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Implications of leaf fluence opening factors on transfer of plans between matched helical tomotherapy machines

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Abstract

When helical tomotherapy plans are transferred between two matched machines, the leaf opening times are changed. A published method of checking these is based on the differences in leaf latency between the two machines. We have extended this method to account also for the differences in leaf fluence opening factors (LFOF) between the two machines. When LFOF is not taken into account, the number of false negatives (with under 95% of opening times agreeing within 5 ms or under 99% agreeing within 10 ms) is approximately 10% of patients. After correcting for LFOFs, all transfers meet the criteria.

Introduction

A paper by Yaddanapudi et al (2012) described a method for independent verification of plans that had been transferred between two matched helical tomotherapy machines. The technique involved removing the latency correction for the source machine, and applying the latency correction for the destination machine. They found that >95% of leaf opening times (LOTs) being within 5 ms and >99% of LOTs being within 10 ms could be used as a tolerance for accepting that an acceptable transfer had taken place. We have implemented their method in our clinical workflow.

Recently Accuray have updated their method of defining leaf latency1, and in place of the slope and offset varying with projection time described in table 2 of (Yaddanapudi et al 2012), they now use a slope of unity, and a constant intercept (which still differs between machines). This change has been applied by Accuray when multi-leaf-collimators have been replaced or modified, or on request by customers, so some machines in the field will still have the older parameters. With this simplification, we would expect to find even closer agreement between transferred plans. However when comparing the sinograms for some chest wall plans we noticed some with <95% of LOTs agreeing within 5 ms. On investigation these turned out to result from differences in leaf fluence opening factors (LFOFs) between the two machines (Balog et al 2003). These are mentioned in (Yaddanapudi et al 2012) but no method is given to correct for them. The purpose of this note is to describe an extension to the method to correct for LFOF variation between machines.

Method

The LFOF values are stored in the machine archive files for each machine, which are written in extended markup language (XML). The values are stored under the labels of ‘leafTAGPLowerLeaf’, ‘leafTAGPHigher-Leaf’, and ‘leafTAGPBothLeaf’ for the corrections required where the lower leaf, the higher leaf, and both neighbouring leaves respectively are closed. The values stored are equal to LFOF-1. The latency is corrected following the methods of (Yaddanapudi et al 2012) to remove the latency from the source machine and insert the latency from the destination machine.

\[
\text{LOT}_{\text{Intermediate}} = \text{LOT}_{\text{Source}} \times \text{slope}_{\text{Source}} + \text{intercept}_{\text{Source}}\]

\[
\text{LOT}_{\text{Destination, noLFOF}} = (\text{LOT}_{\text{Intermediate}} - \text{intercept}_{\text{Destination}}) \div \text{slope}_{\text{Destination}}
\]
It should be noted that in order to reproduce the results of (Yaddanapudi et al 2012) it was necessary to invert the equations from those in their paper. The accuracy of the transfer process between our machines had been confirmed by performing phantom measurements on a large number of transferred plans. The LOTsource and LOTdestination represent the LOTs that need to be in the plan file applied to the source and destination machines respectively, to ensure that a leaf opening LOTintermediate is actually delivered.

The new step we have added is to correct the results of equation (2) for the difference in LFOF between the two machines. The opening times from equation (2) are compared with the opening times for the leaves with higher and lower leaf indices, to determine the fractions of the LOT where the lower-indexed leaf is closed with the higher open \((f_{lo})\), where the higher indexed leaf is closed with the lower open \((f_{hi})\), both adjacent leaves are closed \((f_{both})\), or both adjacent leaves are open \((1-f_{lo} - f_{hi} - f_{both})\). By incorporating this step, we now more closely replicate the processes being followed by the TomoTherapy system when transferring a plan, and so are better able to detect any potential cases where an error has occurred in this process. Since the commercial software includes the LFOF difference in the transfer process, ignoring it in the independent check will falsely flag, as an incorrect transfer, plans that have in fact been correctly transferred.

The LFOF for the source and destination machines can then be calculated as

\[
\begin{align*}
\text{LFOF}_{\text{source}} &= 1.0 + f_{\text{both}} \times (\text{LFOF}_{\text{both,source}} - 1) \\
&\quad + f_{\text{lo}} \times (\text{LFOF}_{\text{lo,source}} - 1) \\
&\quad + f_{\text{hi}} \times (\text{LFOF}_{\text{hi,source}} - 1), \\
\text{LFOF}_{\text{Dest}} &= 1.0 + f_{\text{both}} \times (\text{LFOF}_{\text{both,dest}} - 1) \\
&\quad + f_{\text{lo}} \times (\text{LFOF}_{\text{lo,dest}} - 1) \\
&\quad + f_{\text{hi}} \times (\text{LFOF}_{\text{hi,dest}} - 1), \\
\text{LOT}_{\text{Destination}} &= \text{LOT}_{\text{Destination}} \times \frac{\text{LFOF}_{\text{Dest}}}{\text{LFOF}_{\text{Source}}}, \\
\end{align*}
\]

Results

Over an 8 month period, 295 transferred plans had been evaluated using equations (1) and (2). They were regarded as a ‘pass’ if at least 95% of the LOTs agreed within 5 ms, at least 99% agreed within 10 ms, and the sum of LOTs agreed within 1%. None of the transfers failed the final criteria (all sums agreed within 0.4%), but 29 plans failed on one or other of the first two criteria (12 failed both, 7 failed just the first and 10 failed just the second). For the 29 plans that failed, a delivery quality assurance (DQA) was performed in a phantom; all passed within normal clinical tolerances.

Figure 1 shows the effect of incorporating the LFOF correction into the transfer check, for thirteen patients. With the original algorithm, six patients failed the criterion of \(>99\%\) of values being within 10 ms; four of these also failed the criterion of \(>95\%\) being within 5 mm. With the new algorithm, taking LFOF into account, all patients passed these criteria.

Figure 2 shows the LFOF values for the two machines at our centre. It can be seen that whilst the LFOF values are similar for leaves near the centre, large differences between the machines (of up to 4.3%) are seen for leaves 2–22.

The LFOFs for a particular machine are determined by Accuray at commissioning, using the methods described by Balog, and will be applied for all plans produced on that machine. The assumption made by

\[
\begin{align*}
\text{LOT}_{\text{Destination}} &= (\text{LOT}_{\text{source}} + \text{intercept}_{\text{source}} \\
&\quad - \text{intercept}_{\text{destination}}) \times \frac{\text{LFOF}_{\text{Dest}}}{\text{LFOF}_{\text{Source}}}, \\
\end{align*}
\]
Accuray is that the apparent random noise in figure 2 is a real phenomenon that is stable over time. We have not been able to make any measurements to confirm this assumption. This is because any phantom measurements on a treatment plan will have contributions from very many different leaf opening segments. This randomness will subsequently have very little impact on measured doses.

Discussion and conclusion

An examination of the plans that failed the original transfer check shows whilst a low proportion of prostate and head & neck plans failed the transfers, a high proportion of chest wall plans failed. Chest wall plans tend to be heavily blocked, and to have the target volume distant from the centre of the patient. This can lead a large amount of the dose being given by narrow fields using leaves 4–19, which from figure 2 can be seen to exhibit the largest difference in LFOF between machines.

Incorporating the LFOF into the transfer check reduces the number of false negatives, where we unnecessarily investigate a transfer that has in fact proceeded correctly.

References
