Data Analysis in Radiotherapy Treatments: Planning, Predicting, and Assuring Treatment Quality

Ana Anacleto, Faculty of Economics, University of Coimbra, Coimbra, Portugal
Joana Dias, Inesc-Coimbra, CeBER, Faculty of Economics, University of Coimbra, Coimbra, Portugal

ABSTRACT

Radiotherapy is one of the main cancer treatments available today, together with chemotherapy and surgery. Radiotherapy treatments have to be planned for each patient in an individualized manner. The knowledge acquired from one single treatment can be used to improve the treatment planning and outcome of several other patients. In the last years, attention has been drawn to the added value of using data analysis for radiotherapy treatment planning, prediction of treatment outcomes, survival analysis and quality assurance. In this article, existing literature is reviewed.

KEYWORDS
Cancer, Data Analysis, Prediction, Radiotherapy, Survival Analysis, Synthetic Databases, Treatment Planning

INTRODUCTION

Radiotherapy is one of the possible cancer treatments available, many times used in conjunction with surgery or chemotherapy. The National Cancer Institute states that about half of all cancer patients will be submitted to radiotherapy at least once. Radiation therapy uses high-energy radiation to kill cancer cells, trying at the same time to spare as much as possible all healthy cells. The treatment of each patient is planned using the patient’s medical images, where all the structures of interest are delineated (both the volumes to treat, usually denominated as PTV – Planning Target Volumes – and also the volumes to spare, OAR – Organs At Risk). The planning is individualized for each patient, depending also on the underlying technology that is going to be used (Intensity Modulated Radiation Therapy-IMRT, Cyberknife, Arctherapy, Tomotherapy, for instance). The treatment is planned considering the medical prescription, that usually consists of several different constraints of lower and upper bounds to the dose to be delivered to the different delineated structures. These bounds are usually defined considering existing information of the radiosensitivity of the different organs for the population as a whole. The prescription is not the ideal plan for each given patient, due to the fact that there is not enough information available to determine this best plan. It is, in fact, a compromise solution between what is believed to be a sufficient radiation dose for tumor eradication or control, minimizing the complications in the organs that are not yet affected by the disease (Gulliford, Webb, Rowbottom, Corne, & Dearnaley, 2004). It is necessary to look for the best balance between the

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benefits (survival and life quality) and the induced damages (toxic effects, complications and even financial costs associated with these undesirable effects) (Lambin, van Stiphout, et al., 2013).

In this paper, a review on recent advances of data analysis applied to radiotherapy is presented. Radiation therapy generates discrete, quantitative and structured data that could be exploited to be able to generate comprehensive patient-specific data sets. Moore, Kagadis, McNutt, Moiseenko, & Mutic (2014) state that aggregate data analysis, in conjunction with cloud computing, parallel computation and automation, are likely to be implemented in the clinical oncology in the coming years. The American Society for Radiation Oncology (ASTRO) acknowledges the importance of exploring the opportunities for radiation oncology associated with data availability (Benedict et al., 2016). The European Society for Radiotherapy & Oncology has stated its Vision 2020 as follows: “Every cancer patient in Europe will have access to state of the art radiation therapy, as part of a multidisciplinary approach where treatment is individualized for the specific patient’s cancer, taking into account the patient’s personal circumstances.” Turning this vision into reality will no doubt require the intensive and extensive use of data analysis. This is thus the perfect timing to understand what has already been achieved and what are the challenges ahead.

Data in radiation therapy can be used in three different stages: to plan and manage treatments, to predict outcomes and to measure the quality of the outcome. The use of computerized systems that allow the storage and analysis of data related to treated patients set the grounds for the use of data analysis techniques with the aim of improving radiotherapy treatments. These techniques can be used in different stages of the treatment and with different purposes. They can be used to improve the planning of the treatments, considering similar treated patients, and helping to predict the treatment’s outcomes. The outcome of a radiotherapy treatment should be considered not only from the point of view of tumor control, but also from the point of view of complications that might arise due to the treatment. As a matter of fact, it is not possible to spare all healthy cells, meaning that the functioning of some organs can be jeopardized. Being able to predict a priori what will be the complications associated with different treatments can help to personalize even more the treatment planning, trying to minimize those complications.

This review considers this global view which is a distinguishing feature when compared with other reviews on similar topics. Moreover, a discussion about the possibilities of using synthetic databases as a way of circumventing ethical issues is also promoted.

Figure 1 illustrates the relative number of papers found in each of the categories considered, namely treatment planning, treatment outcome, quality assurance and databases. It is clear that the effort has been much more concentrated on predicting treatment outcomes.

It also interesting to try to find out where these works are published. Figure 2 tries to depict this information, by considering the classification of journals into one of four different types: journals dedicated to oncology and medical physics, journals dedicated to computer science and similar disciplines (including those that deal explicitly with medical applications), and statistical journals. It also clear that most of the works is published in oncology and medical physics journals.

There have been recent reviews of the literature on similar topics. Bibault, Giraud, & Burgun (2016) present a review where methods that could be used to create integrative predictive models in radiation oncology are described. Anacleto & Dias (2016) also present a short review considering predictive models only. El Naqa (2014) reviews recent advances in the use of big data in radiotherapy.

This review is based on papers published in the last ten years, by searching several databases (Google Scholar, Web of Science, PubMed, among others). The main keywords used were “data analysis,” “data mining,” “radiation therapy,” “radiotherapy,” “knowledge-based,” “machine learning,” “cancer,” “carcinoma,” “prediction,” “outcome,” “regression”.

It is also possible to find many applications of data analysis to the problem of image segmentation, related not only to radiotherapy planning (especially in the case of adaptive radiotherapy) but also to many other medical fields. This particular topic is considered out of the scope of this review, due to its specificities.
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