Comprehensive quality assurance for base of skull IMRT

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Abstract. Six base of skull IMRT treatment plans were delivered to Presage dosimeters within the RPC Head and Neck Phantom for quality assurance (QA) verification. Isotropic 2mm 3D data were acquired by optical-CT scanning with the DLOS system (Duke Large Optical-CT Scanner) and compared to the Eclipse (Varian) treatment plan. Normalized Dose Distribution (NDD) pass rates were obtained for a number of criteria. High quality 3D dosimetry data was observed from the DLOS system, illustrated here through colormaps, isodose lines, and profiles. Excellent agreement with the planned dose distributions was also observed with NDD analysis revealing > 90% pass rates (with criteria 3%, 2mm), and noise < 0.5%. The results comprehensively confirm the high accuracy of base-of-skull IMRT treatment in our clinic.

1. Introduction
The accuracy of base-of-skull (BOS) IMRT treatment was evaluated in six patients treated at Duke between 2008 and 2011. A condensed summary analysis was presented in Oldham et al [1], which focused on evaluating the clinical significance of 3D verification QA data after transform back to the patients CT data set [2]. The current work compliments this analysis by focusing on a direct dosimetry comparison, measured to calculated, in the RPC head phantom geometry. Particular attention is paid to investigating the quality of the 3D dosimetry data acquired with the DLOS system [3], and on a detailed comparison of the 3D measured and calculated (Eclipse) distributions.

2. Methods
Six patients that received base of skull IMRT treatment were randomly selected. The fractionation scheme and target volumes varied, with PTVs ranging from 4.4cm³ up to 46cm³, and dose per fraction ranging from 1.8 Gy to 12.5 Gy. All data was anonymized prior to analysis, and all patients were treated with a Novalis Tx system commissioned for radiosurgery treatment at Duke. The prospective verification measurements described here were made on the same machine for consistency.

2.1. 3D IMRT QA Data Acquisition
3D dose measurements were performed with cylindrical PRESAGE® dosimeters (10cm diameter, 12cm long) which were compatible with the RPC head-and-neck IMRT credentialing phantom [4]. PRESAGE® (Heuris Pharma, Skillman, NJ) is a polyurethane based dosimetry material which changes color when exposed to ionizing radiation, causing an optical density change (ΔOD) for visible light [5, 6]. The radiation induced ΔOD is proportional to the locally absorbed dose, and can be imaged using optical-CT [7-9]. Recent comprehensive evaluations have shown PRESAGE® to be an excellent material for accurate 3D dosimetry [5, 10].
The RPC phantom-dosimeter combination was scanned on a GE Lightspeed X-ray-CT scanner with a 1.25mm slice thickness. A verification treatment plan was created for each patient, by recalculating the patient’s original treatment plan onto the RPC phantom CT data. The isocenter of the verification plan was positioned centrally in the PRESAGE® dosimetry insert to ensure a 3D measurement of the whole distribution would be feasible. Re-calculation was performed with the Eclipse planning system, using the Analytic-Anisotropy-Algorithm (AAA), at 2.5mm³ isotropic resolution, with the heterogeneity correction applied. Each verification plan was delivered to the RPC phantom containing the dosimeter. Each plan (except plan HN5 which had high dose/fx) was delivered 4 times to the phantom in order to get close to ~8Gy, the optimal dose for the dynamic range of the DLOS system for small treatment volumes.

To obtain the delivered 3D dose distribution, the radiation-induced ΔOD throughout the dosimeter was imaged using the DLOS system (Duke Large Field-of-view Optical-CT Scanner). The ΔOD is determined by reconstructing corrected projection images utilizing parallel beam filtered back-projection. A corrected projection consists of a post-irradiation projection that has been divided by the corresponding pre-irradiation projection to obtain the radiation-induced change. Details of this method are given in [3]. 3D data are acquired through the accumulation of 360 projection images over 360° to meet Nyquist sampling criteria for 2mm³ isotropic reconstructions. Each projection image is captured 20 times and averaged to increase the SNR at each angle. The projection images are dark noise and flood field corrected to reduce the effects of particulates on glass surfaces, non-uniformity of CCD pixel response, dark current and readout noise. Each pre- and post-projection image is corrected for stray light following the method described in [11].

2.2. 3D IMRT QA Data Analysis
The methods described above yielded isotropic 2mm relative 3D dosimetry data throughout the Presage dosimeter volume for all patients. The dose response of Presage is known to be linear [10], and the 3D relative ΔOD distribution was converted to dose by scaling to a point of known absolute dose within the head-phantom. This point of known dose was determined by a second delivery to the head-phantom, this time incorporating a Presage dosimeter of identical dimensions but containing a central channel for a micro-ion-chamber (CC01 Scandatronix/Wellhofer). The location of the active volume of the chamber was in the middle of the uniform high-dose treatment region. The measured and planned absolute dose distributions were then compared using the CERR tool (Deasy et al. [12]). Comparison methods included line-profiles, isodose lines, and NDD plots (criteria 3%,3mm and 3%, 2mm, with 5% threshold) [13]. The outer 5mm rind of the dosimeter was not included in the analysis due to loss of superficial data from edge artifacts.

3. Results
3.1. Overall Pass Rates
The pass rates according to the NDD algorithm are recorded in Table 1. Pass rates for [3%, 3mm] [3%, 2mm] and [5%, 3mm] are given. Even with the stringent [3%, 2mm] criteria all plans tested recorded pass rates over 90%. Noise for each scan is also given and was obtained as the standard deviation in a high dose region divided by the mean in that same high dose region.

3.2. Specific Cases
Figures of each patient are not shown due to space limitations, however, the cases with the highest and lowest NDD pass rates are shown as well as a case that seemed more typical. Each set of figures contains a sagittal view of the measured dose wash accompanied by a vertical and horizontal line profile to give the reader an appreciation of the low noise and close agreement as indicated by the NDD pass rates.
Table 1: NDD results for all six patient cases analysed with a 5% dose threshold.

| Patient | 1   | 2   | 3   | 4   | 5   | 6   |
|---------|-----|-----|-----|-----|-----|-----|
| NDD Pass Rate 3%, 3mm | 98.5% | 98.1% | 99.7% | 96.5% | 98.7% | 95.7% |
| NDD Pass Rate 3%, 2mm | 93.9% | 97.2% | 98.9% | 93.1% | 96.0% | 90.1% |
| NDD Pass Rate 5%, 3mm | 99.1% | 99.6% | 99.9% | 96.9% | 99.9% | 97.6% |
| Noise   | 0.35% | 0.64% | 0.30% | 0.32% | 0.58% | 0.57% |

Figure 1: 3 cases – Best (1st row), Worst (2nd row) and Typical (3rd row) as indicated by NDD pass rates. Sagittal dose planes showing the PRESAGE measurements overlayed on the CT of the RPC phantom (1st column). Vertical line profiles (2nd column) and horizontal line profiles (3rd column). Legend has plan (P) and measurement (M) showing the nearly identical agreement of the treatment planning system calculation and the 3D measurement.

**Best Case** – patient case #3. The delivery consisted of 5 fields and 4 couch angles with 1.8 Gy delivered to the target 4 times for proper contrast in the PRESAGE. Low noise from the data acquisition can be seen from both the line profiles and the dose plane displayed.

**Worst Case** – patient case #4. This plan gave the lowest overall passing rate of 93.7%. Visual inspection line profiles show disparities within this treatment verification plan relative to the other two
displayed. The other plans verified in this study lead us to believe the differences seen in the measured distribution, while slight, are real and most likely due to using the same CT scan for each patient case. Each dosimeter top is not molded identically and thus any beams initiating superiorly may not be modeled correctly in the planned dose.

**Typical Case** – patient case #1. The delivery consisted of 9 fields and 3 couch angles with a 1.8 Gy delivery to the isocenter 4 times. The low noise in the data can be seen qualitatively from the reconstructions and isodose lines.

4. Conclusions
This work is the first application of high resolution 3D dosimetry to verify the accuracy of base-of-skull IMRT delivery. The high NDD pass rates (Table 1) comparing the planned and measured distributions illustrates the high accuracy of this technique in our clinic. 3D data acquisition time with the DLOS was under 20 minutes (including set-up time) and produced low noise data (< 0.5%) throughout the dosimeters to within just a few millimetres from the edge. The convenience, practicality and cost of the system is approaching clinical feasibility for routine use.

5. Acknowledgments
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6. References
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