Quantitative evaluation of transmission EPID daily imaging on a Halcyon Linac

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Abstract. The recently published AAPM TG100 has advocated streamline IMRT/VMAT QA procedure based on Failure Mode and Effects Analysis (FMEA) criteria, i.e., the product of incidence severity, occurrence probability, and detection probability. Transmission EPID has proven to be able to detect dose errors at a detection probability of 60% vs. those based on pre-treatment patient specific QA, at a detection probability of less than 5%. The objective of this study is to retrospectively evaluate the gamma index (3%, 3mm) using composite transmission EPID images for various treatment sites on a Halcyon Linac. Transmission EPID images are recorded during treatment and compared to first day EPID as reference. Over 1000 treatment fractions, the average gamma index and standard deviation of gamma for various treatment sites are 99.04±1.64, 99.95±0.093, 100±0 and 99.7±0.567 and 95.65±3.57 for head and neck, brain, prostate, pelvis and breast respectively. In conclusion: Our data show very high inter-treatment consistency for most treatment sites except breast. For breast cases, using second day treatment images as reference, the gamma index is much higher and standard deviation is lower than using day1 images as reference. Overall a threshold of gamma passing rate of 95% is a reasonable value.

1. Introduction

With the increased complexity introduced by ever increasing popularity of IMRT and VMAT treatments, in-vivo patient QA using on-board EPID during each RT treatment becomes popular [1-7]. The recently published AAPM TG100 has advocated streamline IMRT/VMAT QA procedure-based FMEA criteria, i.e, the product of incidence severity, occurrence probability, and detection probability [8]. Transmission EPID [9-11] has proven to be able to detect dose errors at a detection probability of 60% vs. those based on pre-treatment patient specific QA, at a detection probability of less than 5% [12]. The variation of the daily treatment transmission images reflects possible changing in patient setup [13], patient anatomy changes and unexpected errors in beam delivery [14], which could potentially cause significant dose error in the patients. Halcyon Linac records the transmission portal images and exit dosimetry of each field during actual patient RT treatment using on board EPID. A retro-prospective gamma analysis of the composite daily treatment transmission images with day 1 treatment images as reference was conducted in this study for different treatment sites (H&N, Brain, Breast, Prostate and Pelvis).
2. Materials and Methods
Varian Halcyon Linear accelerator is equipped with EPID imager which records the transmission images during treatment without any additional effort or time for therapists. Before this study, such existing information were not utilized for patient QA purpose. In this retrospective study, the existing EPID images from daily treatment were used to create the composite images, then they are compared to a reference images, such as day 1 or day 2 EPID images of the plan using gamma index. The Gamma criteria is 3mm and 3%, and it is calculated using Varian Eclipse software. The threshold is 5%, the ROI is MLC CIAO +1 cm, where MLC CIAO +1 cm is a complete irradiated area outlined by MLC plus 1 cm margin.

3. Results and discussion
3.1. Head and neck cases
19 patients with total of 264 fields were examined for head and neck cases. The average gamma of the all head neck plans = 99.04, SD = 1.67. For cases 1 and 2 (see Fig. 1), gamma passing rate variation is mostly due to patients’ anatomy change. Excluding case 1 and 2, for the rest of 17 patients, the gamma index passing rate based on 209 treatments is 99.6% with SD 0.3 (see Table1), indicating that head and neck patient treatment reproducibility is very high.

![Figure 1. Mean gamma passing rate and standard deviation (SD) for patients treated to Head and Neck.](image)

| Site          | # of Patients | # of Treatments reviewed | Avg. Gamma | SD  | Minimum Gamma | Possible Cause of Gamma deviation |
|---------------|---------------|--------------------------|------------|-----|---------------|-----------------------------------|
| Head & Neck   | 19            | 264                      | 99.04      | 1.67| 75.5          | Anatomy change                    |
| Head & Neck 2 | 17            | 209                      | 99.58      | 0.32| 95.9          | *Negligible variation             |
| W. Brian + P.B. | 6            | 88                       | 99.94      | 0.09| 98.2          | Negligible variation              |
| Breast        | 10            | 280                      | 95.65      | 3.57| 75.5          | Setup +breathing                  |
| Prostate      | 1             | 44                       | 100.00     | 0.00| 100.0         | Negligible variation              |
| Pelvis        | 4             | 108                      | 99.70      | 0.57| 95.5          | Setup + Gas                       |

*Head and Neck 2 excluded first two patients which have visible anatomy change, so total case number in this group is 17 patients.
3.2. A Case study

We noticed gamma index for case #1 decreased after 17 fractions (see Fig. 2). Patient’s left side anatomy had visible changes based on MVCBCT difference images (see Fig.3 a, b). According to the evaluation CT scan and evaluation plan, patient PTV 95% coverage reduced from 7000cGy to 6622cGy (Fig. 4), which is about 6% decreasing. Figure 5 (b) is the setup error trend vs time. The treatment # 2 and treatment # 27 had similar setup errors (less than 3mm in longitudinal, lateral and vertical). However their gamma index have significant difference (Fig. 5a), 100% (Fig. 5c) vs 82.7 %. (Fig. 5d) This indicates that the gamma variation is not from setup error but anatomy change, which is consistency with MVCBCT vs Plan CT images. Re-plan was performed later for that patient.

Suggestion for clinical application: for head and neck case, if the gamma index is below 90%, an evaluation scan and planning would be need.

Figure 2. Composite gamma vs. time for Patient #1.
Figure 3. (a) sagittal view of difference images between MVCBCT of treatment 27 and planning CT for patient #1; (b) axial view of difference image between day 27th MVCBCT and planning CT.
Figure 4. DVH of PTV for patient #1 from original CT scan (red color) and PTV from evaluation CT scan (blue color), PTV dose decreased by over 6%.

Figure 5. (a) Gamma index for each day’s composite Gamma compared to day 1 composite Gamma vs. fraction number for patient #1; (b) setup error trend vs. time; (c) Gamma index (100%) of fraction #2; (d) Gamma index (82.7%) of fraction #27.
3.3. Brain
Six patients with whole or partial Brain with 88 fractions were studied (see Table 1). The average gamma passing rate of all the plans is 99.94% with SD= 0.09%. The results indicate high treatment setup reproducibility for the brain cases (see Fig. 6a).

3.4. Pelvis and Prostate
Four pelvis cases with 108 treatments were reviewed (see Table 1). The average gamma for the 108 treatment is 99.69% with SD=0.56%. The overall reproducibility of pelvis treatment is excellent (see Fig. 6b). One prostate patient with 4 plans and 44 treatments were reviewed (see Fig. 6c). The overall average gamma is 100% associated with a 0% SD. This indicated prostate treatment reproducibility between treatments is as excellent as brain cases.

3.5. Breast cases
Ten patients with total of 27 plans and 280 fractions of treatment were evaluated for breast treatment (see Table 1). Nine cases were treated with supine setup and 1 with prone setup. Four patients are with DIBH and six patients are using free breathing. Among all ten patients, three are treated to right breast, three to left breast patients, two to bilateral breasts and two to left chest-wall. The average gamma index for breast treatment is 95.65% with SD= 3.7%. The results show much high variation in the gamma index than in head and neck or brain cases.

Notice that by selecting day 2 images instead of day1 images as reference for breast cases, higher gamma index and lower standard deviation are obtained (see Fig. 7). This indicates that the day 2 treatment is more consistent with the remaining treatment than the day 1 treatment (see Fig. 7).
There is a slight gamma improvement with free breathing than DIBH with similar amount of standard deviation in breast treatment (see Fig. 8). For all breast cases, the average gamma for right breast is slightly higher than left breast. But there is no significant difference in standard deviation. The same phenomenon was observed in the bilateral breast cases.
Figure 8. (a) Average Gamma passing rate and (b) Standard Deviation for breast patients with different immobilization and different laterality.

4. Conclusion
We have analyzed gamma index passing rate over 1000 treatment fractions for different sites and found that different sites have very different mean gamma passing rate (See Table 1). We found a good threshold value of gamma passing rate of 95% to be a reasonable value for all sites except breast. For breast, 90% threshold is a reasonable value. Furthermore, second day images are a better reference image than first day of treatment in gamma evaluation for breast. For the two head and neck patients, who had noticeable anatomy variation, the gamma passing rate appears to be lower than the rest of the 17 patients.

5. References
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