QUANTITATIVE ANALYSIS OF OPTIMIZED DOSE DISTRIBUTIONS IN IMAGE GUIDED BRACHYTHERAPY

PhD thesis booklet

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Introduction

In my doctoral dissertation I dealt with the analysis of brachytherapy dose distributions. During brachytherapy, the range of irradiation is short, so radioactive sources are placed in the tumor or close to it, and accordingly, this form of irradiation is favorable for keeping the dose on the organs at risk low. In my dissertation, I analyzed the interstitial brachytherapy of breast and prostate cancer, which had a long tradition at the National Institute of Oncology, Budapest [1–4]. Breast cancer is the most common cancer in the female population in developed countries and also in Hungary, while prostate cancer is the third most common cancer in men. In the case of brachytherapy breast treatment, the target volume is the part of the breast that contains the surgical cavity and its immediate surroundings (partial breast irradiation), while in the case of prostate cancer, the whole prostate is the target volume.

In the course of my work, I performed a comparative dosimetric analysis of different techniques with the same therapeutic purpose. In the case of breast tumors, I was one of the first in the literature to compare the dosimetric results of interstitial brachytherapy and the CyberKnife which was recently introducedin Hungary. CyberKnife is a linear accelerator mounted on a robotic arm that can irradiate the target volume from almost any direction in space, making it the most similar technique to brachytherapy among the teletherapy methods for partial breast irradiation.

In most institutions the brachytherapy dose calculation in the clinic is still performed using a method introduced in the mid-1990s, that assumes a homogeneous medium. The reason is that it provides adequate accuracy and allows very fast dose calculation [5]. In the last decade, however, dose computational methods have been developed that take into account intra-patient tissue inhomogeneities and approximate real scattering conditions [6]. I examined the effects of the accuracy of the dose calculated by different methods and its possible clinical consequences in partial breast brachytherapy.

One method for prostate brachytherapy is the permanent implant prostate brachytherapy, in which iodine (I-125) isotopes, enclosed in a metal capsule, are permanently implanted in the prostate. At our institute the implantation can be done in two different ways. One of the methods gives us complete freedom in the placement of the radiation sources (loose seed technique), while in the other one the radiation sources are located 1 cm apart (stranded seed technique). I analyzed and dosimetrically compared the different implantation methods used for permanent implant prostate brachytherapy at our institute. In the case of permanent implant prostate

brachytherapy, 4 weeks after implantation, so-called post-implant plan was made, that takes into account the effects of possible isotope shifts after implantation and can therefore be considered as a plan with the final dose distribution. The differences in postimplant and intraoperative dose distributions were examined for both implantation techniques.

Objectives

1. To dosimetrically analyse and compare the multicatheter interstitial brachytherapy and CyberKnife techniques for accelerated partial breast irradiation based on real clinical plans.
2. To dosimetrically analyse and compare the multicatheter interstitial brachytherapy and CyberKnife techniques for accelerated partial breast irradiation based on plans performed on the same anatomical conditions.
3. To dosimetrically analyse and compare the conventional (TG-43) and model-based (TG-186) dose calculation algorithms for accelerated partial breast irradiations performed with multicatheter interstitial brachytherapy.
4. To dosimetrically evaluate the irradiation plans for prostate implants performed with loose and stranded I-125 radiation sources and to compare the two techniques in terms of target volume dose coverage and dose to the organs at risk.
5. To compare of the intraoperative and post-implantation dosimetry performed by loose and stranded seed techniques in patients treated by permanent implant prostate brachytherapy.

Methods

I compared the dosimetric parameters of partial breast irradiation in two approaches. I selected thirty-two patients treated with brachytherapy and thirty-two patients treated with CyberKnife, and retrospectively collected and compared the relevant dosimetric data for the target volume and organs at risk. The advantage of this method is that we compare real clinical plans, but the disadvantage is that the different anatomical conditions in different patients affect the results. In the other approach, I used the clinical brachytherapy plans and made treatment plans for the same anatomy using the CyberKnife technique. I conducted this study by

comparing thirty-one brachytherapy plans and thirty-one CyberKnife plans for the same anatomy. The advantage of this method is the identical anatomy, but, because there are differences in the preparations for the two irradiation methods, these CyberKnife plans are not exactly the same as we would get if patients were actually treated on CyberKnife.

I recalculated the interstital brachytherapy clinical plans of seventy-two patients using a calculation algorithm that also takes into account inhomogeneities inside the patient and real scattering conditions. Because the two dose calculation algorithms result in small differences, calculation for the same anatomy is a prerequisite for this study. For comparison, I collected the appropriate dosimetric parameters from the organs at risk and the target volume, and calculated dose-volume histograms.

I compared the clinical plans of forty-five patients undergoing loose seed technique permanent implant prostate brachytherapy with plans prepared for the same anatomy using the stranded seed technique. Furthermore, I compared seventy-nine loose seed technique clinical plans with one hundred and twenty-six stranded seed tecghnique clinical plans, in which case, naturally, the anatomical conditions were different. In these studies, I was also able to examine parameters of the target volume and the organs at risk. I compared the intraoperative and post-implantation plans of thirty patients using the loose seed technique and another thirty patients using stranded seed technique in terms of target volume coverage and dose homogeneity. The post-implant plan is based on a CT scan, so in this case it is not possible to determine the exact contours of the organs at risk, and a dosimetric comparison cannot be performed on them.

New scientific results

T1) By dosimetric comparison of real clinical plans, I found that in accelerated partial breast radiotherapy, irradiation of the target volume with both multicatheter interstitial brachytherapy and CyberKnife techniques can be performed appropriately. Furthermore, based on a dosimetric comparison of the organs at risk, I concluded that the brachytherapy method gives less dose on the examined organs, except for the contralateral breast and lung. I found no differences in the heart. At the same time, the dose to the organs at risk in both techniques remains well below the dose limits set out in our protocol. [P1]

T2) Based on multicatheter interstitial brachytherapy and CyberKnife plans performed on the same anatomical conditions, I found that multicatheter interstitial brachytherapy provides better results than CyberKnife for the organs at risk. I found an advantage for CyberKnife only in one of the examined parameters. The ipsilateral non-target breast is irradiated in a smaller percentage with the prescribed dose by CyberKnife. [P2, P3, P7]

T3) I found that in the case of accelerated partial breast radiotherapy with multichateter interstitial brachytherapy, the results of the new model-based and the conventional, clinically used dose calculation algorithms slightly differ for both the target volume and the organs at risk (except for the heart). Assessing the extent of the deviations, I came to the conclusion that the clinical consequences are negligible, and therefore I did not recommend to change the current clinical practice of dose calculation. [P4]

T4) Examining various permanent implantation prostate brachytherapy methods, I found that the criteria for dose coverage of the target volume can be fully met with both loose and stranded seed technique during intraoperative planning. Furthermore, the loose seed technique is more favorable for the organs at risk with a higher dose conformity, but higher dose inhomogeneity within the target volume. [P5, P8, P9]

T5) I found that in the case of permanent implant prostate brachytherapy, the post-implant plans (prepared on CT scans in four weeks after implantation) show a lower target volume dose coverage than the intraoperative plans for both the loose and stranded seed techniques with increasing homogeneity of the dose distribution. I found no difference in the extent of changes between the two techniques. [P6, P10, P11]

Original articles related to the thesis points

[P1] **Herein A**, Stelczer G, Pesznyák Cs, Fröhlich G, Smanykó V, Mészáros N, Polgár Cs, Major T. Multicatheter interstitial brachytherapy versus stereotactic radiotherapy with CyberKnife for accelerated partial breast irradiation: a comparative treatment planning study with respect to dosimetry of organs at risk.
Radiology and Oncology 55 (2) pp. 229-239 (2021), IF: 2,991

[P2] **Herein A**, Stelczer G, Pesznyák Cs, Fröhlich G, Smanykó V, Mészáros N, Polgár Cs, Takácsi-Nagy Z, Major T. CyberKnife radiotherapy versus multicatheter interstitial

brachytherapy for accelerated partial breast irradiation: a dosimetrical assessment with special focus on dose to organs at risk
Reports of Practical Oncology and Radiotherapy – in press

[P3] Fröhlich G, Mészáros N, Smanykó V, Stelczer G, **Herein A**, Polgár Cs, Major T. Is stereotactic CyberKnife radiotherapy or multicatheter HDR brachytherapy the better option dosimetrically for accelerated partial breast irradiation?
Brachytherapy 20 (2) pp. 326-331 (2021), IF: 2,362

[P4] Zourari K, Major T, **Herein A**, Peppa V, Polgár Cs, Papagiannis P. A retrospective dosimetric comparison of TG43 and a commercially available MBDCA for an APBI brachytherapy patient cohort.
Physica Medica 31 (7) pp. 669-676 (2015), IF: 1,763

[P5] Major T, Ágoston P, Fröhlich G, Baricza K, Szabó Z, Jorgo K, **Herein A**, Polgár Cs. Loose versus stranded seeds in permanent prostate brachytherapy: Dosimetric comparison of intraoperative plans.
Physica Medica 30 (8) pp. 909-913 (2014), IF: 2,403

[P6] **Herein A**, Ágoston P, Szabó Z, Jorgo K, Markgruber B, Pesznyák Cs, Polgár Cs, Major T. Intraoperatív és posztimplantációs dozimetria összehasonlítása permanens implantációs prosztata-brachyterápiával kezelt betegeknél.
Magyar Onkológia 59 (2) pp. 148-153 (2015)

Abstracts related to the thesis points

[P7] **Herein A**, Stelczer G, Mészáros N, Pesznyák Cs, Major T, Polgár Cs. Intersticiális brachyterápia és markervezérelt, CyberKnife-fal végzett besugárzás dozimetriai összehasonlítása gyorsított részleges emlőbesugárzás esetén.
MST XIV. Kongresszusa, Lillafüred, Absztrakt: Magyar Onkológia 63 (2) pp. 133-133 (2019)

[P8] **Herein A**, Major T, Ágoston P, Polgár Cs. Sugárforrás-elrendezések dozimetriai hatásai permanens prosztata-brachyterápiánál.
MST XI. Kongresszusa, Tihany, Absztrakt: Magyar Onkológia 57 (2) pp. 120-120 (2013)

[P9] **Herein A**, Ágoston P, Polgár Cs, Major T. Dosimetric effects of different source arrangements in permanent prostate brachytherapy.

ESTRO 33, Bécs, Absztrakt: Radiotherapy and Oncology 111 (Suppl. 1) pp. S328-S329 (2014)

[P10] **Herein A**, Ágoston P, Szabó Z, Jorgo K, Pesznyák Cs, Polgár Cs, Major T. Intraoperatív és posztimplantációs dozimetria összehasonlítása permanens implantációs prosztata-brachyterápiával kezelt betegeknél.
MST XII. Kongresszusa, Kecskemét, Absztrakt: Magyar Onkológia 59 (2) pp. 168-168 (2015)

[P11] **Herein A**, Major T, Ágoston P, Polgár Cs. Comparison between intraoperative and postimplant dosimetry in patient receiving permanent implant prostate brachytherapy.
6th Alpe-Adria Medical Physics Meeting, Budapest, Absztrakt: Proc. of the 6th Alpe-Adria Medical Physics Meeting, Budapest, Hungary, 29-31 May 2014. pp. 47 (2014)

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