Consistency check of photon beam physical data after recommissioning process

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Abstract. In radiotherapy, medical linear accelerator (Linac) is the key system used for radiation treatments delivery. Although, recommissioning was recommended after major modification of the machine by AAPM TG53, but it might not be practical in radiotherapy center with heavy workloads. The main purpose of this study was to compare photon beam physical data between initial commissioning and recommissioning of 6MV Elekta Precise linac. The parameters for comparing were the percentage depth dose (PDD) and beam profiles. The clinical commissioning test cases followed IAEA-TECDOC-1583 were planned on REF 91230 IMRT Dose Verification Phantom by Philips’ Pinnacle treatment planning system. The Delta4PT was used for dose distribution verification with 90% passing criteria of the gamma index (3%/3mm). Our results revealed that the PDDs and beam profiles agreed within a tolerance limit recommended by TRS430. Most of the point doses and dose distribution verification passed the acceptance criteria. This study showed the consistency of photon beam physical data after recommissioning process. There was a good agreement between initial commissioning and recommissioning within a tolerance limit, demonstrated that the full recommissioning process might not be required. However, in the complex treatment planning geometry, the initial data should be applied with great caution.

1. Introduction
Radiotherapy treatment is a high risk procedure since it is complicated, involves multiple data and interaction of many professional groups [1]. The treatment planning and treatment delivery are two major sub-processes in this procedure which may be further sub-divided into several tasks [2]. Therefore, the quality assurance (QA) process is necessary to ensure the correct patient delivery dose [3]. The commissioning management is an important part of QA program for both the radiotherapy treatment planning system (RTPS) and the planning process [4]. As stated by IAEA-TECDOC-1583, the commissioning involves testing of system functions, documentation of the different capabilities and verification of the ability of the dose calculation algorithms to reproduce measured dose calculations. In radiation treatment delivery, medical linear accelerator (Linac) is the key system used in this process. Recommissioning was recommended by AAPM TG53 [5] after major repairs, tuning, changing of beam parameters or machine’s parts. The amount of work involved can vary from a few hours to several days works or even longer for a complex 3D dose calculation algorithm. Full
recommissioning process is a laborious task that might not be practical in heavy workloads radiotherapy center.

The main purpose of this study was to compare photon beam physical data between initial commissioning and recommissioning in terms of PDD data, beam profiles, and verify by point dose and dose distribution treatment planning.

2. Materials and methods

2.1. The basic beam data sets comparison

The two sets of basic measured beam data from initial commissioning and full recommissioning process for 6MV Elekta Precise linac machine at the Lampang Cancer Hospital were imported to the Pinnacle\textsuperscript{3} version 9.8 treatment planning system for photon beam modelling. Measurements of the dose profiles and the depth dose were performed at the source to surface distance of 100 cm in water with a Wellhofer dosimetric system. In this study, the measured open field depth doses and profiles for the 2×2, 3×3, 4×4, 5×5, 10×10, 20×20, 30×30 and 40×40 cm\textsuperscript{2} field size were compared. The difference values between commissioning and recommissioning data were expressed as $\%\delta$, a percentage of the dose deviation calculated by equation 1 and $\delta$, difference distance at point of interested with normalization dose at $d_{\text{max}}$ ($D_{\text{max}}$) calculated by equation 2 modified from TRS430.

\begin{equation}
\%\delta = 100 \times \frac{(D_{\text{recom}} - D_{\text{com}})}{D_{\text{com}}} \tag{1}
\end{equation}

where $\%\delta$ is a deviation of percentage difference, $D_{\text{recom}}$ is the recommissioning dose at a particular point and $D_{\text{com}}$ is the commissioning dose of the same point.

\begin{equation}
\delta = d_{\text{recom}} - d_{\text{com}} \tag{2}
\end{equation}

where $\delta$ is a deviation of distance, $d_{\text{recom}}$ is the recommissioning position at a particular dose level and $d_{\text{com}}$ is the commissioning position of the same dose.

Graphical examples in figure 1 showed the analytical criteria of depth dose curves and beam profiles. The tolerance limits were shown in table 1.

\begin{figure}[h]
\centering
\begin{subfigure}{0.45\textwidth}
\centering
\includegraphics[width=\textwidth]{PDD_curve.png}
\caption{Depth-dose (PDD) curves for comparison.}
\end{subfigure}
\hfill
\begin{subfigure}{0.45\textwidth}
\centering
\includegraphics[width=\textwidth]{beam_profile.png}
\caption{Beam profiles.}
\end{subfigure}
\caption{Regions of validity of the criteria $\%\delta_1$ and $\%\delta_2$ to compare commissioning data and recommissioning data for depth-dose (PDD) curves (a) and $\delta_3$, $\%\delta_4$, $\%\delta_5$, $\delta_{50-90}$ and $\delta_{RW50}$ for beam profiles (b).}
\end{figure}
Table 1. The tolerance limits for the $\delta$ and $%\delta$[1].

| photon beam physical data | parameter | location | tolerance limit |
|---------------------------|-----------|----------|----------------|
| PDD                       | $%\delta_1$ | build up region : surface and the depth of the 90% isodose surface | 10% |
|                           | $%\delta_2$ | central beam axis : the high dose and small dose gradient region | 2% |
| beam profile              | $\delta_3$ | penumbra region of profiles : high dose and large dose gradient regions | 2 mm |
|                           | $%\delta_4$ | outside central beam axis : high dose and small dose gradient region | 3% |
|                           | $%\delta_5$ | outside beam edges: data points off the geometrical beam edges and below shielding blocks | 30% |
|                           | $\delta_{50:90}$ | beam fringe : distance between the 50% and the 90% point | 2 mm |
|                           | $\delta_{RW50}$ | radiological width : width of a profile measured at half its height compared to the value at the beam axis | 2 mm |

2.2. Point dose verification
Test cases in this study were based on guidelines described in the IAEA-TECDOC-1583 representing the typical techniques in radiotherapy clinical practices. The test cases were planned on REF 91230 IMRT Dose Verification Phantom by Philips’ Pinnacle treatment planning system and the defined point doses were measured by 0.6 cm$^3$ PTW-Freiburg TW30013 cylindrical ionization chamber and PTW-Freiburg T10009 UNIDOS E electrometer. The measured doses were compared with corresponding calculated points from Philips’ Pinnacle treatment planning system that used photon beam data from both initial commissioning and recommissioning sets. In brief, the purpose of each test case was as followed:

- Test case 1: Testing for reference
- Test case 2: Oblique incidence, lack of scattering and tangential fields
- Test case 3: Significant blocking of the field corners
- Test case 4: Four field box
- Test case 5: Automatic expansion and customized blocking
- Test case 6: Oblique incidence with irregular field and blocking the center of the field
- Test case 7: Three fields, two wedge paired, asymmetric collimation
- Test case 8: Non coplanar beams with couch and collimator rotation

2.3 Dose distribution verification
In this study, dose distribution of all test cases on the REF 91230 IMRT Dose Verification phantom were measured by ScandiDos Delta$^{PT}$ pre-treatment verification system. The passing criteria of the dose distribution was 90% of a gamma index (3% of dose difference and 3 mm distance to agreement). The measurement was performed only for test cases 1-7 and test case 8 was omitted as the crucial electronic part of Delta$^{PT}$ was in beam direction.

2.4 Statistical analysis
For $%\delta$ (deviation of percentage difference) and $\delta$ (deviation of distance), this difference can be demonstrated in a comparison of the criteria of TRS 430 and analyzed using SPSS version 17.0 with 95% confidence interval. Mean and standard deviation of three measurements were used for point dose and dose distribution verification.
3. Results
As shown in table 2, according to the tolerance limit recommended by TRS430, the $\%\delta_i$ of PDDs for all field sizes were within tolerance limit of 10%. The PDDs in build-up region of initial commissioning and recommissioning were not statistically significantly different ($p$-value = 0.261). However, the $\%\delta_i$ for field sizes of 20×20 cm$^2$ and larger were out of the tolerance limit of 2%. The PDDs along central axis of initial commissioning and recommissioning were not statistically significantly different ($p$-value = 0.053).

For beam profiles, at the penumbra region of profiles, $\delta_3$ for both inplane and crossplane were analyzed, only the crossplane was statistically significantly different ($p$-value = 0.003) but both were within tolerance limit of 2 mm. Outside central beam axis region, there were no statistically significantly different parameter of $\%\delta_4$ in both planes and the $\%\delta_4$ value in all plane were in tolerance limit of 3% except for field size 2x2 cm$^2$. Outside beam edges, there were no statistically significantly different parameter of $\%\delta_5$ in both planes and the $\%\delta_5$ value were all in tolerance limit of 30%, except for field size 20×20 cm$^2$ and larger. At beam fringe, there were statistically significantly different $\delta_{50-90}$ in both planes ($p$-value = 0.000), but both were within tolerance limit of 2 mm. For radiological width, there were no statistically significantly different $\delta_{RW50}$ in both planes and the $\delta_{RW50}$ value were all in tolerance limit of 2 mm, except the large field size as 40×40 cm$^2$ in crossplane.

For point doses verification, the measured doses for all test cases agreed well within a tolerance limit compared to the corresponding calculated point using both initial commissioning and recommissioning data sets. The percentage difference of measured dose using both data sets for monitor unit calculations were within ±2%.

Dose distribution verified by Delta4PT passed the acceptance criteria 88.9% of the case except in test case 6.

Table 2. The result of commissioning and recommissioning physical beam data comparison.

| Field sizes (cm$^2$) | PDD | Beam profiles |
|---------------------|-----|---------------|
|                     | $\%\delta_1$ | $\%\delta_2$ | $\delta_3$ | $\%\delta_4$ | $\%\delta_5$ | $\delta_{50-90}$ | $\delta_{RW50}$ |
| CR. | IN. | CR. | IN. | CR. | IN. | CR. | IN. | CR. | IN. |
| 2×2 | -2.2 | -0.4 | -0.6 | -0.6 | -2.5 | -3.1 | 2.7 | 22.3 | 1.0 | 1.5 | 0.1 | 0.1 |
| 3×3 | 4.6 | -1.6 | -1.0 | -0.7 | -2.9 | -0.7 | 20.5 | 28.5 | 1.5 | 1.8 | 0.0 | -0.4 |
| 4×4 | 4.1 | -1.8 | -1.0 | -1.2 | -0.6 | 1.2 | -8.3 | 12.7 | 1.3 | 1.7 | 0.3 | 0.3 |
| 5×5 | -4.1 | -0.8 | -1.1 | -0.7 | -0.1 | -0.6 | -13.2 | 8.0 | 0.8 | 1.8 | 0.2 | -0.4 |
| 10×10 | -8.1 | -1.0 | -0.9 | 0.1 | -1.2 | -0.9 | -24.5 | 27.0 | 0.5 | 1.2 | 0.0 | 0.2 |
| 20×20 | -8.1 | -5.0 | -0.1 | 0.0 | -0.5 | -0.6 | -65.7 | 61.7 | 0.8 | 1.6 | -0.4 | -0.9 |
| 30×30 | -4.2 | -13.6 | -0.1 | -0.1 | -1.7 | 0.0 | -54.4 | 50.9 | 0.7 | 1.5 | -0.5 | -0.4 |
| 40×40 | 1.3 | -20.6 | -1.3 | 0.7 | -1.1 | 0.1 | -72.9 | 50.6 | 1.1 | 2.0 | 2.3 | -2.0 |

4. Discussion
For PDDs, in the build-up region, no difference of the $\%\delta_1$ for all field sizes was observed, but at higher depth, the $\%\delta_2$ for field sizes larger than 20×20 cm$^2$ were out of tolerance limit. This was shown in the PDDs curves, the commissioning dose was higher than recommissioning dose at the same depth, indicated that the photon energy was slightly lower in the latter case. As energy of incident photon decreases, the contribution of the scattered radiation to the absorbed dose is obviously seen at larger field sizes.

The effect of decreasing photon energy was also pronounced for beam profiles. Most of the analysed parameters were within a tolerance limit, except for the $\%\delta_5$ of field sizes larger than 20×20 cm$^2$. For data points out off the geometrical beam edges in large field sizes, the doses of recommissioning data were lower than that of commissioning. The lower fraction of the central axis energy fluence is due to the lower scattered of flattening filter when the collimator jaws are wide.
The Gaussian height, Gaussian width, and jaw transmission parameters affect the dose in the low-dose regions of the off-axis profile [7].

All of the point doses verification in the designed test cases agreed well within a tolerance limit for both data sets.

In dose distribution verification, only test case 6, the irregular central blocked fields was not met the acceptable criteria for both data sets. The accuracy of a leaf leakage calculation in treatment planning system depends on the accuracy of an input data while the Delta4PT actually responds to both scattered and leakage radiations. The other test cases representing the typical techniques in radiotherapy clinical practices passed the acceptable criteria, deduced that the isodose plan from initial commissioning and recommissioning data were compatible.

5. Conclusion
In our study, the physical beam data from initial commissioning and recommissioning process were compatible confirmed by point dose and dose distribution verification, demonstrated that the full process of recommissioning might not be required. However, in some circumstance where the treatment depth exceeds 10 cm or in the complex treatment planning geometry, the initial data should be applied with caution.

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Acknowledgement
I am greatly thankful for Lampang Cancer Hospital for providing the instruments in this project.