

A Novel Radiotherapy Technique

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INTRODUCTION

Cancer is the second leading cause of death behind heart disease in the United States (National Center for Health Statistics, 2006). Various cancer treatments are available now, but the three most common types are surgery, chemotherapy, and radiotherapy. Radiotherapy uses radiation—in the form of a special kind of x-rays, γ -rays, electrons, or protons to kill cancer cells. The advance of modern radiotherapy is closely linked to the evolution of computer and information technology. Intensity-modulated radiation therapy (IMRT) is an advanced form of three-dimensional conformal radiotherapy (3DCRT). It has become today's standard for state-of-the-art radiation treatment. IMRT is based on the concept of inverse treatment planning. By optimizing a constrained objective function, IMRT can modulate the shape and intensity of radiation beams to create a dose distribution highly conformal to the target volume. In this article, we report the results of our investigation on the feasibility and potential benefits of combining electrons with intensity-modulated photons, called IMRT+e, for selected types of cancer, particularly for superficial tumors with critical organs underneath. The aim is to deliver high radiation dose to the tumor while sparing all the surrounding normal tissues, thereby minimizing radiation induced side-effects.

BACKGROUND

IMRT uses nonuniform beam intensities within a radiation field to provide more degrees of freedom for dose shaping and dose escalation, resulting in dose distributions that conform more tightly to the tumor shape. As a novel treatment modality, IMRT consists of three major components: a CT-based simulation system, an inverse treatment planning system with computerized optimization, and a computer-controlled linear accelerator delivery system. Unlike traditional IMRT, IMRT+e

incorporates static electron fields into photon IMRT fields, taking advantage of electron beams' shallow penetration depth. The novel feature of this approach is that the optimization takes the exiting electron dose distributions into account, resulting in a treatment plan superior to a composite plan whose component plans are optimized independently. Our earlier study (Chan, 2006) has quantified the potential benefits of IMRT+e using established dosimetric parameters for malignant pleural mesothelioma (MPM). Details of various radiation techniques for MPM, such as photon and electron matching (Kutcher, Kestler, Greenblatt, Brenner, Hilaris, & Nori, 1987; Yajnik, Rosenzweig, Mychalczak et al., 2003), intraoperative radiotherapy (IORT) (Hilaris, Nori, Kwong, Kutcher, & Martini, 1984; Lee, Everett, Shu et al., 2002; Rosenzweig, Fax, Zelefsky, Raben, Harrison, & Rusch, 2005), IMRT (Ahmad, Stevens, Smythe et al., 2003; Baldini, 2004; Forster, Smythe, Starkschall et al., 2003; Munter, Christian et al., 2005; Munter, Nill, Thilmann et al., 2003), and intensity-modulated arcs (Tobler, Watson, & Leavitt, 2002), have been published. The first three techniques have been implemented clinically. As demonstrated by our data (Chan, 2006), IMRT+e provided superior target dose coverage compared to the conventional techniques. In addition, IMRT+e also improved critical organ sparing. Here, we present the results of IMRT+e for the treatment of various superficial tumors.

To further explore its potential benefits, IMRT+e was used on a patient with extensive lesions of the scalp covering the entire forehead and both temporal surfaces (Chan, 2006). Traditionally, these lesions have been treated with various electron beams. The relatively high skin dose provided by the electron beams, as well as the limited particle range, allows for adequate dose to the superficial target volume while sparing the underlying normal tissue, principally the brain. To eliminate the field-matching problem with electrons for extensive lesions, several investigations have been attempted by adding photon fields (Akazawa, 1989; Tung, Shiu,

Starkschall et al., 1993). Electron arc techniques can also be used although designing an arc to deliver a sufficient dose to the target is difficult. The use of arcing photon fields was also reported (Kinard, Zwicker, Schmidt-Ullrich et al., 1996). Energy- and intensity-modulated electron beams have been investigated (Bedford, Childs, Hansen et al., 2005; Karlsson, Karlsson, & Zackrisson, 1998; Klein, 1998; Locke, Low, Grigireit et al., 2002; Ma, Pawlicki, Lee et al., 2000; Yarpalvi, Rontenla, & Beitler, 2002). IMRT is able to modulate the photon fields, thereby customizing the dose distribution more specifically to the target. Locke et al. (2002) evaluated the use of tomotherapy with the Peacock system (NOMOS Corporation, Sewickley, PA) for this type of problem. It was found that IMRT provided improved dose homogeneity in the planning target volume (PTV) compared with the more conventional techniques, but resulted in higher doses to the brain and lens. More recently Bedford et al. (2005) further examined the possibility of using IMRT for extensive scalp lesions. They compared photon IMRT with either two or four matched electron fields and arcing electron fields. Their results showed that IMRT offered a feasible alternative to electron techniques for the treatment of extensive scalp lesions. Although it was considered to be clinically acceptable, the brain dose was higher with photon IMRT. In our study, the IMRT+e plan produced a more desirable dose distribution in terms of the dose reduction to the brain with the same dose conformity and homogeneity in the target volumes.

We also employed the IMRT+e technique to treat a patient with Merkel cell carcinoma of the left upper eyelid. A complex IMRT+e plan was computed to cover the left upper eyelid and the left lateral periorbital soft tissues, as well as the facial, periparotid, and cervical lymphatics. The plan consisted of three 6 MV IMRT fields and one enface 6 MeV electron field, delivering a total dose of 54 Gy in 30 fractions.

IMRT+e METHODOLOGY

The key concept of IMRT+e is to incorporate existing static electron fields into the photon beam inverse planning optimization. The goals are to improve the target dose conformity, boost the skin dose, and spare the distant critical organs. Although the photon beam IMRT has been shown to be an effective treatment for

deep-seeded tumors, it is not suitable for treating very shallow targets like skin cancer, certain types of MPM, and breast cancer. This is due to the low surface dose and deep photon beam penetration. The slow attenuation of photon beams can still deliver a significant dose to the distant critical organs. The rapid dose falloff of electron beams makes electron therapy a viable treatment modality for these shallow targets. In addition, electron beams have negligible scatter radiation, compared to photon beams. Furthermore, electron beam therapy uses normal incidence; it is, therefore, less affected by patient's respiration than photon beam IMRT, particularly beamlet-based IMRT.

Prior to optimization, the PTV is delineated on CT images by a radiation oncologist. An appropriate margin is added to the PTV to account for patient setup uncertainty and internal organ movement. Critical structures are also delineated by either a medical physicist or a radiation oncologist. The IMRT+e plan is computed on a planning system developed at the Memorial Sloan-Kettering Cancer Center. The photon-only IMRT plan is computed first using six MV photons with several beam directions. Depending on disease sites, the beam configuration varies with the target and critical organ geometry. To create an IMRT+e plan, one or two electron fields using 6-16 MeV are added to the computed photon IMRT plan. The IMRT plan is then optimized again. This new round of optimization takes the existing electron dose distributions into account. Therefore, for those voxels with exiting electron dose, the photon IMRT fields will deposit less of a dose there. Normally, enface electron field arrangement is sufficient to achieve the acceptable tolerance levels for critical structures. When these acceptable levels can not be met, alteration of electron energy or differential weighting of the electron plan is attempted. In general, the electron fields are manually optimized to contribute about 50% of the prescribed dose. The quality of the final plan is evaluated using dose-volume histograms (DVHs). The photon IMRT component of the plan is designed to be delivered using the dynamic multileaf collimator (DMLC) technique while the static electron component is treated with custom electron cutouts.

The IMRT optimization algorithm uses an iterative gradient search method to minimize an objective function (Chui & Spirou, 2001; Spirou & Chui, 1998). The objective function consists of terms corresponding to the targets and the organs at risk (OAR).

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