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TOPICAL DEBATE

Kilovoltage therapy is well and truly alive and needed in a modern radiotherapy centre

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Introduction and overview: Clive Baldock, moderator

After Wilhelm Röntgen discovered "a new kind of ray" in November 1895 [1] he showed radiographs of his wife's hand to colleagues [2]. As soon as March 1896 radiographs were being used on the battlefield [2] followed by the first publication of clinical radiographs in April 1896 [3]. By July 1896 X-rays were being utilised therapeutically for the first time, arguably by Victor Despeignes who attempted to treat stomach cancer [4].

Since the earliest days of using X-rays clinically there have been many developments in their therapeutic use [5]. In recent years, major advances have utilised technologies for planning and delivering highly conformal radiation dose distributions in association advanced dosimetry techniques [6, 7]. Advanced external beam techniques include intensity modulated radiation therapy, tomotherapy and volumetric modulated arc therapy. Of particular note is the emergence of magnetic resonance imaging (MRI) systems integrated with linear accelerators (linacs), commonly known as an MR-linacs which have become established for the purposes of MR image-guided radiation therapy (MRgRT) systems [8] for MR-linacs.

With such advances in the therapeutic use of X-rays it has often been questioned whether therapeutic kilovoltage X-rays still have a role clinically. Kilovoltage X-ray beams, which have the property that the maximum dose occurs very close to the surface, are predominantly used in the treatment of skin cancers. Kilovoltage X-ray beams are also used in intra operative units, animal irradiators and in on-board imagers on linear accelerators.

In this Topical Debate, Drs Robin Hill and David Eaton debate whether kilovoltage therapy is well and truly alive and needed in a modern radiotherapy centre.[1]

Dr Robin Hill works at the Chris O'Brien Lifehouse in Sydney, Australia where he is the Head of Research and Education in Radiation Oncology Medical Physics and an Adjunct Senior Lecturer in the School of Physics at the University of Sydney. Robin's first interest in kilovoltage X-ray beams came about from the opportunity to complete an Honours project at the University of Adelaide under the guidance of Professor Alun Beddoe. This was followed by an MSc in Medical and Health Physics which led to moving to Sydney to work as a clinical radiotherapy physicist. His interest in kilovoltage X-ray beams continued when he subsequently undertook research into his PhD through the University of Sydney for which he graduated in 2012. This work lead to the publication of the review paper *Advances in kilovoltage X-ray beam dosimetry* in Physics in Medicine and Biology. While his interest covers different aspects of clinical radiation oncology and medical physics, he continues to engage in research in kilovoltage X-ray beam dosimetry. He is a member of the IAEA working group updating the chapters in the TRS398 Code of Practice relevant to kilovoltage X-ray beams and a member of the editorial board of Biomedical Physics and Engineering Express.

Dr David Eaton studied physics at the University of Cambridge in the UK, and first became aware of medical physics through a short series of lectures in his final year. He was drawn to the mixture of applied science and practical human benefits, completing his training as a clinical scientist at Addenbrooke's hospital in the same city. From

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[1] Contributors to Topical Debates are selected for their knowledge and expertise. Their position for or against a proposition may or may not reflect their personal opinions.

there, he has worked in a number of UK centres as a clinical radiotherapy physicist, and was also the lead physicist for the national radiotherapy trials quality assurance group (RTTQA). In this role he led a credentialing programme for stereotactic radiosurgery, as well as the dosimetry audit programme for the group. He currently leads the radiotherapy physics service at Guy's and St Thomas' Hospitals in London. Throughout his career, he has also pursued research and development alongside clinical work. His PhD was in practical dosimetry for intraoperative radiotherapy, and other interests have included kilovoltage and megavoltage dosimetry, radiation protection and clinical trials QA. These have led to about 50 publications and 10 book chapters, including co-editing Institute of Physics and Engineering in Medicine (IPEM) Report 75 on shielding design for radiotherapy, and the revised IPEM/NPL code of practice for megavoltage therapy dosimetry. He is a fellow of IPEM, past chair of their radiotherapy special interest group, and currently an associate editor for the British Journal of Radiology and the Journal of Medical Physics. The past year has seen many restrictions, but working from home a few days each week has allowed him to enjoy more time with his children, and the whole family have explored many muddy local woodlands together. He has also been watching classic sci-fi drama Battlestar Galactica, exploring space, leadership and the nature of humanity.

For the proposition: Robin Hill

Opening Statement

Kilovoltage X-ray beams have a long and established history of being used to treat skin cancers, keloids and other conditions and so are an important component of a comprehensive radiotherapy centre. It is just over 125 years from when Wilhelm Roentgen reported the discovery of X-rays at his lab in 1895 [9]. X-ray tubes were developed and used all around the world including clinical experiments on their possible use for different diseases. It is of note that in 1904, Leopold Freund published the textbook *Elements of general radio-therapy for practioners* [10]. It is from these radiotherapy pioneers we have established that kilovoltage X-ray beams are effective for treating skin cancers with good outcomes for our patients [11]. The simplicity of kilovoltage treatments provides other benefits to these patients. Radiotherapy departments are busy and efficient to ensure we treat many patients each day. However, patient numbers on kilovoltage units tend to be lower and as a radiation oncologist once stated: "kilovoltage treatments can be given with a lot of TLC (tender loving care)".

From a medical physics perspective, kilovoltage radiotherapy provides an opportunity for us to engage in and stay connected to experimental physics work in the clinic. It could be argued that advanced dose calculation algorithms, image fusion and VMAT, for example, are based more on mathematical algorithms and often embedded within black box solutions from the vendors. The dosimetry and treatment planning of kilovoltage X-ray beams is challenging and often seemingly contrary to megavoltage X-ray beams [12–14]. It is important for our medical physics trainees who need a solid foundation of the physics involved in radiotherapy [15]. Access to a kilovoltage treatment unit is one important key to develop that strong foundation in clinical training.

The importance of the accuracy of kilovoltage beam dosimetry is recognised by the numerous codes of practice for reference dosimetry of kilovoltage beams [16, 17]. In fact, kilovoltage dosimetry is so important, the IAEA provides two separate sections in the TRS398 Code of Practice for both low and medium energy X-rays while the megavoltage X-ray beam dosimetry recommendations are contained within one section [17]. In addition, primary standard dosimetry laboratories around the world continue to maintain and develop their standards for kilovoltage X-ray beams [18, 19].

This means that kilovoltage therapy is well and truly alive and is needed in a modern radiotherapy centre to ensure that our patients have the best clinical options for their treatments.

Against the proposition: David Eaton

Opening Statement

Kilovoltage X-rays have been used since the earliest days of radiotherapy, but the standard technique has changed little in decades and lacks many of the hallmarks of modern radiotherapy. There is no computerised treatment planning based on CT or MR imaging, no intensity-modulation of delivered beams and no image-guided treatment verification using CBCT, MRI or ultrasound.

A survey of practice in the UK from 2015 found that 27% of centres had no kilovoltage unit [20]. The main reasons given for this absence was the use of electrons or HDR brachytherapy instead, and insufficient patient numbers. Of the centres with a kilovoltage unit, 35% were more than 10 years old and 73% had no plans for replacement. Although a few centres reported treating hundreds of patients each year, 41% treated less than 50 patients per year. Low equipment utilisation is an inefficient use of medical physics and radiotherapy resources, and also risks major human errors occurring through lack of familiarity.

Kilovoltage X-rays are typically valued for their steep dose fall-off with depth in tissue, however they are not the only modality with this selling point. Every talk on proton therapy in the world probably starts with a depiction of the Bragg peak, but it should be remembered that electrons also demonstrate this effect. Although greater scatter leads to a broader peak in this case, the very low exit dose remains. For example, to treat a 10 cm lesion to 90% of maximum dose at 1 cm depth, 150 kVp X-rays would still give approximately 70% at 3 cm depth, whereas with a 6 or 9 MeV electron beam and appropriate bolus the dose could be as low as 5%. Kilovoltage X-rays can also give 3–4 times higher absorbed doses to bone compared to soft tissue, which is rarely accounted for [21]. Thirdly, kilovoltage treatments are more sensitive to small variations in stand-off across a treatment area, for example a 5 mm variation could lead to 5% differences at 20 cm source-to-surface distance, but only 1% at 100 cm.

My esteemed opponent has reviewed areas of development in kilovoltage dosimetry [13], which have provided a rich vein of research and professional guidance for physicists, right up to the present day [22–24]. However, the clinical acceptance of techniques such as electronic brachytherapy for partial breast or skin treatments is not widespread. Several professional bodies have urged caution regarding their use outside of oncology departments, for example in stand-alone dermatology clinics [25]. Use of radiation by unfamiliar staff groups, relying on manual calculations, and lack of integration with oncology management systems (even within an established radiotherapy service) risks major incident that can have catastrophic consequences [26].

In conclusion, there may well be a role for kilovoltage X-rays in specialist high volume centres and in some niche research applications, but it is not needed in every modern radiotherapy centre.

For the proposition: Robin Hill

Rebuttal statement

My esteemed opponent has made excellent points regarding how we can treat superficial cancers in the modern radiotherapy clinic. Many options have been proposed as alternatives and introduced into the clinic such as electronic brachytherapy, HDR brachytherapy applicators, further of megavoltage electrons beams and one could even consider very low energy proton beams. However, none of these provide the simplicity, functionality and dosimetric properties of a therapeutic kilovoltage X-ray beam. This does however highlight that additional clinical research would be warranted in establishing some of these newer treatment techniques. That could include large scale clinical trials of comparing kilovoltage beams against these newer techniques.

One argument that does appear against kilovoltage X-ray beams is that the equipment is unfamiliar and mistakes can be easily made. My opponent has rightly highlighted some of the possible errors that can occur and their dosimetric consequence. However, this is the same for any new equipment in a radiotherapy department. Current recommended practice is such that appropriate training, documentation and quality assurance is established in order to minimise the possibility of errors. This includes participating in ongoing audits such as recent Australian Clinical Dosimetry Service (ACDS) audits to ensure compliance with national standards. By following this process, any radiotherapy department looking to establish a kilovoltage treatment service can do so with confidence in providing quality care. In cases where the kilovoltage X-ray unit cannot be directly integrated into the radiation oncology information system (including the record and verification software), safety processes can be developed based on well-established process like checklists and risk assessments such as those published in the AAPM TG-100 report [22, 27].

Our patients deserve to have the best possible care in their radiotherapy and this includes the use of kilovoltage X-ray beam therapy for superficial cancers. For that reason, I believe that kilovoltage therapy is well and truly alive and needed in a modern radiotherapy centre.

Against the proposition: David Eaton

Rebuttal statement

'This kind of radiotherapy might well be advantageous in treating certain conditions, but it is not widely practised, and requires specialist physics knowledge to deliver accurately, otherwise quality will be compromised'. These concerns have previously been discussed in this journal for brachytherapy [28], but could they also be applied to external beam kilovoltage therapy? To make the case to funders or hospital directors to invest in these specialist techniques requires clear statement of clinical benefits over the alternatives, clear development of new science, and clear mitigation of risks from lack of expertise or familiarity.

In the field of intraoperative radiotherapy for breast treatment, several groups including my own tried to determine a robust framework for dosimetry, in the face of steep dose gradients and substantial energy dependence of dosimeters [29]. However, we lacked the tools to accurately measure the dose to very small volumes, and relied on manufacturer provided equipment for output determination, leading to partial volume errors of 14–30% that were only recently demonstrated through Monte Carlo simulations [30]. Should we have challenged our own assumptions more at the time? In hindsight yes, but this lesson is a humble reminder that there is much we do not know, and part of the role of a medical physicist is to accept our limitations and mistakes, yet nonetheless continually strive to improve our understanding going forwards.

I agree with my esteemed opponent that training is a vital aspect of ensuring safety and accuracy with less common techniques. The role of inter-centre audit is also crucial to avoid substantial errors [31, 32]. This debate also depends on geography. In regions where several treatment centres are in close proximity, it makes sense to limit specialist techniques to just a few of these. However, in regions where centres are more widely spaced, patient access may require all centres to offer a full range of services. In this model, mutual support and remote collaboration will be vital to ensure high quality services. If kilovoltage therapy is to be kept alive in the modern radiotherapy centre, then the medical physics community will need to step up to these challenges in every region, to the benefit of all our patients.

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