In 2000, a detailed cost-calculation model was developed for the UHL-RT department [1]. This model computed accurate estimates of RT input costs, costs of different activities within the RT process and RT product costs. It also provided insight into the global departmental cost structure.

In the past decade, the steady increase in imaging and information–communication opportunities has led to an important medical–technological evolution in RT. Novel treatment strategies such as IMRT, image-guided (IGRT), respiratory-gated (RGRT), stereotactic RT (SRT) and volumetric arc RT have been implemented in daily practice. These sophisticated techniques however require increased QA and inevitably come with a higher workload and larger investments in infrastructure.

Since 2000, the UHL-RT department replaced three linear accelerators by new linacs with tools for modern radiotherapy delivery, such as multileaf collimators, electronic portal imaging device (EPID), cone-beam CT (CBCT) and infrastructure for respiratory gating and rapid arc delivery. Two simulators were replaced by one simulator with CBCT and one CT-simulator. For brachytherapy, one new after-loading machine was purchased. Software and hardware were upgraded.

Next to these acquisitions, the department underwent major renovations. Apart from the refurbishing that came along with the new equipment, a new brachytherapy unit with operating theater was installed and the planning area was extended. Finally, in order to accommodate the higher complexity simultaneously occurring with the yearly increases in patient numbers, the levels of medical and non-medical personnel increased.

As a consequence of these changes, the need arose for an update of the original cost calculation model in order to evaluate and quantify the differences in costs that occurred over time. The design of the new model (“2009-model”) was based on the design of the “2000-model” to allow benchmarking between the two time frames.

This paper describes how the 2009-model was constructed (emphasizing the difference with the 2000-model) and presents the results of the cost calculations, with special attention for the financial consequences of the increased workload and QA of modern high-tech treatment techniques.

**Materials and methods**

In analogy with the former model of the UHL-RT department [1], the actual cost calculation model uses the ABC costing methodology, i.e. the concept that activities consume resources to produce products [2]. The vast majority of resource costs within a RT department is consumed during the delivery (production) of the different RT treatments (products) but are mostly not directly traceable to these products. In order to overcome this, ABC identifies the various activities performed during the RT process. Cost
drivers, often the time spent on these activities, are subsequently used to assign the resource costs to the products.

The actual model has been developed with Filemaker Pro software instead of Excel, allowing to more easily modify the level of detail and adapt the inputs as a function of the study requirements. As such, it can be used for benchmarking between departments and different economic settings.

For the present analysis, product and activity data of the UHL-RT department of the year 2009 were used: 2354 external beam RT (EBRT) courses were delivered, of which 280 (12%) using IMRT. The department operated five linear accelerators (all with multi-leaf collimators and electronic portal imaging, three with on-board cone-beam CT and two tailored for gated and volumetric arc RT delivery) and two simulators (one with cone-beam CT, one CT-simulator). The personnel consisted of 16.8 FTE (full-time equivalents) radiation oncologists (7.3 staff; 9.5 residents), 26.2 FTE nurses, technologists and other paramedical staff, 7.8 FTE physics staff, 3.2 FTE administrative personnel and 1 FTE engineer.

To allow comparison with the 2000-data, this article describes EBRT only, although in contrast with the former, this model allows to calculate brachytherapy costs as well. Its structure with different allocations steps is nevertheless very similar to the original model [1], as visualized in Fig. 1. The following model-description will therefore be brief and focus on the differences between the two models.

**Resource costs**

All costs are expressed in year 2009 Euros.

Conform with the 2000-model, five cost categories were defined: wage, building, equipment, overhead and material costs. The vast majority of wage, building and equipment costs consumed during the RT process can be allocated to specific products using the stepwise ABC-methodology with “time consumption” as cost driver [1,2,6]. They are referred to as treatment-related resource costs. Costs that cannot be allocated as such are reallocated to overhead costs.

Wage costs were derived from the reference UHL wage costs and the number of FTE per personnel category working in the RT department in 2009.

For the space costs, the yearly cost per room was obtained by multiplying the square meters by the equivalent annual cost per square meter, depending of the building category (low cost, e.g. administrative space; medium cost, e.g. examination room and high cost, e.g. bunkers, simulation, planning).

Annual equipment costs were derived from the real purchase price and adapted on the basis of year of purchase, estimated lifetime and interest rate. Whenever applicable, this equivalent annual cost was augmented with the cost of annual external maintenance contracts.

Material costs of immobilization masks and stereotactic frame were defined for direct assignment to the products for which they are used as a standard. The remainder of the material costs (i.e. consumables and “low-priced” durables) were defined as overhead costs.

Overhead costs consist of hospital support and departmental support. The former are costs assigned by the hospital to the RT department, partly based on the number of square meters of the department and partly on the FTE personnel working in the department. Departmental support costs cover wage, space, equipment and material costs not traceable to specific RT products.

**Activities**

All activities taking place in the RT production process were listed. In analogy with the 2000-model distinction was made between treatment-related activities and supporting activities. The former are directly linked to the RT delivery. Seven major activity-groups were defined, each one consisting of different sub-activities influencing the level of complexity of the basic activity (Table 1). For all activities (basic as well as sub-activities) reference time consumption per personnel category was defined, based on information from time slots, time measurements and interviews with the different personnel categories. These reference times can be further adapted by using a multiplication factor.

The latter are supporting the RT process without being directly linked to a specific treatment. They contain departmental-supporting activities (care and non-care related), performed by the UHL-RT personnel and hospital-supporting activities, performed by personnel not belonging to the RT department but of which costs are assigned to the department.

**Products**

The list of irradiation treatments – defined as products – was derived from the departments’ registration system. Conform the
2000-model the products were ordered per organ type. Other than 
the 2000-model, palliative treatments were not differentiated per 
organ type as our former analysis showed that this does not impact 
on costs.

Further differentiation in products was made in function of 
treatment complexity (two-dimensional (2D), three-dimensional 
conformal RT (3D-CRT), IMRT, SRT, field set-up, the use of a CT scan 
or personalized immobilization), since these parameters do influence 
the cost.

For each product the applying activities (and sub-activities) 
were defined, with a multiplication factor to account for complexity 
as required. The number and complexity of the treatment sessions 
were the most important variables influencing product costs. In line with 
the evolving technology, the number of fields was no longer withheld as a factor influencing treatment complexity, in contrast with the 2000-model.

Another point of difference with the 2000-model is that boosts 
are not defined as separate products, but are accounted for by 
increasing time consumption when defining the activities for treat-
ment preparation. Exception to this rule is made for breast treatments 
since different techniques are used for the boosts and the major treatment fields.

**Cost calculation**

**ABC allocation**

The model utilizes the three-step ABC allocation principle of the 
2000-model (for a detailed description we refer to [1]), time con-
sumption being the cost driver to allocate treatment-related re-
source costs to the products. A first step allocates resource costs to 
activity-groups (e.g. the global simulation cost), followed by a 
second allocation to the specific activities per type of product 
(e.g. simulation for pelvic irradiation with 3D-CRT). The final step 
consists of a mere summation of wage, space and equipment costs 
per specific activity and product to obtain the product cost.

Wage costs of personnel involved with the actual RT process 
(physicians, nurses/technologists and physicists) are allocated fol-
lowing the ABC-principle based on time spent per type of person-
nel for each activity per specific product.

Similarly, space costs are allocated on the basis of time spent in 
a room for a certain activity. To overcome the problem of rooms 
sharing place among different activities and other rooms being 
only used a few hours a day, the same approach as in 2000 was fol-
lowed: all activities are linked to “critical personnel”, i.e. the per-
sonnel category most closely related to the activity. Critical 
personnel time-estimates are then used for the space cost calcula-
tion following ABC. The same approach is used for equipment 
costs.

In order to allow calculation of QA-related costs for equipment, 
the time-estimated wage cost for QA of engineers and physicists is 
calculated separately and added to each specific equipment. The 
remaining time (cost) of the engineer, together with the wage costs 
of social assistants and dietician are not directly linked to activities 
or products as such and are allocated to care-related departmental 
support costs.

**Overhead**

Departmental (care- and not-care-related) support costs nor 
hospital-support costs are allocated with the ABC-methodology. 
In analogy with the 2000-model, each product is assigned a pro-
portion of these costs based on treatment complexity using the 
number of fractions as a proxy.

**Specific material costs**

Being standard for certain treatment types, they are directly traced to these products.

**Results**

The total UHL-RT resource costs consumed for EBRT rose 89% 
between 2000 and 2009 (€4,552,105 to €8,605,987) due to the 
investment in more sophisticated equipment along with personnel 
expansion, compensating for the 33% increase in treatment num-
ber (2354 EBRT treatments in 2009 vs. 1769 in 2000) and the in-
creased complexity. The overall cost distribution remained grossly the same, with a predominance of personnel costs (Fig. 2).

Table 2 shows a cost comparison at the activity-group level, i.e. 
space, equipment and personnel costs allocated to the different 
activities. It demonstrates a significant shift compared with 2000, 
with clearly higher requirements for QA-related activities as well 
in the preparatory as in the treatment phase. Overall, treatment 
delivery remains most costly, but now with almost one third of 
its costs being consumed by portal imaging, that evolved from a 
predominantly off-line portal image control at start towards a more 
frequent – often daily – on-line portal image control nowadays.

Table 3 shows the average treatment cost and some specific 
costs of frequently delivered treatments. Costs of 2000, adapted 
to the 2009 level applying the Belgian consumer price index (CPI: 
1.19) are compared to the calculated 2009 costs.

For those treatments delivered similarly (e.g. palliative sched-
ules without CT-planning, RT for glottic cancer), a baseline cost in-
crease of about 20% is observed over time.
In general, when treatment complexity increases, costs follow. The introduction of 3D-CRT, as in tangential breast and high-grade palliative treatments, resulted in cost increases of approximately 30%. IMRT further boosted the costs compared to 3D-CRT, not as a consequence of IMRT techniques as such, but rather due to a combined effect of IMRT with higher fraction numbers and more portal imaging. The impact of the latter is most obvious in lung and prostate cancer treatments, where daily on-line portal imaging is now performed as a standard.

As expected, fraction numbers and costs are closely related. More fractions translate into higher costs. Conversely, a shift towards more hypofractionated schedules, such as in the coin lesion example, can annihilate the cost increases related to more intense on-line QA.

**Discussion**

The rapid diffusion of technological innovations has been identified as one of the most important factors driving the escalating health-care expenses [3]. Owing to new imaging and information-communication opportunities, RT indications and technical possibilities are continuously evolving. Hence the permanent need to prove the effectiveness of novel treatments and techniques, but also for critical and quantitative appraisal of their economic impact.

Two publications give us some insight in the evolution of radiotherapy costs over time. The Swedish Council on Technology Assessment in Health Care (SBU) calculated a 16% increase in total RT cost in Sweden between 1991 and 2000, be it with a parallel increased efficiency (37% more fractions) due to gradual automation and computerization [4]. Based on the available RT costing literature, a Canadian analysis estimated the annual cost increase in Western countries at roughly 5% [5].

These data are however all derived from costing exercises performed before the introduction of techniques such as IMRT or SRT, which since have become common practice in many RT departments. There is only limited information on the financial implications of these novel approaches, yet it is intuitively accepted that

**Fig. 2. Distribution of EBRT resource costs in 2000 vs. 2009.**

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Comparison of the costs at the activity-group level for respectively 2000 and 2009.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000 (€)</td>
</tr>
<tr>
<td>Treatment preparation</td>
<td>839,247</td>
</tr>
<tr>
<td>First patient contact</td>
<td>137,066</td>
</tr>
<tr>
<td>Simulation</td>
<td>423,162</td>
</tr>
<tr>
<td>Delineation</td>
<td>25,540</td>
</tr>
<tr>
<td>Dose calculation</td>
<td>253,479</td>
</tr>
<tr>
<td>Treatment delivery</td>
<td>1,872,695</td>
</tr>
<tr>
<td>Quality assurance (QA)</td>
<td>283,192</td>
</tr>
<tr>
<td>General at start</td>
<td>40,561</td>
</tr>
<tr>
<td>Patient specific</td>
<td>69,606</td>
</tr>
<tr>
<td>Supervision plan</td>
<td>60,324</td>
</tr>
<tr>
<td>Portal imaging</td>
<td>32,423</td>
</tr>
<tr>
<td>In vivo dosimetry</td>
<td>44,820</td>
</tr>
<tr>
<td>Chart round</td>
<td>36,377</td>
</tr>
<tr>
<td>Total</td>
<td>2,711,942</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Average product costs and examples of specific costs per product in 2009 compared with 2000.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>Nr. of fractions</td>
</tr>
<tr>
<td>Palliative 1 × 8 Gy</td>
<td>1</td>
</tr>
<tr>
<td>Palliative 5 × 4 Gy</td>
<td>5</td>
</tr>
<tr>
<td>Palliative 10 × 3 Gy</td>
<td>10</td>
</tr>
<tr>
<td>Breast tangential + boost</td>
<td>25 + 8 (boost)</td>
</tr>
<tr>
<td>Lung involved field</td>
<td>35</td>
</tr>
<tr>
<td>Lung coin lesion</td>
<td>15</td>
</tr>
<tr>
<td>Lymph node</td>
<td>10</td>
</tr>
<tr>
<td>Prostate IMRT</td>
<td>37</td>
</tr>
<tr>
<td>Head and neck glottis</td>
<td>25</td>
</tr>
<tr>
<td>Head and neck IMRT</td>
<td>35</td>
</tr>
<tr>
<td>Average of all products</td>
<td>20</td>
</tr>
</tbody>
</table>

Abbreviations: 3D-CRT: three-dimensional conformal radiotherapy; PI: portal imaging; IMRT: intensity-modulated radiation therapy.

* € costs are adapted to the evolution in Belgian Consumer Price Index.
their higher complexity will come with higher costs. A time and motion study performed in our department showed that both the use of IMRT and IGRT significantly influence daily treatment time, hence, increase costs [6]. Similar observations have been made for IGRT in Canada [7] and for IMRT and RGRT in France [8–10].

In order to reduce variability and improve validity in reported costs, the importance of valid cost accounting models cannot be overstated. Although so far infrequently used in RT, activity-based full-costing analyses have been suggested as the most appropriate tools for studying the financial impact of RT technology and process changes [5,11]. Using activities as an intermediary step to allocate resource costs to treatments, the power of ABC lies in the possibility to in- or exclude particular activities (such as IMRT or image guidance), thus estimating their financial impact. It further allows modeling different fractionation schedules – important in this era of renewed interest for hypofractionated schedules – without simply assuming that cost scales linearly with the number of fractions, a shortcoming often found in less advanced costing exercises [12].

In both our former and actual cost calculation models, ABC was used to calculate the UHL-RT costs. The 2009-model in fact redrew the 2000-model in order to more accurately capture the impact of increased complexity and associated QA of current RT practice.

Why this is important, is demonstrated by the activity cost data. Even if the preparatory phase has become more demanding due to higher accuracy in both target definition and planning, treatment delivery remains the most costly activity. This is understandable as it is requiring daily repetitive investment of personnel and costly linear accelerators. But in contrast to the former analysis it also becomes clear how daily QA through image guidance, introduced along with the more complex treatment techniques, now consumes a large part (31%) of these delivery costs.

The more important the change in complexity, the more the cost was boosted. Prostate and head and neck (H&N) treatment costs, e.g. rose with respectively 88% and 38%. This cost evolution is related to the introduction of IMRT, due to the acquired dose escalation and the necessity of more thorough QA, both translating into higher costs. The latter is especially so for prostate cancer, daily image-based repositioning using fiducial markers having become standard practice in our department. The lung cancer example shows a similar impact of daily PTV’s in 3D-CRT.

Our former analysis [6], which introduced time estimates from a time-and-motion study and 2007 costs in the 2000-model, resulted in a somewhat higher cost of IMRT, especially for H&N. The main reason for this is a different cost-allocation principle for imaging: in 2000, these costs were driven by the number of fields, images being taken at the start of treatment only, one per field. Nowadays, two orthogonal images are taken simultaneously. The allocation per field falsly boosted the required time, underpinning the importance of a costing model build in line with the actual practice.

Table 4 compares our data to the limited available literature evidence [8,9,12–17].

<table>
<thead>
<tr>
<th>Country</th>
<th>Indication</th>
<th>Context</th>
<th>Cost data</th>
</tr>
</thead>
<tbody>
<tr>
<td>France [8]</td>
<td>H&amp;N</td>
<td>Modeled costing analysis</td>
<td>Full direct costs</td>
</tr>
<tr>
<td>Switzerland [17]</td>
<td>Prostate</td>
<td>Modeled costing analysis</td>
<td>Full direct costs</td>
</tr>
<tr>
<td>USA [14]</td>
<td>Accelerated partial breast</td>
<td>Cost-minimization analysis</td>
<td>Medicare reimbursement</td>
</tr>
<tr>
<td>USA [15]</td>
<td>Prostate</td>
<td>Cost-utility analysis</td>
<td>Medicare reimbursement</td>
</tr>
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<td>USA [15]</td>
<td>Prostate</td>
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<td>Medicare reimbursement</td>
</tr>
<tr>
<td>The Netherlands [12]</td>
<td>H&amp;N</td>
<td>Modeled costing analysis</td>
<td>Full direct costs</td>
</tr>
<tr>
<td>Belgium [this study]</td>
<td>H&amp;N</td>
<td>Activity-based costing analysis</td>
<td>Full direct costs</td>
</tr>
</tbody>
</table>

Abbreviations: H&N: head and neck; ND: not defined.

€ refer to dollars converted into € at the exchange rate of 1 US$ = 0.708.

Table 4 is too simple.
33%. Hence, the average treatment cost increased with only 42% (€3656 vs. €2573), averaging out cost increases of novel technologies with treatments of which the cost remained relatively stable over time (see Table 3).

When inflation is additionally accounted for, these differences become even smaller. Applying the Belgian CPI results in an actual value for the 2000-cost of €3062, i.e. a cost increase over the last decade limited to 19%. When conversely allowing a 4.5% annual inflation – the accepted yearly growth in Belgian health care expenses – the figure of €3824 would even exceed the calculated cost!

Similar observations can be made for the Belgian RT budget (€88.8M in 2009). Although it doubled between 2001 – the introduction of the new reimbursement system – and 2009, this is partly explained by 40% higher patient numbers. Moreover, although these figures are considerable, comparable trends are observed for other oncology treatments as well. The sales of oncology drugs in 19 European countries, for example, rose from €840M to €6170M between 1993 and 2004. Many new innovative – and costly – molecules have been introduced on the market since, with expectedly a substantial impact on the expenses [18].

Whether governments remain able and willing to cover such cost increases largely depends on the economical and political climate both determining the accepted growth in health care budget. Experiences such as the QUARTS project have previously highlighted how a nation's wealth may influence the availability of radiotherapy resources, hence the potential uptake of radiotherapy (technology) [19,20]. But there is more. In negotiations defining the amount allotted to different health care interventions, cost-effectiveness data have become unavoidable. In order to qualify for reimbursement, solid evidence on the added medical effectiveness of new interventions combined with accurate data on their extra cost is requested by government and health insurers alike.

Our study may contribute to such cost data. The regrettable scarcity in long-term outcome data of novel RT technologies – in terms of impact on local control and survival, on quality of life resulting from decreased toxicity – however hampers the easy implementation of economic evaluations in RT. It is therefore imperative that the radiotherapy community starts to invest in this type of research. ESTRO has rightly recognized the necessity and imperative that the radiotherapy community starts to invest in this implementation of economic evaluations in RT. It is therefore expectedly a substantial impact on the expenses [18].

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Conclusion

Our study shows that ABC remains an appropriate cost accounting system for RT, helping to determine the impact of novel treatments and techniques on the actual cost. Treatment complexity plays a key role in the observed cost increases at the treatment level, which will inevitably translate into higher RT budgets. It is, however, our firm belief that this improved quality, along with more optimal RT uptake, will ultimately improve patient outcomes.

References