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Test cases for commissioning an add-on micro multi-leaf collimator Apex for stereotactic radiosurgery treatments

Casos teste para comissionamento de um micro colimador Apex multicamada para tratamentos de radiocirugia estereotáxica

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Abstract

Two comprehensive test cases are presented for dosimetric commissioning of a radiosurgery system, in a hospital where dedicated phantoms are not available. The system consisted of an Elekta Precise linear accelerator, an Apex micro multi-leaf collimator, and a Monaco treatment planning system (TPS). The purpose of Test I was to assess the dose accuracy with coplanar arc beams. Test II was an end-to-end type test, a rigid Leksell stereotactic frame was fixed to a watermelon phantom and Ergo++ TPS was used for stereotactic coordinates definition. The purpose of Test II was to assess the dose accuracy with non-coplanar arc beams and the influence of geometrical accuracy in the whole process. Ionization chambers were used for dose measurements. Results of Test I showed that discrepancies below 1% are achievable, while results of Test II allowed detection of geometric shifts < 1 mm with dose discrepancies lower than 1%. To the best of our knowledge, there are not published works reporting test cases for commissioning a stereotactic radiosurgery system like the one tested in this work. The designed test cases showed adequacy for assessment of TPS accuracy in complex treatment configurations, like those used in stereotactic radiosurgery.

Keywords: stereotactic radiosurgery; commissioning process; test cases.

Resumo

Dois casos-teste abrangentes são apresentados para o comissionamento dosimétrico de um sistema de radiocirugia, em um hospital sem phantoms disponíveis. O sistema consistiu em um acelerador linear Elekta Precise, um micro colimador Apex e um sistema de planejamento de tratamento (TPS) Mônaco. O objetivo de Teste I foi avaliar a precisão do cálculo da dose com feixes de arco coplanar. O Teste II foi um teste do tipo ponta a ponta, uma estrutura estereotáxica rígida de Leksell é fixada a um phantom de melancia e o Ergo ++ TPS é usado para definição de coordenadas estereotáxicas. O objetivo do Teste II foi avaliar a precisão da dose com feixes de arco não coplanares e a influência da precisão geométrica em todo o processo. Câmaras de ionização foram usadas para medições de dose. Os resultados do Teste I mostrou que as discrepâncias inferiores a 1% são alcançáveis, enquanto os resultados de Teste II permitiram a detecção de mudanças geométricas inferiores a 1 mm com discrepâncias de doses mais baixas que 1%. Até onde sabemos, não existem trabalhos publicados relatando casos de teste para o comissionamento de um sistema de radiocirurgia estereotáxica como o testado neste trabalho. Os casos-teste projetados mostraram adequação para avaliação da precisão do TPS em configurações de tratamento complexas, como as usadas na radiocirugia estereotáxica.

Palavras-chave*: radiocirugia estereotáxica; comissionamento dosimétrico; casos-teste*

1. Introduction

The intracranial stereotactic radiosurgery (SRS) is an effective treatment technique to treat lesions in the cranial region and functional disorders. Due to the sizes of the targets and the proximity of organ at risk, it is necessary to achieve a radiation delivery that conforms dose distributions tightly in the region of interest. The available technology, i.e., CyberKnife, GammaKnife, Tomotherapy, dedicated Linear Accelerators (LINACs) and LINAC with stereotactic cones or add-on micro multi-leaf collimator (mMLC), allows that to be possible.

It is necessary to complete the commissioning process in order to introduce in the clinic a new radiosurgery system. This process includes beam data collection, machine modeling in the treatment planning system (TPS) and TPS testing. The last step must allow evaluating the system's capacities for the planning work in an integral way, from connectivity of the elements of the system, the manipulation of the information in the different steps of the process, until the final evaluation of each treatment [1–4]. There are not clear reports which establish a set of test cases for commissioning specialized techniques such as SRS [5-8]. In this work we performed test cases for commissioning a SRS system, following the acceptance criteria provided in the document AAPM-RSS Medical Physics Practice Guideline 9.a. for SRS-SBRT [8].

The National Institute of Oncology and Radiobiology from Havana, Cuba, acquired a new radiosurgery system. The acceptance testing process of the system included beam data collection, stereotactic coordinates acquisition and TPS plan. There are not dedicated phantoms available in the hospital to perform the accuracy of SRS system. For this reason, the main objective of this paper was to design and implement two comprehensive test cases for dosimetric commissioning of a SRS system, according to the dosimetric set available in the hospital.

2. Materials and Methods

The system to be commissioned consists on an Elekta Precise LINAC with an add-on mMLC model Apex, a TPS Monaco v.5.11 and TPS Ergo++ v. 1.7.8.

The mMLC Apex allows performing treatments by using a beam modulation with a constant dose rate (VMATc). Another modality is dynamic conformal arcs without beam modulation using coplanar or non-coplanar arcs. In our Hospital we will start these treatments using the second modality. For this reason, we meant to asses this treatment technique.

Once the tests described in references [2], [3] y [4] were completed, two radiosurgery test plans were created in the TPS Monaco. Monte Carlo calculation algorithm was used, in both cases, with a grid size of 2 mm and a statistical uncertainty of 2 %. Standard Monaco IMRT cost functions were planned. However, the objective was not to achieve an optimum plan according to some critical criteria, but to attain a logical dose distribution. The beam energy used in this work was 6 MV WFF. The dose calculated by the TPS was compared with the absolute dose measured with ionization chambers.

In order to perform Test I, the PTW's Matrix Phantom (model T40026) was used. This is a cylindrical RW3 phantom with 25 Semi-flex ionization chambers inserts uniformly distributed in its center that allows measurements at different locations and depths. A CT study of this phantom with the PTW ionization chamber Semi-flex 31010 inside the central hole was carried out. Using the Monaco contouring tools, the chamber cavity was set as the CTV. A PTV was created consisting on an ellipse around the CTV. The ellipse had a major axis of 5 cm (anterior-posterior direction) and a minor axis of 2 cm (lateral direction). Two coplanar arcs were planned (0° to180° CW and 180° to 360° CW) with an angular increment of 10°. Figure 1 illustrates the beam arrangement.

The leaves were required to conform the PTV shape with a margin of 0.5 cm and the leaves edges outside. The isocenter was set at the center of the CTV. A dose of 10 Gy in a single fraction was prescribed for 95% of the PTV.

The following IMRT cost functions were applied to the target: Target Penalty (1000 cGy to 95%) and Quadratic Overdose (1050 cGy). The purpose was to assess the dose calculation accuracy with coplanar arc beams.

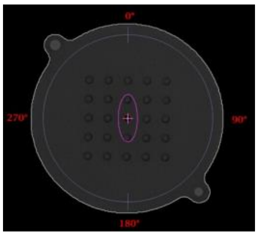
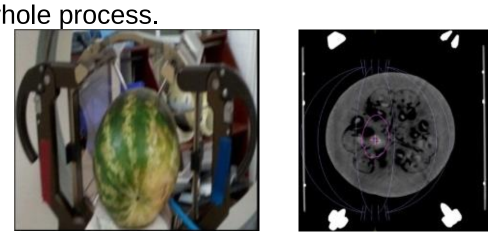


Figure 1-Transverse phantom view at the isocenter plane for the Test I plan.

Test II is an end-to-end type test. The immobilization system consists in a rigid Leksell stereotactic frame, it was needed a phantom which could be fixed to the frame in order to obtain and assess the stereotactic coordinates calculation. Since dedicated phantoms were not available, we used a watermelon for this purpose. A natural phantom was prepared by inserting a PTW Pinpoint 3D 31016 ionization chamber inside a watermelon, following Elekta engineer's recommendation [9] as an alternative to commercial phantoms when you want to assess the stereotactic coordinates calculation using a rigid frame. A rigid Leksell stereotactic frame was fixed to the phantom, as presented in Figure 2a, and a CT study was performed. Radio opaque markers (BBs) were placed on the phantom surface for stereotactic coordinates verification. The CTV defined in the TPS consisted on the chamber cavity. An irregular structure around it was selected as the PTV. Six non-coplanar arcs were planned. Table 1 lists the gantry arcs and couch angles. The beam arrangement is showed in Figure 2b.

An isocenter configuration at the middle of the CTV was planned with the leaves conforming the irregular PTV with a margin of 0.5 cm. A dose of 12 Gy in a single fraction was prescribed for 95% of the PTV. The following IMRT cost functions were applied to the target: Target EUD (1200 cGy) and Quadratic Overdose (1250 cGy). Ergo++ TPS was used for stereotactic coordinates definition. The coordinates calculated were verified using the BBs at the LINAC room. For this objective, the watermelon phantom was positioned in the coordinates of the BBs. The distance between the lasers incidence and the real position of the BBs was then taken as the quality of the stereotactic localization. The purpose of Test II was to assess the dose accuracy with non-coplanar arc beams and the influence of geometrical accuracy in the whole process.



a b

Figure 2 - (a) Watermelon phantom attached to a Leksell stereotactic frame. (b) Transverse phantom viewatthe isocenter plane for the no-coplanar arcsradiosurgeryplan.

Once both plans were ready, they were delivered on the phantoms and the dose was registered with the ionization chambers inside. Three measurements were performed in each test in order to obtain the measured dose reproducibility and uncertainty.

In order to calibrate the ionization chambers used, a cross calibration was performed using a PTW ionization chamber Farmer model 30013 as reference. A solid water phantom was used for the calibration process of the Semi-flex ionization chamber, due to the fact that its composition is similar to the phantom used in Test I. A PTW water tank MP3 was used for the Pinpoint 3D ionization chamber, taking into account that the watermelon phantom used in Test II is water equivalent.

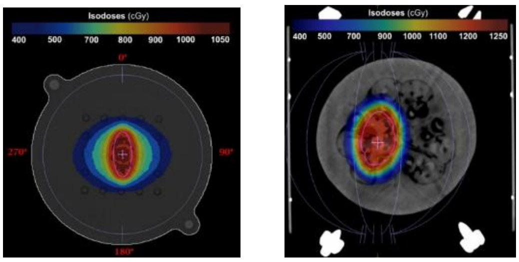
The uncertainty budget of the measured dose was calculated following the recommendations of the IAEA-TECDOC-1585 [10]. The total uncertainty was reported taking into account a confidence level of 95 %.

Table 1–Beam and couch angles (°) setup for Test II.

Beam	Gantry start	Arc	Inc	Couch
1	190	160	10	5
2	190	160	10	40
3	190	160	10	75
4	10	160	10	285
5	10	160	10	325
6	10	160	10	355

3. Results

Once both plans were sent from TPS, they were received in the Record and Verify system Mosaiq and delivered in the LINAC room. This allowed the verification of the correct connection of all system elements in the hospital network. Figure 3 shows the obtained isodoses distribution in each phantom. The comparison between the measured doses, with its respective uncertainties, and the one calculated by the TPS, for both test cases, is reported in Table 2.



a **b**

Figure 3–Isodoses shapes obtained by the TPS plan: (a) Test I, (b) Test II.

Table 2 - Dose comparison for both test cases.

Dose (cGy)	Test case I	Test case II
Calculated	1076.5	1232.5
Measured	1080.1(2σ = 2%)	1243.2(2σ = 2%)
Relativediscrepancy (%) [a]	0.33	0.86
Geometric error (cm)	-	< 1 mm

[a]Relative to measuring point

4. Discussion

Several papers and guidelines have been published related to the dosimetric and geometric accuracy in SRS. They recommend acceptance values for SRS commissioning [7, 8, 11, 12, 13]. In these works, values of dosimetric accuracy up to 5% and geometric accuracy down to 1 mm are presented. The results of this paper agree with this criteria. Results of Test I showed that dose discrepancies below 1% are achievable. The perform of Test II allowed detection of geometric positioning uncertainties lower than 1 mm and dose discrepancies lower than 1%.

The statistical uncertainties relative to the measured doses agree with the values reported in references [10] y [11] and with the one established in both plans for Monte Carlo dose calculation.

Most cases of SRS with a dynamic mMLC system, such as the present Apex, consist of variations of these test cases, adding different numbers of arcs, from different angles, and varying the relative weight of each arc. The TPS has in these cases its most difficult tests. It has to consider the radiation beam entry from the different directions, to different target depths, and with a continuously modified cross section. In this work, the correspondence between expected and obtained results suggests a correct implementation of the overall technique and the advantageous capabilities of the SRS system under study.

5. Conclusions

To the best of our knowledge, there are not published works reporting test cases for commissioning a stereotactic radiosurgery system like the one tested in this work. Two comprehensive test cases were designed and implemented for commissioning a micro multi-leaf collimator Apex for stereotactic radiosurgery treatments. After successfully passing the conventional tests included in references [2], [3] y [4], the test cases described in this work showed their adequacy for further assessment of treatment planning system accuracy in more complex treatment configurations, like those used in stereotactic radiosurgery. These test cases can be an alternative in hospitals where there are not available dedicated phantoms to assess stereotactic radiosurgery systems accuracy.

6. Recommendations

Due to the fact that in SRS are often used small fields and the recently studies in small fields dosimetry [16], we recommend to perform test cases that include the use of these field sizes and the procedure to obtain absolute dose in that kind of fields.

The treatment technique (dynamic conformal arc) that is going to be used does not include beam modulation. Nevertheless the dose distribution is an issue that is necessary to asses due to the presence of organs at high risk. For this reason, we recommend to perform test cases in order to evaluate bidimensional or three-dimensional the dose distributions.

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