International Journal of
Radiation Oncology
biology • physics

www.redjournal.org

Physics Contribution

An Innovative Tool for Intraoperative Electron Beam Radiotherapy Simulation and Planning: Description and Initial Evaluation by Radiation Oncologists

Javier Pascau, Ph.D.,[*,§] Juan Antonio Santos Miranda, M.D., Ph.D.,[†,¶] Felipe A. Calvo, M.D., Ph.D.,[†,¶,‡] Ana Bouché, M.D.,[‖] Virgina Morillo, M.D.,[‖] Carmen González-San Segundo, M.D., Ph.D.,[†,¶] Carlos Ferrer, M.D., Ph.D.,[‖] Juan López Tarjuelo, M.Sc.,[‖] and Manuel Desco, M.D., Ph.D.[*,§]

[*]Unidad de Medicina y Cirugía Experimental, [†]Servicio de Oncología Radioterápica, and [‡]Departamento de Oncología, Hospital General Universitario Gregorio Marañón; [§]Departamento de Bioingeniería e Ingeniería Aeroespacial, Universidad Carlos III de Madrid; and [¶]Facultad de Medicina, Universidad Complutense de Madrid, Madrid; and [‖]Consorcio Hospitalario Provincial de Castellón, Castellón, Spain

Received Sep 1, 2011, and in revised form Dec 12, 2011. Accepted for publication Dec 18, 2011

Summary

The lack of specific treatment planning tools limits the spread of Intraoperative Electron Radiation Therapy. An innovative simulation and planning tool is presented. Applicator positioning, isodose curves, and dose−volume histograms can be estimated for previously segmented regions to treat/protect. Evaluation by three radiation oncologists on 15 patients showed high parameter agreement in nine cases, demonstrating the possibilities in cases involving different anatomical locations, and

Purpose: Intraoperative electron beam radiation therapy (IOERT) involves a modified strategy of conventional radiation therapy and surgery. The lack of specific planning tools limits the spread of this technique. The purpose of the present study is to describe a new simulation and planning tool and its initial evaluation by clinical users.

Methods and Materials: The tool works on a preoperative computed tomography scan. A physician contours regions to be treated and protected and simulates applicator positioning, calculating isodoses and the corresponding dose−volume histograms depending on the selected electron energy. Three radiation oncologists evaluated data from 15 IOERT patients, including different tumor locations. Segmentation masks, applicator positions, and treatment parameters were compared.

Results: High parameter agreement was found in the following cases: three breast and three rectal cancer, retroperitoneal sarcoma, and rectal and ovary monotopic recurrences. All radiation oncologists performed similar segmentations of tumors and high-risk areas. The average applicator position difference was 1.2 ± 0.95 cm. The remaining cancer sites showed higher deviations because of differences in the criteria for segmenting high-risk areas (one rectal, one pancreas) and different surgical access simulated (two rectal, one Ewing sarcoma).

Conclusions: The results show that this new tool can be used to simulate IOERT cases involving different anatomic locations, and that preplanning has to be carried out with specialized surgical input. © 2012 Elsevier Inc.

Keywords: Intraoperative electron beam radiation therapy, Intraoperative radiotherapy, Treatment planning, Treatment simulation, Electrons

Reprint requests to: Javier Pascau, Ph.D., UMCE, Hospital General Universitario Gregorio Marañón, Dr. Esquerdo, 46. E-28007 Madrid, Spain. Tel: (+34) 914265067; Fax: (+34) 914265108; E-mail: jpascau@mce.hggm.es

Supported by grants PI08/90473, IPT-300000-2010-3, ARTEMIS-S2009/DPI-1802(CAM), TEC2010-21619-C04-01, PI09/90568, ERD Funds.

Conflict of interest: none.

Int J Radiation Oncol Biol Phys, Vol. 83, No. 2, pp. e287−e295, 2012

doi:10.1016/j.ijrobp.2011.12.063

identifying the importance of specialized surgical input in the preplanning process.

Introduction

Intraoperative radiation therapy (IOERT) refers to the delivery of radiation to the postresected tumor bed, or to an unresected tumor, during the surgical procedure (1). The technique enables the precise application of a high radiation dose to the target area while minimizing exposure to surroundings tissues, which are displaced or shielded during the procedure (2). However, running an IOERT program involves several aspects from the institutional point of view because it is necessary to organize structural and human resources. Conventional or mobile linear accelerators are used for IOERT. A multidisciplinary group of surgeons, anesthetists, medical physicists, radiation oncologists (ROs), and technical and nursing staff have to be involved. The two main actors are the surgeon and the RO, and both must provide their knowledge and experience in the decision-making process, identifying the high-risk areas and mobilizing noninvolved dose-sensitive organs. Finally, the RO will define the treatment volume, prescribe the dose, and report the results (3).

Although treatment planning is a necessary step in external radiotherapy, the corresponding procedure has not been available in IOERT up to now. There are several reasons for this: most organs at risk are displaced or protected during surgery, the electron beam presents a very high dose gradient (4), and the treatment volume is directly visualized by the surgeon and the RO. Although all these circumstances support IOERT practice, this does not mean that treatment planning is not desirable. In current clinical practice, all necessary parameters such as applicator diameter, bevel angle, position, and electron beam energy are decided by the RO in real time, with high dependence on accumulated expertise (5). This also means that postsurgical follow-up cannot include objective variables such as volume coverage for target and healthy tissue; consequently, local tumor control and toxicity are not completely documented.

Although there are several treatment planning tools for brachytherapy that work on imaging studies (6), no such developments have been available for IOERT. The first proposal on IOERT simulation was reported by our own research group (7). The underlying idea was that simulating the IOERT procedure was feasible by displaying the virtual position of the applicator superimposed on the patient's computed tomography (CT) or magnetic resonance image. With this approach, the treatment parameters could be predefined depending on the patient's anatomy, and the RO could improve the preoperative planning for the procedure. This initial proposal was later implemented and improved, becoming the so-called Radiance IOERT simulation and planning tool (GMV Aerospace and Defence, Madrid, Spain). Development of the system has brought together industrial and academic partners: Hospital General Universitario Gregorio Marañón (HGUGM) and Consorcio Hospitalario Provincial de Castellón (HPC). The simulation and planning process is performed in several steps: segmentation, applicator positioning using CT images, and parameter selection (applicator diameter, bevel angle, and electron beam energy) by optimizing the dose—volume histograms on the regions. The results of the process can be stored in a single file, allowing for comparison of different procedures. The main features and advantages of this approach will be presented in this article, together with an initial evaluation in clinical cases by three ROs.

Methods and Materials

The system allows IOERT simulation and planning, giving the user support in the different steps of this workflow. A CT image of the patient including the tumor location is acquired before IOERT. The user navigates through the axial, sagittal, and coronal sections, and also with a three-dimensional (3D) volume rendering (Fig. 1). The rendering engine takes advantage of the graphics process unit capabilities, providing real-time updates when the rendering parameters are modified. The steps followed to simulate and plan the IOERT are described below. The RO can interact with the surgeon to define several aspects of the procedure.

Image segmentation

The RO performs the segmentation on axial, coronal, or sagittal sections, and these contours can be combined into a single 3D region of interest. This contouring process is slightly different from the one performed in external radiotherapy. First, the tumor is not the target volume, because it might be resected during surgery, but it must be segmented for correct placement of the IOERT applicator. At the same time, only the organs at risk that could not be displaced and manipulated during the surgical process should be taken into account. Finally, the planning treatment volume (PTV) is the region surrounding the tumor (residual or tumor bed) that is considered to have a high risk for relapse, or the tumor itself for unresectable cases. Tumor location, the patient's clinical history, and radiologic reports are factors to consider when contouring the PTV. Regions that are not expected to be present during surgery can be hidden from the two-dimensional and 3D display (virtual surgery effect). The result will be the definition of a series of regions of interest (Fig. 2), with their corresponding labels, which will be the basis for the following steps.

Surgical frame definition

With this optional tool, the RO defines the expected anatomic regional access (*e.g.,* lateral, anterior, perineal) and dimensions of the surgical incision. This feature improves the representation of the procedure in the 3D volume rendering and at the same time limits the possible movements of the IOERT applicator in the next steps (navigation effect), resembling the physical geometric limitations of the real procedure (Fig. 3).

Definition of applicator parameters

With the organs at risk, target areas, and surgical procedure defined, the user can now decide on the applicator best adapted for the desired treatment and also the proper position and orientation related to the patient's anatomy and limited by the surgical frame.