformal treatments (3D CRT) and IMRT, a record and verify/oncology management system (R&V-OMS), a high-dose rate (HDR) brachytherapy (BT) afterloader and a BT TPS. Purchase prices, in US$, are considered the same for all income levels and are the same as those used in the GTFRCC report [1]. Service contracts and amortisation are included in the calculations, with the latter assuming the time-period over which the equipment is replaced, i.e., 12 years, or 5 years for computer-related equipment. Service contracts are assumed to be 10%/year of the original capital purchase cost of the equipment and annual equipment amortisation cost is assumed to be the original capital cost divided by the number of years of service.

For the *buildings*, the number of square metres (m^2) are defined for general spaces, consultation areas, treatment preparation and delivery spaces, all valued by their cost/m^2 in US$. Construction costs are based on internationally accepted standards (i.e., 2236 US$/$m^2$ for HIC, 1000 US$/$m^2$ for LIC, the same as used by the GTFRCC), yet adapted to the radiotherapy environment by applying a multiplication factor (1.8 for linac bunkers, 1.44 for BT suites, and 1.2 for the rest of the department) [9].

Activities

Time estimates are defined for a whole range of activities performed throughout the radiotherapy process, per type of personnel, per treatment course and accounting for complexity level. These data are found in the supplementary file. An equal share between 3DCRT and IMRT has been modelled for external beam radiotherapy (EBRT). Furthermore, the proportion of courses requiring daily image guidance (IGRT, 50% is assumed), and some type of immobilisation and/or customised accessories such as blocks, are defined. BT is assumed to be CT-based. In addition, time estimates for quality assurance are defined per type of equipment and included in the supplementary file.

Products

The annual number of EBRT courses that can be delivered per linac is obtained by combining the average number of fractions per course (i.e., 19.4) [10] with the treatment complexity. Each BT case is considered to receive three fractions. BT is only accounted for in cervical cancer with a utilisation rate based on Thompson et al. [11] with an assumption of more advanced cases

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