Developing time-driven activity-based costing at the national level to support policy recommendations for radiation oncology in Belgium

Noémie Defourny[a,b], Sophie Hoozée[c,d,*], Jean-François Daisne[e,f], Yolande Lievens[c,g]

[a] *European Society for Radiotherapy and Oncology, Belgium*
[b] *University of Manchester, UK*
[c] *Ghent University, Belgium*
[d] *FlandersMake@UGent - Corelab CVAMO, Belgium*
[e] *Leuven University Hospital, Belgium*
[f] *Belgian Society for Radiotherapy and Oncology, Belgium*
[g] *Ghent University Hospital, Belgium*

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* Corresponding author.
E-mail addresses: noemie.defourny@manchester.ac.uk (N. Defourny),
sophie.hoozee@ugent.be (S. Hoozée), jean-francois.daisne@uzleuven.be (J.-F. Daisne),
yolande.lievens@uzgent.be (Y. Lievens).

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ABSTRACT

We use time-driven activity-based costing (TDABC) to estimate the cost of radiation treatments at the national level. Although TDABC has mostly been applied at the hospital level, we demonstrate its potential to estimate costs at the national level, which can provide health policy recommendations. Contrary to work on reimbursement or charges representing the health care system perspective, we focus on resource costs from the perspective of health care service providers. Using the example of Belgian inputs and results, we discuss development of a TDABC model. We also present insights into the challenges that arose during model design and implementation. Finally, we discuss recent examples of policy implications in Belgium as well as some caveats that should be considered when developing resource allocation models at the national level.

Keywords: Cost allocation; Health care; Reimbursement; Time-driven activity-based costing

1. Introduction

Reimbursement in most European countries is organized at the national level (Lievens et al., 2020; Slotman et al., 2005). As a result, treatment cost information at the national level is crucial to enable negotiations for tariff setting with health authorities. However, cost estimates reflecting health care practices across a country or even across hospitals are scarce because of multiple challenges in collecting and aggregating available data (Defourny et al., 2016). This variety in practices stems from factors such as differences in technological infrastructure, organization of workflow and clinical portfolios of departments, the profile of the hospital in which departments are embedded (e.g., private vs. public, academic vs. non-academic), and different costing methods (Chapman et al., 2014). Moreover, increasing costs, especially related to the continuous influx of new health care interventions, require that governments be well-equipped to estimate the resource needs as well as the costs of alternate scenarios, which account for changes in patient profiles, treatment protocols, and technologies.

Using the example of Belgium, in this study, we demonstrate how time-driven activity-based costing (TDABC) can be applied to meet this need. In contrast to ABC, TDABC has two types of flexible features that can reflect a complex and dynamic environment such as radiation oncology. On the one hand, TDABC permits cost objects, i.e., treatments, to consume resources in different proportions depending on specific treatment characteristics. On the other hand, ongoing adjustments are still possible after the model development phase by adding new terms in the cost equation, i.e., activities or steps, to accommodate for new treatment protocols, and for technical and technological innovations. We demonstrate how TDABC can be used to estimate the cost of radiation treatments and the resources needed at the national level without requiring bottom-up aggregation of departmental data or availability of transactional data at the national level. Our methodological analysis illustrates the dual potential of TDABC: 1) to calculate costs; and 2) to estimate resource needs. In particular, we show how TDABC can be used to model different scenarios, such as the impact of increasing complexity and more intense use of hypofractionation, which are two evolutions in radiotherapy practice that counterbalance each other in terms of costs and resource needs. This dual function is now being used in Belgium to update the legal recommendations for radiotherapy and support development of a new reimbursement system.

We contribute to the literature in two ways. First, rather than investigating the theoretical implications of using cost accounting models for price setting of health services (Raulinajtys-Grzybek, 2014), we provide insight into the challenges of developing a TDABC model at the national level. Our focus on the perspective of the health care service providers complements prior studies that employed a governmental perspective and focused on reimbursement or charges instead of treatment costs. Second, our interest in the national level and associated limitations of this approach as well as our examples of recent policy implications in Belgium complement prior research on health care costing. Although TDABC has been promoted for its application in health care (e.g., Mercier and Naro, 2014) and despite its potential to inform decision-making processes at more aggregated levels (Campanale et al., 2014; Stouthuysen et al., 2014), TDABC has mostly been used at the hospital level to increase efficiency in times of budgetary cuts (e.g., Andrawis et al., 2013; Keel et al., 2017). More general studies focusing on the cost of resources used (as opposed to reimbursement or charges) have also typically examined costing system adoption at the level of hospitals (e.g., Cardinaels et al., 2004; Hill, 2000). This paper illustrates benefits of TDABC beyond the hospital level.

We organize this paper as follows. We begin by presenting the necessary background of this specialist medical field. We then describe the procedure used to design and implement a generalized TDABC model, which was developed as part of an international effort. We illustrate operation of the model by presenting Belgian inputs and results, deferring details to an appendix. We report on the challenges that we encountered in designing and implementing our TDABC model and the lessons that we learned when addressing them. We then provide examples of recent policy implications of our model in Belgium and discuss how our costing model is starting to inform policy work in other countries. We end this discussion by highlighting some caveats in the development of resource allocation models at the national level.

2. Background and literature review

2.1. Setting: radiation oncology

Along with surgery and systemic oncology treatments (e.g., chemotherapy, targeted therapy, immunotherapy), radiotherapy is one of the three core therapeutic modalities for treating cancer. The current study focuses on photon external beam radiotherapy (EBRT), which is the mainstay of radiotherapy (Hoskin and Bhattacharya, 2014). EBRT destroys cancer cells by using beams of ionizing radiation, either photons such as high-energy x-rays or particles such as protons. These beams are generated by sophisticated equipment, such as linear accelerators in the case of photons, and are typically delivered in multiple sessions (or 'fractions').

As emitted radiation energy does not distinguish between cancer cells and normal tissue, there is need for an individualized approach considering the specificities of the tumour and the patients' anatomy. Well-trained staff ensure that physical accuracy is achieved and quality assurance is run throughout the process. The process starts with careful treatment preparation including imaging of the tumour, target volume definition and treatment planning, followed by the delivery of irradiation to the tumour using various beam set-ups. In each EBRT treatment course, the decision regarding the fractionation schedule defining the number of radiotherapy sessions is based on the difference in radio-sensitivity between various tumour types and their surrounding organs, and depends on the treatment indication (i.e., curative or palliative). As such, the treatment protocol is complex and is customized for each patient.

Radiotherapy practice has significantly changed over the past few decades. New technologies, including new types of linear accelerators, more advanced and faster Information and Communication Technology (ICT) algorithms and better imaging modalities, integrated before and during treatment, have become available. These have all paved the way towards more accurate radiotherapy techniques, such as image-guided radiotherapy (IGRT), intensity-modulated radiotherapy (IMRT) and stereotactic radiotherapy (SRT). Using these techniques, the tumour can be better targeted while optimally sparing the surrounding organs. Overall, these improvements have enabled the development of new treatment approaches (such as hypofractionation, where the dose is delivered in fewer treatment sessions or fractions) and treatment indications (such as curative radiotherapy for oligometastatic disease) (Lewis et al., 2017).

The advances in radiotherapy inevitably come at a cost, partly because of the higher investment cost of the new technologies, but also because new techniques typically require more time in terms of use of capital and human resources for treatment preparation, delivery and quality assurance (Van de Werf et al., 2012). If this higher cost is deemed acceptable in terms of the incremental clinical outcomes achieved (Whittington et al., 2016), then accurate cost data are necessary to support decisions for setting reimbursement, which, in turn, will secure access for patients to these new technologies and interventions (Andrawis et al., 2013; Lievens et al., 2015a).

Radiotherapy is important from an economic perspective. It is predicted that about half of all cancer patients should receive radiotherapy at least once during the course of their disease, irrespective of their geographic or socio-economic region (Atun et al., 2015; Barton et al., 2014; Borras et al., 2015b). In addition, as a result of the increasing incidence of cancer due to demographic changes (age structure and population size), the number of required radiation treatments is expected to further increase (Borras et al., 2016). This situation of increasing demand intensifies the importance of informing policy makers about the optimal planning and use of resources and associated budgets (Borras et al., 2015c).

Studies evaluating the economics of radiotherapy (Barbieri et al., 2014; Defourny et al., 2016; Monten et al., 2017; Nguyen et al., 2016; Rahman et al., 2016) include a large proportion of studies that use a governmental perspective, focusing on reimbursement or charges instead of the cost of resources used. Despite the established importance of such cost data to inform payment systems (Chapman et al., 2013), cost evaluations of radiotherapy are scarce and insufficiently consider the care delivery costs incurred by hospitals (Defourny et al., 2016). The lack of attention to the costs for health care service providers is surprising, since inaccurate information on treatment costs may impact the quality of decision making on the allocation of scarce health care resources (e.g., undesirable treatment incentives). Moreover, health care costing systems typically do not measure the cost of unused capacity (Anderson, 2017).

2.2. Review of TDABC in health care

TDABC has been demonstrated to be a successful health care cost management tool thanks to its ability to support operational improvements and compare the cost of care against reimbursement tariffs (Keel et al., 2017). Unlike ABC, TDABC has the capacity to model complex activities (i.e., consisting of multiple sub-steps) using cost rates that vary by resource (Hoozée and Hansen, 2018). Given rapid technological evolution, individualization of treatment protocols and the relatively high complexity of care pathway and resource interactions, TDABC has been proposed as the most accurate method to calculate the cost of radiotherapy courses (Defourny et al., 2016; Lievens et al., 2003, 2015a; Van de Werf et al., 2012), due to its ability to evaluate different radiation treatments with specific characteristics.

Most TDABC studies in health care have been conducted within the confines of a department or hospital (Keel et al., 2017). This is also the case for costing studies specific to radiotherapy (Bauer-Nilsen et al., 2018; Dutta et al., 2018; Laviana et al., 2016; Lievens et al., 2003; Perez et al., 1993; Ploquin and Dunscombe, 2008; Poon et al., 2004; Schutzer et al., 2016; Van de Werf et al., 2012; Yong et al., 2012). Examples of TDABC studies in health care performed at more aggregated levels are rare. This scarcity may be due to the higher time and resource requirements to collect more accurate data at the national level (e.g., Raulinajtys-Grzybek, 2014; Tan et al., 2009; Wordsworth et al., 2005).

2.3. Review of radiotherapy costing studies

In their review of costing studies focusing on radiotherapy, Defourny et al. (2016) found only two aggregated examples: one national study and one international study. Both studies estimated the cost of resources spent and did not present any result on the cost of unused capacity. The national study (KCE, 2013; Lievens et al., 2015c) conducted TDABC in ten radiotherapy facilities, representative of the then twenty-five centres in Belgium. Although definitions of activities and products were set beforehand, the actual interpretation was left to the discretion of the participating centres to ease the burden of data collection. The challenge when such TDABC exercises leave room for local interpretation is that the results may be very dependent on and vary greatly in terms of treatment description details and process map structures. Importantly, the departmental TDABC calculations presented in the Belgian national study have demonstrated the large impact of departmental characteristics on cost estimates, including the patient population mix treated, equipment and infrastructure characteristics, economies of scale and possible academic involvement. Consequently, despite the use of a uniform costing method, individual estimations in these studies were very wide ranging, making it difficult for departmental calculations to inform national reimbursement.

To address the low levels of worldwide access to radiotherapy, a large international project defined the costs and investments needed to close the gap of radiotherapy provision globally. To calculate radiotherapy costs at the international level, the project used a TDABC approach (Atun et al., 2015; Van Dyk et al., 2017; Zubizarreta et al., 2017), including variations in treatment complexity and resource costs reflecting four income groups according to the World Bank. While the authors stressed the significant real-world variability of economic determinants across income groups, the sparsity and challenge of obtaining actual cost data made it necessary to rely on projections and assumptions. While the Belgian study discussed the issue of generalizability, the international study mentioned the need for accurate resource input and cost data to refine the general results. Hence, discussing methodological choices and limitations is crucial if the aim is to effectively support public policy, particularly to inform reimbursement and investment schemes.

3. Developing the TDABC model

3.1. History of the HERO project

The national level TDABC model for EBRT was developed by experts of the 'Health Economics in Radiation Oncology' project of the European Society for Radiotherapy and Oncology (ESTRO-HERO) project. Launched in 2010, the ESTRO-HERO project aims to support European radiation oncology National Societies in their interaction with policy makers. In view of making informed decisions about reimbursement and resource planning in radiation oncology (Lievens et al., 2015b), the project provides a knowledge base and a health economics framework for radiation oncology at the European country level (Lievens and Grau, 2012). The project started by mapping the available radiotherapy resources and recommendations across Europe (Dunscombe et al., 2014; Grau et al., 2014; Lievens et al., 2014). Afterwards, the current and future number of radiotherapy treatments, required to serve the cancer population in each individual European country, were estimated (Borras et al., 2015a, 2015b, 2015c, 2016). As a next step, the HERO costing model was developed, estimating radiation treatment costs and resource needs at the national level using TDABC (Defourny et al., 2019). In collaboration with Invessel Ltd (Oegstgeest, The Netherlands), the national TDABC model was transformed into an online tool, launched on the 5th of December 2017.

In Belgium, the interest in this model was prompted by a new law regarding radioprotection with potential impact on medical physics staffing, urging for revision of the outdated Belgian recommendations[1] on radiotherapy resource needs (Dunscombe et al., 2014). This revision focused on staff and equipment requirements in the current radiation oncology context, characterized by complex techniques. Already before its formal launch as an online tool, a Belgian task force was created with the aim to populate the HERO model. Twelve experts representing all Belgian National Societies for radiation oncology[2] were appointed, resulting in a broad interdisciplinary expert group, including radiation oncologists, medical physicists, radiation therapists and quality managers, with ESTRO acting as a facilitator. A representative of the Federal Agency for Nuclear Control (FANC/AFCN) participated in the expert meetings as an observer. The strong demand for new radiotherapy recommendations and prior interdisciplinary collaboration facilitated interaction amongst these professionals, who met in six face-to-face meetings between March 2017 and October 2018.

In the following sections, the different steps and constituting components of the national TDABC model developed in the context of the ESTRO-HERO project are illustrated through the data collection and data analysis performed for Belgium.

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[1]http://www.ejustice.just.fgov.be/cgi_loi/loi_a1.pl?DETAIL=1991040530%2FN&caller=list&cn=1991040530&table_name=wet&la=N&ddfm=04&language=nl&choix1=EN&choix2=EN&fromtab=wet_all&nl=n&tri=dd+AS+RANK+&trier=afkondiging&ddfa=1991&ddfj=05

[2] BeSTRO (Belgian SocieTy for Radiotherapy and Oncology), BARO (Belgian Association of Radiotherapy Oncology), College of Physicians for Radiation Oncology Centres (further referred to as the 'College'), VVRO (Flemish Association for Nurses in Radiotherapy and Oncology), AFITER (Association of French-Speaking Belgian Nurses and Technologists in Radiotherapy) and BHPA (Belgian Hospital Physicists Association).

3.2. Developing the process map for EBRT

The EBRT care pathway forms the core of the TDABC computations. In order to define a uniform care pathway through which the patient transitions from the first consultation to the last irradiation session and the closing medical check-up, we adapted the internationally acknowledged process map developed by the American Association of Physicists in Medicine (AAPM; Ford et al., 2012)[3] by giving it a costing orientation. More specifically, the activities were reorganized: in addition to the 'core steps' in the EBRT care pathway, we identified 'optional steps' for which we wanted to estimate the cost separately. This approach enabled us to distinguish between the standard activities common to all radiation treatments and the optional activities, which are only relevant for and applicable to certain complex treatments, such as image-guided radiotherapy (IGRT). Activity definitions can be found in the Appendix (see Section A.1).

In the national TDABC model, an EBRT course is defined by four main characteristics: the type of cancer (tumour site), the treatment intent (curative or palliative), the treatment technique and the fractionation schedule used. The combination of cancer type and treatment intent results in a list of 34 different indications. In addition, six distinct treatment techniques are defined, ranging from simple to very complex: one-dimensional radiotherapy (1D-RT), two-dimensional radiotherapy (2D-RT), three-dimensional conformal radiotherapy (3D-CRT), intensity-modulated radiotherapy (IMRT), rotational IMRT (IMRT rot) and stereotactic radiotherapy (SRT). For a radiation treatment to be effective and avoid (long-term) toxicities, radiotherapy courses are typically delivered in multiple sessions, called 'fractions'. The number of fractions ranges between one single fraction and multiple daily fractions over several weeks.

[3] The established process map is a consensus recommendation developed by a panel of experts including representatives from all major North American radiation oncology organizations. It was supported by the AAPM.

Fractionation is addressed in the model by multiplying the treatment delivery care pathway step, along with its related optional steps depending on the tumour site and intent or the technique. The structure of the TDABC model enables it to serve as a uniform, transparent and versatile tool at the national level to address the variability of contemporary EBRT treatments, both financially and in terms of resource utilization.

3.3. Belgian inputs: data sources and approximations

Because the national TDABC model aims to model differences amongst tumour types, treatment intent, treatment techniques and fractionation schedules in terms of costs and resource utilization, the expected level of detail of the calculated results is high. Consequently, the model requires a large amount of data inputs, which are typically not readily available at the national level.

Generally, data may be available from different national sources, such as the health care insurance system, the cancer registry or the national cancer plan. Information may also have been previously collected by the professional and/or scientific organizations in radiation oncology or may be available in reports and publications. Model implementation and data collection therefore require a dedicated approach in each country under evaluation, starting with an overview of the available country-specific data, either at the national or at the departmental level. Additional data can then be collected via surveys, expert opinions or real-world data. Typically, a sample of 'top-down' data from registries or surveys has to be combined with data generated in a more 'bottom-up' approach through dedicated data collection in a selected number of centres. To ease implementation of the national TDABC model in a particular country, a standard dataset (based on a hypothetical country 'Europalia'; Defourny et al., 2019) was defined as a reference base for initial testing. Typically, once a first complete set is generated, further fine-tuning and validation is needed to ensure the reliability of the information.

The strategy used in Belgium was to complement existing national data with expert opinions representing all professional bodies through a modified Delphi approach. Real-world data collection was undertaken to cross-validate the national data with one reference department. Table 1 provides an overview of the specific data sources used in Belgium for the various components of the TDABC model: EBRT courses (i.e., transactional data regarding treatment volumes and types), care pathway times and resource costs.

[Table 1]

3.3.1. Estimating treatment volumes and types

In Belgium, national data on the overall number of radiation treatments is available in reimbursement databases. Whereas techniques can be inferred from the structure of the reimbursement categories, the fraction numbers can also be partially collected in the reimbursement databases. However, further fine-tuning by experts is required for both (Nevens et al., 2020). Linking this information on treatments delivered, with their related complexity and fractionation, to the actual cancer types, requires additional interoperability with the cancer registry systems. Given that these data have a certain delay before they become available - due to data collection and cleaning requirements - data collection has to rely on data from previous years. As the current exercise was launched in 2017, our choice of the reference year was constrained to 2014, in which 33,389 treatment courses were delivered across all Belgian radiation oncology departments.

3.3.2. Estimating resource times

For each of the resources, information on the time involvement in each step of the EBRT care pathway is required to quantify the share of resource cost dedicated to each treatment.

Defining the time per EBRT care pathway step for the various resources required different approaches. For equipment, the time consumption is based on personnel involvement time. We assume that the presence of personnel conditions the operating time of the equipment as the latter cannot treat patients in isolation. For personnel time, while some data may ultimately be captured through available ICT systems at the departmental level (e.g., the time for patient assessment through appointment scheduling or the timeslot of each treatment fraction delivered in the Oncology Information System (OIS)), others require dedicated time-and-motion studies or rely on estimates.

At the Belgian national level, consensus across experts from all professions was necessary to account for the diversity in practice across departments. To minimize the required input data collection, we assume identical activity durations per technical complexity, regardless of the cancer type or the various commercial solutions implemented. This is a simplification of reality, as in daily clinical practice, resource occupancy for specific activities may differ considerably amongst tumour types and even amongst departments. Although some data are available in the literature, they are highly variable, typically limited to specific parts of the care pathway and often outdated, pertaining to time estimates generated during the learning phase of new techniques (Bonastre et al., 2007; Sack et al., 2015; Vorwerk et al., 2014). Consequently, these data have only served as a reference to complement the time estimates that were gathered through a specific survey amongst the Belgian expert group. These data pertained to the then accepted standards of care and were further fine-tuned in discussions to reach consensus amongst experts in Belgium.

3.3.3. Calculating resource cost rates

The three groups of resource cost pools (i.e., personnel task forces, equipment and consumables) are defined in detail in the Appendix (see Section A.2). Availability of information on resource cost pools typically varies across the three resource types. Whereas data on the existing numbers of personnel and equipment may be found in governmental or professional datasets or build further on data from the first HERO work package (Grau et al., 2014; Lievens et al., 2014), this is not the case for salaries or equipment purchase values.

In Belgium, the number of available resources is recorded annually by the College. For the current TDABC project, we used data from 2015, i.e., the first available dataset. For salaries of the health care professionals, we used reference salary data from a manual on cost-based pricing, published by the Belgian Health Care Knowledge Centre (KCE) (KCE, 2012). For the purchase value of equipment and consumables, consensus amongst experts was based on recent acquisitions. Table A.3 in the Appendix displays the cost and practical capacity for each of the resources. We clustered personnel and equipment resources according to the task performed by calculating a weighted average, for instance across different professional sub-categories performing planning or different types of simulators grouped under imaging equipment.

The *personnel* cost refers to annual salaries to the employer including social contributions. The practical capacity of personnel is defined as 80% of their theoretical capacity (i.e., the legal work hours reported in their contract). The 20% refers to unavoidable inefficiencies such as breaks, sick leaves, etc. (Kaplan and Anderson, 2004). This assumption is in line with other TDABC studies in health care (Keel et al., 2017).

The *equipment* cost consists of the annual depreciation of the actual purchase value of the equipment (with its related bunker infrastructure) and the initial set-up costs, in addition to the annual costs of operating the machine. The set-up costs refer to the initial commissioning (i.e., validation) by the physicists and engineers in the department. The annual equipment operating costs are two-fold: the maintenance contract paid annually and defined as a share of the initial price, and the annual machine-specific quality assurance performed by the engineers and physicists. Hence, the personnel time required for quality assurance and commissioning -

and its related cost - is incorporated in the equipment cost and extracted from the personnel cost. The practical capacity of equipment resources is calculated based on the time of the staff operating the machine, with a capacity of 40 hours per week. As such, personnel shifts and extended opening hours are included in the calculation. Electricity consumption is assumed to be covered in the operating maintenance of the bunkers.

As the two types of *consumables* are each linked to a specific optional treatment step, i.e., customized immobilization and contrast administration, a fixed lump sum is added when treatment complexity requires these activities.

3.3.4. Non-core radiotherapy overheads

In the radiotherapy literature (as well as in health care more generally, see Jacobs and Barnett, 2017; Keel et al., 2017), the costs of resources and activities running in the background to ensure the delivery of care indirectly have not been systematically accounted for. Moreover, studies that did account for institutional or running costs have used heterogeneous definitions and data inputs (Defourny et al., 2016). The KCE (2013) Report 198C added a fixed percentage of 56.6%[4] of the treatment cost excluding the cost of physicians.

In the national TDABC model, non-core radiotherapy overheads were specifically estimated. They consist of two separate components:

- *RO Support:* the radiation oncology-supporting overheads encompass resources and activities associated with the treatment but that cannot be allocated to the treatment courses on a time basis, such as radiation safety and protection, academic and research activities;

[4] This percentage includes both the cost of personnel overheads (administrative personnel, blue-collar workers, engineers, top and middle management) and operational overheads (general cleaning and maintenance (except for medical equipment), heating and administrative costs).

- *Beyond EBRT:* these overheads encompass activities performed by radiation oncology professionals outside of the EBRT care pathway, such as the follow-up consultations for patients treated before the period under consideration, or multidisciplinary oncology team discussions.

While previous radiotherapy costing studies have used a lump sum to estimate non-core radiotherapy overheads, in line with Balakrishnan et al. (2018), we calculated them using the resource costs and proportional time consumption related to non-core radiotherapy activities. Non-core radiotherapy overheads are allocated to EBRT treatments by adding a proportional charge, of which 20% is allocated to treatment courses and 80% to fractions, as suggested by the KCE (2013) Report 198C. For the Belgian project, the estimates of proportional time that resources devote to non-core radiotherapy activities have been defined through expert consensus.

3.4. Belgian results

3.4.1. Calculating costs in different scenarios

The time for delivering a specific treatment course depends on the fractionation and the treatment complexity. Figures 1 and 2 illustrate these differences in time required by different resources by displaying inputs for lung tumours treated with curative intent with two different techniques, 3D-CRT and SBRT (or stereotactic body radiotherapy), implying different fractionation schedules and optional activities. The time and resource inputs for these two examples are based on expert consensus (Nevens et al., 2020).

[Fig. 1; Fig. 2]

Tables 2 and 3 show the proportion of treatment cost imputable to each resource cost pool and EBRT care pathway step. The difference in the weight of ‘treatment delivery’ and its optional activities illustrates the shift in complexity towards more frequent use of optional steps such as daily image-guidance and motion management, despite the large reduction in the number of fractions for SRT. The treatment preparation is more intensive in such complex techniques compared to 3D-CRT in this specific example.

[Table 2; Table 3]

Figure 3A displays an overall estimation (in cost terms) of any possible combination of technique, fractionation schedule and complexity for the most frequent tumour localizations treated with curative and palliative intent. The data clearly illustrate the considerable variations in cost across the different tumour localizations and fractionation schedules, with larger ranges for curative intent treatments. Figure 3B presents an overview of the impact of technique and fractionation on treatment cost. While the number of fractions is an important determinant of the cost, more complex treatments are associated with a higher cost for each of the three fractionation ranges. This is clearly the case when moving from 3D-CRT to IMRT, while IMRT rot, typically allowing for shorter treatment times, again has a mitigating impact on treatment cost. It should be noted, however, that the cost of IMRT is quite strongly driven by the treatment time slots, as defined by the experts, but these times may change substantially as learning curves are overcome or technology evolves towards faster solutions. A similar important cost-increasing impact is observed for SRT in the context of extreme hypofractionation.

[Fig. 3]

3.4.2. Estimating different cost components and resource needs

Building on the granular results across all possible EBRT course types, we estimated a national overview of both proportional cost and resource needs. Figure 4 provides the proportional cost breakdown for delivering 33,389 treatment courses (in 2014) in Belgium, distinguishing between the TDABC results (EBRT Core) and the non-core radiotherapy overheads (RO Support and Beyond EBRT). Figure 4B shows that equipment costs represent slightly over half of the total TDABC costs, with the linear accelerators being the largest resource cost pool overall. In line with the large amount of time that treatment delivery represents, the second largest proportion of resource costs is from the delivery task force, while the clinical task force ranks third due to their salaries being highest. Taken together, both components of the non-core radiotherapy overheads account for one quarter of the total EBRT cost (see Figure 4A), mainly driven by the supporting personnel and activities in RO support (see Figure 4C) and the multidisciplinary tumour board meetings in the Beyond EBRT overheads (see Figure 4D).

In addition to the cost estimations, the national TDABC model may also be used to estimate the resource requirements for different scenarios simulating the impact of changes in patient profiles, treatment protocols and changing technologies, as shown in Figure 5. Multiplying the time inputs of the EBRT care pathway by the various types of EBRT courses delivered annually, gives insight into the annual time utilized per resource. In Belgium, actual resource utilization was estimated to be within the available capacity for the year 2014. Estimation of resource utilization for the different scenarios shows that increasing the academic and research activities (scenario 1) intensifies the need for clinical and physics task forces by 13% and 12% respectively, while it increases other personnel needs by only 1%. Treating patients with more advanced techniques such as IMRT (scenario 2) increases the burden for the planning and delivery task forces by 13% and 10% respectively, with its equivalence in terms of equipment, as these resources are the most involved. For the physics and clinical task forces, a respective increase of 4% and 5% is observed. Lastly, compared to the base case analysis, the impact of shifting from 27% palliative and 73% curative intent treatments to a fifty-fifty representation (scenario 3), reduces the pressure on resources overall and, more specifically, on the delivery task force and treatment machines by 21% and 24% respectively. Such scenario estimates are relevant for policy making as they model the impact of changes in cancer care practice on resource needs.

[Fig. 4; Fig. 5]

3.5. Model validation

To demonstrate the reliability of our estimates, we validated part of our model by comparing our national cost estimates with the average real-life cost estimates for 10 Belgian radiation oncology centres, pertaining to 2011/2012, defined in the multi-centre TDABC study of the KCE (KCE, 2013). This comparison focuses on the relative cost variation across techniques and fractionation schedules for curative intent lung cancer courses and across two palliative treatment schedules. In Figure 6, for our national cost estimates, the size of the box is determined by the cost differences of all treatment combinations, blending possible treatment fractionation schedules with the optional complexity steps. It is obvious from the figure that longer fractionation schedules and more complex techniques are associated with higher costs in both studies.

[Fig. 6]

Although our national cost estimates are slightly higher for curative intent treatments, the palliative treatment costs in both studies are well aligned. For curative intent lung cancer treatments, similar differences are found for standard fractionation schedule costs. That the hypofractionated treatment costs in the KCE project are about 25% lower than our national cost estimates, is related to the lower fraction numbers defined (12 to 20 fractions in the KCE study compared to 24 fractions defined as the standard hypofractionated schedule in our national analysis). Interestingly, the average costs of SRT in the KCE project are well above those obtained by our national model and, in addition, show huge variations across centres. This illustrates that novel advanced techniques that are still in the adoption phase, which was the case for SRT in the KCE project, will typically entail higher costs, which tend to level off after the technique has become broadly implemented.

The finding that slightly higher costs are obtained by our national study may also be explained by structural differences between the two TDABC projects. First, our national study captures a more recent standard of care reflecting practice of 2014 onwards while the KCE project collected data for the year 2011/2012. The evolution towards more accurate techniques requires more quality assurance, not in the least more advanced image guidance, which is known to considerably impact resource time and thus treatment cost (Van de Werf et al., 2012). Second, equipment costs in the KCE report were based on historical data, which were typically lower than the actual costs and depreciated over their total lifetime instead of 10 years, as in our national exercise. This resulted in lower equipment cost components in the KCE report, especially in departments with aged equipment. Finally, some RO Support overheads such as administrative personnel or general spaces are considered in both models, but the two models have a different approach for dealing with these overheads. As explained in Section 3.3.4, we specifically estimated non-core radiotherapy overheads, while the KCE project added a fixed percentage on top of treatment costs. This difference is illustrative of the variability found amongst published studies, in which the share of non-core radiotherapy overheads varies between about 15% to more than 50% (Defourny et al., 2016). Importantly, the KCE project defined follow-up consultations, multidisciplinary tumour boards and research and teaching activities as out-of-scope costs and excluded the related personnel costs from their estimations, whilst these activities are included in our non-core radiotherapy overheads, representing an important share of the total treatment costs. In fact, as insight into different cost layers is particularly important in the context of policy making (Eldenburg and Kallapur, 2000), we made a distinction between RO Support and Beyond EBRT overheads, making this gradual pooling of overheads more visual by using a three-layer structure.

3.6. Limitations regarding the collection and aggregation of data

As accuracy should be traded off against data collection costs, the presented national level estimates are subject to some limitations regarding the collection and aggregation of data. First, while the use of expert opinion in economic models in health care has been found to support timely informed assessment (Morgan, 2014) and resource allocation decisions (Sullivan and Payne, 2011), expert elicitation refers to 'consensued knowledge' (Gibert et al., 2010), which may introduce cognitive heuristics. To mitigate evident estimation errors (e.g., observed tendency to overestimate the time needed for the various steps), the time duration inputs of the physics and delivery task forces were intensively discussed and questioned. Ideally, a closer and more structured collaboration towards data collection between the multiple interested stakeholders - governmental parties (such as cancer registries, health insurance providers and health technology assessment institutes), professional bodies and individual experts, along with the industrial partners - should ultimately allow for better interoperability and utilization of the data already being captured, with potential for expansion in the future. In this respect, recent recommendations issued for radiotherapy reimbursement in Europe have suggested that a continuous collection of real-life data should be stimulated to regularly revise and adapt reimbursement to actual practice (Borras et al., forthcoming).

Second, the non-core radiotherapy overheads in the model only account for those costs directly related to radiotherapy and oncology services, excluding the ones related to the hospital facility in which the department is embedded (Defourny et al., 2019). This methodological choice was driven by the awareness of insufficient data in the literature, already for department-level applications (KCE, 2013; Öker and Özyapici, 2013; Van de Werf et al., 2012; Van Dyk et al., 2017), which made it even more complex to accommodate for hospital-related overheads at the national level. It would additionally require information on the share of stand-alone institutes compared to the share of hospital-embedded departments and on the share of private centres compared to public and non-profit centres.

Third, bottom-up aggregation of departmental data may result in more accurate estimates of various treatment costs within a country, on the condition that those data are uniformly structured to ensure compatibility. Conversely, directly building a TDABC model at the national level allows capturing specificities at the country level, while requiring a realistic level of inputs. For instance, we calculated the numerator of the capacity cost rates of equipment as a weighted average of the cost of the various machine types. The numerators therefore reflect the features present in most machines, but the cost of treatments requiring less complex machines will be overestimated while the cost of treatments delivered with more complex or dedicated equipment will be underestimated. While it would be interesting to link machine types to specific treatments (e.g., stereotactic treatments delivered by dedicated stereotactic machines), the information systems in place do not allow such information to be captured, neither at the national level nor at the departmental level (KCE, 2013; Lievens et al., 2003). For personnel, the remuneration difference between professionals within one task force is also averaged out. Moreover, the use of a single national rate per resource cost pool hides significant local differences between departments that have been observed in previous cost calculations (KCE, 2013).

Finally, using any costing model at the national level assumes extreme centralization, disregarding geographical spread and considering all departments as working in one overarching entity, without accounting for variations in facilities' size (Defourny et al., 2019). This results in cost and resource estimates assuming extreme economies of scale. It is well-known that due to the semi-fixed nature of most radiotherapy resources, larger departments with higher throughput have a more optimal use of the resources, translating into lower costs (Dunscombe et al., 1999; Lievens et al., 2003; Van de Werf et al., 2012; Van Dyk et al., 2017).

One example in this project is the seemingly low utilization of the simulators. Indeed, our national TDABC approach reveals that fewer simulators would be required if they could all be clustered in one centralized department. Yet, the practicalities of a more dispersed radiotherapy environment and the legal context mandate each radiation oncology department to have one simulator, leading to a much higher number of simulators in reality. Based on the assumed economies of scale, our national TDABC model tends to underestimate EBRT costs. Moreover, due to the centralization assumption, it also overlooks departments' slack needed to face peaks of patient influx at each location (Defourny et al., 2019), resulting in an underestimation of EBRT resource requirements. In order to correctly inform negotiations on resource planning and reimbursement setting, the above methodological limitations of a national model should be recognized and compensated for when forecasting actual and future EBRT resource needs and estimating costs at the national level.

4. Applying the TDABC model for policy making

Our methodological analysis clearly illustrates the dual potential of TDABC, i.e., to calculate costs and estimate resource needs. In addition, TDABC can also be used to model the impact of different scenarios, such as the impact of increasing complexity and more intense use of hypofractionation, two evolutions in radiotherapy practice that counterbalance each other in terms of costs and resource needs. This dual function is being used in Belgium to update the legal recommendations and to inform the development of a new reimbursement system for Belgian radiation oncology. After a short introduction on prior experience with TDABC for radiation oncology policy making in Belgium, we present the use of our national TDABC model for ongoing policy implications. Next, we describe some expansions to other countries. We end by discussing some caveats in the development of cost and resource allocation models at the national level.

4.1. Prior experience with TDABC for radiation oncology policy making in Belgium

The initial use of (TD)ABC in Belgian radiation oncology dates back to the turn of the century, when an ABC programme was set up in the Leuven radiation oncology department. While not strictly developed with that aim, cost estimates derived from the initial calculations were used to inform reimbursement setting in the Belgian radiotherapy nomenclature established in 2001, which is still in use today (Lievens et al., 2003, 2020).

More importantly, about a decade later, a TDABC project was carried out, with the aim of defining the financing level for innovative radiotherapy - in particular, extra-cranial SRT and accelerated partial breast irradiation (APBI) - in the context of a temporary 'coverage (i.e., financing) with evidence development' project (KCE, 2013). This close collaboration between the National Institute for Health and Disability Insurance (NIHDI), the KCE and 10 centres representing the 25 radiation oncology departments active in Belgium at that moment, resulted in a large collection of EBRT cost data. Calculated by department, a large variation in cost estimates became evident, resulting from different clinical and operational practices and different use of human and capital resources, which also differed in number, type, investment cost and age (Lievens et al., 2015c). In particular, the cost estimates for SRT varied considerably: in lung cancer SRT, for example, a factor of three was observed, with costs ranging between 3,175 euros and 10,177 euros. Even larger ranges were observed when other SRT indications, with different fractionation schemes, were considered. In addition, it became clear that those departments having more recently implemented extra-cranial SRT tended to have higher costs, a finding of novel techniques that had already been described in France (Bonastre et al., 2007). While the level of provisional financing was defined as close to the calculated weighted average for extra-cranial SRT treatments, it was still by and large the result of a negotiation process between the radiotherapy providers and the NIHDI.

The large volume of interesting real-life cost data collected in this KCE project (KCE, 2013) spurred the interest to use them for supporting future updates of the reimbursement system. However, because of the flexibility allowed in capturing the data along the care pathway, the resulting costing levels were too inconsistent to draw relevant conclusions and to inform national reimbursement. Although the evidence generation in the coverage programme was completed with success and resulted into the inclusion of SRT in the Belgian radiotherapy reimbursement system as of January 1st 2020[5], the underlying cost calculation programme did not meet its expectation. This experience illustrates that highly variable cost estimates obtained from departments cannot be used as such to define a national reimbursement level. Rather, a cost estimate representing 'an acceptable national standard' should be aimed for. Moreover, despite the use a common methodology, the lack of standardization of data collection and categorization undermined the practical usability of the cost results. Hence, a more centralized and standardized approach was needed.

4.2. Ongoing policy implications in Belgium

In 2017, the KCE approached ESTRO to collaborate in a project evaluating the Belgian hospital capacity required by 2025, in which radiation oncology was one of the specific sub-topics analyzed (KCE, 2017). Applying our national TDABC model, actual and optimal resource needs were calculated, extrapolating from 2015 towards 2025 based on the expected increase in cancer incidence and related radiotherapy courses required. Based on the calculations, the report suggested that the need for EBRT equipment would increase by about 24% over a decade, assuming that the treatment delivery situation were to remain identical, i.e., only accounting for demographic and cancer incidence changes. This is obviously a simplification of reality, as radiotherapy techniques and indications continuously change.

[5] https://www.vbs-gbs.org/fileadmin/user_upload/e-specialist/2020/KB-AR_2020.04.16_-_BS-MB_2020.04.27_art._18-19_RXT.pdf

Therefore, as illustrated in Section 3.4, scenarios modelled the resource impact of various treatment complexities and fractionation schedules, demonstrating that shorter fractionation schedules can in part compensate for the increased EBRT device needs. However, the report also stressed that the use of advanced techniques along with complexity features remains mandatory to avoid unintended increases in toxicity, which again increase resource needs. Interestingly, the high resource impact of implementing extremely hypofractionated radiotherapy in 5 fractions for the frequent indication of breast cancer was also highlighted. While at the time of the report this was considered with caution as long-term clinical evidence was still outstanding, this treatment approach has now become standard, not in the least because it has been an elegant manner to reduce hospital contacts during the COVID-pandemic. This demonstrates how quickly practice patterns can change, urging for model inputs that can be easily adapted. Although this is a prerequisite to continuously inform policy, this does not mean that the required radiotherapy resources can be adapted as swiftly, as investment in radiotherapy equipment and personnel typically requires a long-term perspective.

Besides providing policy advice on actual and future resource needs, our national TDABC model has also been used to generate cost data. The analyses presented in this paper resulted from a further elaboration on a refined data set, validated by the Belgian expert group. Cost data generated with this data set were used to estimate the budget impact of introducing extra-cranial SRT for oligometastatic disease in the reimbursement system (Nevens et al., 2020). Interestingly, the analysis showed good alignment between the reimbursement defined and the provider cost calculated with our national TDABC model. Based on this experience, our costing model is proposed to inform the new radiotherapy reimbursement nomenclature. Indeed, in the context of a revision of the entire financing system for specialist care in Belgium, it has been concluded that the actual radiotherapy reimbursement needs to be completely revised because it is outdated and does not conform to the current standards of care. With the aim to move towards a largely episode-based reimbursement system (Borras et al., forthcoming), data from our national model will be used to find the optimal basis on which to define episode-based payments and to evaluate whether physician fees can be separated from the reimbursement covering other personnel and capital resources. While the available national data may be sufficient to inform the structure and categorization of the new reimbursement system, an update of the model will be required for the valuation phase, where the concrete financing levels per episode will be defined. An updated data collection has already been initiated by the Belgian expert group. Moreover, keeping in mind the previously described caveats of economies of scale, potentially resulting in an underestimation of the costs at the departmental level, it is anticipated that the national-level data will have to be supplemented with evidence from a range of departments, to benchmark the national estimates to the real-life environment. Also, in-depth analyses will be required to define which parts of the non-core radiotherapy overheads should be covered in the radiotherapy reimbursement, and which ones should be included in other financing mechanisms, such as hospital budgets.

4.3. Expansion to other countries

To date, Belgium is the first country to have taken active steps to translate evidence generated by the national TDABC model into policy work for radiotherapy. Yet, other countries are currently looking into it as well. In the UK, insights on resource needs are of interest due to the National Health Service's review of radiation oncology services' organization and because of an anticipated lack of medical physicists following the introduction of proton therapy in the country. The Royal College of Radiologists has been conducting a project applying the model to England, with a dedicated working group collecting data to feed the TDABC model currently finishing its validation. In France, interest in generating costing evidence stems from the need to support the pending update of the national reimbursement system. Here too, the National

Society for radiation oncology (Société Française de Radiothérapie Oncologique) has set up a dedicated working group, primarily looking into the differences in cost structures between private, public, university and non-profit centres, in order to define a national approach that can optimally support reimbursement for all different types of centres. In Hungary and Catalonia, the TDABC estimates are being used to enhance their understanding of treatment costs and how they vary across techniques and complexities. Despite the value of generating such costing and resource evidence to support the radiation oncology community in their interaction with policy makers, the implementation of a national scale TDABC model can only be achieved through strong engagement from leading experts across the country. The ongoing national projects have demonstrated that continuous commitment over several years as well as alignment with the national political agenda are equally important.

4.4. Caveats in the development of resource allocation models at the national level

Due to professional groups' political agendas, time inputs may be upwardly biased to hide unused capacity and claim higher needs. In fact, during the Belgian data collection, we observed a tendency to overestimate time by using a distinct equipment profile (outlier) as a referent for time estimates rather than a median machine type. To avoid the creation of this slack, we developed a two-phased approach in using the model, in which we first only showed the cost of all resources spent in order to avoid the gaming of time inputs to match political agendas. It was not until after the finalization of the unmodifiable dataset that we revealed the distinction between the cost of used and unused capacity. Saini et al. (2017) note that although biases have been described and investigated in psychology research, few studies have been done in medicine. Moreover, health care costing systems typically do not measure the cost of unused capacity (Anderson, 2017). As mentioned in the literature review, previous examples of the application of (TD)ABC in radiation oncology all estimated the cost of resources spent rather than used. Yet, to support strategic decisions, policy making also requires insights into resource utilization in order to inform resource investment planning and, if applicable, disinvestment. The importance of the latter has recently been described in the TDABC model developed for the Leeds department in the UK, investigating the impact of various hypofractionated schedules for bone metastases. In this paper, Spencer et al. (2022) demonstrate the complexity of disinvesting in radiotherapy, where the vast majority of resources and related treatment costs are fixed/semi-fixed, possibly resulting in imbalances between demand and capacity within the life expectancy of linear accelerators. Such variations in resource usage result in imbalances between incurred provider costs and prevailing reimbursement schemes.

Our study is based on country-level data to overcome the interdepartmental variability that may hamper national policy making. To understand appropriateness of the national estimates in various departments, the national analysis can be supplemented by departmental-level analyses for a set of departments of various sizes and types, taking into consideration local practice, resource availability and the hospital context. In this analysis, definition of and whether or not to include certain activities in the non-core radiotherapy overheads will be key. This will not only impact the total calculated costs, it will also be important to determine if they should be taken into account for reimbursement setting. For example, the fact that academic centres devote more time to research and development, education and training, is by and large determined by their academic mission, which should be financially supported separately from the formal reimbursement (Borras et al., forthcoming). A national TDABC model allows disentanglement of the costs related to academic activities. We note that all departments need to implement new technologies, techniques, treatment approaches and indications. This involves more time, resources and money, and should ideally go hand in hand with advanced quality management and data collection. These aspects should be accounted for in the reimbursement system, since there is a risk that departments will refrain from innovation if they are not financially supported (Borras et al., forthcoming). Recommendations on optimal resource deployment and health care financing are both excellent policy levers to stimulate the introduction of and access to evidence-based practice. A national TDABC model can play a crucial role in producing evidence to support this. But as the swift uptake of extremely hypofractionated breast radiotherapy during the COVID-pandemic has shown, these are only components that should be seen in a broader landscape of potential incentives and barriers.

5. Concluding comments

Accurate data at the national level is needed to negotiate adequate financing and cancer care planning. However, radiotherapy has evolved considerably over the last few decades towards more accurate techniques, new treatment approaches (e.g., 'hypofractionation', i.e., the reduction of the number of fractions while increasing the dose per fraction) and treatment indications (such as curative radiotherapy for oligometastatic disease) (Lewis et al., 2017). These improvements as well as the relatively high complexity of the care pathway and resource interactions make it difficult to aggregate patient-level data. Even if accurate treatment cost information per patient may be available at the hospital department level, aggregation of departmental data is either too costly or infeasible due to the lack of harmonization of hospitals' information systems. Due to the variety in practice amongst departments, it would also be inappropriate to choose one reference department for reimbursement organized at the national level. It is also challenging to directly obtain transactional data about the treatment modalities delivered or the procedure time at the national level.

The cost evidence that we gathered is currently being used to inform the development of a new reimbursement system, embedding incentives for health care providers to introduce advanced radiotherapy approaches, such as hypofractionation. Our study highlights the need to increase awareness about the impact of representative costing data to warrant state-of-the-art practice and stimulate innovative treatment for patients. Although the national costing model was specifically developed to support policy recommendations for radiotherapy, we believe that our insights can also inform future national level TDABC implementations for other health care specialties that require medical devices (Drummond et al., 2009, 2018), provided that the core and ancillary activities are clearly defined.

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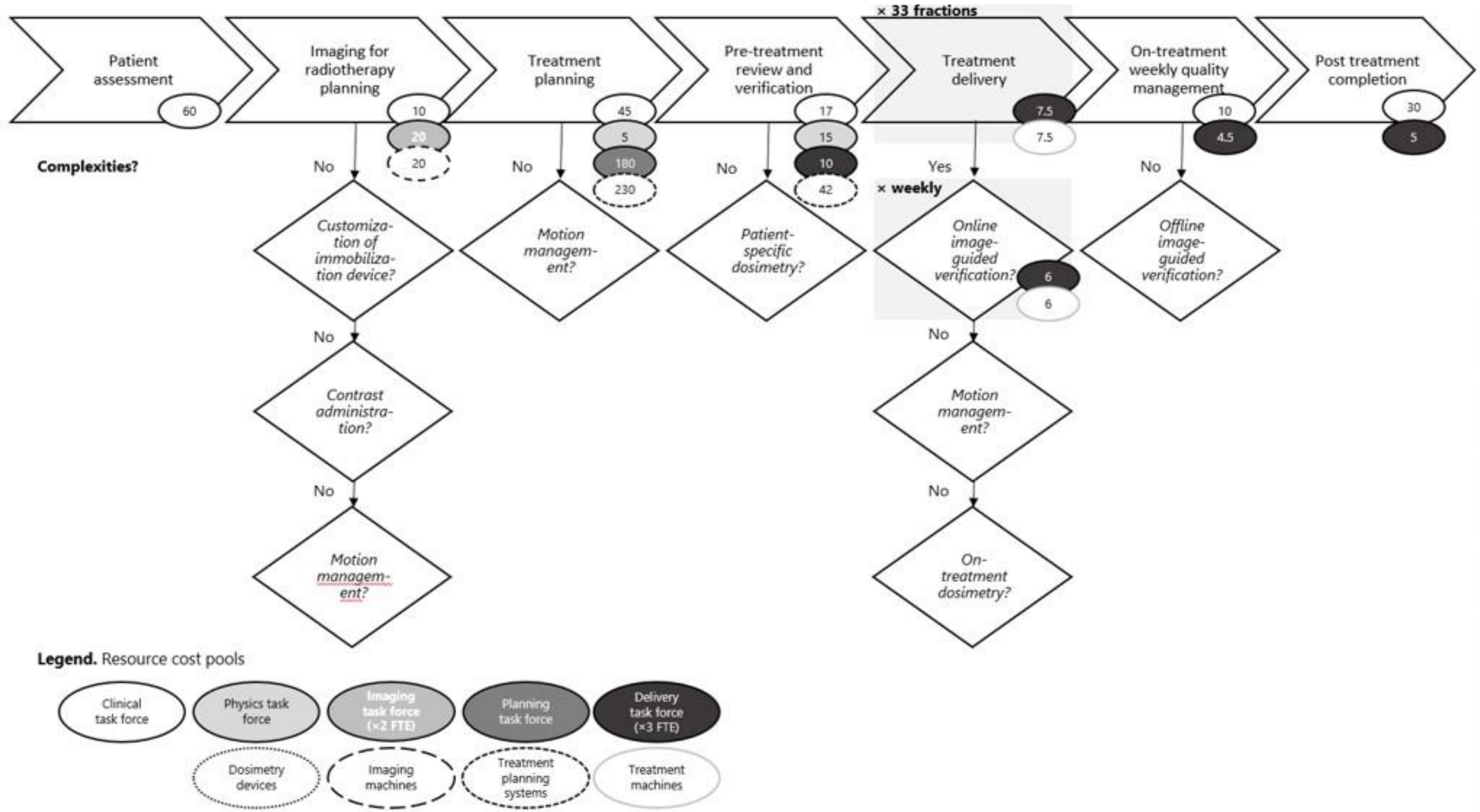
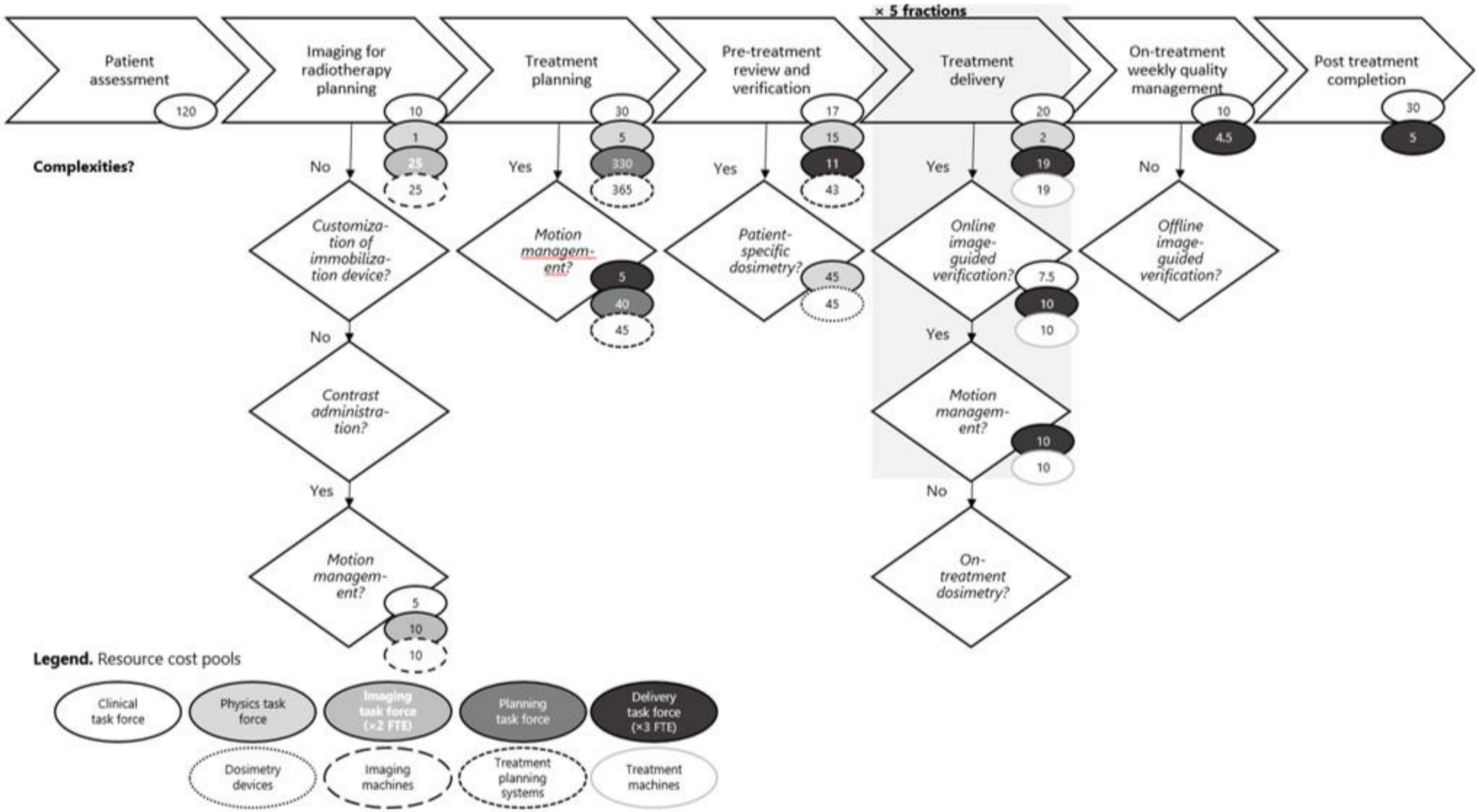
Fig. 1. Inputs in the EBRT care pathway for a lung tumour treated with curative intent with a 3D-CRT standard fractionated treatment of 33 fractions.



The numbers presented in the ovals are average time estimates in minutes. This figure refers to data of 644 EBRT courses.
'No' before a rhombus means that a particular optional step is not required for this particular care pathway. 'Yes' implies that a particular optional step is needed; in that case, additional time (presented in the ovals) and corresponding costs are added.

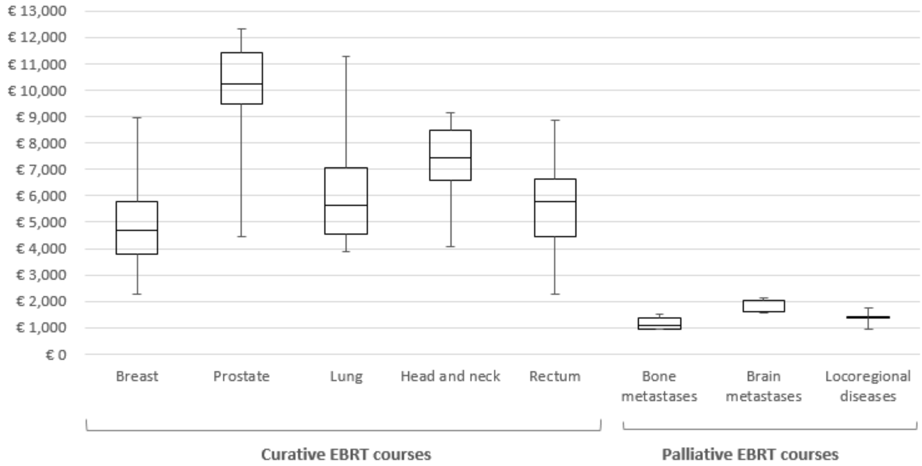
Fig. 2. Inputs in the EBRT care pathway for a lung tumour treated with curative intent with a stereotactic, extremely hypofractionated treatment of 5 fractions.



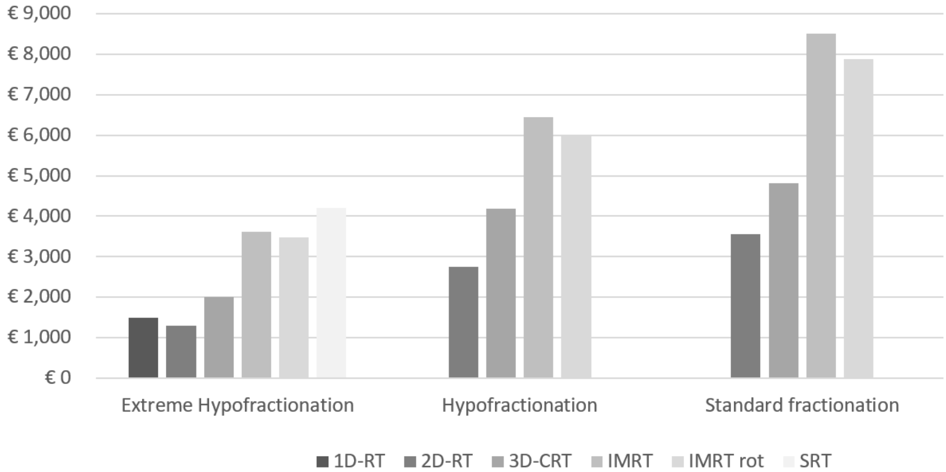
The numbers presented in the ovals are average time estimates in minutes. This figure refers to data of 396 EBRT courses.
'No' before a rhombus means that a particular optional step is not required for this particular care pathway. 'Yes' implies that a particular optional step is needed; in that case, additional time (presented in the ovals) and corresponding costs are added.

Fig. 3. Cost estimates (EBRT Core and RO Support) for EBRT courses in 2014.

A. Relative cost of EBRT courses for the main tumour localizations treated with curative and palliative intent.



B. Relative cost of EBRT courses per technique and fractionation schedule.



1D-RT: one-dimensional radiotherapy; 2D-RT: two-dimensional radiotherapy; 3D-CRT: three-dimensional conformal radiotherapy; IMRT: intensity-modulated radiotherapy; IMRT rot: rotational IMRT; SRT: stereotactic radiotherapy.

Fig. 4. Proportional costs (resources spent) of EBRT Core, RO Support and Beyond EBRT, for 33,389 EBRT courses in 2014.

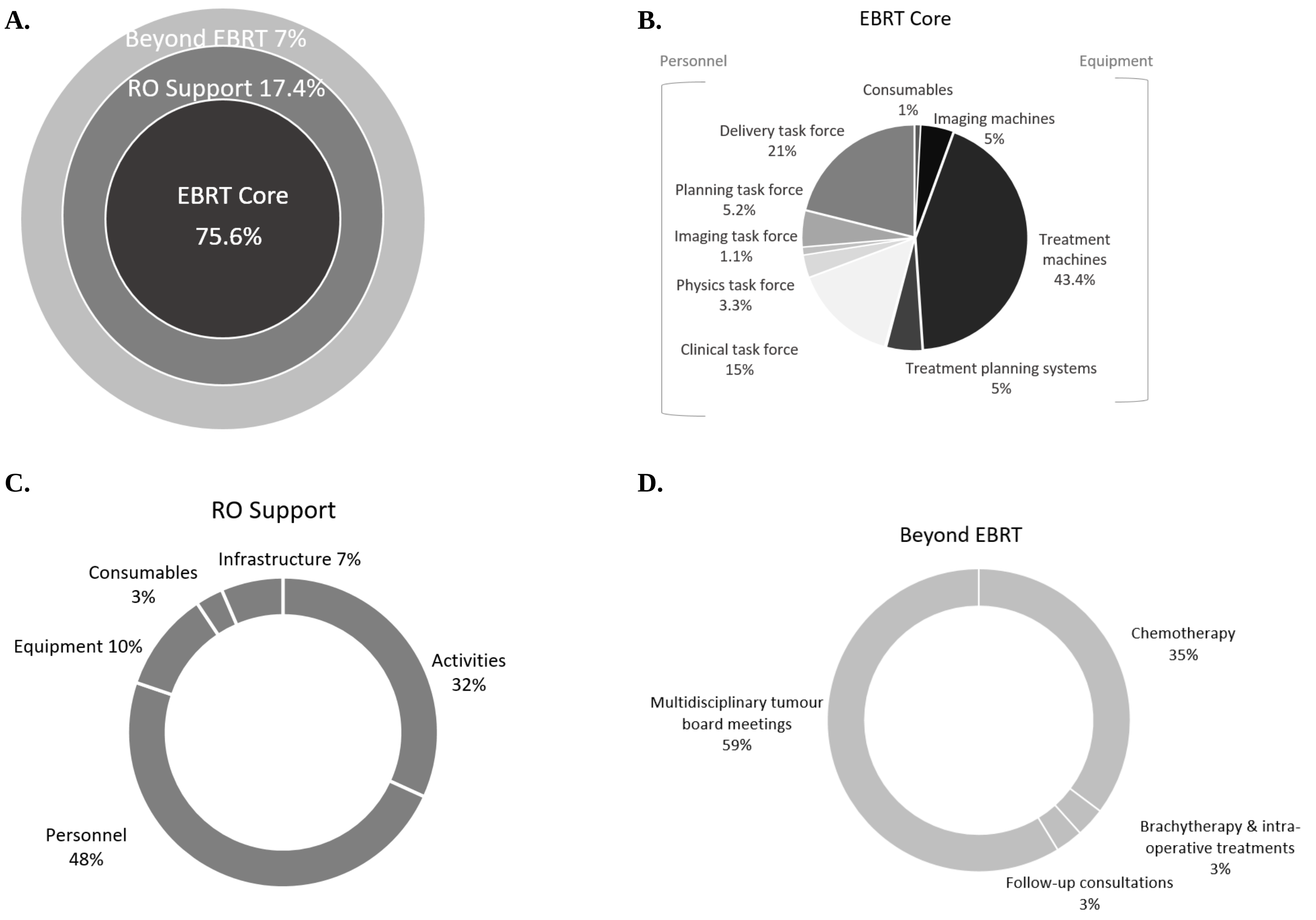


Fig. 5. Impact of simulated changes on resource planning for EBRT Core.

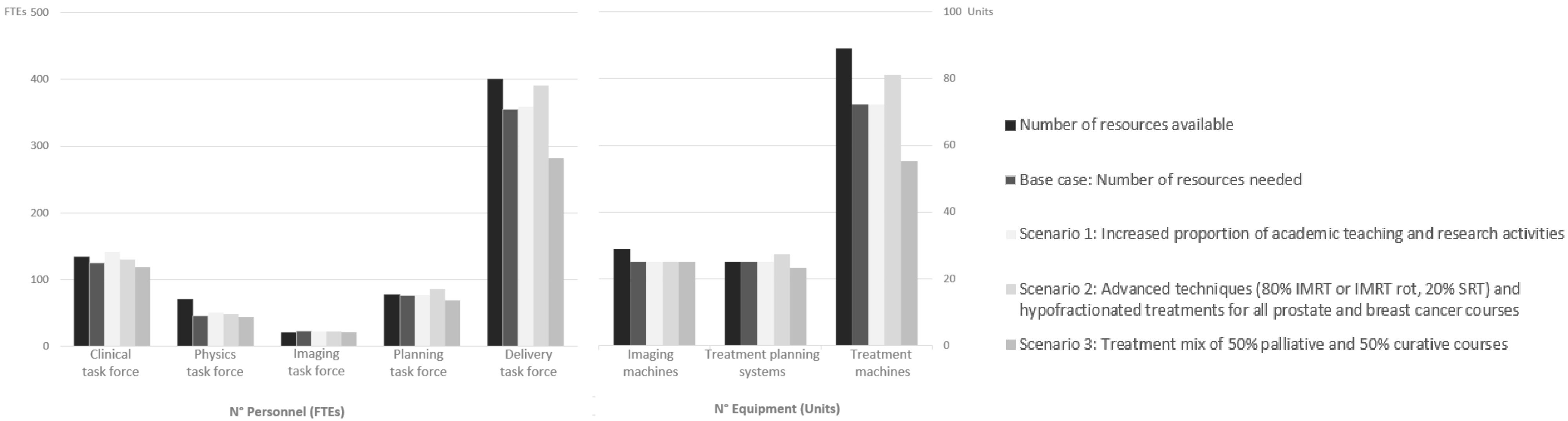
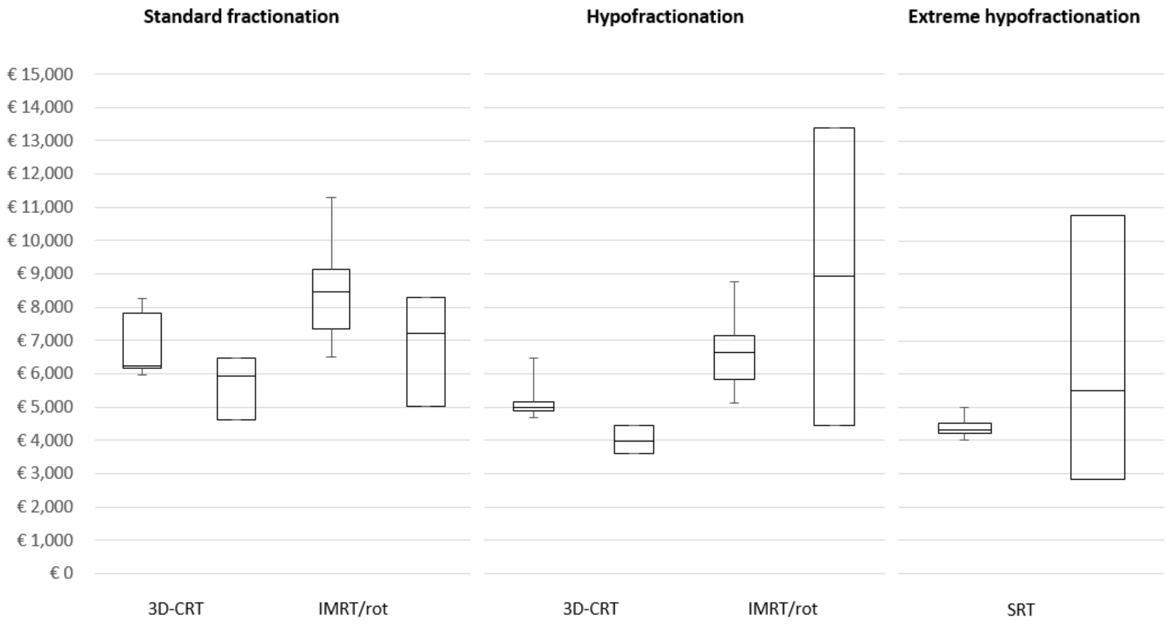
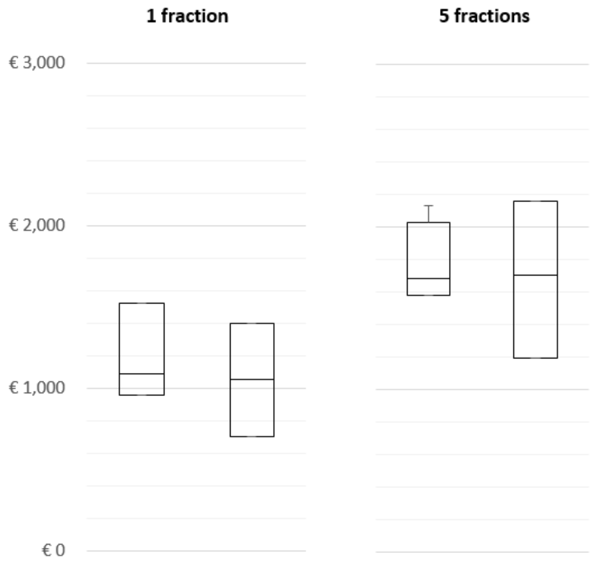


Fig. 6. Comparison of cost estimation of EBRT treatments, by technique and fractionation schedule.

A. Curative treatments (lung cancer)



B. Palliative treatments



1D-RT: one-dimensional radiotherapy; 2D-RT: two-dimensional radiotherapy; 3D-CRT: three-dimensional conformal radiotherapy; IMRT/rot: standard and rotational intensity-modulated radiotherapy; SRT: stereotactic radiotherapy.
In this figure, we do not make a distinction between standard and rotational IMRT to enhance comparability with the results from the KCE Report 198C, in which IMRT restrictively groups all types of intensity modulation, including rotational IMRT.
The columns on the left are the national cost estimates (EBRT Core and RO Support) for Belgium, obtained from the ESTRO-HERO TDABC model. The horizontal line represents the median and the size of the box is determined by the cost differences of all treatment combinations. The columns on the right are the real-life TDABC cost estimates from the KCE Report 198C. The horizontal line represents the average across 10 Belgian radiotherapy centres.

Table 1.
Belgian implementation strategy and data sources.

Implementation strategy	General data sources	EBRT courses	Care pathway times	Resources and their costs
National expert consensus using a modified Delphi approach amongst radiotherapy stakeholders representing all National Societies for radiation oncology in Belgium, cross-validated with the data of one reference department	- Existing data from the National Insurances (IMA), the Cancer Registry and the College - Expert opinions from the experts of the represented National Societies - Real-world local data collection in one reference department - Published KCE Report 178C on salaries for health care costing	IMA and Cancer Registry data, complemented by information from a dedicated scientific sub-project	Expert concertation	Belgian College database complemented by expert concertation, salaries from KCE Report 178C

Abbreviations
IMA: Intermutualistic Agency; KCE: Belgian Health Care Knowledge Centre; College: College of Physicians for Radiation Oncology Centres

Table 2.
Results breakdown per process step and resource cost pool for an average treatment cost, produced from applying the TDABC tool to Belgium, for a lung tumour treated with curative intent with a 3D-CRT standard fractionated treatment of 33 fractions.

EBRT care pathway steps and *optional steps*											**Activity cost**
	Clinical task force	Physics task force	Imaging task force	Planning task force	Delivery task force	Imaging machines	Treatment planning systems	Dosimetry devices	Treatment machines	Consumables	
Patient assessment	2.6%										2.6%
Imaging for radiotherapy planning	0.4%		0.5%			2.3%					3.2%
Customization of immobilization device											
Contrast administration											
Motion management											
Treatment planning	2%	0.3%		3.1%			2.7%				8.1%
Motion management											
Pre-treatment review and verification	0.75%	0.9%			0.2%		0.5%				2.35%
Patient-specific dosimetry											
Treatment delivery					12.35%				26.4%		38.75%
Online image-guided verification					*2%*				*4.2%*		*6.2%*
Motion management											
On-treatment dosimetry											
On-treatment weekly quality management	2.9%				0.5%						3.4%
Offline image-guided verification											
Post-treatment completion	1.3%				0.1%						1.4%
EBRT Resource cost pool	9.95%	1.2%	0.5%	3.1%	15.15%	2.3%	3.2%		30.6%		66%
RO Support resources and activities						24.3%					24.3%
Beyond EBRT activities						9.7%					9.7%

Table 3.

Results breakdown per process step and resource cost pool for an average treatment cost, produced from applying the TDABC tool to Belgium, for a lung tumour treated with curative intent with a stereotactic, extremely hypofractionated treatment of 5 fractions.

EBRT care pathway steps and *optional steps*	Clinical task force	Physics task force	Imaging task force	Planning task force	Delivery task force	Imaging machines	Treatment planning systems	Dosimetry devices	Treatment machines	Consumables	**Activity cost**
Patient assessment	6.6%										6.6%
Imaging for radiotherapy planning	0.5%		0.8%			3.6%					4.9%
Customization of immobilization device											
Contrast administration											
Motion management		*0.4%*	*0.3%*			*1.4%*					*2.1%*
Treatment planning	1.6%	0.4%		7.3%			5.4%				14.7%
Motion management	*0.3%*			*0.9%*			*0.7%*				*1.9%*
Pre-treatment review and verification	0.9%	1.2%			0.2%		0.6%				2.9%
Patient-specific dosimetry		*3.5%*						*1.7%*			*5.2%*
Treatment delivery timeslot	5.5%	0.8%			6%				13.5%		25.8%
Online image-guided verification	*2.1%*	*0.4%*			*3.1%*				*6.7%*		*12.3%*
Motion management		*0.4%*			*3.1%*				*6.7%*		*10.2%*
On-treatment dosimetry											
On-treatment weekly quality management	0.5%				0.1%						0.6%
Offline image-guided verification											
Post-treatment completion	1.6%				0.1%						1.7%
EBRT Resource cost pool	19.6%	7.1%	1.1%	8.2%	12.6%	5%	6.7%	1.7%	26.9%		88.9%
RO Support resources and activities					8%						8%
Beyond EBRT activities					3.1%						3.1%

Appendix

This appendix provides definitions of the activities and resource cost pools as well as details on the calculation of the cost of an EBRT course.

A.1. Defining activities

Table A.1
Definitions of activities (adapted from Ford et al., 2012)

Activities	Definition
Standard activities	
Patient assessment	The acquisition and analysis of the patient's medical information to define the treatment indication and make the treatment prescription, which permits the initiation of the radiotherapy process.
Imaging for radiotherapy planning	The acquisition of the patient's tumour and anatomical data in treatment position, mostly by means of a Computed Tomography (CT) scan.
Treatment planning	The process of translating the radiation oncologist's prescription into the target definition and the dose distribution based on the patient's tumour and anatomy, thus generating instructions for the treatment delivery device.
Pre-treatment review and verification	The confirmation that the instructions to the treatment delivery system will result in a treatment in compliance with the physician's directive and treatment planning.
Treatment delivery	The process of administering radiation to the patient in accordance with the radiation oncologist's prescription and the treatment planning.
On-treatment weekly quality management	Checking the conformity of the treatment delivery with the treatment prescription and planning.
Post-treatment completion	The retrospective evaluation of the delivered treatment course and assessment of the patient's outcome.
Optional activities in imaging for radiotherapy planning	
Customization of immobilization device	The production of a customized device for establishing and maintaining the correct patient position during imaging and treatment delivery.
Contrast administration	The administration of radiocontrast agents to enhance the visibility of anatomical structures in X-ray-based imaging techniques, for example on a simulator or CT scanner.
Motion management in imaging	The acquisition, during imaging, of information on tumour motion or motion of the organs at risk, especially as a consequence of breathing.
Optional activities in treatment planning	

Motion management in planning	Using the information on tumour motion or motion of the organs at risk, acquired during imaging, to account for its impact on the dose distribution in the treatment plan.
Optional activities in pre-treatment review and verification	
Patient-specific dosimetry	The measurement and verification of calculated doses and dose distributions in preparation for the treatment of individual patients treated with complex plans, for example, IMRT.
Optional activities in treatment delivery	
Online image-guided verification (IGRT)	Taking images prior to the delivery of a treatment fraction to confirm that the patient is correctly positioned and/or during treatment delivery to confirm that the radiation beams are as prescribed with respect to the tumour target and organs at risk. Based on such images, corrections can be made prior to the delivery of the full fraction dose.
Motion management online	The use of a real-time motion tracking device, to follow or guide the radiation beam during the breathing cycle.
On-treatment dosimetry	To monitor doses delivered to individual patients during treatment delivery and comparing these with the calculation of the treatment plan.
Optional activities in on-treatment weekly quality management	
Offline image-guided verification (IGRT)	Images taken during treatment delivery are reviewed following the delivery of the fraction. Corrections, if necessary, can be made before subsequent fractions. Note: it is generally not necessary to perform both online and offline image verification on the same patient, by the same type.

A.2. Defining resource cost pools

A.2.1. Personnel task forces

Human resources are organized differently across countries in terms of professionals' names, competencies, roles and responsibilities (Lievens et al., 2014). To overcome these discrepancies and ensure international comparability, a 'task force' approach was adopted. Several professions can make up a specific task force, such as in the planning task force, where medical physicists and dosimetrists may work on similar activities. The proportion of physicists in charge of other specific responsibilities would then be registered under the physics task force. In total, *five task forces* were defined for the radiation oncology staff as presented in Table A.2.

Besides these five main professional task forces, supporting personnel is also organizing the care. As their involvement duration is difficult to trace to specific timeslots, they are grouped together under RO Support (see Section 3.3.4).

A.2.2. Equipment

In contemporary radiotherapy, equipment diverges highly in terms of hardware and software with different complexity. For example, recent linear accelerators (Linacs) have kilovoltage Cone-Beam Computed Tomography (CBCT) features while older versions have Electronic Portal Imaging Devices (EPIDs) for daily quality monitoring through image guidance.

Four main types of equipment resources are defined and allocated through TDABC (see Table A.2). Each type of equipment requires specific infrastructure, set-up and maintenance. For both image acquisition as well as treatment delivery, we computed weighted averages of cost and time across the different machine types because specific information on each type of machine per treatment is difficult to obtain at the national level. The capacity cost rates therefore reflect the features present in most machines, but the cost of treatments requiring simple machines will be overestimated while the cost of complex treatments will be underestimated. For personnel, the remuneration difference between professionals within one task force is also averaged out. In addition, the use of a single national rate per resource cost pool hides significant local differences between departments, as has been observed in previous cost calculations (KCE, 2013).

Besides these four main types of equipment, radiotherapy operating systems, general IT equipment (servers and computer workstations) and machine-specific dosimetry equipment are grouped together under RO Support as their utilization is difficult to trace to a specific timeslot. Radiotherapy operating systems (frequently referred to as the Oncology Information System (OIS)) ascertain the correct transition of radiotherapy data throughout the care pathway and may allow other activities such as patient scheduling or outcome data collection. General IT equipment runs in the background, at different times and places. Machine-specific dosimetry equipment (such as scanning water tanks, used for machine beam characterization and during weekly machine quality control) ensures safe radiotherapy delivery and is critical to any treatment, yet without being traceable to specific treatment courses.

Apart from this general equipment, we also account for the general infrastructure of the department, which consists of reception, waiting room, consultation spaces, hallways, offices, staff and meeting rooms, storage rooms and all other spaces of a department besides the planning room and the bunkers for imaging and treatments machines.

A.2.3. Consumables

Unlike for example in chemotherapy, consumables are not used to a great extent in radiotherapy. There are only *two patient-specific consumables* that the patient may need (see Table A.2 for definitions).

Table A.2
Definitions of resource cost pools

Resources	**Definition**
Personnel task forces	
Clinical	All professionals in charge of the clinical approach of radiotherapy. This task force largely consists of radiation oncologists as well as radiation therapists and nurses who assist physicians in performing their clinical responsibilities.
Physics	Professionals specialized in medical physics for radiotherapy, who oversee the calculation and verify the treatment plan. They also guarantee the machine- and patient-specific quality assurance. This task force excludes technical support personnel, such as engineering and IT support. The latter are captured as RO Support, together with other non-medical personnel.
Imaging	All professionals that are taking part in the imaging for treatment planning.
Planning	All professionals that participate in the preparation of the radiation treatment plan, translating the physician directive (treatment prescription) into set-up parameters for treatment delivery.

Delivery	All professionals participating in the treatment delivery steps.
Equipment	
Imaging machines	For the image acquisition of the patient, we defined four different types of machines: 2D simulators with and without CBCT options, CT simulators and Positron Emission Tomography (PET) scanners.
Treatment planning systems	The information system used to generate a representation of the dose distribution within a patient, depending of the treatment prescription and the anatomical specificities of the patient and his/her tumour, is called a planning system. It consists of hardware (one or more servers and workstations) and software licences.
Treatment machines	For the treatment delivery, we decided to aggregate the equipment across three types (cobalt machines, linear accelerators and dedicated stereotactic equipment), disregarding, for example, differences between single- and multiple-energy accelerators and additional features such as image guidance.
Patient-specific dosimetry devices	A wide range of devices (such as thermoluminescent dosimeters, diodes, phantoms, or software applications) used to control the conformity between the planned and the actually delivered dose.
Consumables	
Customizable immobilization devices	Masks only needed for some patients, mainly depending on the tumour localization.
Contrast medium	Injected for the image acquisition of specific indications.

A.3. Calculating the cost of an EBRT course

For each of the 11 resource cost pools *j*, the capacity cost rate (CCR_j) is calculated by dividing the annual cost of resource supply by the practical capacity, i.e., the annual available time in minutes. Details are provided in Table A.3.

Combining the time information with the capacity cost rates (CCRs), results in the following *cost equation*, which calculates the cost of an EBRT course, i.e., an EBRT treatment with specific characteristics:

$$\hat{c}_{a,b} = \sum_{j=1}^{11} \sum_{i=1}^{16} \left(T_{j,i\,|a,b} \times X_{i\,|a,b} \times \mathrm{CCR}_j \right)$$

With

a = tumour site and intent (curative or palliative),

b = technique (1D-RT, 2D-RT, 3D-CRT, IMRT, IMRT rot, or SRT),

i = EBRT step (see the example process maps in Figures 1 and 2; there are seven core steps at the top and nine optional steps below);

j = resource cost pool (there are five personnel task forces, four equipment types and two consumables[6]),

T = (average) estimated unit time,

X_i = frequency of step *i*, depending on the fractionation schedule, *a* and *b*.

[6] For consumables, there is no time involved. Hence, the estimated unit time takes value 1.

Table A.3.
Resource cost pool parameters for EBRT Core.

Resources EBRT Core		**N° departments: 25**				**Annual practical capacity[1]**	**Data source**	75.6% of total cost
Personnel	**Sub-category**	**FTEs***	**Annual Salary****			**EBRT capacity hours/FTE*****		
Clinical task force		134	€ 256,240			1,048 hours	* Belgian College	15%
Physics task force	*Physicists*	71	€ 106,750			780 hours	database (year 2015)	3.3%
Imaging task force		21	€ 73,894			1,316 hours	** KCE Report 178C	1.1%
Planning task force[2]		77.3	€ 87,389			1,406 hours	*** expert estimates	5.2%
	Physicists	*38*	*€ 106,750*					
	Dosimetrist	*39.3*	*€ 68,669*					
Delivery task force		401	€ 73,894			1,294 hours		21%
Equipment	**Sub-category**	**Units***	**Purchase price/unit****	**Lifetime ****	**Annual maintenance cost, quality control and commissioning cost/unit[3] ******	**Capacity hours/unit**		
Imaging machines[2]		29	€944,828	10	€ 96,518	2,080 hours		5%
	Simulator without CBCT	*8*	*€800,000*	*10*				
	Simulator with CBCT	*7*	*€1,000,000*	*10*				
	CT simulator	*14*	*€1,000,000*	*10*				
	Associated bunkers	29	€300,000	33	€6,000			
Treatment planning systems		25	€850,000	5	€89,523	2,080 hours		5%
	Associated planning spaces	25	€150,000	33	€3,000			
Treatment machines[2]		89	€2,808,989	10	€286,225	2,080 hours	* Belgian College	43.4%
	Cobalt	*1*	*€1,500,000*	*10*			database (year 2015)	
	Linac	*85*	*€2,800,000*	*10*			** expert estimates	
	Dedicated stereotactic	*3*	*€3,500,000*	*10*				

	Associated bunkers	89	€1,000,000	33	€20,000	
Patient-specific dosimetry devices		25	€50,000	10	€5,995	
Consumables			**Units**	**Purchase price**		1%
Customized immobilization devices			8,366	€ 90		
Contrast medium (per unit)			6,801	€ 44		

Legend

This table presents only the resource cost pools accounted for in the TDABC estimation (i.e., EBRT Core). Resources outside the EBRT care pathway are accounted for in RO Support.

[1] Available time of 80% of the theoretically paid time accounts for unplanned breaks, sick leaves, etc.

[2] Personnel and equipment performing similar tasks are grouped together, their average weighted cost is applied.

[3] In the annual maintenance contract, the energy consumption is assumed to be included. The purchase value is depreciated over the equipment lifetime. Commissioning represents the cumulated time spent by the physics task force on initial commissioning, depreciated over equipment lifetime. In addition, the annual number of days dedicated to machine-related quality control is displayed. Required training time of other task forces to use the equipment is foreseen as well.

Abbreviations

FTEs: full-time equivalents, CT: computer tomography, CBCT: cone-beam CT