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Dosimetry of dose distributions in radiotherapy of patients with surgical implants

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AUTHOR-HIGHLIGHTS

- We measured doses at contact surfaces between titanium implants and RW3 phantom.
- We measured doses at contact surfaces between resorbable implants and RW3 phantom.
- We compared doses measured on contact surfaces and doses in homogeneous phantom.
- Doses at contact surfaces between RW3 phantom and titanium were distorted about 8–9%.
- Doses at RW3 phantom and resorbable implant contact surfaces were distorted about 2%.

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ABSTRACT

The investigation was performed in order to evaluate the use of Gafchromic EBT films for measurements of dose distributions created during radiotherapy in tissues surrounding titanium or resorbable implants used for joining and consolidating facial bones. Inhomogeneous dose distributions at implant–tissue interfaces can be the reason of normal tissue complications observed in radiotherapy patients after surgery with implants. The dose measured at a depth of 2.5 cm on contact surfaces, proximal and distal to the beam source, between the titanium implant and the phantom material was 109% and 92% respectively of the reference dose measured in a homogeneous phantom. For the resorbable implants the doses measured on the proximal and the distal contact surfaces were 102% and 101% respectively of the reference dose. The resorbable implants affect the homogeneity of dose distribution at a significantly lesser degree than the titanium implants. Gafchromic EBT films allowed for precise dose distribution measurements at the contact surfaces between tissue equivalent materials and implants.

1. Introduction

Radiochromic dosimetry films became an alternative for the well-known radiographic films, because of the near-tissue equivalent mean atomic number and electron density. The radiochromic films do not need chemical processing and are not sensitive to room light. Because of negligible thickness, the radiochromic films seem to be the best 2D detector for the dosimetry at the contact surfaces between materials with different physical and chemical properties, such as tissues and metallic reconstruction implants.

The treatment of patients with advanced head and neck cancer is a complex issue and requires a combined therapy consisting of surgery, radiation therapy and sometimes also chemotherapy. In the process of bone fixation, the most commonly used are plates and screws made of titanium or titanium alloy. Titanium provides high mechanical strength, biocompatibility compared with other metals, resistance to corrosion and biotolerance in the tissue environment. Reconstruction implants made of metal provide quick and one-step consolidation of facial bones after oncological surgery resections. This technique ensures the early reconstruction and restoration of functions with acceptable morbidity. Many patients who underwent such treatment had indications for post-operative radiotherapy. Our attention was drawn to the evaluation of the impact of the presence of metallic or resorbable implants on the

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uniformity of dose distribution during radiotherapy. The widespread availability of resorbable implants has prompted us to perform a comparative study of effects that resorbable and titanium implants exert on patients requiring post-operative radiotherapy. The effects of an increase of the dose in the area in front of the metal layer and the decrease of the dose behind it are well-known and described for such metals as aluminium, steel, copper, cadmium or lead (Menard et al., 1999; Eichhorn and Gerlach, 1988; Ravikumar et al., 2001, 2004). An empirically derived formula for estimating doses in the vicinity of metal plates was proposed (Das and Kahn, 1989). On the other hand, Studer et al. (2004, 2006) investigated the influence of dose distribution obtained with different radiotherapy techniques on the risk of osteoradionecrosis of the mandible. Basing on research results obtained with thermoluminescent detectors (TLDs) (de Mello-Filho et al., 2003; Allal et al., 1998; Rozema et al., 1990) or ionization chambers (Shimozato et al., 2010; Das et al., 1990), we decided to use films. Kodak XV-2 radiographic films, formerly used in a similar experiment (Melian et al., 1999) contained metal halides as an active component and therefore were not tissue equivalent. Following other authors we decided to use radiochromic films (Son et al., 2012) in our experiment comparing the dose distribution in the vicinity of titanium or resorbable implants (Loo et al., 2005; Rozema et al., 1990).

2. Materials and methods

The study was performed in two stages. In the first stage, the dose distributions measured with radiochromic films in tissue equivalent phantom in the presence of both types of implants were evaluated. In the second stage, the results of the measurements of dose distributions were compared with calculations performed with the Oncentra MasterPlan treatment planning system for the two types of implants. The same arrangement of implants in the phantom was used in both study stages. In this study, the standard equipment used for treatment planning and the treatment of patients, as well as standard diagnostic and therapeutic procedures, was used. Compact 2-0 Mandible-Lock pure titanium implants (Synthes, USA) and CPS 2-0 resorbable implants composed of L-lactide (LPLA), D,L-lactide (DLPLA), Poliglycolide (PGA) and Trimethylene carbonate (TMC) polymers (Inion, Finland) were irradiated. Implants of both types (titanium or resorbable) are designed for joining and consolidating the same type of facial bones of the skull. The titanium implants are strip-like plates with holes (see Fig. 1).

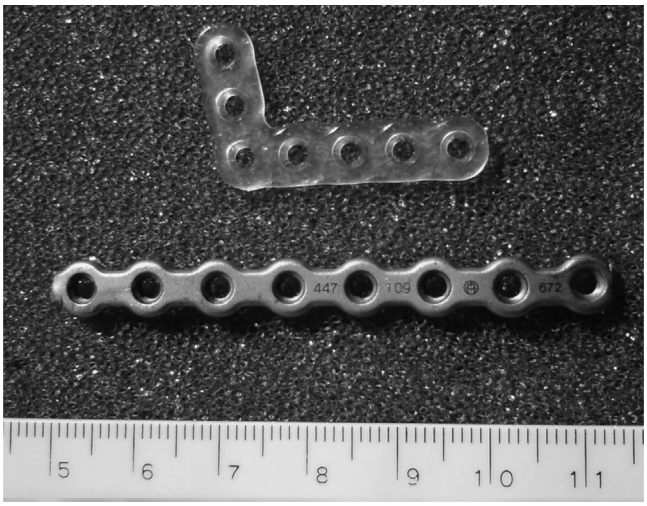

Fig. 1. The implants investigated in this study. In upper part of the photo – CPS 2-0 resorbable implant composed of L-lactide (LPLA), D,L-lactide (DLPLA), Poliglycolide (PGA) and Trimethylene carbonate (TMC) polymers (Inion, Finland). In lower part of the photo – Compact 2-0 Mandible-Lock pure titanium implant (Synthes, USA).

2.1. Measurements

During the measurements, the plates 30 cm × 30 cm in size and 1 cm thick, made up of RW3 water equivalent material, and the 0.5 cm thick tissue equivalent gel boluses of 30 cm × 30 cm size were used. The implants were positioned on the top of a stack of 10 RW3 plates, between the two gel blankets so that no air spaces were formed around the implants. On the top of the gel blankets, the two polystyrene plates were placed in order to obtain an electron equilibrium in the material surrounding the implants. In order to measure the absolute dose distribution, Gafchromic EBT (ISP, USA) dosimetry films were used (Devic et al., 2005).

Gafchromic EBT films are made of 97 μm thick clear polyester sheets, between which two 17 μm thick active layers are sandwiched, with a 6 μm thick single surface layer (Lewis, 2010). The active layers consist of lithium pentacosa-10,12-diynoate (LiPCDA) monomers that polymerise when they are irradiated with UV or X-rays. The monomer molecules of LiPCDA have to be parallelly oriented in order to react to the radiation to form a polymer. Photopolymerization of LiPCDA changes the film colour to blue proportionally to the exposure to the radiation. The films do not need any chemical processing. The atomic compositions of Gafchromic EBT films are near tissue equivalent (Fuss et al., 2007) with effective atomic numbers $Z_{eff} = 6.64–7.14$ for the compounding materials (Lewis, 2010) similar to Z_{eff} for water (Taylor et al., 2012).

The use of Gafchromic films for dose distribution measurements in radiotherapy and for verification of treatment planning system calculations is a common method (Poledniak et al., 2007; Prokic et al., 2012). In our experiment, the films were placed in the phantom, in the immediate vicinity of the implants. The experimental set-up and the location of the films are presented in Fig. 2. During the irradiation and during the film processing procedures, the films were handled in accordance with the "Recommendations of the AAPM Radiation Therapy Committee Task Group 55" (Niroomand-Rad et al., 1998). Next, the phantom with the implants and the films were irradiated perpendicularly to the film surface with a 4MV X-ray beam from a Varian Clinac 600 C/D medical linear accelerator . All films used in measurements were from the same batch. Due to the low sensitivity of the Gafchromic EBT films (Chelminski et al., 2010), the films at the implant depth were irradiated with 10 cm × 10 cm wide fields to doses of around 400 cGy. The films were placed in the phantom at depths of 2 cm, 2.5 cm (under and above the implant) and 3 cm. For the 4 MV X-ray beam used, the percentage depth dose (PDD) in water of these depths was 96.2%, 93.9% and 91.6%. The absolute doses in water at depths where the films were positioned were assessed using the PDD value (60.5%) for the reference depth of 10 cm – at which the accelerator output was calibrated to 0.70 cGy/MU. This resulted in different doses at different depths (425.66 cGy at 2 cm, 416.61 cGy at 2.5 cm and 404.87 cGy at 3 cm). The measurements were performed for three situations: without implants, with the titanium implant and with the resorbable implant. For comparison, the dose measurements using the films were taken without the implants at the same depths. The films were digitized with an Epson 10000XL Expression flat bed scanner (Devic et al., 2005; Lynch et al., 2006), 24 h after irradiation, in order to achieve stable colouration (Cheung et al., 2005). Before the scanning of each film, the scanner with the film was warmed by performing three preview scans to obtain a stable temperature for each film (Rink et al., 2008). The digital images of the films were converted to dose maps and evaluated using 3Cognition FilmQA software using only a red colour channel (Butson et al., 2005).