Novel independent dosimetry audit based on end-to-end testing in proton beam therapy.

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Introduction

The purpose of end-to-end testing (E2E) is to confirm that the entire logistic chain of a radiation treatment starting from CT imaging, treatment planning, patient positioning and verification and beam delivery is adequately implemented resulting in sufficient accuracy of planned dose delivery. A novel methodology for dosimetric E2E test was established at MedAustron Ion Therapy Center in proton beams. In this work, we present the dosimetric audit based on E2E tests performed at 5 scanned proton therapy facilities in Europe including overall 7 beam lines. All the data reported in this work are anonymized.

Material & Methods

The E2E tests were performed at 7 beam lines as reported in table 1.

Facility /when	Beam Line	S/C/SC* - Vendor	OIS	TPS/algorithm
MedAustron (AT)/ Nov 2016	IR3HBL**	S - In-house	In-house	RayStation v5.0 / Pencil Beam v3.5
MedAustron (AT)/ July 2017	IR2HBL**	S - In-house	In-house	RayStation v6.1 / Monte Carlo v4.0
MedAustron (AT)/ March 2018	IR2VBL***	S - In-house	In-house	RayStation v6.1 / Monte Carlo v4.0
HollandPTC (NL)/ Sep 2018	Gantry 2	C - Varian ProBeam v3.5	ARIA v13.7	RayStation v7 / Monte Carlo v4.1
ZON-PTC (NL)/ Dec 2018	Gantry	SC - Mevion S250i	ARIA v15.5	RayStation v8A / Monte Carlo v4.2
DCPT (DK)/ Dec 2018	Gantry 3	C - Varian ProBeam v3.5	ARIA v13.7	Eclipse v13.7/ Proton Convolution Superposition v13.7
APSS (Trento, IT)/ March 2019	Gantry 2	C - IBA proteus plus 235	MOSAIQ v2.64	RayStation v7 / Monte Carlo v4.1

Table 1 : List of the 7 beam lines with additional details on the date of E2E tests, the accelerator type, the Oncology Information System (OIS) installed, the Treatment Planning System (TPS) and dose engine commissioned for treatment planning at each facility.
*S/C/SC = Synchrotron (S) or Cyclotron (C) or SynchroCyclotron (SC)
**HBL = fixed Horizontal Beam Line
***VBL = fixed Vertical Beam Line

A homogeneous polystyrene phantom [1] and two anthropomorphic phantoms (pelvis and head phantom) [2] have been customized to allocate different detectors such as radiochromic films, ionization chambers and alanine pellets. The phantoms were transferred through the workflow as real patients to simulate the entire clinical procedure [2]. The CT scans were acquired with pre-defined scan protocols used at each facility for cranial and pelvic treatments. Facility specific treatment planning was performed with 3 different version of RayStation and with Eclipse TPS (see table 1). A physical dose of 10 Gy was planned to regular-shaped target volumes. In the treatment room the plans were delivered to the phantoms loaded either with alanine pellets and radiochromic EBT3 films or ionization chamber (see figure 1). The alanine pellets (5.0 mm diameter and 2.4 mm thickness) and their read-out were provided by the National Physical Laboratory (NPL). Corrections for 'quenching' were derived by a Monte Carlo dose calculation platform implemented in a non-clinical version of the TPS RayStation v5.99.50 [2].

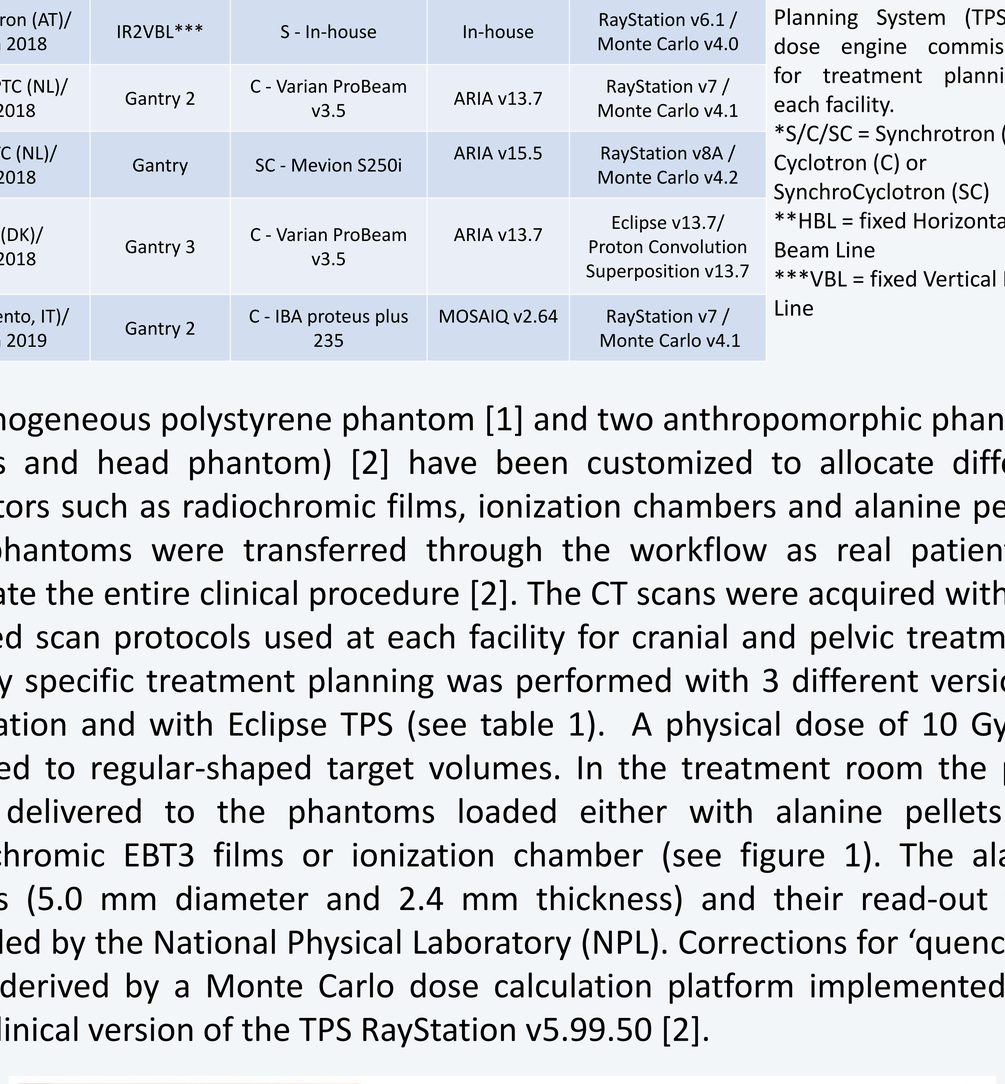
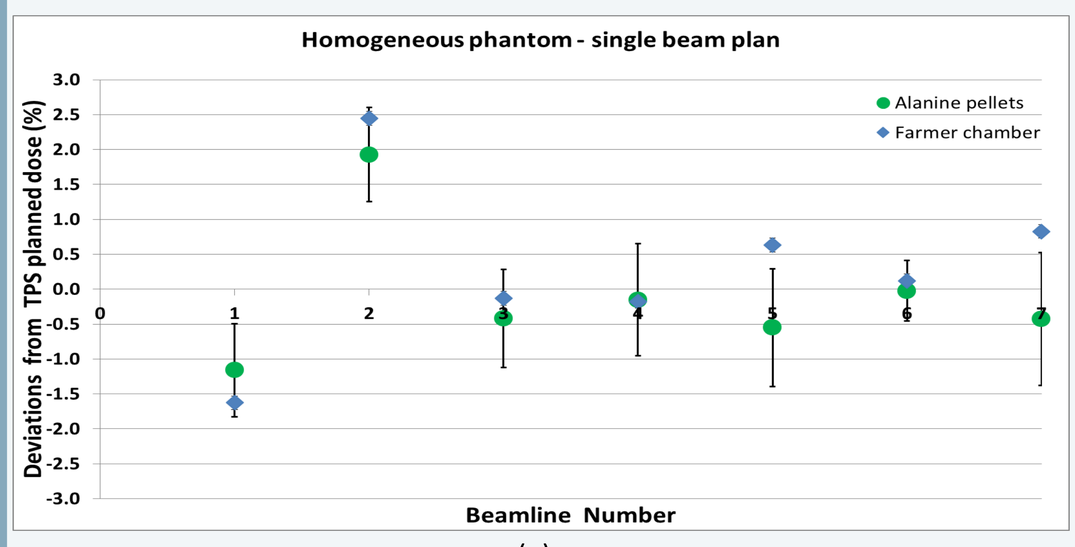


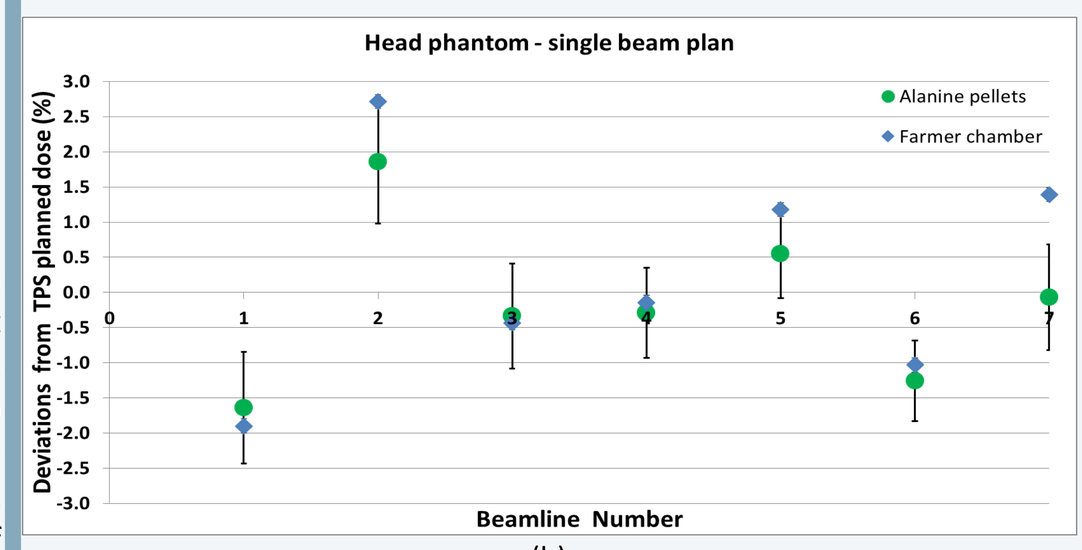
Figure 1: End-to-end test procedure with the head phantom. Top left: the loading of the phantom with alanine pellets and EBT3 films. Top right: the treatment plan preparation in the TPS. Bottom: the positioning and position verification with x-rays as well as the irradiation with scanned proton beams at IR3HBL.

Results

For single beam plans at the homogeneous polystyrene phantom the average deviation overall the 7 beam lines between the dose determined with 20 alanine pellets compared to the TPS dose was -0.1 ± 1.0 % (see fig. 2 (a)). For single beam plans delivered to the head phantom the average deviation overall the 7 beam lines between the dose determined with 22 alanine pellets compared to the TPS dose was -0.2± 1.2 % (see fig. 2 (b)). Dose determined with Farmer chamber compared to the TPS planned dose show similar behavior as the alanine with a maximum deviation of -1.2 ± 0.7 % between the two dosimetric techniques (see fig. 3).



(a)



(b)

Figure 2: in green deviations between the dose determined with alanine pellets and the TPS planned dose at each beam line. Each point in the plot is the average over 20 alanine pellets for the homogeneous phantom and 22 alanine pellets for the head phantom.
In blue deviations between the dose determined with Farmer chamber and the TPS planned dose at each beam line.
The plotted error bars are standard uncertainties.
(a) Deviations for one single beam plan in the *homogeneous phantom*.
(b) Deviations for one single beam plan in the *head phantom*.

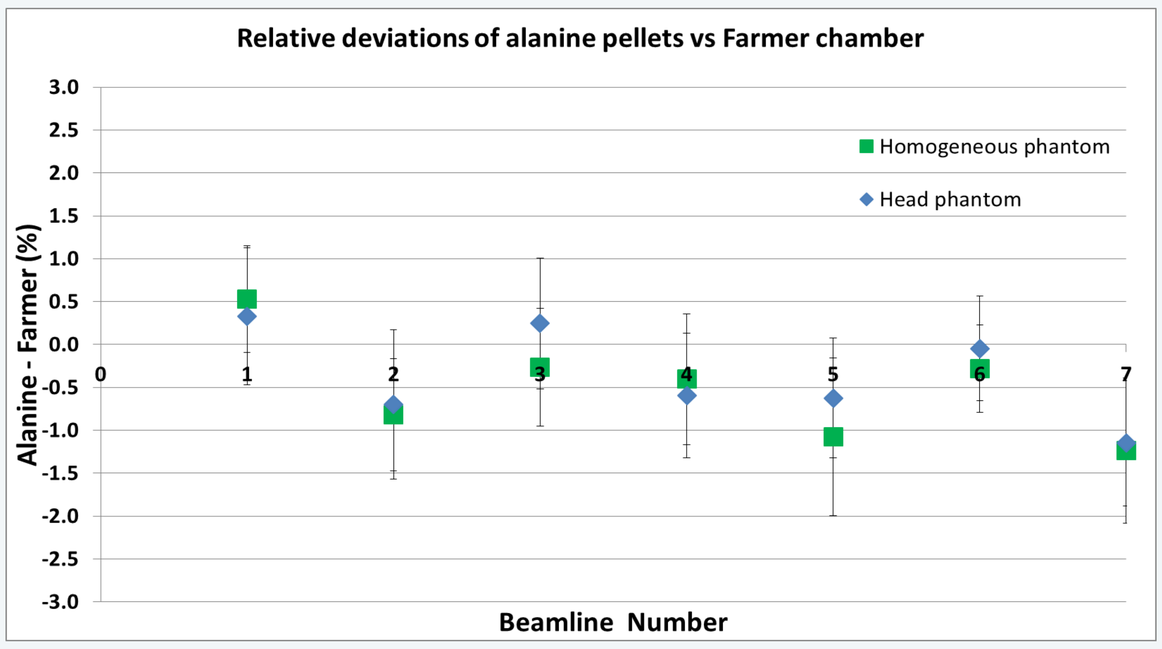


Figure 3: Relative deviations of the two dosimetric techniques alanine pellets vs Farmer chamber as function of the beam line number. In green the deviations related to the plan delivered to the homogeneous phantom and in blue the deviations related to the plan delivered to the head phantom.

Conclusion

The innovative dosimetry audit method presented was successfully performed at 5 proton therapy centers in Europe including various vendors for "turn-key" solutions like IBA, Varian and Mevion. For the homogeneous polystyrene phantom all deviations from the TPS dose are within 2.5% both for alanine and Farmer chamber. For the head phantom all the deviations from the TPS dose are within 2.7% both for alanine and Farmer chamber. The two systems based on alanine dosimetry and Farmer ionization chamber dosimetry showed high consistency at all the proton facilities with an average deviation of -0.5 ± 0.6 % and maximum deviation -1.2% (see fig. 3). The observations and analysis of audits performed at 5 centers have not indicated any major concerns regarding the local practices for the specific aspects of dosimetry for scanned proton beam delivery. Successful completion of dosimetry audit based on E2E tests may also serve in future as a dosimetric credentialing for clinical trials.

References:
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[2] A. Carlino et al. End-to-end tests using alanine dosimetry in scanned proton beams. Physics in Medicine and Biology, 63 055001 (17p), 2018

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