Analysis of uncertainties in dose distribution due to geometrical deviation of target from isocenter in serial tomotherapy

C. Capomolla [1], S. Quarta [1], G. Ciccarese [2], M. Natali [1], M. Cazzato [3], A. Papaleo [4], D.Russo[4], A. Zagari [1]

[1]*U.O.C. Fisica Sanitaria P.O. "Vito Fazzi", Lecce (Italy) capomolla.caterina@gmail.com*
[2]*Servizio di Radioterapia – Istituto Clinico "Beato Matteo" Vigevano (PV) (Italy)*
[3] *Scuola di Specializzazione in Fisica Medica – Università "Sapienza" Roma (Italy)*
[4] *U.O. Radioterapia - P.O. "Vito Fazzi", Lecce (Italy)*

Abstract

The tomotherapy system in radiation therapy department of "V. Fazzi" hospital in Lecce (Italy) is a serial device. It means that the coverage of the target is obtained by moving the couch in and out the gantry position. It has been shown that the choice of target positioning respect to the isocenter reflects on dose distribution in terms of heterogeneities. The entity of the heterogeneities can reach 10% in abutment regions nearby the isocenter. Moreover, by using gantry rotations less than 300 degrees, hot and cold spots can be seen above and over the isocenter.
Aim of the present work is to characterize the performance of the serial tomotherapy device in order to avoid, as more as possible, heterogeneities in the abutment regions.

Introduction

Serial tomotherapy is a dinamic arc IMRT higly conformal it allows a slice by slice target irradiation thanks to the poor dimension of the collimator.
Treatment is performed by rotating the gantry over a certain arc for a fixed couch position and the leaf positions changing during rotation. To deliver the dose distribution to a volume of greater collimator size, sequential treatment arcs are required, with the patient moved (indexed) longitudinally between arcs [1] [2].
The analysis of dose distribution in abutment regions due to adjacent arcs is the aim of this work.

Materials and methods

The tomotherapy system in use in our hospital is made with a dynamic multi-vanes collimator (MIMiC - Best Nomos ®) and a device for couch translation (Autocrane - Best Nomos ®) attached on a 6 MV linac (mod. Primus Siemens).
MIMiC collimator (Fig. 1a) is constituted by two opposite parts each constituted by 20 tungsten vanes 8 cm thick and 1 cm large.
The binary aperture (closed or opened) of each vane allows the photon beam modulation during the gantry rotation according three modalities: *1cm mode*: with each pencil-beam ~ 1cm x 1cm so that each

Fig.1 MIMiC view from patient toward target of the gantry

slice treats ~2 cm of tissue, *2cm mode:* requiring fewer slices and less time since each pencil-beam is ~ 1 cm x 2 cm so that each slice treats ~4 cm of tissue **and** *Beak mode.* In the last mode a pencil-beam 1 cm x 0,4 cm slices treats ~ 0,8 cm of tissue. The beak mode is used only for stereotassic treatment.

In order to treat target longer than 1.7 cm longitudinally the couch is moved in and out in gantry direction by a device called Autocrane (Fig. 2). It is a simple double motorized translation rail whose precision is 0.1 mm.

Fig.2 AutoCrane mounted on linac couch

The couch index is very important in terms of heterogeneities in the abutment regions in fact overlapping should be considered with a lot of attention [3].

If ideal delivery conditions are assumed, the heterogeneity within the abutment region should be minimal if each delivery is conducted using 360° arcs. However, the total arc angle range is often limited by physical constraints, such as the patient support hardware. When a reduced angle range is used, dose heterogeneity may be generated in the abutment region up and down the rotation axis due to beam divergence uncompensated by a symmetrical irradiation (Fig. 3).

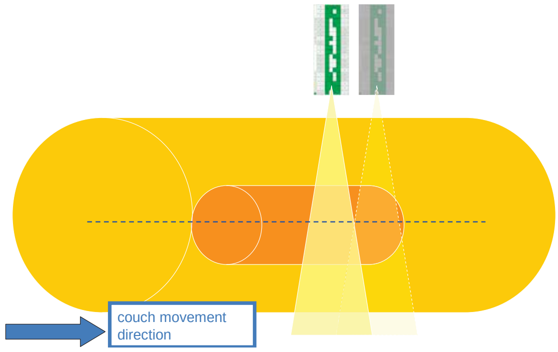

Fig. 3

Two irradiation positions dotted lines are for the former situation, continuos for the latter. Under-beaming and over-beaming situations are compensated if gantry rotation is complete (a). They remain in case of uncomplete gantry rotation.

It has been shown [4] that the magnitude of the heterogeneities will depend on:

the total arc angle range, the projected leaf size (1cm mode, 2 cm mode, use of beak), the distance from gantry rotation axis.

In our work, in order to evaluate the performance of the entire tomotherapy system, several dose distributions were analyzed:

- at different **distances** from the rotation axis, and arc delivery limited to 290°
- at different **arc angle range** (180° and 290°)
- at different **modality** (1cm and 2cm)

Dose distribution heterogeneities was investigated by examining treatment plans generated using 8.0 cm diameter cylindrical target volumes within a homogeneous rectilinear phantom.

EDR2 type radiographic films were used to estimate dose distribution at various depths inside the water equivalent multi-layer phantom. The films were analyzed by

Omnipro I'mrt® software. The experimental set-up is show in Fig.4

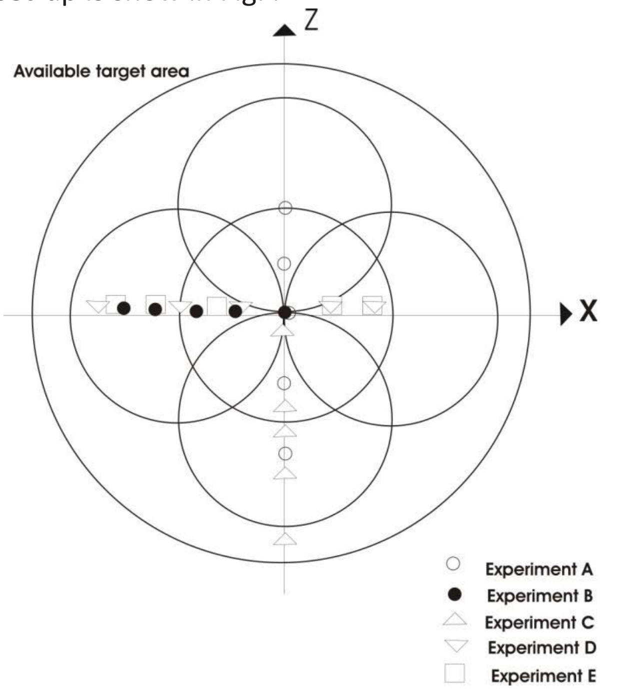

Fig.4 -Relative geometry of the 8 cm diameter target volumes used to measure the intrinsic abutment region dosimetry The measured dose profile locations are shown positions (on the figure surface)

Results

Figure 5 shows an example of inhomogeneities (film obtained according to *experiment A set-up in z=+7 cm): five regions* of underlap, corresponding to the abutments of the six delivered arcs.

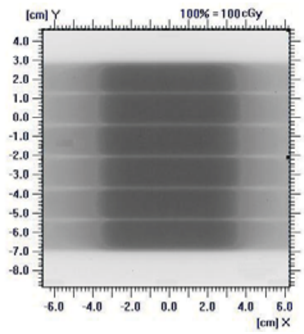

Fig.5 - film obtained according to experiment A set-up in z=+7 cm

The profiles in Fig.6 (a), (b) and (c) describe respectively the situation in z = 3cm, z = 0 cm and -3 cm.

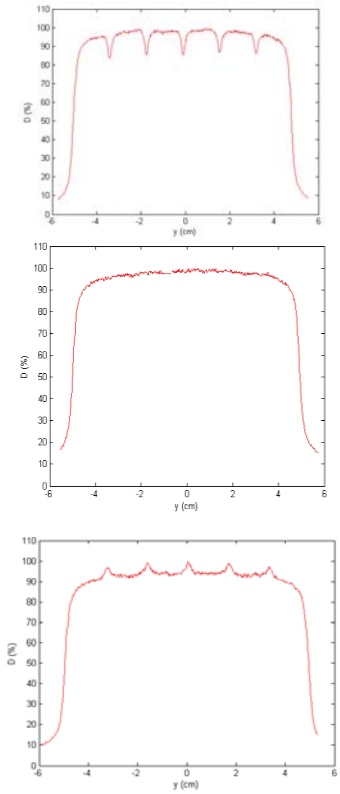

Fig.6- Dose profiles acquired perpendicularly respect to the abutment regions

The results of the different experiments are summarized in the following figures (Fig.7, Fig.8, Fig.9, fig.10).

In Fig. 7 and Fig.8 heterogeneity vs the distance of the target from isocenter are plotted. Heterogeneities are almost zero near gantry axis rotation and are quiet different in the peripheries.

Moreover, a clear dependence of the heterogeneity on the *z* position can be observed in Fig.7 with 6% hot spots and -16% cold spots at *z* = - 7 and *z* = 7 respectively. Little heterogeneity is observed as function of a x off-axis, with -4% cold spots and 2% hot spots in Fig.8.

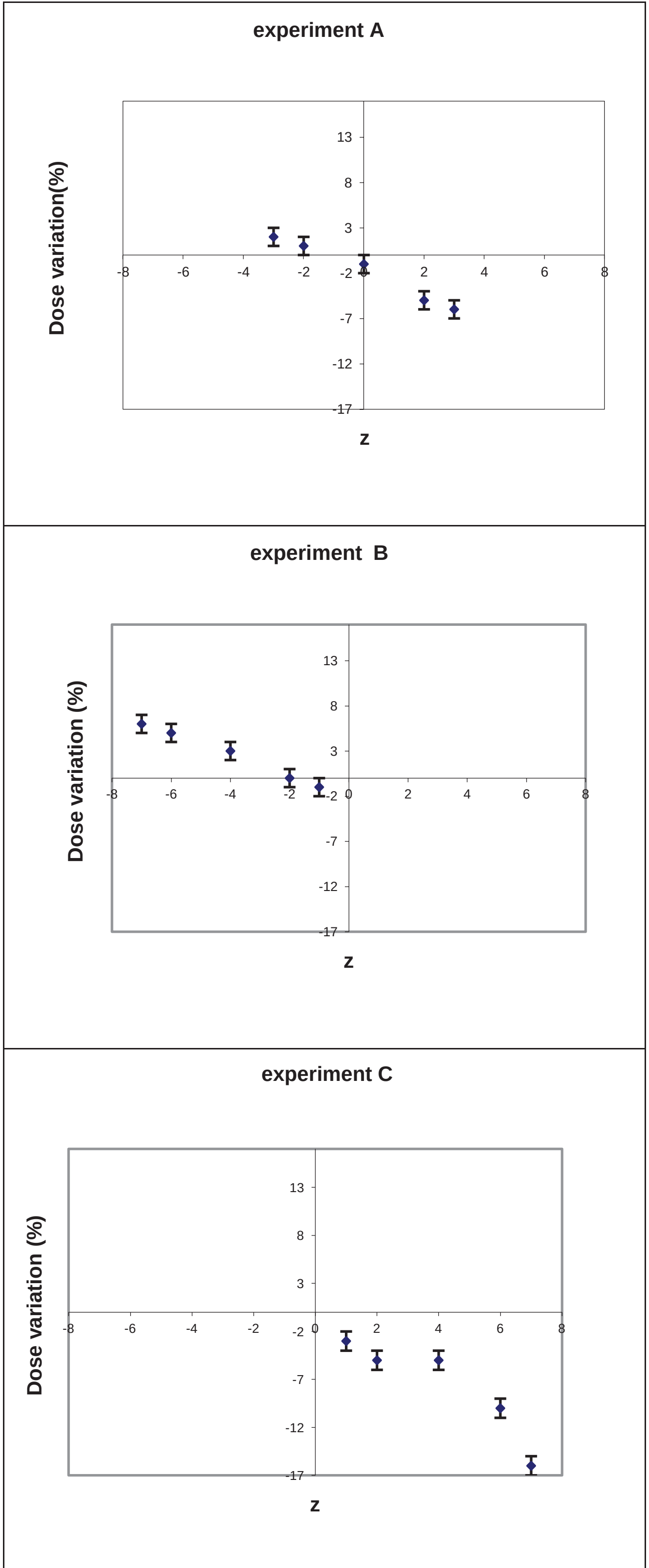

Fig.7: Dose variation trend as a function of off-axis position along the vertical direction:
(a) target center and axis of rotation coincide; (b) target centered 4 cm upper the rotation axis; (c) target centered 4 cm lower the rotation axis.

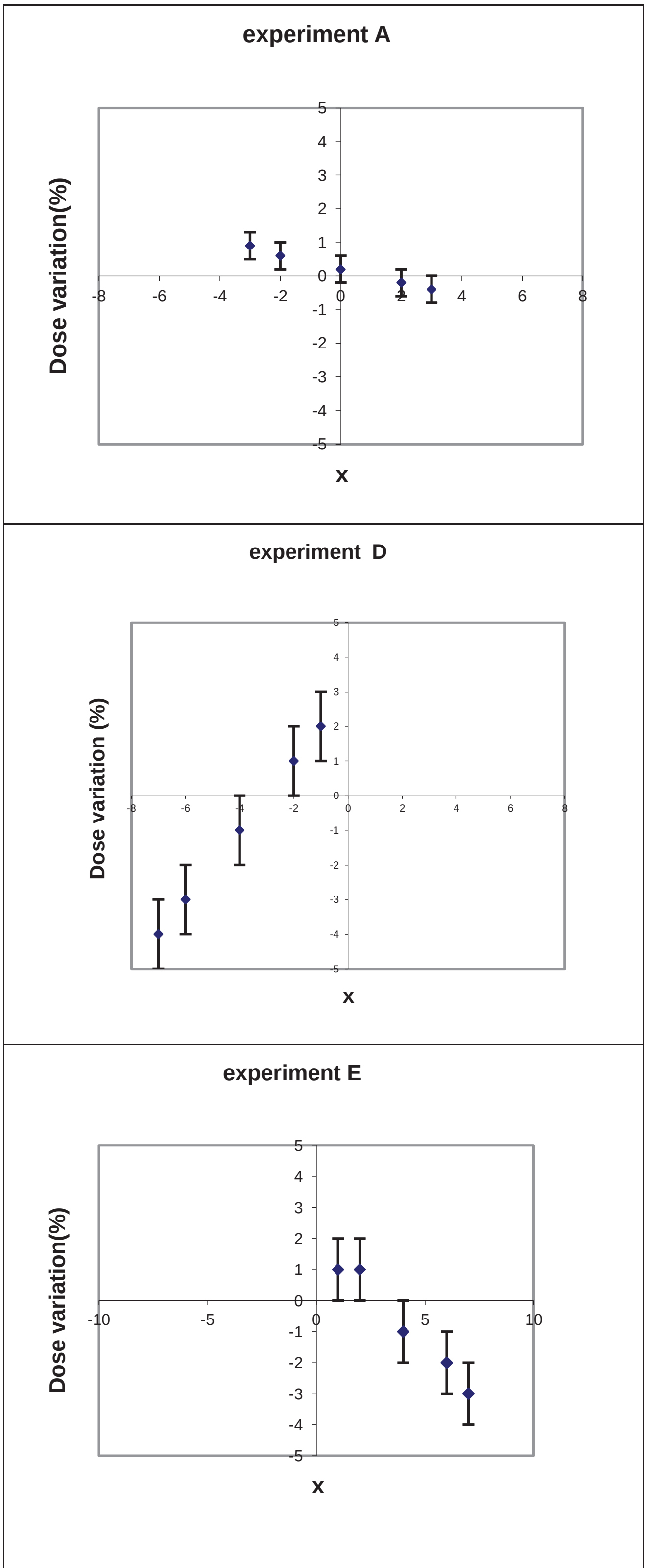

Fig.8: Dose variation trend as a function of off-axis position along the horizontal direction:
(a) target center and axis of rotation coincide; (b) target centered 4 cm right the rotation axis; (c) target centered 4 cm left the rotation axis.

In Fig.9 an increment in dose variation can be seen as the size of the radiation field grows. The highest dose variation according to ”1 cm mode” irradiation was -6% . In “2 cm mode” the maximum dose variation was 12%.

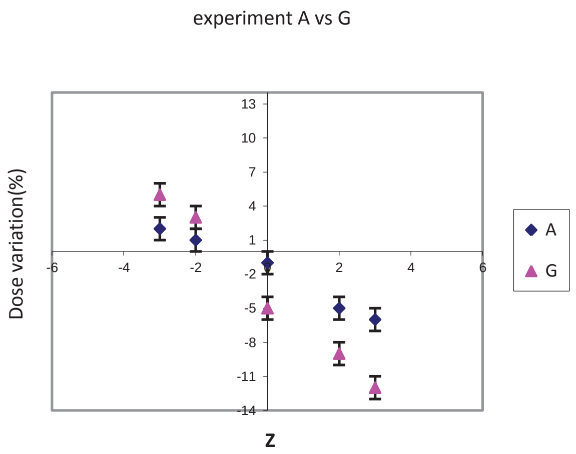

Fig.9: Dose distribution heterogeneities investigated at 1 cm mode (experiment A) and at 2 cm mode (experiment G).

Experimental data fora n arc lenght equalto 290 degrees (A) and 180 degrees (F) are shown are shown in Fig. 10

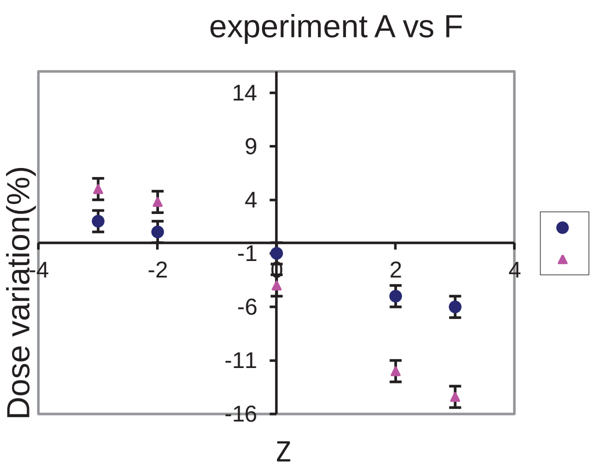

Fig.10: Dose distribution heterogeneities investigated at different ***arc angle range :*** *290° (experiment A) and 180° ((experiment F).*

Using 290° gantry angle and 1 cm mode yielded 2% hot and 6% cold spots 3 cm below and above isocenter, respectively. When a 180° gantry angle was used, the values changed to 5% hot and 14.4% cold spots for the same locations.

Discussion and Conclusions

The use of arc-based IMRT delivery requires an understanding of the consequences of isocentre placement. The measurement have confirmed that under-dose and over-dose areas depend strongly on target position respect to isocenter, on collimator aperture (1 cm mode or 2 cm mode) and on arc length. As a consequence it would be preferable to align target and isocenter and to use the maximum allowed arc length.

As regards the choice of collimation it depends on the clinical requirements, a more extensive area in the abutment region in “2 cm mode” is compensated by a double number of smaller inhomogeneities in “1 cm mode”. The current work permitted us to verify assumptions made by other authors [5] [6] and to evaluate the real performance of the tomotherapy system. The obtained results have lead us to spend more time in treatment planning in order to minimize and, when possible, to avoid inhomogeneities.

References

[1] Verellen D, Linthout N, Berge DVD, *et al*. *Initial experience with intensity-modulated conformal radiation therapy for treatment of the head and neck region*. *Int J Radiat Oncol Biol Phys* 1997;39:99 –114.

[2] Tsai J-S, Wazer DE, Ling MN, et al. Dosimetric verification of the dynamic intensity-modulated radiation therapy of 92 patients. Int J Radiat Oncol Biol Phys 1998; 40:1213–1230.

[3] Low DA, Chao KSC, Mutic S, et al. *Quality assurance of serial tomotherapy for head and neck patient treatments*. Int J *Radiat Oncol Biol Phys* 1998;42:681– 692.

[4] Low DA, Mutic S. A*butment region dosimetry for serial tomotherapy* Phys Med Biol 1997;42:1465–1470

[5] D. A. Low, S. Mutic, M.S. James, F. Dempsey, J. Markman, S. M. Y Goddu, J. A. Purdy *Abutment region dosimetry for sequential arc imrt delivery Int. J. Radiation Oncology Biol. Phys.*, Vol. 45, No. 1, pp. 193–203, 1999

[6] Carol M, Grant WH, Blier AR, et al. *The field-matching problem as it applies to the Peacock three dimensional conformal system for intensity modulation*. Int J Radiat Oncol Biol Phys 1996;34:183–187.