Physica Medica xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Original paper

Measuring dose from radiotherapy treatments in the vicinity of a cardiac pacemaker

Samuel C. Peet [a,c,*], Rachael Wilks [a], Tanya Kairn [b,c], Scott B. Crowe [a,c]

[a] Royal Brisbane and Women's Hospital, Butterfield Street, Herston, QLD 4029, Australia
[b] Genesis Cancer Care Queensland, 1/40 Chasely Street, Auchenflower, QLD 4066, Australia
[c] School of Chemistry, Physics and Mechanical Engineering, Queensland University of Technology, GPO Box 2434, Brisbane, QLD 4001, Australia

ARTICLE INFO

Article history:
Received 16 June 2016
Received in Revised form 3 November 2016
Accepted 7 November 2016
Available online xxxx

Keywords:
Radiotherapy
Out-of-field dose
Pacemaker
Cardiac device

ABSTRACT

This study investigated the dose absorbed by tissues surrounding artificial cardiac pacemakers during external beam radiotherapy procedures. The usefulness of out-of-field reference data, treatment planning systems, and skin dose measurements to estimate the dose in the vicinity of a pacemaker was also examined. Measurements were performed by installing a pacemaker onto an anthropomorphic phantom, and using radiochromic film and optically stimulated luminescence dosimeters to measure the dose in the vicinity of the device during the delivery of square fields and clinical treatment plans. It was found that the dose delivered in the vicinity of the cardiac device was unevenly distributed both laterally and anteroposteriorly. As the device was moved distally from the square field, the dose dropped exponentially, in line with out-of-field reference data in the literature. Treatment planning systems were found to substantially underestimate the dose for volumetric modulated arc therapy, helical tomotherapy, and 3D conformal treatments. The skin dose was observed to be either greater or lesser than the dose received at the depth of the device, depending on the treatment site, and so care should be if skin dose measurements are to be used to estimate the dose to a pacemaker. Square field reference data may be used as an upper estimate of absorbed dose per monitor unit in the vicinity of a cardiac device for complex treatments involving multiple gantry angles.

1. Introduction

Implantation rates of artificial cardiac devices have progressively increased over the last several decades. A recent survey of pacemaker and implantable cardioverter-defibrillator implantation rates reported global growth in annual implantations between 2005 and 2009 [1]. Cardiovascular disease and cancer are both primarily associated with the elderly, and so with an ageing population the intersection between these two patient groups will continue to grow [2]. Additionally, there are several other risk factors that pertain to both cancer and cardiovascular disease simultaneously, further conflating the two groups [3]. A substantial portion of these patients will be prescribed radiation therapy, and so the incidence of cardiac devices in radiotherapy clinics can be expected to rise.

Cardiac device manufacturers suggest dose limits to avoid damaging the radio-sensitive electronics contained within a device. These limits are manufacturer specific, and can range from approximately 0 to 30 Gy [4]. There are several classes of malfunction that may be caused by irradiation: transient pacing effects that cease following exposure, memory corruption that affects the execution of device firmware, and lasting damage that renders a device unsuitable for clinical use [5,6].

Many retrospective studies have been reported in the literature investigating potential links between treatment modalities and pacemaker malfunctions. A recent review of this body of work concluded that while device malfunctions do increase with dose, beam energy and neutron activation also contribute to the failure rate [7]. Clinical guidelines for classifying the risk to patients using the estimated dose to the pacemaker have been developed by Hurkmans et al. [8]. For patients considered pacing-independent, a pacemaker dose less than 2 Gy is considered low-risk. A dose between 2 Gy and 10 Gy is categorised as intermediate-risk to all patients, and extra precautions should be taken such as having a crashcart present during radiotherapy. A dose greater than 10 Gy is classed as high-risk, and options such as relocating the pacemaker before radiotherapy begins should be investigated.

* Corresponding author at: Royal Brisbane and Women's Hospital, Butterfield Street, Herston, QLD 4029, Australia.
E-mail address: Samuel.Peet@health.qld.gov.au (S.C. Peet).

http://dx.doi.org/10.1016/j.ejmp.2016.11.010
1120-1797/

The dose delivered in the vicinity of a cardiac device can be estimated in several ways. Firstly, manual calculations can be performed using out-of-field reference data presented in the literature [9,10]. Alternatively, treatment planning systems can be used to provide estimates. However, planning systems are not designed to accurately calculate out-of-field dose, and as such their performance is often poor [11–13]. Additionally, out-of-field doses have been shown to be substantially greater during intensity modulated treatments compared to 3D conformal treatments [14].

No study has yet characterised the out-of-field dose delivered in the vicinity of a physical cardiac device. Investigations have been performed into cardiac devices distorting beam profiles inside of primary treatment fields, but did not consider softer out-of-field spectra [15,16]. Also, the dose delivered to the location of a cardiac device during clinical treatments has been studied with a variety of dosimeters, however, no physical cardiac device was included in the methods [17]. Similarly, the efficacy of lead shielding has been investigated without a physical device present [18]. Therefore, the objective of this study was to characterise the out-of-field dose delivered in the vicinity of a physical cardiac device in a range of reference and clinical scenarios. These measurements could then be used to examine the validity of applying out-of-field reference data, treatment planning system calculations, and skin dose measurements to estimate the dose in the vicinity of a cardiac device.

2. Methods

2.1. Artificial cardiac pacemaker

The cardiac device used in this study is a St. Jude Medical Victory XL DR 5816 dual chamber implantable pacemaker (St. Jude Medical, Saint Paul, USA), with maximum dimensions $52 \times 44 \times 6\ mm^3$. The device consists of three major parts: a titanium-alloy casing, battery, and pacing circuitry. A diagram of the pacemaker is shown in Fig. 1 demonstrating the location of the constituent parts.

2.2. Measurement assembly

In order to reproduce the position and orientation of the pacemaker reliably between measurements, a frame was designed in `Blender` (Blender Foundation) modelling software and printed on a Formlabs Form 1+ stereolithographic printer (Formlabs, Somerville, USA). Formlabs grey photopolymer resin (formulation FLGPGR02) was used, having radiological thickness $1.07\ g/cm^2$. The frame featured a cut-out for the cardiac device, tapered edges to reduce air pockets surrounding the frame, and slots to immobilise either film or optically stimulated luminescent dosimeters (OSLDs) on both sides of the pacemaker. The pacemaker can be seen inside the frame in Fig. 2.

The pacemaker and frame formed the core of the measurement assembly (Fig. 3a). The assembly allowed for the measurement of absorbed dose at four different depths during each irradiation. The assembly was built upon a Rando anthropomorphic phantom (Radiology Support Devices, Long Beach, USA) and consisted of several layers. First, a piece of film was placed on the phantom surface (measurement position M_{phant}) and covered with 5 mm of jelly bolus (Jel Products Australia, Singleton, Australia). Next, the pacemaker and frame were placed on the bolus with film directly abutting both the deep surface of the pacemaker (measurement position M_{deep}) and the superficial surface of the pacemaker (measurement position M_{super}). The frame was then covered with a further 5 mm layer of bolus to simulate skin, and a final piece of film was placed on the skin surface (measurement position M_{skin}). If desired, any piece of film could be replaced with a frame to support OSLDs, as shown in Fig. 2b.

2.3. Film dosimetry

Measurements were performed using $5 \times 5\ cm^2$ pieces of Gaf-Chromic EBT3 radiochromic film (International Specialty Products, Wayne, USA). Each film piece was scanned before and after irradiation using an Epson 10000XL flatbed scanner (Seiko Epson Corp., Nagano, Japan). In all cases, post irradiation scanning was completed one week after exposure. Post-irradiation darkening has been shown to approach a steady-state at around 24 h, and a one week delay allowed for a consistent readout time over the length of the study [19]. A frame was constructed out of scrap film and attached centrally on the scanner bed to allow for precise and reproducible placement of each consecutive film piece. An unexposed reference piece of film was also placed on the frame during every scan to allow for the correction of any variation in scanner light output [20]. The orientation of the film was monitored and kept constant at all times. Scans were performed in transmission mode at 75 dpi resolution, and saved as 48 bit (16 bit per channel) RGB Tagged Image File Format (TIFF) files.

The red-channel mean pixel values and standard deviations of two $1 \times 1\ cm^2$ regions of interest (ROI) were extracted from each scan, corresponding to the location of the pacemaker battery and circuitry shown in Fig. 1. All processing was performed using

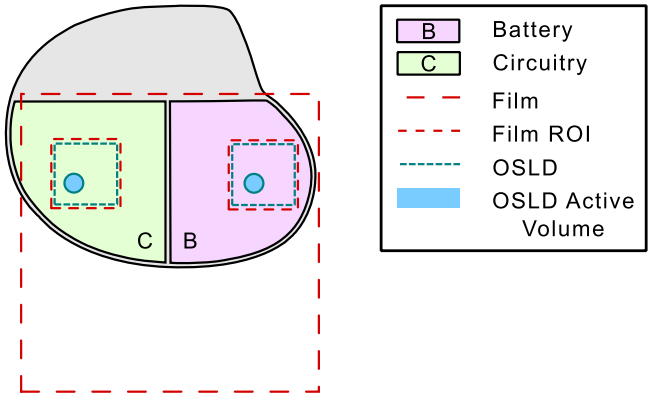

Fig. 1. A diagram of the St. Jude Medical Victory XL DR 5816 pacemaker used in this study. The interior of the unit can be broken into two sections: battery, and circuitry. The positions of measurement films and OSLDs are shown overlaid onto the diagram.

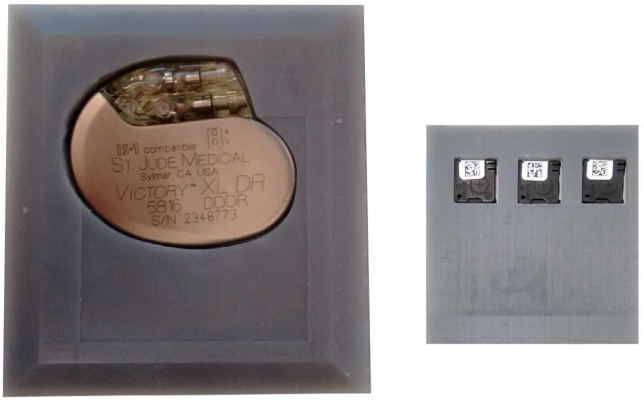

Fig. 2. (a) The cardiac device placed in the supporting frame. The frame was printed with a Formlabs Form 1+ stereolithographic printer and allows measurement films and OSLDs to be placed in reproducible positions on either side of the device. (b) An OSLD frame that can attach to either side of the the pacemaker frame.

Please cite this article in press as: Peet SC et al. Measuring dose from radiotherapy treatments in the vicinity of a cardiac pacemaker. Phys. Med. (2016), http://dx.doi.org/10.1016/j.ejmp.2016.11.010