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Empirical estimation of beam-on time for prostate cancer patients treated on Tomotherapy

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ABSTRACT

Background and aim: This study proposed a method to estimate the beam-on time for prostate cancer patients treated on Tomotherapy when FW (field width), PF (pitch factor), modulation factor (MF) and treatment length (TL) were given.
Material and methods: The study was divided into two parts: building and verifying the model. To build a model, 160 treatment plans were created for 10 patients. The plans differed in combination of FW, PF and MF. For all plans a graph of beam-on time as a function of TL was created and a linear trend function was fitted. Equation for each trend line was determined and used in a correlation model. Finally, 62 plans verified the treatment time computation model – the real execution time was compared with our estimation and irradiation time calculated based on the equation provided by the manufacturer.
Results: A linear trend function was drawn and the coefficient of determination R^2 and the Pearson correlation coefficient *r* were calculated for each of the 8 trend lines corresponding to the adequate treatment plan. An equation to correct the model was determined to estimate more accurately the beam-on time for different MFs. From 62 verification treatment plans, only 5 disagreed by more than 60 s with the real time from the HT software. Whereas, for the equation provided by the manufacturer the discrepancy was observed in 16 cases.
Conclusions: Our study showed that the model can well predict the treatment time for a given TL, MF, FW and it can be used in clinical practice.

1. Background

Helical Tomotherapy (HT) is one of the novel approaches that enable intensity-modulated radiation therapy (IMRT) delivery technique. HT can provide a high conformity and homogeneity at the target volume and at the same time spare organs at risk (OAR).[1–7] This is achieved by a different dose delivery in reverse to a classic linear accelerator.[8] In HT, the gantry rotates in a helical manner around the patient, while the couch moves toward the gantry. Fan beam is modulated by a binary multileaf collimator that generates an enormous number of beam elements that irradiate the target volume.[9,10] Treatment planning parameters in HT, namely field width

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(FW), pitch factor (PF) and modulation factor (MF), are also different. They are chosen individually for each treatment plan, based on the shape and volume of the planning target volume (PTV). Moreover, those parameters influence not only the dose distribution but also the beam-on time.[11]

FW determines the size of the beam in the longitudinal axis and can have three discreet values: 1.05, 2.5 and 5 cm. The larger FW, the worse dose gradient in cranial–caudal direction but the shorter beam-on time.

PF is defined as the axial couch distance traveled for one gantry rotation divided by FW.[12] Contrary to the helical computed tomography (CT), in HT the PF should be less than 1. Another aspect worth considering when choosing PF is the thread effect. This effect occurs due to the helical junctioning of the divergent fan beam used in HT. Kissick et al.[12] proposed a solution to minimize the thread effect. They suggested to use a PF of $0.86/n$, where n is an integer. The more complex PTV, the lower PF should be used to sculpt the dose distribution in the cranial–caudal direction.

MF is defined as the ratio of the maximum leaf open time to the mean leaf open time for all non-zero projections.[13] It modulates the beam by limiting leaf open times. Higher MF increases the spectrum of beam modulation; however, it also increases the beam-on time.

In routine practice, the quality of dose distribution is very important.[14–16] The aim is always to spare OARs and at the same time to irradiate the target volume very conformally and homogeneously.[17] However, the treatment time is also a very important issue.[18] Prolonged beam-on time influences patient's comfort and increases the possibility of intra- and inter-fraction movements. Another important issue is that it decreases the number of patients irradiated per day. Taking all these facts into account, we usually have to make compromise between the quality of the treatment plan and the treatment time. It has been shown[11] that for prostate cancer patients the most optimal treatment planning parameters are: FW = 2.5, PF = 0.215, MF = 2.5. However, the MF value of up to 3.5 may also be considered.

Treatment time depends not only on the above mentioned treatment planning parameters but also on dose per fraction, target length in the longitudinal direction and average dose rate. Taking all these issues into account, one can see that estimation of the beam-on time is difficult. Moreover, the irradiation time is not known to the planner (for versions of up to 3.x) until final dose is calculated, that is at the end of treatment planning. In case where the dose distribution is not acceptable or the treatment time is too long, one needs to change the treatment planning parameters (FW, MF, PF) and start the whole procedure from the beginning. This is cumbersome since the optimization of the plan takes more than 2 h and it is not possible to make a copy of a plan (except the newest version of the Tomotherapy software (VoLO Technology) introduced in May 2012) or compare two versions of the plan.[19] It would be useful to know the beam-on time in advance because it would reduce the workload of the treatment planning unit. According to the manufacturer, the irradiation time can be calculated based on the equation:

$$t = \frac{\mathrm{MF} \cdot (\mathrm{TL} + \mathrm{FW}) \cdot D_\mathrm{f}}{\mathrm{FW} \cdot \dot{D}} \qquad (1)$$

where MF – modulation factor, FW – field width, TL – target length, D_f – dose per fraction, and $\dot{D}$ – average dose rate.

However, one does not know the exact dose rate during plan optimization. Mackie et al.[20] proposed a constant value. For example, for prostate treatment it would be 4.8 Gy/min, assuming exponential decay from an effective depth of 12 cm and an effective attenuation coefficient of 0.04 cm^{-1}. This can lead to some inconsistencies.

2. Aim

The aim of this study was to propose a method of treatment time computation based on empirical data gathered in our institution. This analysis was performed for three cases – a target volume covering the prostate alone, prostate with seminal vesicles and that including prostate, seminal vesicles and lymph nodes.

3. Materials and methods

3.1. *Patients*

This study included 10 patients treated for prostate cancer on Tomotherapy in our institution in order to develop a correlation model of beam-on time estimation. Then, 40 (treated on Tomotherapy version 3.1.5.3) and 22 (treated on Tomotherapy version 4.0.4.17) randomly chosen patients were used to verify this model.

For all 72 patients, CT images (Somatom Sensation Open, Siemens Corp.) were performed with slice reconstruction of 5 mm. Ten patients for whom the model was built were scanned only in a supine position with a knee-fix (Sinmed Corp.) immobilization system. However, the group of patients that verified our model was scanned both in a supine (49 patients) and prone position (13 patients) with a belly-board stand (Sinmed Corp.) The procedure before the CT was always the same – patients were asked to empty the bladder 30 min before the scanning and then to drink 500 ml of water. No preparations to empty the rectum (endorectal balloon or enema) were used. All OARs and target contours were created in the Eclipse 7.3.10 (Varian Corp.) treatment planning system. CT scans as well as structure sets were exported in DICOM format to the Hi-Art Tomotherapy planning system. Prostate gland, seminal vesicles and pelvic lymph nodes were delineated as a clinical target volume (CTV). For patients from the correlation model, a margin of 1 cm was always added to CTV to create a planning target volume (PTV). For patients who verified the model, margins from 0.7 cm to 1 cm were used. The correlation model was based on two cases: the first (PTV1) included the prostate gland, seminal vesicles, pelvic lymph nodes and a 1 cm margin; the other one (PTV2) included only the prostate gland with a 1 cm margin. However, in this study we verified our model for three groups of patients who had: only prostate (10 patients), prostate and seminal vesicles (38 patients) or prostate gland, seminal vesicles and pelvic lymph nodes (14 patients) irradiated.