

Accuracy and precision of an IGRT treatment technique using Elekta Synergy®

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Purpose: Traditional concepts for measuring the accuracy and precision of linear accelerators in terms of a series of simple mechanical and dosimetric parameters becomes a redundant concept when considering recent advances in image guided radiation therapy (IGRT) techniques. Ultimately what is required is the ability to deliver planned dose gradients to a certain accuracy and within a certain precision.

Intensity modulated radiation therapy (IMRT) provides the ability to reliably and accurately deliver highly complex dose distributions on modern linear accelerators. IMRT therefore provides a more appropriate test for accuracy agreement with measurements and precision repeatability of measurements, of IGRT than traditional tests. An accuracy of 2% and precision of 1% should be the target requirement for an IGRT approach. This can only be achieved by having accuracy at every stage of the process. The process includes treatment planning algorithm, good imaging and registration, dose delivery and the geometric calibration of the imaging linear accelerator and MLC.

Accuracy study

Accuracy and precision of an IGRT treatment technique using Elekta Synergy®

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Method

A perspex head-and-neck phantom developed in-house for the verification of IMRT techniques was used to test an IGRT treatment technique (see figure 1). The treatment involved the imaging of the phantom in the treatment position, followed by the delivery of an IMRT plan designed to spare salivary function. The complex IMRT plan involved five step-and-shoot fields with a total of 82 segments delivered at 6MV on Elekta Synergy®. The treatment planning was carried out using Philips Pinnacle® v7.4f with a beam model incorporating the effects of rounded leaf ends and transmission through the tongue and groove of the MLC leaves.



Figure 1: the perspex head-and-neck phantom (HANK) in the treatment position – the micro-mosfet lead wires can also be clearly seen.

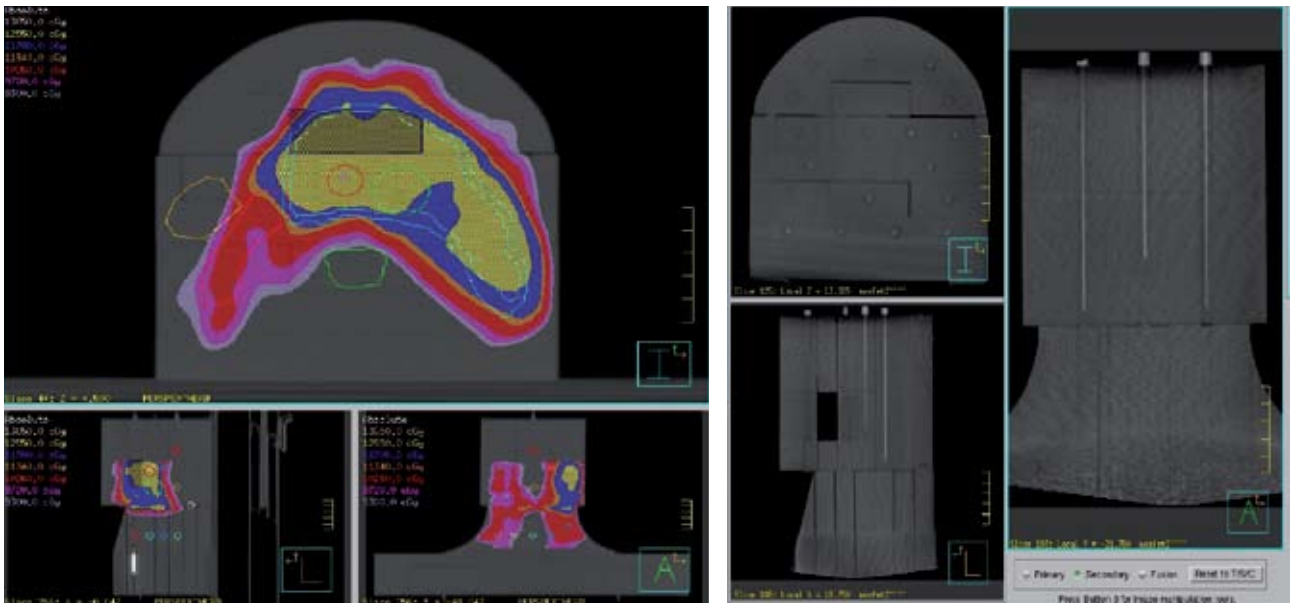
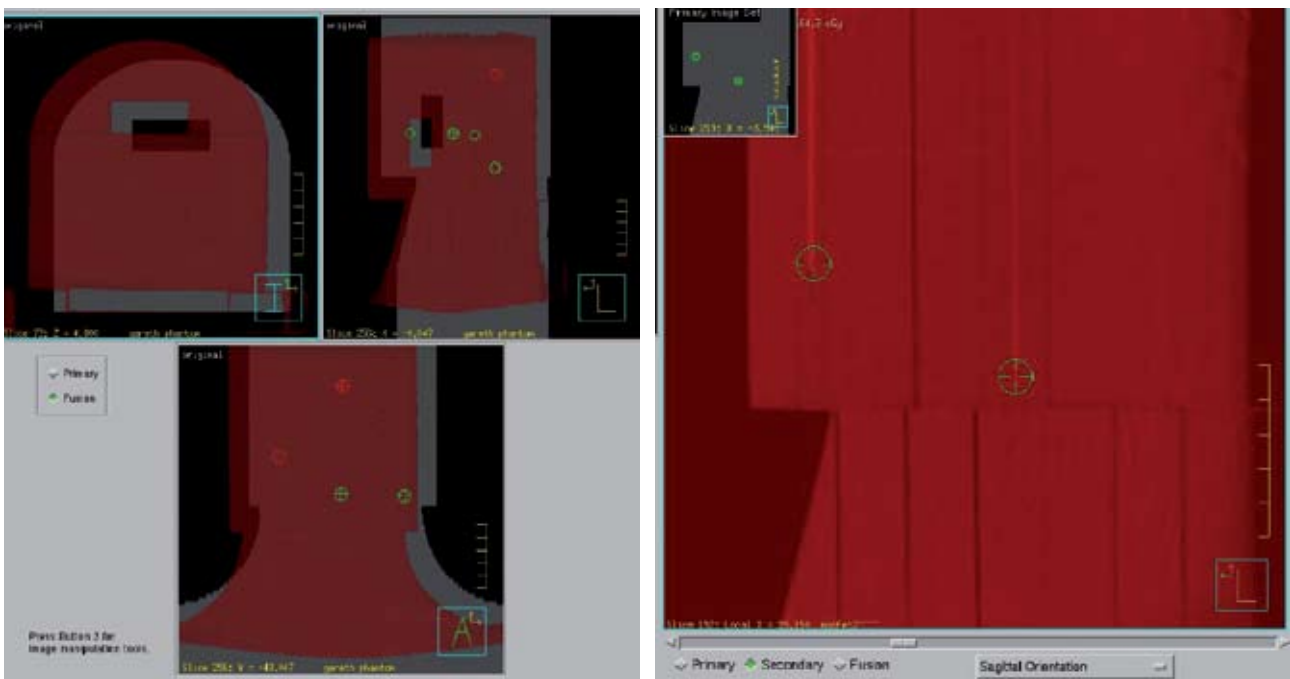


Figure 2: a) the IMRT dose distribution used for testing of the IGRT system
 b) the XVI image of the phantom clearly showing the micro-mosfets



c) the image registration within Pinnacle allows the removal of the set-up error when comparing planned and delivered doses
 d) a sagittal view of the phantom showing how the micro-mosfet positions are obtained.

To optimize accuracy and isolate the contribution of the overall accuracy of couch movement and IGRT method, the phantom was not moved between the imaging and delivery phases of the experiment. Any set-up error was removed by registering the IGRT scan with the planning scan on the treatment planning system and moving the isocenter to account for any set-up error (see figure 2).

The dose was initially measured at six points distributed in the phantom simultaneously via the use of micro-mosfets. The use of micro-mosfets was seen as advantageous as they are small in size (1mm active dimension), and clearly visible on CT. Development of the phantom has subsequently allowed up to 20 points of interest to be independently measured. As the overall accuracy of the treatment was sought the dose from the whole treatment only was considered. Doses from individual beams were not analyzed, but rather the ability of the IGRT system to deliver the overall dose produced by the treatment planning system.

In the final analysis, 19 separate points were simultaneously measured to sample the dose distribution in all three dimensions with micro-mosfets connected to either standard or high sensitivity bias.

The points were chosen to sample different parts of the dose distribution including high gradient regions, but needed to receive a high enough dose to allow reasonable results to be attainable from the micro-mosfets. The plan delivery was performed five times without disturbing the phantom set-up to investigate the precision of the IGRT delivery.

Results

Initial experiments demonstrated the relationship between the coefficient of variation with dose on the micro-mosfet. The shape of the curve for both standard and high sensitivity bias were similar with a minimum dose of 85cGy required to produce a consistent level of experimental noise. Figure 3 shows the curve for the high sensitivity bias. When using micro-mosfets with the standard bias the variation above 85cGy was approximately 3% of the measured dose. For the high-sensitivity bias, this variation was reduced to 1.5% and could potentially be reduced further if higher doses were measured. Measuring dose less than 85cGy led to a marked increase in the variation. For this reason the measurement points for subsequent measurements were designed to coincide with planned dose greater than 85cGy for a single fraction.

Figure 3 demonstrates that differences between measured and planned doses of less than 1.5% will be difficult to resolve with the present system. The stability of individual micro-mosfets have also been investigated by repeat measurement over several days with a mean standard deviation of $\sim 1.5\%$ for a high sensitivity bias micro-mosfet. This is of the same order of magnitude as the coefficient of variation on readings for a single experimental session.

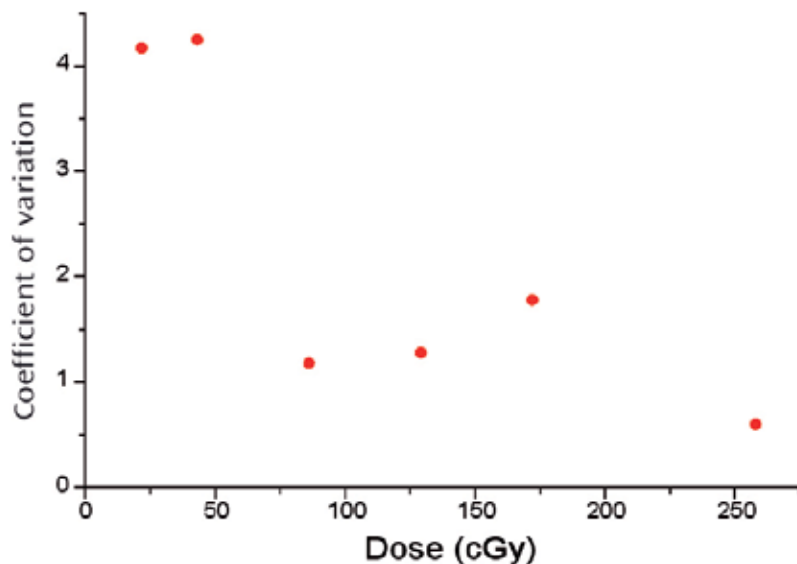


Figure 3: the variation of detector noise with measured dose over a range of 20cGy to 260cGy is defined using the coefficient of variation ($COV = 10 \times 2SD/mean$).

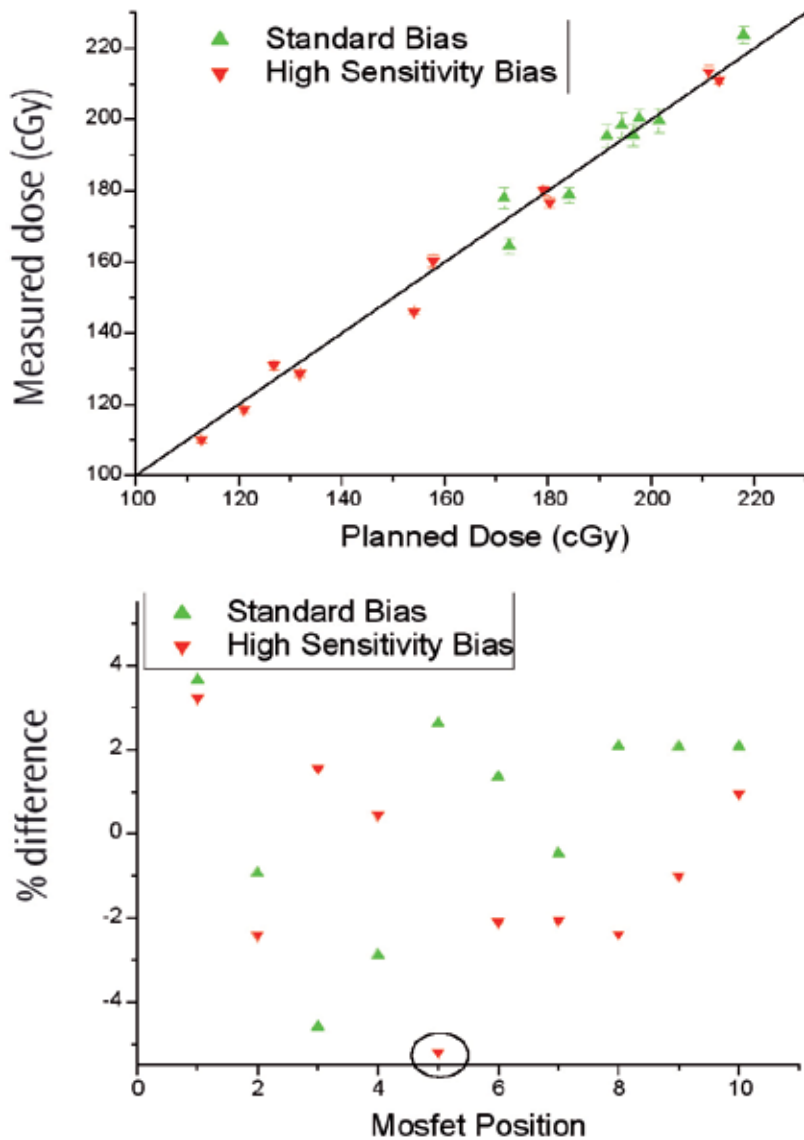


Figure 4:

(top) a – planned versus measured dose for the 19 sample points

(bottom) b – the % difference between measured and planned doses for the sample.

Figure 4a) plots the measured versus planned doses for the 19 measurement points chosen for the experiment. The results for the micro-mosfets attached to standard and high-sensitivity biases are plotted independently as the standard bias micro-mosfets are expected to be less accurate than the high sensitivity ones.

The small error bars on the figure demonstrates the precision of the delivery to the phantom and highlights the improved precision of the micro-mosfets attached to the high sensitivity bias. What is causing the difference between measured and planned doses? Tests confirmed in turn that 2mm shifts in delivery isocenter, systematic 0.3mm shifts in the MLC offset position and 0.5mm shifts to specific leaves, whilst significantly affecting individual point doses, resulted in no overall reduction in the discrepancy. It is therefore unlikely that a systematic delivery error is the cause of this difference. A more likely source of the discrepancy is the treatment planning system model of the linear accelerator.

Figure 4b) shows the percentage difference between measured and planned doses for the 19 points sampled in the experiment. High sensitivity bias position 5 has been highlighted with a circle in the figure as a problem position.

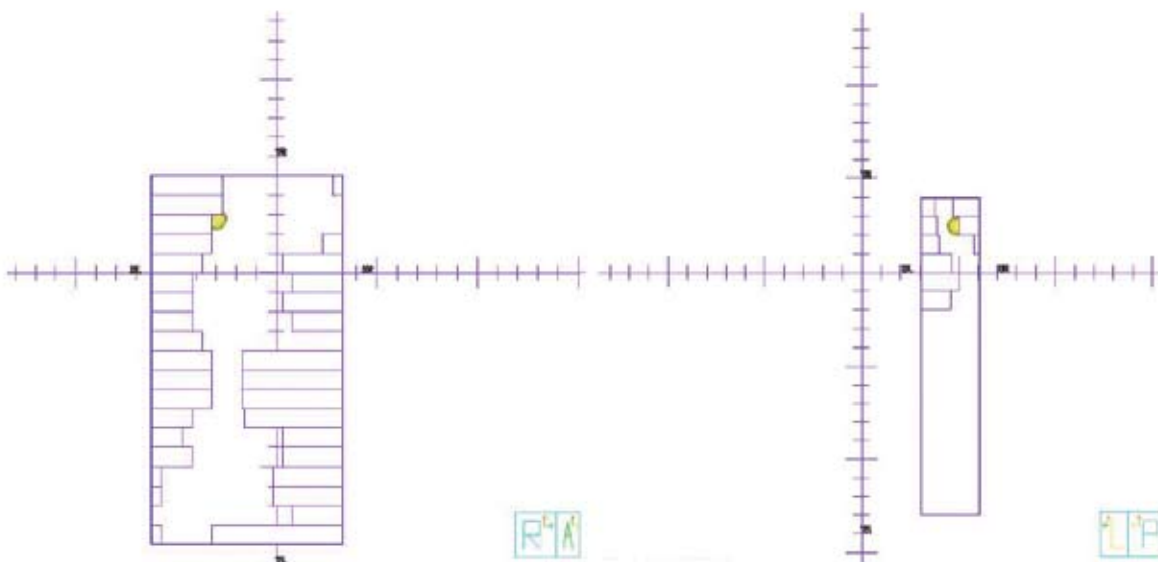


Figure 5:
 (left) a – the dose distribution around high sensitivity mosfet position five (red point). The green isodose line indicates the level of measured dose suggesting a distance to agreement of 0.8mm.
 (center and right) b – further investigation demonstrated that two individual segments out of 82 gave rise to approximately 2.4% of the dose difference seen for position five.

Figure 5 highlights a deficiency in the current system in that the micro-mosfets are unable to resolve a distance to agreement for differences in dose. It is clear from figure 5a) that the distance to agreement is very small despite the error of 5% in dose. Another potential issue is whether, having seen a difference in dose for a point, the source of the difference is the planning system or the delivery system? It is very difficult to isolate the source of error.

Conclusions

A system has been developed to test the accuracy and precision of an IGRT technique. The main rationale for such a test was to establish the clinically relevant accuracy and precision for delivering a highly complex dose distribution via IMRT. Development of the system will allow a series of IMRT plans to be developed and delivered to phantoms to provide clinically relevant tests of precision and accuracy of new technology such as IGRT.

Micro-mosfets are usable dosimeters for this test. However, the experimental variation is likely to be of the order of 1.5%* unless much higher doses of radiation are delivered. If a detection of accuracy and precision below this level are required, then another dosimeter is required for the experiments.

It has been confirmed that the accuracy of a complex IMRT dose delivery using an image guided approach using Elekta Synergy® is $\pm 3\%$ in dose over a range of sample points including high dose gradients. The precision of the delivery system was also demonstrated to be within the experimental noise of the system of 1.5% (2SD) for high-sensitivity micro-mosfets.

** Cannot measure better than 1.5% due to the experimental noise of mosfet.*

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