SOME QUESTIONS OF THE QUALITY CONTROL IN THE MEGAVOLTAGE THERAPY

(PHYSICAL AND INFORMATICAL ASPECTS)

Ph.D. Theses

Csilla Pesznyák

Semmelweis University
Doctoral School of Theoretical Medicine

Supervisor: Prof. Györgyi Rontó, D.Sc.

Opponents: Zoltán Vígváry, C.Sc.
Jenő Pálvölgyi, Ph.D.

Examination Committee: Prof. Péter Sótonyi, academic
Pál Gróf, C.Sc.
Takácsi Nagy László, Ph.D.

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1. Introduction

The rapid technical developments of the radiation therapy necessitated the initiation of proper quality assurance (QA) that is necessary for the exact realization of the radiation treatment plans. There is no organic QC protocol in Hungary and what is more one cannot find any kind of regulation in this topic. Because of this, the actions and regulation connected with the quality and reproducibility are depending on the local speciality of the given institute.

2. Objectives

The aim of the investigation is to give answer to some questions of the QC in the megavoltage therapy for the sake of making the treatments more trouble-free.

(**A**) To determine the terms of usage of CT and PET/CT equipments in treatment planning that were made originally for diagnostic purposes, and comparison of four different QC CT phantom.

(**B**) Quality control of the Varian CadPlan™ and CMS XiO® treatment planning systems (TPS) and comparison of their calculation algorithms for photon and electron radiations of different energy. Review the effect of the CT number for dosimetry on photon dose calculation in the function of tissue inhomogeneities and different calculation algorithms.

(**C**) To determine the terms of usage of the PTW EPID QC Phantom® in the case of EPID's (**E**lectronic **P**ortal **I**maging **D**evices) and classical portal images. Measuring the quality parameters of portal images.

3. Methods

A. If the CT is used not only for diagnostic purposes, a properly stored plane indexed tabletop shall belong to it on which the patient immobilizing devices can be fixed in a proper and reproducible way. Measurement of the CT tabletop's inclination with digital spirit level, controlling the horizontal movement with laser.

When planning on CT base the determination of the CT numbers is important since for the inhomogeneity correction of the 3D TPS's we need to know the electron density of the different tissues; so we need the CT number – relative electron density calibration curve.

- We performed the CT number measurements with four different CT phantoms: MINI CT QC Phantom, 76-430 (Inovision Company), RMI 467 CT electron density phantom (Gamex), CIRS 062 type electron density reference phantom and CIRS Thorax IMRT phantom. During the measurements, we could evaluate the calibration of the CT and the quality of each phantom in the same time.

- We investigated the dependence of the CT number on the tube voltage at 110 and 130 kVp.
- Some CT phantoms are good for controlling of the geometric distortion of the CT images as well. We can derive the distortion of the CT images by measuring the given distances on the phantom.

B. We chose eight different radiation treatment planning techniques from the IAEA-TECDOC-1583 protocol compiled by the International Atomic Energy Agency that fit best the daily practice. For the measurements, we used the CIRS Thorax IMRT phantom in which there are inhomogeneities with the same electron densities as the human organs. We made CT scans from the phantom and used them during the treatment planning. We carried out the measurements on Varian linacs at 6 and 18 MV photon energies. We used calibrated equipments: PTW Unidos electrometer, NE Farmer ionization chamber, thermometer and barometer. The dose measurements were evaluated on the base of IAEA TRS 398 protocol. I investigated the effect of the CT number changing on the dose as a function of calculation algorithms, photon energies and depth.

I have used two different TPS's:

1. Varian CadPlan™ TPS: Pencil Beam convolution with Modified Batho Power Law correction algorithm (*PBMB*), Pencil

beam convolution with equivalent TAR/TMR, (*EqTAR)* and the calculation algorithm without inhomogeneity correction (*IKN*)

2. CMS XiO® TPS: Fast-Fourier transform convolution algorithm (*FFTC*) and the Multigrid superposition (*MGS*).

The results were analysed on the base of the equation given in the IAEA TRS 430 protocol:

$$\text{Error}\ (\%) = 100\bullet(D_{\mathbf{calc}}-D_{\mathbf{meas}})/D_{\mathbf{meas,ref}},$$

where $D_{\mathbf{calc}}$, $D_{\mathbf{meas}}$ and $D_{\mathbf{meas,ref}}$ are the calculated, the measured and reference point's dose, respectively.

For electron energies I prepared the treatment plans for the CT images taken from the CIRS Thorax IMRT phantom. The performance of the phantom is unsuitable for measurements with Roos chamber so I could use only the Farmer chamber applicable above electron energies of higher than 10 MeV. The measurements were carried out on the Varian 2100C linac at 12, 16 and 20 MeV electron energies. For the irregular electron field we used cutout blocks made from Rose metal. For treatment planning, we used:

1. Varian CadPlan™ TPS: generalized Gaussian pencil beam model calculation algorithm with full 3D inhomogeneity correction.
2. CMS XIO® TPS: applies Hogstrom's pencil beam algorithm with inhomogeneity correction.

We controlled nine different field arrangements at 100 and 108 cm SSD and analyzed the calculated and measured values with the equation mentioned above.

C. In my work, I tested the image qualities of different field control systems. I examined four different EPID's: Siemens OptiVue500aSi®, Siemens BeamView Plus®, Elekta iView®, Varian PortalVision™, and I tried out the use of PTW EPID QC PHANTOM® in the QC of traditional portal films. Two systems were tested: the Kodak X-OMAT® cassette with Kodak X-OMAT V® film and the Kodak EC-L Lightweight® cassette with Kodak Portal Localisation ReadyPack® film.

For the measurements, I used the PTW EPID QC PHANTOM®. I can analyse with the epidSoft®2.0 program the following parameters of the images: the signal linearity and the signal-to-noise ratio (SNR), the isotropy of signal linearity, the geometric distortion, the low contrast resolution, and the high contrast resolution – for determining the modulation transfer function (MTF). I also controlled the image quality with the Las Vegas phantom and compared the image with that made by the PTW EPID QC PHANTOM®.

4. Results and discussion

A. We measured 0 – 8 mm inclination of the tabletops at the tested CT equipments. During the CT number verification, we recognised that two equipments needed recalibration. The results of the measurements for different CT equipments are shown in figure 1.

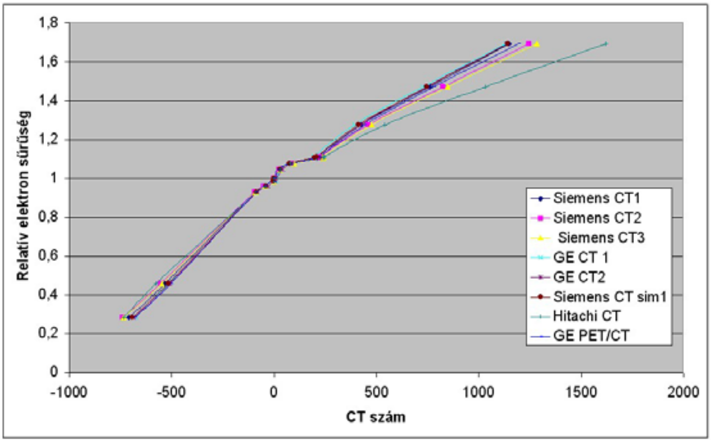

Figure 1: The results for CT number measured with Gamex RMI 467 CT electron density phantom

Out of the four CT phantoms, the measured and expected values differ significantly only for the MINI CT QC phantom. According to our measurements, the geometrical distortion of the CT equipments is negligible.

B. In the case of the CMS XiO® TPS, the MGS algorithm agrees to the IAEA criteria. For this algorithm, the greatest error was 4.2%

on 6 MV energy in the penumbra region. For materials of small relative electron density, like the lung the FFTC algorithm results in an error of 8.5% and this reaches 12.5% at high energy. In the case of the Varian CadPlan™ TPS, we have got the best results with the PBMB algorithm. We observed the greatest error in the lung equivalent material (5.6%) in contrast to the IAEA criterion of 5% (the measurement point was under the skin in a depth more than 20 cm in lung equivalent material). The EqTAR calculation algorithm is unsuitable for calculation of non-coplanar treatment plans. The results were worse than with the PBMB algorithm, but it is still acceptable for low energy but for high energy, the error goes up to 10%. We mentioned the results that we got with neglecting the inhomogeneity correction just to see the effect of inhomogeneity correction on results. We have never used this algorithm for patient treatment because in lung or bone equivalent material on the radiation path the error can be even 20%.

The effect of CT number changes on the dose at 6 and 18 MV photon energies was about 2% for ±100 HU changing while for the EqTAR algorithm of the Varian CadPlan™ TPS this value was 5% in the case of Co-60 source.

In the case of the controlled electron energies, the measured values agreed well with the results of the Varian CadPlan™ TPS when the gantry was in 0°, but for the CMS XiO® TPS the error was 10% in lung equivalent material. For water equivalent materials, the greatest difference between the calculated and measured values was 3.4%. The results of both TPS's were good on both SSD's and handled the cutout blocks properly. Up to now there are no accepted IAEA criteria for electron measurements.

When the gantry was in 90°, the CMS XiO® TPS resulted in the better agreement for 12 MeV while for 16 MeV the Varian CadPlan™ gave better agreement. At oblique incident treatment field (gantry angle 315°) in the reference point we stated 3% error at 12 MeV and 0.1% at 16 MeV for the Varian CadPlan™ TPS. Figure 2. is a comparison of our TPS's with two other treatment planning systems.

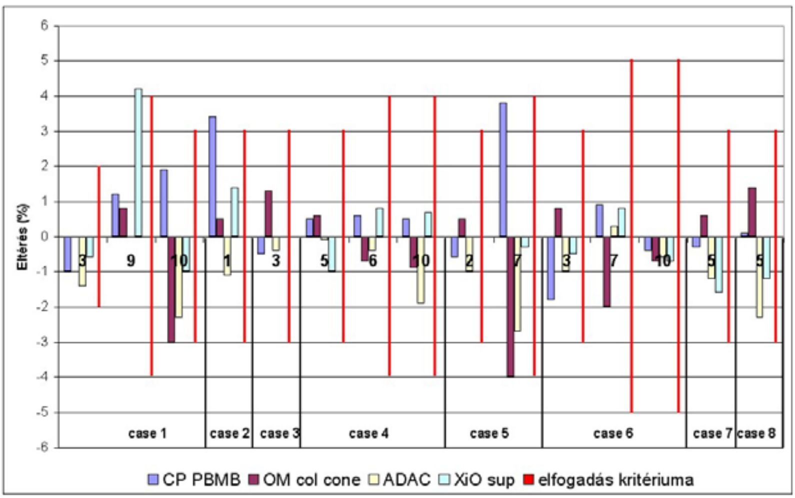

Figure2: Comparison of four different TPS's based on our measurements: Pinnacle ADAC® (collapsed cone), CMS XiO® (MGS), Varian CadPlan™ (PBMB) and Nucletron Oncentra™ MasterPlan (collapsed cone).

C. Analyzing the images made by the Siemens OptiVue500aSi®, the Elekta iView® and the Kodak Portal Localisation ReadyPack® film we got the best results with 2 MU irradiation. For double exposure, we offer the 2 + 1 or the 2 + 2 MU's. For the Siemens BeamView Plus®, the Varian's PortalVision™ and the Kodak X-OMAT V® film we offer 7 + 7 MU's.

Test of the DICOM implementation: the epidSoft® 2.0 program was not able to accept the DICOM images exported from the Siemens BeamView Plus® VEPID. Because of this first, we read the images with the DicomWorks® program and converted them to a file of bmp extension. The software could analyze these images. Analyzing the Varian® DCM files we did not get contrast values that is to say the epidSoft® 2.0 program did not evaluate the absorption of the holes that could be seen well on the images. By exporting the images to bmp format, the holes appeared on the images even for low doses. The DICOM implementation was incomplete in both cases.

5. Conclusion

A. We have to derive in a protocol the terms that are necessary for the CT equipments to be used in radiation therapy. These terms make the diagnostic CT and PET-CT equipments suitable for treatment planning too.

B. The differences between the point doses determined from the treatment plans and the measured values are of different origin. The errors of the measurements should be added according to the Gaussian error propagation rule. Such errors are the following: the calibration and configuration errors of the TPS, the errors of the calculation algorithm, the error of the measuring system (electrometer and ionization chamber) and the errors of the phantom positioning.

On the base of the measurements, we can state that on photon energies the superposition algorithm can be used for patient treatments in the case of the CMS XIO® TPS while in the case of Varian CadPlan™ TPS the PBMB algorithm is the proper choice. At the EqTAR and FFTC algorithm, we got greater differences than the criteria given by the IEAE for different inhomogeneities. These were more significant in lung than in bone. A qualified medical physicist's task is to decide in which case which algorithm is the proper one.

The 1-2% dosimetric effect of the CT number changes looks like insignificant if, however we take into account that the convolved error can be 2-5% this value cannot be neglected.

The CIRS Thorax IMRT phantom is good only at electron energies higher than 10 MeV since one cannot insert into the phantom plan parallel (Roos or Markus) chamber that is appropriate under 10 MeV. The volume of the Farmer chamber is too large so it is worthwhile to repeat the measurements with chamber of smaller volume or with solid state (e.g. diamond) detector. We plan a homemade phantom equipped with lung and bone equivalent materials that is appropriate for measurements with plan parallel chamber.

On the base of the electron measurements we can state that in lung equivalent material the calculated values of the Varian CadPlan™ are in better agreement with the measured values, behind the bones, however non of the two TPS's calculate sufficiently.

C. We tested the constancy of the characteristic in the case of portal images with PTW EPID QC PHANTOM®. The reference values shall be determined during the acceptance test of the equipments (31/2001 order of the health minister). It would be useful if the manufacturers inform the end user about the measured or suggested reference values since nowadays, there are very few published data about the MTF or the SNR. The PTW EPID QC PHANTOM® is usable in the QC process not only for the amorphous silicon EPID's but also for the video based Siemens BeamView Plus® and the Varian's PortalVision™ operating with scanning liquid ionization chamber. In the measurement protocol, the usable file format shall be defined since the implementation of DICOM is not complete at these systems.

All the three manufacturers improved the arising DICOM problems at their amorphous silicon systems so we could handle and analyse the images. It is recommended to make a control exposition when opening a new package of portal film so that to certify the quality of the portal image and to control the film processing.

6. Publications and abstracts related to theses

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10. Weisz Cs, Polgár I, **Pesznyák Cs**. (1996) A CADPLAN használatba vételével kapcsolatos tapasztalatok, Rad Közlemények, 32(1): 54-60.

Poster abstracts

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2. Pesznyák Cs, Polgár I, Zaránd P. (2007) Mezőellenőrző berendezések összehasonlítása és alkalmazása a minőség-biztosításban, MBFT – Magyar Orvosfizikai Társaság XIV. konferenciája, Magyar Onkológia, 51(3): 247.
3. Pesznyák Cs, Polgár I, Zaránd P. (2007) Újgenerációs mezőellenőrző berendezések bemutatása, Magyar Sugárterápiás Társaság VIII. Kongresszusa, Magyar Onkológia, 51(3): 273.
4. Pesznyák Cs. Sugárbalesetek megelőzése, Magyar Sugárterápiás Társaság VII. Kongresszusa, (2005) Magyar Onkológia, 49(3): 272.