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Overview

Innovations in Radiotherapy Technology

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Abstract

Many low- and middle-income countries, together with remote and low socioeconomic populations within high-income countries, lack the resources and services to deal with cancer. The challenges in upgrading or introducing the necessary services are enormous, from screening and diagnosis to radiotherapy planning/treatment and quality assurance. There are severe shortages not only in equipment, but also in the capacity to train, recruit and retain staff as well as in their ongoing professional development via effective international peer-review and collaboration. Here we describe some examples of emerging technology innovations based on real-time software and cloud-based capabilities that have the potential to redress some of these areas. These include: (i) automatic treatment planning to reduce physics staffing shortages, (ii) real-time image-guided adaptive radiotherapy technologies, (iii) fixed-beam radiotherapy treatment units that use patient (rather than gantry) rotation to reduce infrastructure costs and staff-to-patient ratios, (iv) cloud-based infrastructure programmes to facilitate international collaboration and quality assurance and (v) high dose rate mobile cobalt brachytherapy techniques for intraoperative radiotherapy.

Key words: Brachytherapy; image-guided; innovation; low–middle income; planning; radiotherapy

Statement of Search Strategies Used and Sources of Information

Literature searches were conducted using keyword searches on Pubmed and Web of Science as well as reviewing reference lists of relevant journal articles found through that process. Contributing co-authors also provided new figures based on their own research and the research of their peers.

Introduction

There is a well-documented, urgent, global demand for technologically simpler, affordable, locally sustainable solutions for delivering safe and effective external beam radiotherapy [1–3]. Current approaches are unable to provide economical and well-supported technologies, particularly in low- and middle-income countries where cancer rates are highest, staff shortages are the most severe and resources are severely limited [1]. The outcome of this is little or no access to treatment in 55 countries and shortages in 80 others [2]. Even in the developed world, the tyranny of distance caused by geographically dispersed patient populations (for example in Canada, Australia and the UK) means that the conventional model of highly centralised radiotherapy networks has resulted in significantly reduced rates of radiotherapy utilisation and access to care as a function of the distance away from a centre that a patient lives [4–10].

The recommended minimum infrastructure requirements from International Atomic Energy Agency (IAEA) guidelines for a basic radiotherapy centre are: a teletherapy unit, a brachytherapy unit, a mould room, a simulator and some basic dosimetric quality assurance equipment [11]. For staffing, the minimum IAEA recommendations are one treatment planner per 300 patients and one radiation physicist per 400 patients receiving treatment annually [11]. It is estimated that, by 2020, low- and

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middle-income countries will have deficits of about 10 000 teletherapy units, 12 000 radiation oncologists, 10 000 medical physicists, and 29 000 radiation therapy technologists [2,11]. These estimates are based on data sets in the public domain (e.g. IAEA), with staffing levels based on recommendations from the European Society for Radiotherapy & Oncology and IAEA [12]. Hence, there is a crucial need for radiation therapy staff at all levels, in addition to the need for corresponding training and ongoing professional development for these individuals. The training burden is enormous: for medical physicists, most guidelines recommend a 2–3 year internship or residency, often after completion of medical physics graduate school [13–15]. Although various educational initiatives bring young radiation oncologists and medical physicists from low- and middle-income countries to academic cancer centres in high-income countries, they are often insufficient in addressing the current and future staffing deficits [16]. Furthermore, the failure of professionals who receive training in a high-income country to return home after training in the high-income countries is a historical challenge in radiation oncology and other fields [17–19].

Developing and executing on innovative and locally sustainable radiotherapy solutions requires co-operation and co-ordination between academia, hospital, government, private enterprise and non-governmental organisations. There are many marvellous recent examples that serve to highlight the impact strong collaborations can have on redressing the staggering global underutilisation of radiotherapy (e.g. [20,21]).

Here we describe some innovative technology developments across the radiotherapy ecosystem with the potential to provide treatments with affordable state-of-the-art technology. Utilising real-time control systems, automation and cloud-based infrastructure that is now widely available allows lean innovation in radiotherapy technology with the potential to deliver affordable solutions that are neither obsolete nor second-rate [22,23] and enables collaboration across borders. Each of these innovations targets a different part of the radiotherapy treatment ecosystem but all aim to transform global access to safe, high-quality, accurate radiotherapy.

Automated Planning

In many countries, the roles of treatment planner and medical radiation physicist are combined. In some countries, planning responsibilities even fall to radiation oncologists [12]. For both of these scenarios, fully automated treatment planning could reduce the severe workforce shortages of medical physicists and radiation oncologists [11]. Automated planning requires a much-reduced skillset compared with manual planning, meaning that training requirements could be considerably lowered and that lesser skilled staff could manage routine planning activities.

Before 2000, much work was spent on automation of treatment-planning decisions in conventional radiotherapy, such as determining wedge filters and beam weights [24,25] and beam orientations [26]. With the emergence of intensity-modulated radiotherapy (IMRT) [27–29], most of these efforts were redirected to the automatic delineation of normal tissues and targets [30,31] and plan optimisation [27,32]. However, the clinical introduction of automated treatment planning overall has been slow. The many reasons for this include the complexity of several advanced treatments (e.g. IMRT) that have become the standard of care in high-resource settings, and the requirements for these treatments (e.g. accuracy of normal tissue delineation) can be very high. A recent point/counterpoint article [33] in the journal *Medical Physics* debated whether, within the next 10 years, treatment planning will become fully automated without the need for human intervention. The arguments against automated treatment planning were focused on examples of treatments that remain difficult to automate, such as bilateral post-implant chest wall irradiation. There are, however, many simpler clinical situations that are possible to fully automate. Examples include four-field box treatments used to treat cervical cancer, which a group at The University of Texas MD Anderson Cancer Centre has automated as part of a project to create a radiation planning assistant for automatically planning patients for low-resource settings [34]. Their approach, illustrated via a process-oriented workflow in Figure 1, uses standardised treatment approaches to automatically create radiation plans for cervix, breast and head/neck treatments, including automatic secondary checks of many of the planning tasks, including contouring [35].

Although automated treatment planning has yet to be fully realised in a clinical setting, it will probably occur within 5 years. Much of the necessary research and development has already taken place, leaving the essential steps of integration (into a commercial planning system), deployment and training. Such an achievement could realise significant reductions in the number of physicists needed for planning purposes.

Real-time Adaptive Image-guided Radiotherapy

The inclusion of image guidance and adaptation enables a change in the patient set-up paradigm, from the current iterative external/internal alignment to a patient adaptive approach. Currently, patients are typically set-up for treatment using one or a combination of room lasers, indexing systems and X-ray imaging. The patient position is measured, corrected and often measured again before treatment. In the patient adaptive approach, variations in the patient position, inter- and intrafraction changes can be dosimetrically accounted for, even for large displacements. For example, for conformal prostate radiotherapy, patient positioning shifts of up to 10 cm could be robustly adapted to via geometry-based adaptation [36] and intrafraction organ motion of 2 cm could be similarly accounted for [37]. For IMRT it has been shown that, with geometry-based adaptation, plan quality was maintained despite target rotations of up to five degrees and translations up to 15 mm