Investigations on the effects of the flattening filter free treatment mode in radiotherapy based on the therapy of localized prostate carcinoma and pituitary adenoma

Marius Treutwein

Radiotherapy Department, University Medical Center, Regensburg, Germany

Keywords— **flattening filter free, plan quality, secondary malignoma risk, IMRT, VMAT.**

I. Introduction

Modern linear accelerators for radiotherapy are optional available with flattening filter free (FFF) mode. In the beginning, this mode has been developed to increase the dose rate and to reduce the treatment time for stereotactic treatments if the flattened field is not necessary as the planning target volumes are small. Fluence modulating techniques as intensity modulating radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) do not require a flattened field either. Moreover, the flattening filter is a source of scattered radiation. Therefore, it has been discussed that peripheral regions of patients treated with flattening filter will obtain a higher dose than in FFF mode. As radiation has the potential to induce secondary malignancies, the risk for such malignancies might be reduced by FFF.

Aim of the present thesis was to investigate the impact of this new mode regarding the plan quality and the secondary malignancy risk. IMRT and VMAT in both modes, with and without flattening filter were investigated. The technical feasibility and quality assurance plays an eminent role at the implementation of new treatment techniques. Therefore, dosimetric plan verifications were performed. The secondary malignancy risk was quantified by the application of different mathematical models to peripheral dose measurements and to the calculated dose distributions in the treated region.

II. Material and methods

Two patient groups were selected for these investigations: The first contained 10 patients with localized prostate carcinoma, the second 11 patients with pituitary adenoma. The applied systems were a linear accelerator, type Synergy™ with Agility™ head and the treatment planning system Oncentra® (all from Elekta Ltd.). The dosimetric plan verification was performed by means of the detector arrays MatrixxEvolution (IBA) and SRS MapCheck® (SunNuclear). The plan quality was evaluated by the following parameters: homogeneity index, conformity index, dose to the organs at risk, and treatment time. The secondary malignancy risk was calculated by the application of different dose response models. In the treated region dose volume data from the treatment planning system were exported; in the periphery measured doses to selected points in an anthropomorphic phantom were used (fig.1). The Wilcoxon signed rank test was used as statistical test.

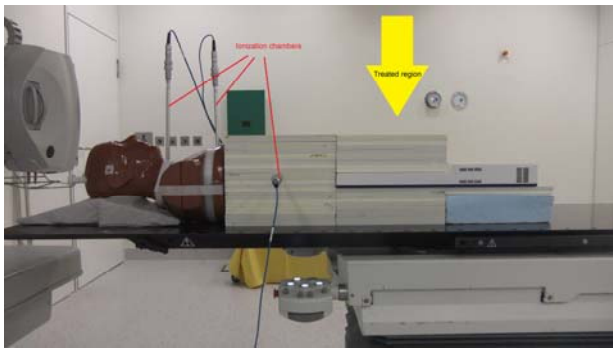

Figure 1. Measurement setup for the prostate cases using an anthropomorphic phantom and stacks of solid water equipped with ionization chambers for peripheral dose measurements and a 2D array for plan verification. The yellow arrow indicates the treated region [2].

III. Results

The dose to the organs at risk in the treated region was similar for both modes. The same was found for the homogeneity index and the conformity index. Both indexes improved by the application of VMAT compared to IMRT. Treatment times have not been shortened essentially by the application of FFF. However, treatment times with VMAT technique were only about one third compared to IMRT. The plan verifications with the detector arrays were successfully completed.

The secondary malignancy risk in the treated region is slightly reduced in the FFF mode. The risk for secondary sarcomas is about one magnitude smaller than for secondary carcinomas for all techniques. Regarding pituitary adenoma treatment, the risk for secondary brain carcinoma is higher for VMAT than for IMRT (fig.2). The peripheral dose point measurements resulted in a statistically significant reduced risk by the application of the FFF mode.

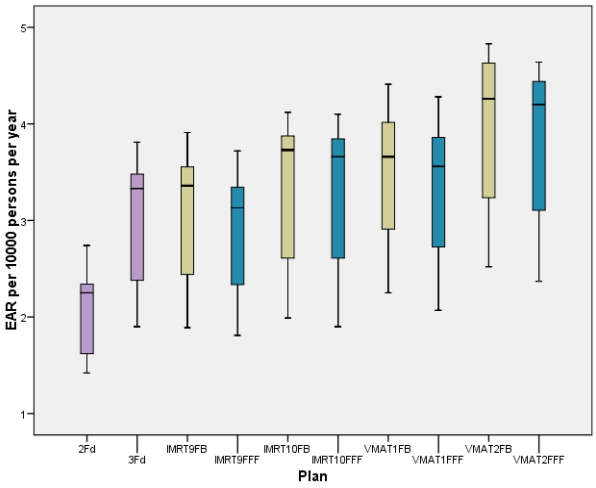

Figure 2. Risk for secondary brain cancer after radiotherapy of the pituitary gland expressed as excess absolute risk (EAR) for different techniques and number of fields, some plans containing non-coplanar fields (IMRT10, VMAT2). With flattening filter (yellow), without (blue) and with 3D conformal technique of 2 and 3 fields (purple) [3]

IV. Discussion and conclusion

From the clinical point of view, the differences between plans with and without flattening filter and for different techniques as IMRT and VMAT were small. This has also been the result of many other publications for different localizations of tumor, treatment units and planning systems.

Shortening of the treatment time was one aim at the development of VMAT. The results of the present investigation are in the same range as found for other entities. Shorter treatment times increase patient comfort and reduce the risk of intrafractional dislocation.

However, treatment times have not been shortened by the application of FFF. Although a higher dose rate is possible, there are counteracting influences: The inhomogeneous dose distribution must be compensated by additional segments which takes time. The limitations of the speed of the gantry or collimator parts constrain the dose rate. Therefore, treatment times are influenced marginally only.

The results of the risk for secondary malignancies in the treated region were statistically significant smaller with FFF, however on a low level. Secondary brain cancer seems to depend on the treated volume (fig. 2). Therefore, non-coplanar techniques cause a higher risk than coplanar, and VMAT more than IMRT. The risk for secondary sarcomas being one magnitude smaller than for secondary carcinomas coincides to the results of the atomic bomb survivors.

There is a clear evidence for a higher risk for secondary malignancies in the periphery using flattening filter mode which can be explained by additional scattered dose from the filter as described in the introduction. This effect has also been observed for other entities and is an argument to use FFF in IMRT and VMAT treatments.

Acknowledgment

Many thanks to the supervisors Prof. Dobler and Prof. Koelbl for their patience and continuous support. Thanks to all coauthors for their contributions in the publication of the papers.

The thesis has been written in German and has been published electronically in the repository of University Regensburg [1]. However, in a large part the important contents have been pulished in English in peer reviewed journals [2, 3, 4].

References

1. Treutwein M (2020) Untersuchungen zu den Auswirkungen der ausgleichskörperfreien Bestrahlungsmodalität in der Strahlentherapie anhand des lokalisierten Prostatakarzinoms und des Hypophysenadenoms. Dissertation zur Erlangung des Doktorgrades der Humanwissenschaften (Dr. sc. hum.), Universität Regensburg. doi: 10.5283/epub.43370
2. Treutwein M, Hipp M, Koelbl O et al. (2017) Volumetric-modulated arc therapy and intensity-modulated radiation therapy treatment planning for prostate cancer with flattened beam and flattening filter free linear accelerators. J Appl Clin Med Phys 18(5): 307–314. doi: 10.1002/acm2.12168
3. Treutwein M, Steger F, Loeschel R et al. (2020) The influence of radiotherapy techniques on the plan quality and on the risk of secondary tumors in patients with pituitary adenoma. BMC Cancer 20(1): 88. doi: 10.1186/s12885-020-6535-y
4. Treutwein M, Loeschel R, Hipp M et al. (2020) Secondary malignancy risk for patients with localized prostate cancer after intensity-modulated radiotherapy with and without flattening filter. J Appl Clin Med Phys. doi: 10.1002/acm2.13088

Contact of the corresponding author:

Author: Marius Treutwein
Institute: Radiotherapy department, University Medical Center, Regensburg
City: Regensburg
Country: Germany
Email: marius.treutwein@ukr.de
Field of study: Medical physics
Supervisors: Prof. Dr. B. Dobler, Prof. Dr. O. Koelbl
Date of graduation: 18.06.2020
Degree: Dr. scientiarum humanarum