Dinamic-arc-IMRT with Serial Tomotherapy

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Abstract

Intensity-modulated radiotherapy (IMRT) has been introduced into a wide spectrum of clinics worldwide. In tomotherapy, literally "slice therapy", highly conformal treatments are possible because of an increase in the number of treatment slices into which the target is segmented would lead directly to an improvement in three-dimensional dose conformality.With Peacock System (NOMOS Corporation), the IMRT is doing so using conventional clinical linear accelerators (Linacs) fitted with an integrated multileaf collimator (MLC). This system comprised of the MIMiC, a tertiary "bolt-on" MLC, and a dedicated inverse treatment planning system (Corvus). The introduction of dynamic-arc-IMRT with Serial Tomotherapy started in the mid 1990. The first patient was treated in 1994. Between November 2007 and September 2012, at the Operative Unit of Radiotherapy of V. Fazzi Hospital of Lecce, 180 patients were treated with Serial Tomotherapy. Of those, 52 patients received Cerebral Ipofractionated Stereotactic IMRT with Talon; 66 prostate cancer patients were designed to deliver SIB-IMRT (78,4Gy to the prostate while simultaneously delivering 66,5Gy to seminal vesicles in 35 fractions); 20 patients received SIB-IMRT for Nasopharyngeal cancer (69.9Gy in 2.33Gy fractions to PTV1, 60Gy in 2Gy fractions to PTV2 and 54Gy in 1.8Gy fractions to PTV3), 28 patients received brain IMRT and 14 patients were irradiated on the spine and bone marrow for palliation or other. This slice-wise method of treatment is known to produce extremely conformal dose distributions due to its ability to specifically match the dose distribution on each slice to the shape of the target volume on that same slice. The major criticism of contemporary IMRT is that we cannot be certain of the geometry (relative position and shape) of the tumour or organs at risk (OARs) at each treatment episode. Careful and exacting protocols are employed to attempt to localize these in the treatment plan and during the patient's set-up.

Introduction

Intensity-modulated radiotherapy (IMRT) is based on the use of optimized non-uniform radiation beam intensities incident on the patient.

IMRT treatment plans are often generated using inverse planning or automated optimization 3D-RTP systems, which use computer optimization techniques to help determine the distribution of intensities across the target volume. (Fig. 1).

IMRT does provide the ability to spare normal tissues that are surrounded by targets with concave surfaces, and this advantage is currently being exploited to escalate tumor dose.

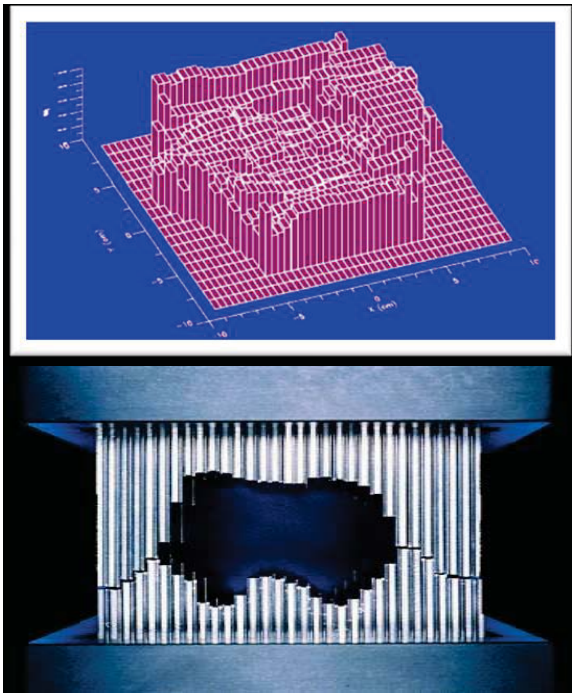

Fig.1. High Conformity to target Volume

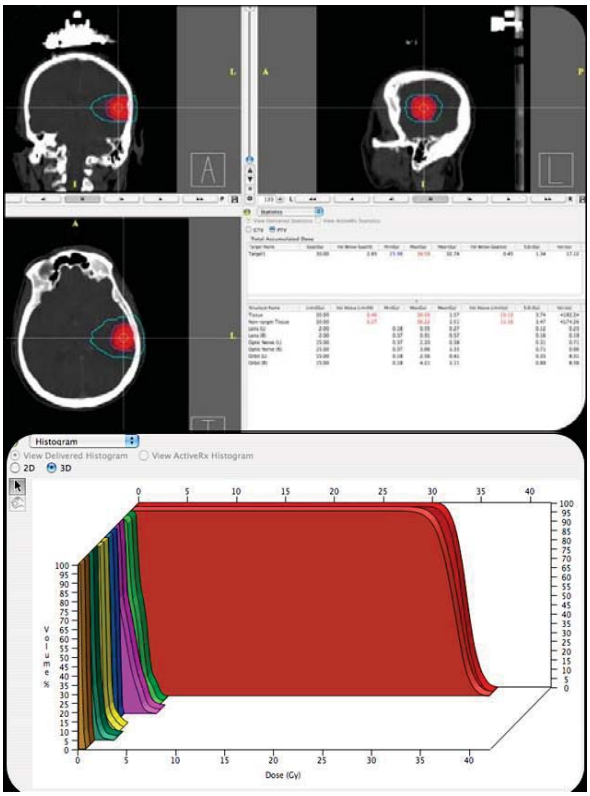

Figure 2. High dose gradients that can be formed at structure interfaces due to Cerebral Stereotactic RT with Talon

Materials and methods

Between November 2007 and September 2012, at the Operative Unit of Radiotherapy of V. Fazzi Hospital of Lecce, 180 patients were treated with Serial Tomotherapy. Of those, 52 patients received Cerebral Stereotactic RT with Talon (Fig. 2); 66 prostate cancer patients were designed to deliver SIB-IMRT: 78,5Gy to the prostate while simultaneously delivering 66,5Gy to seminal vesicles in 35 fractions (Fig. 3); 20 Patients received SIB-IMRT for Nasopharyngeal cancer: 69.9 Gy in 2.33 Gy fractions to PTV1, 60 Gy in 2 Gy fractions to PTV2 and 54 Gy in 1.8 Gy fractions to PTV3 (Fig. 4); 28 patients receveid brain IMRT (Fig. 5) and 14 patients were irradiated on the spine for palliation or other (Fig. 6).

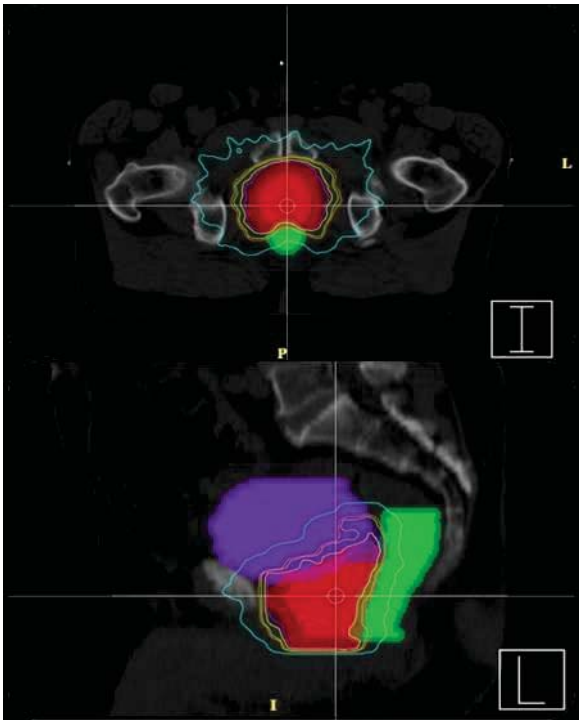

Figure 3. High dose conformity in IMRT plan of a prostate cancer patient

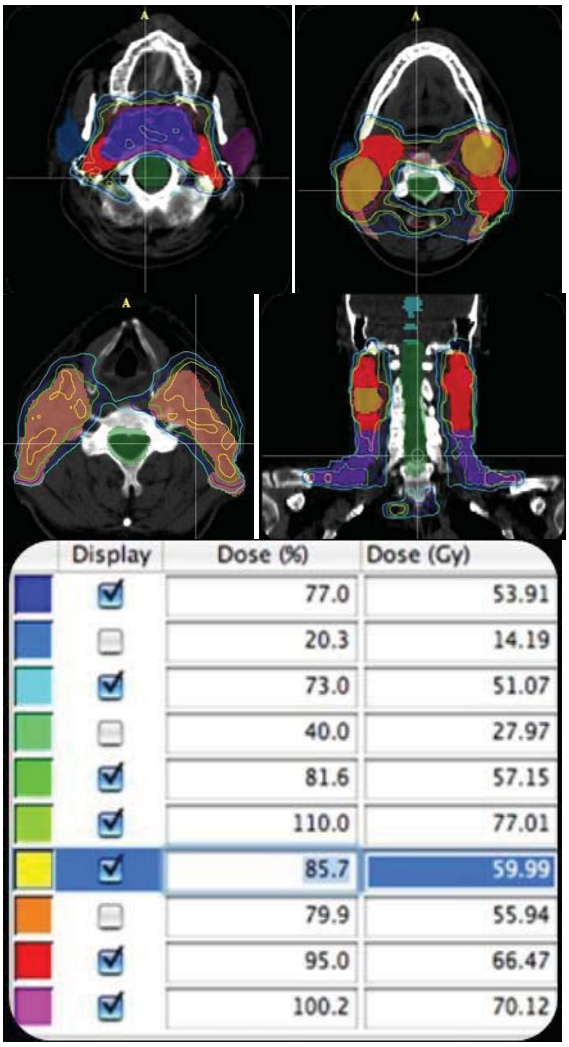

Figure 4. High dose gradients that can be formed at structure interfaces due to Cerebral Stereotactic RT with Talon

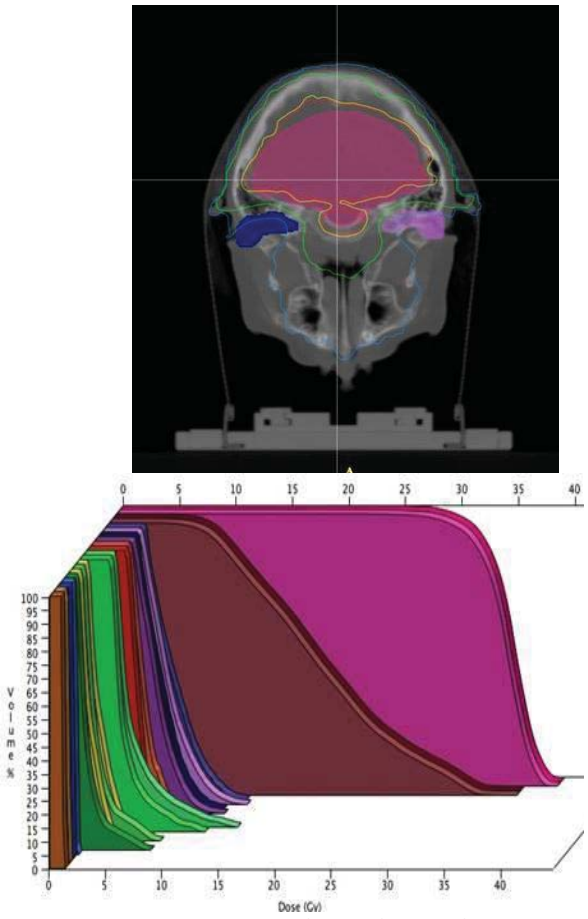

Figure 5. Brain IMRT with Serial Tomotherapy

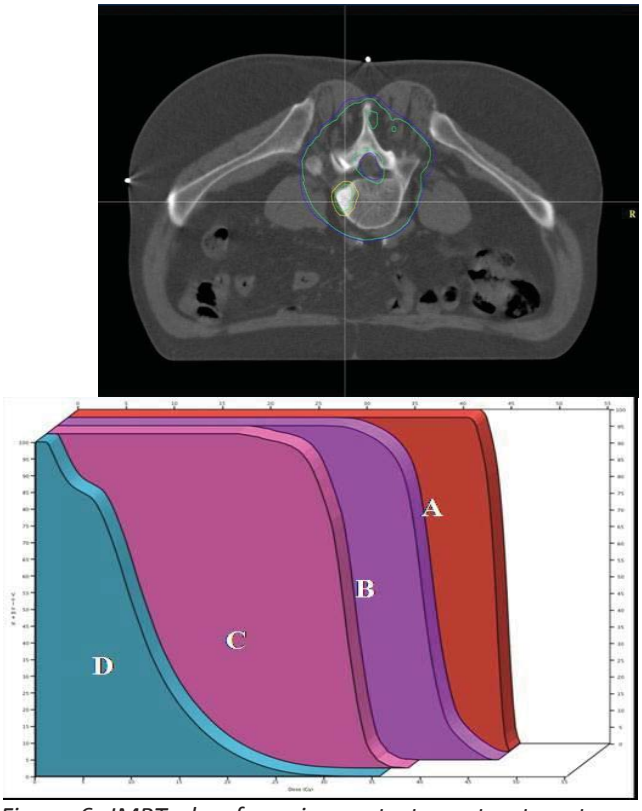

Figure 6. IMRT plan for spine metastases treatment with Serial Tomotherapy

Calculations are based on a Siemens Primus linac with a dose rate of 200 MU/min.

Treatment plans are created with Corvus 6.0 and 7.0. Steepness of dose gradients, homogeneity and conformity were assessed by the following parameters: Volume encompassed by certain isodoses outside the target as well as homogeneity and conformity as indicated by Homogeneity- and Conformity-Index.

Results

Six clinical examples are chosen to illustrate the quality of IMRT treatment plan with serial tomotherapy.

These are 1- and 2-cm modes with single-couch position for prostate, head and neck, brain and spine treatment.

The plan in Fig.2, hilhlights the intracranial ipofractionated stereotactic radiotherapy of brain metastases, with Serial Tomotherapy and Talon Immobilitation. It can be seen that the 0,8-cm mode with beak collimator has the 100% of target volume coverage.

DVHs of the target volumes and selected critical structures highlight the increased dose heterogeneity often encountered as a consequence of conformal avoidance.

The isodose distributions for the rinopharingeal cancer case are shown in Fig. 4. Is a typical head-and-neck IMRT treatment plan showing conformal avoidance of the spinal cord and parotid glands while simultaneously delivering multiple dose prescriptions (69,9 Gy, 60 Gy and 54 Gy in 30 fractions) to the two target volumes.

The average values for the percent volume that received at least 95%of the prescription dose (V95), the target volume covered by 100% of the prescription dose (D100%) and the conformity index of the PTV were 99,3%, 97,8% and 0,9 for IMRT, 100%, 99,8%, and 1 for the Stereotactic-RT, respectively.

Discussion

Computerized RT planning was first reported _40 years ago (1). Early dedicated RTP systems depended on twodimensional (2D) contour information and calculated doses based on relatively simple 2D dose models (2, 3). The first 3D approach to treatment planning dose calculation and display is credited to Sterling et al. (4, 5), who demonstrated a computergenerated film loop that gave the illusion of a 3D view of the anatomy and the calculated isodose distribution (2D color washes) throughout a treatment volume. Van de Geijn (6), Cunningham (7), Beaudoin (8), and Sontag and Cunningham (9) also performed early work in 3D dose-calculation models. Reinstein et al. (10) and McShan et al. (11) took the first real step toward clinically usable 3D-RTP in 1978 with the development of the beam's-eye view display. The beam'seye view display provides the planner with a view from the perspective of the source of the radiation beam, looking down the rays of the divergent beam, and results in a view of the anatomy similar to a simulator radiograph. At the same time, the introduction of CT scanning and its use for RT significantly improved the way patient anatomy could be specified in treatment planning (12). In 1983, Goitein and Abrams (13) and Goitein et al. (14) demonstrated how CT data made possible high-quality color beam's-eye view displays and simulated radiographs computed from CT data (referred to as digitally reconstructed radiographs).

Finally, between 1986 and 1989, several robust university-developed 3D-RTP systems began to be implemented in clinical use (15,16). The additional development of 3D-RTP systems throughout the past 20 years. One of the keys to the acceptance of 3D-RTP throughout the community was a series of research contracts funded by the National Cancer Institute in the 1980s and

early 1990s to evaluate the potential of 3D-RTP and to make recommendations to the National Cancer Institute for future research in this area (17).

Important developments and refinements in 3D planning technology came from these contracts, particularly plan evaluation software tools, such as dose–volume histograms (DVHs) (18, 19), and biologic effect models, such as tumor control probability (TCP) and normal tissue complication probability (NTCP) (20, 21) models, as well as efforts to stimulate and document the current state of knowledge about these effects (22). Many of these features are crucial parts of plan optimization, which is critical to IMRT.

Early IMRT delivery concepts were pioneered several decades ago. Particularly important were the early efforts of Dr. Shinji Takahashi and colleagues, from Nagoya, Japan (23). Their work illustrated some of the important concepts in both conventional 3D-CRT and IMRT delivery. Dynamic treatments were planned and delivered by Takahashi's group using what may have been the first multileaf collimator (MLC) system. The MLC system used a mechanical control system to conform the beam aperture to the projected target shape as the machine was rotated around the patient. Another pioneering effort in CRT was conducted by the group at the Massachusetts Institute of Technology Lahy Clinic (24–26), who independently developed an asynchronous portal-defining device similar to that of Takahashi (23).

The Royal Northern Hospital in England also pioneered an early CRT effort (27). The group developed a series of cobalt-60 teletherapy machines in which the patient was automatically positioned during rotational therapy by moving the treatment couch and gantry during the radiation delivery using electromechanical systems. This was called the "Tracking Cobalt Project," because the planning and delivery system attempted to track around the path of disease spread and subsequently conform the dose distribution.

By the mid-1990s (and before much additional discussion had occurred in the literature about IMRT delivery methods), several other kinds of delivery techniques relevant to modern IMRT had evolved. The use of a computer-controlled scanned beam, available in the Scanditronix Racetrack Microtron System, was the first modern IMRT delivery technique described in the literature (28). Resolution of this technique is limited, as demonstrated by Karlsson et al. (29) and Lief et al. (30, 31).

The second IMRT delivery technique described in the literature defined an approach called tomotherapy by which IMRT is delivered using a narrow slit beam (32).

In tomotherapy, literally "slice therapy", highly conformal treatments are possible because of an increase in the number of treatment slices into which the target is segmented would lead directly to an improvement in three-dimensional (3D) dose conformality (fig. 7).

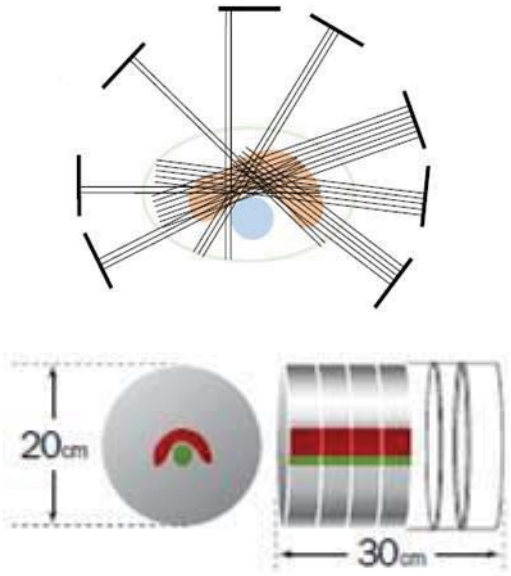

Figure 7. IMRT with Serial Tomotherapy

This technique is very analogous to the tomography techniques used for CT and other such imaging systems. A temporally modulated binary mini-MLC of the type proposed by Mackie et al. (32) for

tomotherapy IMRT was developed commercially (Peacock MIMiC, Nomos Corp.) (33-35). The Peacock system's MIMiC is mounted to a conventional low-energy megavoltage medical linear accelerator, and treatment is delivered to a narrow slice of the patient using arc rotation. The beam is collimated to a narrow slit (approximately 2cm-20cm), and beamlets of varying intensity are created by driving the MIMiC's leaves in and out of the radiation beam's path as the gantry rotates around the patient. A complete treatment is accomplished by serial delivery to adjoining axial slices. The clinical use of the Peacock system was first implemented at the Baylor College of Medicine in Houston, Texas (36).

Since then, it has been implemented in a large number of clinics worldwide, and several other institutions have reported their experience with the Peacock IMRT system (37-38). The treatment delivered by this system is described as serial tomotherapy, since it is delivered by a number of discrete arcs or indexed arcs of finite width, between which the treatment couch is moved longitudinally.

The popular introduction of IMRT started in themid 1990s when the NOMOS Corporation (Swickley, Pennsylvania, USA) introduced the PEACOCK system [33, 39], this comprised of the MIMiC, a tertiary ''bolt-on'' multileaf collimator (MLC), and a dedicated inverse treatment planning system. The first patient was treated in 1994 and until around the turn of the century most patients who received IMRT in the world were treated on this system (39).

CONCLUSIONS

The MIMiC delivery system, when used appropriately, is an extremely versatile system for treating a large variety of disease conditions. Typically, irregular-shaped and small-to-medium size tumors with adjacent critical structures are the most suitable candidates. One has to be vigilant on noting the limitation of the 20-cm width of the collimator.

This slice-wise method of treatment is known to produce extremely conformal dose distributions due to its ability to specifically match the dose distribution on each slice to the shape of the target volume on that same slice.

The major criticism of contemporary IMRT is that we cannot be certain of the geometry (relative position and shape) of the tumour or organs at risk (OARs) at each treatment episode.

Careful and exacting protocols are employed to attempt to localize these in the treatment plan and during the patient's set-up.

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