ORIGINAL ARTICLE | KLİNİK ÇALIŞMA

An institutional experience: quality assurance of a treatment planning system on electron beam

Kurumsal deneyim: Elektron ışınlarında tedavi planlama sisteminin kalite güvenirliği

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OBJECTIVES

This study aims to application of the IAEA TRS-430 QA procedures of Eclipse^{TM} v7.5 TPS for electron energies. In addition, the trends of the deviations found in the conducted tests have been determined.

METHODS

The calculations of TPS and measurements irradiations of the treatment device have been compared. As a result, the local dose deviation values and their confidence limit values have been obtained.

RESULTS

All confidence limit values were detected that it was increased depending on expanding depth. But each confidence limit values were found to show different change depending on expanding field size. Results of CT based inhomogeneity corrections and complex surface shapes tests were found outside tolerances, especially δ3.

CONCLUSION

The QA of our clinic's TPS has been done and it has been found that there aren't drawbacks in its use in treatment. Only the errors found in our study for the parameters used in treatment planning has to be considered.

Key words: Confidence limit; electron beam; treatment planning system; quality assurance.

AMAÇ

Bu çalışmada, elektron enerjileri için Eclipse^{TM} v7.5 TPS üzerinde IAEA TRS-430 QA prosedürlerin uygulanması amaçlandı. Ek olarak, yapılan testlerde bulunan sapmaların eğilimleri tespit edildi.

GEREÇ VE YÖNTEM

Çalışmada, tedavi cihazının ışınlamalarının ölçümleri ve TPS'nin hesaplamaları karşılaştırıldı. Sonuç olarak, yerel doz sapma değerleri ve onların güvenli limit değerleri elde edilmiştir.

BULGULAR

Tüm güvenli limit değerleri derinliğin artmasına bağlı olarak arttığı tespit edildi. Fakat, her bir güvenli limit değeri artan alan boyutuna bağlı olarak farklı değişimler gösterdiği bulundu. BT tabanlı inhomojenite düzeltmeleri ve karmaşık yüzey şekilleri testlerinin sonuçları toleransların dışında bulundu, özellikle δ3.

SONUÇ

Kliniğimizin TPS'nin QA'i yapıldı ve hasta tedavisinde kullanımının hiçbir sakıncası olmadığı bulundu. Ancak, hasta tedavi planlamasında kullanılan parametreler için çalışmamızda bulunan hatalar göz önünde bulundurulmalıdır.

Anahtar sözcükler: Güvenli limit; elektron ışını; tedavi planlama sistemi; kalite güvenirlik.

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The clinical delivery of electron beam process is complex than photon beam as it involves: *(i)* additional devices like cones, fabrication of customized block and differential transmission bolus and *(ii)* issues related with extended SSD, additional shielding for collimation at skin level, oblique incidence and contour irregularity. Some of the above issues are modeled and simulation in the Treatment Planning System (TPS). Therefore, TPS is a crucial component of clinical radiotherapy process. In recent years, complexity of TPS has increased significantly, especially with the advancement of image based on three dimension (3-D) conformal radiotherapy. This has led to need for a comprehensive quality assurance (QA) guidelines. Increased need has been paid to quality assurance of treatment planning systems by several national and international organizations that include Van Dyk et. al.[1] in 1993, Shaw et. al.[2] in 1996, SSRPM report[3] in 1997, Fraass et. al.[4] in 1998, Mayles et. al.[5] in 1999, ESTRO report[6] in 2004 and NCS report[7] in 2006.

In the past, lack of complete TPS QA and quality control of treatment machine procedures led to some serious accidents (such as incorrect repair of accelerator (Spain),[8] accelerator software problems (USA and Canada)[9]). So, QA in the radiotherapy treatment planning process is essential for determination of accuracy in the radiotherapy process and avoidance treatment errors.[10]

A number of task groups[4,7,10] over the past several years have developed guidelines and protocols for systematic QA of 3D radiotherapy treatment planning systems (TPSs) that including specific QA aspects of a TPS, such as anatomical description, beam description, dose calculations, and data output and transfer. Many studies have been performed in which specific problems associated with treatment planning and dose calculation procedures were addressed.[11-14] Some studies were confined to the performance evaluation of the vendor specific TPS.[15-18]

The general need of QA of TPS in radiotherapy has already been discussed in the literature.[1,2,10] Some reports[1-3,10] have been published for help to physicist in QA program. TRS-430 report[10] that includes multiple steps is comprehensive report of IAEA for QA. These steps are acceptance tests, commissioning, periodic QA program and patient specific QA. Acceptance tests perform to verify functionality and agreement with determined specification by manufacturer. Commissioning can be divided into two groups that including non-dosimetric and dosimetric tests. Non-dosimetric tests perform to verify the functionality of the tools of TPS. Dosimetric tests perform to verify the performance of the dose calculation generated by the TPS with the measured dose. Periodic QA program perform to verify reproducibility of planning in accordance with that established in commissioning. Patient specific QA perform to verify the treatments process as a whole.

A number of author as Jamema et. al.[19] and Camargo et. al.,[20] Murugan et. al.,[21] Kragl et. al.[22] implemented QA procedure into TPS for photon beams with the guidance of IAEA TRS 430 report. But there is not found article relevant to TPS QA for electron beams with the guidance of IAEA TRS 430 at literature.

The purpose of the present study carry out application of the IAEA TRS-430 QA procedures of TPS for electron energies. As a result of this, the local dose deviation values and their confidence limit values (including systematic and random errors) have been obtained. In addition, the trends of the deviations found in the conducted tests have been determined.

MATERIALS AND METHODS

The commissioning procedure of IAEA TRS-430 for clinical electron beams was implemented for Generalized Gaussian Pencil Beam (GGPB) algorithm of Eclipse™ v7.5 TPS (Varian Medical Systems, Palo Alto, CA, USA). The beam data measurements of TPS have been carried out RFA-300 3D radiation field analysis system (Wellhöfer Dosimetrie GmbH, Schwarzenbruck, Germany) controlled by OmniPro-Accept v6.5 software and silicon semiconductor diode detectors (Wellhöfer Dosimetrie GmbH, Schwarzenbruck, Germany). Clinac DHX 2300 CD (Varian Medical Systems, Palo Alto, CA, USA) linear accelerator is generated five electron energy beams that becomes 6 MeV, 9 MeV, 12 MeV, 16 MeV, 20 MeV (respectively R_{50}= 2.4 g cm^{-2}, R_{50}= 3.6 g cm^{-2}, R_{50}= 5.0 g cm^{-2}, R_{50}= 6.7 g cm^{-2}, R_{50}= 8.4 g cm^{-2}).

Electron Beam Commissioning

This stage including dosimetric test aimed to compare the measurement dose and the calculated dose of TPS. The IAEA TRS-430 tests were implemented into electron beams of TPS. Calculation grid size of TPS for all test was preferred 2.5 mm because of clinically relevant general use.

The central axis percentage depth dose and beam profile measurements were made using the RFA-300 3D radiation field analysis system (Water Phantom System) controlled by OmniPro-Accept v6.5 software and EFD^{3G} Diode. In addition, the QA tests were applied on solid water phantom and specially formed phantoms. The absolute dose measurements were performed with in 0.65 cm^3 FC65-G farmer type ion chamber and PPC05 parallel plane chamber connected to DOSE1 electrometer. Film dosimetry measurements were made using Gafchromic EBT2 films (International Speciality Products, Wayne, New Jersey) and VIDAR Dosimetry PRO Advantage Film Digitizer (Vidar Systems Corporation, Hendon, Virginia).

Evaluation of Tests

For TPS QA, in principle there are two areas with a homogenous dose, well inside or far outside the beam. In between we have the penumbra and build-up regions with a high dose gradient. Figure 1 show the various regions that can be defined in terms of dose and dose gradient in a photon beam, incident on a homogeneous phantom. Venselaar et. al.[19] have defined a set of criteria of acceptability based on different tolerances for δ based on the knowledge that dose calculation algorithms provide better accuracy in some regions of the beam than in others. At AAPM TG 53,[4] Van Dyk et. al.[1] have defined such regions of different criteria of acceptability. According to Venselaar et. al.,[19] different tolerances for δ are proposed for different regions in the beam which can be distinguished, analogous to the paper of Van Dyk et. al.[1] and the report of AAPM TG 53.[4] According to report of

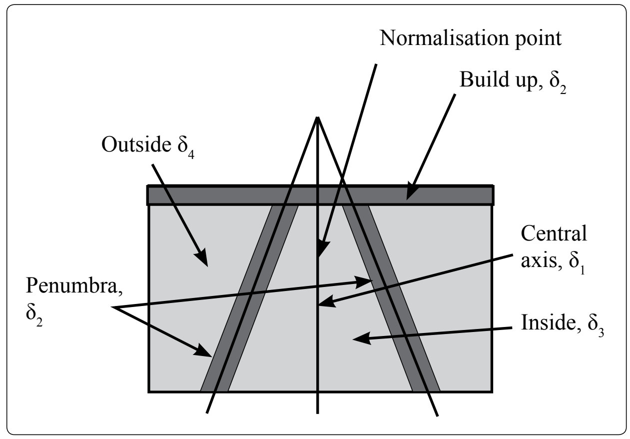

Fig. 1. Definition of different regions in a radiation beam, based on the magnitude of the dose and dose gradient (Adapted, from ESTRO report[6]).

NCS,[7] different tolerances are proposed for the various regions in an electron beam shown in Figure 2, such as δ1, δ_2, δ_3, δ_4, δR85 and RW_{50}. These include the following:[7]

• δ_1: for points on the central beam axis between a depth of 2 mm and R_{95}, with dose gradients less than 3% per mm (i.e. excluding the surface dose points up to a depth of 2 mm): the high dose and small dose gradient region.

• δ2: for points in regions with a high dose gradient, such as on the central beam axis between R_{95} and R_{10}, the penumbra, regions close to interfaces of inhomogeneities: the high dose and large dose gradient regions. The dose gradient is in general larger than 3% per mm. The tolerance criterion is preferably expressed as a shift of isodose lines (in mm).

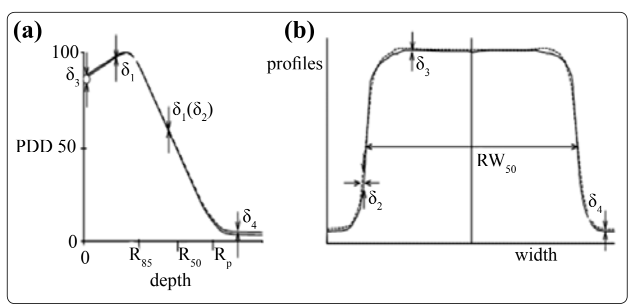

Fig. 2. Different tolerances are proposed for the various regions in a electron beam; **(a)** depth-dose curve: **(b)** beam profile (Adapted, from ESTRO report[6] and NCS report[7]).

• δ_3: for points with a high dose but off the central beam axis and points describing the surface dose: this region is also a high dose and small dose gradient region.

• δ_4: for points outside the geometrical beam edges; this region is a low dose and small dose gradient region, for instance below 7% of the central beam axis normalization dose.

• δ_{RW50}: for deviations in the radiological width, defined as the width of a profile measured at the 50% points.

•δ_{R85} and δ_{Rp}: for deviations in the therapeutical range and the practical range of the electron beam, respectively.

TPS performance was investigated the difference between calculated and measured dose values as a percentage of the dose measured locally. Deviations between results of calculations and measurements can be expressed as a percentage deviation of the local dose according to Venselaar et. al.,[23]

$$\delta = 100\% \times (D_{cal} - D_{meas}) / D_{meas} \quad (1)$$

where Dcal and Dmeas are calculated dose at particular point in the phantom and measured dose at same point in the phantom, respectively. In low dose regions where the points were outside the penumbra or under a block, an alternative comparison accordingly to Venselaar et. al.,[23]

$$\delta = 100\% \times (D_{cal} - D_{meas}) / D_{meas,cax} \quad (2)$$

where $D_{meas,cax}$ is dose measured at a point at same depth on the central axis of the open beam.

The deviations, δ, described above refer to comparisons of individual calculated and measured points. Although this is not strictly correct. Because a study consisting of many points is evaluated, some of these points may exceed or may not the tolerance.

If a study consisting of many points is evaluated, in this case some statistical assessment can be performed on the calculation points and the measurement points. For this purpose, the concept of confidence limit was defined by Venselaar et. al.[23] Accordingly, confidence limit, Δ, as follow,

$$\Delta = |\text{ average deviation }| + 1.5\times SD \quad (3)$$

where SD is the standard deviation. According to complexity of geometry, the tolerance as defined in Table 2 can be applied to the confidence limit rather than to individual points. At equation (3), the factor 1.5 is chosen rather arbitrarily, but Venselaar et. al.[23] and Welleweerd et. al.[24] showed to be useful for this purpose in clinical practice. If a factor greater than 1.5 was used in equation (3), this would have emphasized the random errors, while a factor smaller than 1.5 would increase the relative importance of systematic deviations.[16]

All tests of Electron Beam Commissioning were simulated in the TPS and the performed calculations were compared against that measured on the treatment unit. As a result of this, the local dose deviation values and their confidence limit values (including systematic and random errors) have been obtained. In addition, the trends of the deviations found in the conducted tests have been determined.

RESULTS

Electron Beam Commissioning

Electron beam commissioning tests were given in Table 1 and those tests were applied to confirm the performance and limitations of systems. Results of implementation were given in Table 3 in detail. At Table 3, results were given separately for each energy and confidence limits of individual measurements type (%DD, profile, point dose) in detail.

While all %DD is used to calculate of confidence limit value, confidence limit values of profiles is separated two groups that is including all profiles (Δ_{all}) and including profiles without R_p depth ($\Delta_{without\ Rp}$). Because all values of profiles of Rp depth include high SD and this value causes to increase Δ value.

Many results for square field test were satisfactory found. At depth dose, the confidence limit values of δ_1 and δ_3 was found outside tolerances for low energies. For profiles, Δwithout R_p are found within tolerances but Δall are found outside tolerances because of high value of R_p depths. A no-

Table 1

Detail of dosimetric tests performed on TPS in the present study

Test type	Test	Test geometry	Detail				
			Energy (MV)	Field size (cm×cm)	Depth (cm)	Phantom and dosimetry system	Note
Electron beam commissioning dosimetry system	1	Square fields	6, 9, 12, 16, 20	6x6, 10x10, 15x15, 20x20, 25x25	R_{100}, R_{90}, R_{80}, R_p	WP and EFD^{3G}	
	2	Shaped fields	6, 9, 12, 16, 20	a) convex b) concave c) small non-symmetric oval d) triangular shape e) thin rectangular opening	R_{100}, R_{90}, R_{80}, R_p	WP and EFD_{3G}	
	3	Slab bolus	6, 9, 12, 16, 20	10x10	0.2 cm (preferred surface dose point)	SWP and PPC05	Bolus thickness: 0.3 cm, 0.5 cm, 1 cm, 1.5 cm
	4	Oblique incidence	9, 12,	20x20	R_{100}	WP and EFD_{3G}	Gantry rotation: 345^0
	5	Complex surface shapes	16, 20	20x20	3 cm	SWP and EBT2	Special complex surface phantom
	6	CT based inhomogeneity corrections	12, 16, 20	15x15	4.5 cm	SFP and EBT2	Special inhomogenity phantom

Phantoms: SWP: Solid water phantom; WP: Water phantom; SFP: Specially formed phantom; Dosimetry systems: EFD3G: Electron field semiconductor diode; EBT2: Gafchromic EBT2 film dosimetry FG65-G and PPC05: Farmer type and parallel plate type ion chamber, respectively.

Table 2

According to complexity of geometry, proposed values of the tolerance for percentage deviation of dose at different local (Adapted, ESTRO report[6] and NCS report[7])

Local deviation	Location	Level 1. Simple geometry	Level 2. Complex geometry
δ_1	Central beam axis for PDDs	2%	3%
δ_2 [a]	Central axis points in low energy beams for PDDs, penumbra region for profiles	2 mm or 2%	3 mm or 10%
δ_3	Points in the build-up region for PDDs, outside central beam axis region for profiles	3%	4%
δ_4	Outside beam edges for profiles	2%	4%
RW_{50}	Radiological width for profiles	4 mm	4 mm
δ_{R85} and δ_{Rp}	Practical and therapeutic range for PDDs	2 mm	3 mm

a: These values are preferably expressed in mm. A shift of 1 mm corresponding to a dose variation of 5% is assumed to be a realistic value in the high dose, large dose gradient region.

table point, all confidence limit value of profiles was detected that it was increased depending on expanding depth. But each confidence limit value of profiles was found to show different change depending on expanding field size. For example; while δ_3 value of profiles increased depending on expanding field size, δ_2 value decreased depending on expanding field size.

As results of shaped field test, it was found to same results of the square field test. Results of slab

Table 3

Results of electron beam commissioning performed on TPS

Test name	Test geometry	Energy (MeV)	Number of Points *	Confidence limits								
	%DD	Profile**										
				δ_1 (%)	δ_2 (mm)	δ_3 (%)	δ_4 (%)	R_{85} (mm)	δ_2 (mm)	δ_3 (%)	δ_4 (%)	RW_{50} (mm)
T1	Square fields	6	SaP	4.35	0.67	6.23 [f↓]	0.15	0.87 [d↑]	0.70 (0.93) [f↑, d↑]	2.07 (5.85) [f↓, d↑]	0.45 (0.89) [f↑, d↑]	0.77 (0.99)
		9	SaP	2.22	0.93	2.59 [f↓]	0.09	1.35 [d↑]	0.66 (2.11) [f↑, d↑]	1.72 (4.69) [f↓, d↑]	0.60 (1.88) [f↑, d↑]	1.09 (3.07)
		12	SaP	1.3	0.79	2.33	0.45	0.73 [d↑]	0.82 (2.77) [f↑, d↑]	1.73 (3.30) [f↓, d↑]	0.84 (2.08) [f↑, d↑]	2.06 (3.43)
		16	SaP	1.02	1.51	1.15	0.47	1.13 [d↑]	1.46 (3.30) [f↑, d↑]	1.52 (2.77) [f↓, d↑]	1.28 (3.37) [f↑, d↑]	2.56 (3.48)
		20	SaP	0.94	1.62	1.25	0.43	1.26 [d↑]	2.33 (4.90) [f↑, d↑]	2.36 (7.77) [f↓, d↑]	2.02 (5.39) [f↑, d↑]	0.99 (2.63)
T2	Shaped fields	6	SaP	3.57	0.77	10.10	0.75	0.42	1.79	1.9	0.46 3.94	
		9	SaP	2.44	0.75	6.00	0.33	1.25	1.6	2.47	0.84 3.17	
		12	SaP	1.79	1.74	5.25	0.74	0.74	1.36	1.7	0 3.27	
		16	SaP	1.37	2.45	2.95	1.06	1.12	1.4	1.97	0 0.4	
		20	SaP	1.09	6.17	1.49	2.54	2.92	1.47	1.9	0.2 5	
T3	Slab bolus	6	9	–	–	4.76	–	––	–	–	–	
		9	9	–	–	2.80	–	––	–	–	–	
		12	9	–	–	4.96	–	––	–	–	–	
		16	9	–	–	4.84	–	––	–	–	–	
		20	9	–	–	4.34	–	––	–	–	–	
T4	Oblique incidence	9	SaP	2.2	0.25	2.60.26	0	0.5	1.15	0.5	1	
T5	Complex surface shapes	12	SaP	1.05	0.6	1.40.1	1.25	1.43	1.5	0.2	1.25	
		12	SaP	–	–	– –	–	2.49	7.45	3.2	0.5	
		16	SaP	–	–	– –	–	1.95	10	3	1.25	
		20	SaP	–	–	– –	–	4.25	11.5	2	0.5	
T6	CT based inhomogeneity corrections	16	SaP	–	–	– –	–	5.5	3.52	9.80	1.75	
		20	SaP	–	–	–	–	–	3.63	4.1	3.86	0.75

*: SaP: Scanned all Points; measurement precision was accepted 0.1cm, for example obtained point number is 130 for 1D profile measurement of 10 cmx10cm field size (%DD and Profile)

**: While all %DD is used to calculate of confidence limit value, confidence limit values of profiles is separated two groups that is including all profiles (Δall) and including profiles without Rp depth (Δwithout Rp). For profiles, Δwithout Rp and Δall are given outside parenthesis and inside parenthesis, respectively. Note: The trends of deviations depending on depth, field size and shaped field, are denoted by [d↑↓], [f↑↓] and [b↑↓], respectively. For example; it has been denoted that, when the depth is increased, the increasing of dose deviation is showed in the form [d↑], while the reduction of dose deviation is showed in the form [d↓].

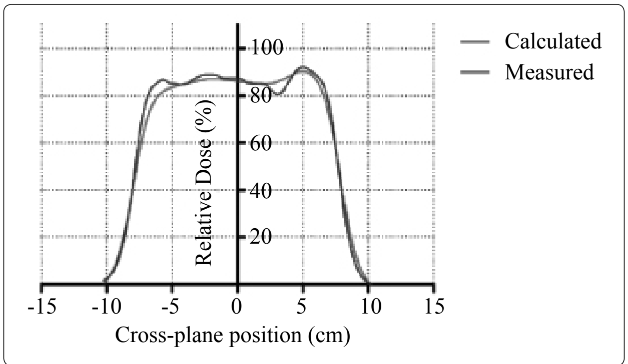

Fig. 3. Comparison between measured and calculated dose profiles for 16 MeV electron beam (CT based Inhomogeneity corrections tests With Gafchromic EBT2 film).

bolus test were found within the tolerance limits given in the ESTRO report[6] and NCS report.[7]

Results of CT based inhomogeneity corrections and complex surface shapes were found outside tolerance limits given in the ESTRO report[6] and NCS report,[7] especially δ_3 and shown in Figure 3. At CT based inhomogeneity corrections test, maximum deviations were found 7.9% for 16 MeV and 4.2% for 20 MeV electron beam.

DISCUSSION

In this study, we had commissioned Varian Eclipse™ v7.5 TPS in accordance with procedure of IAEA TRS-430 for clinical electron beams. Result of commissioning was investigated and the trends of the deviations found in the tests conducted have been determined. All confidence limit value of profiles was detected that it was increased depending on expanding depth. But each confidence limit value of profiles was found to show different change depending on expanding field size.

According to results of CT based inhomogeneity corrections tests, values of δ_3 were found outside tolerance limits given in the ESTRO report[6] and NCS report.[7] Deviations between measurement and TPS calculation has defined by technical specifications of VARIAN Eclips GGPB algorithm. According to these technical specifications, deviation values can find about 2% for homogenous media and 5% for non-homogenous media.

There isn't found article about apply QA procedure into TPS for electron beams with the guidance of IAEA TRS 430 and other guidelines at literature.

According to Hogstrom et. al.,[25] despite the significant progress in calculating dose, treatment-planning systems currently fail the practice of radiation therapy and the treatment of patients with electron beam therapy by being unable to model actual treatments. Treatment-planning tools, such as skin collimation, internal collimation and bolus, are modelled inadequately or not at all.

At study relevant comparison of electron beam dose calculation of pencil beam and Monte Carlo algorithm by Ding et. al.,[26] the comparison has demonstrated some serious limitations of the pencil beam algorithm implemented in CADPLAN to accurately predict hot and cold spots for 3D inhomogeneous phantoms. The pencil beam model is unable to predict sharp high- and low- dose variations (10%) for simple 3D inhomogeneities and a complex 3D inhomogeneous phantom consisting of overlying both low-(air) and high-(bone) density materials, even when the calculation resolution is much smaller than the size of high- and low-dose regions. The Monte Carlo results generally have much better agreement with measurements, especially in predicting sharp increases or decreases in absorbed dose caused by the perturbation of adjacent 3D inhomogeneities.[26]

Generally, there are differences between measurements and calculations. It should not be forgotten that the factors affecting discrepancies between measurement and calculation include;

i. TPS beam data input,

ii. Beam model fitting,

iii. Dose calculation algorithm,

iv. The computation of the number of MUs,

v. Verification measurement set-up.

In case the TPS fails to meet these accuracy requirements, NCS report[7] suggests the following:

i. Check the basic beam data entered in the TPS and the test beam data set.

ii. Adjust the model parameters.

iii. Restrict the clinical use of the TPS to geometries that passed the test.

iv. Inform the vendor about the findings.

According to this study, it does not need application to above suggestions for our Eclipse™ TPS. Only the errors found in our study for the parameters used in patient treatment planning has to be considered.

CONCLUSION

At commissioning of Eclipse™ TPS, it has been observed that the conducted test is generally within tolerance and is outside of tolerances in some cases. In addition the trends of the deviations found in the conducted tests have been determined. Only the errors found in this study for the parameters used in patient treatment planning has to be considered. This procedure must perform entirely after upgrade of TPS.

This study has ensured the correctness of the beam data entered in the TPS during the commissioning. With commissioning tests, it was identified as a baseline data for an ongoing QA program.

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