The impact of IGRT for prostate radiotherapy on dosimetry and the traditional workflow practice of focus to skin distance measurements

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Abstract Purpose: To assess the relevance of focus to skin distance (FSD) measurements for patients with intraprostatic gold seeds using an image guided radiation therapy (IGRT) protocol. The second aim of this study was to analyse the frequency and nature of isocentre shifts made during a course of treatment for patients with prostate cancer. Additionally, the impact of isocentre shifts on dosimetry, relative to the traditional method of basing dosimetric recalculations on FSD measurements was assessed. Methods and materials: Ten patients underwent prostate radiotherapy with intraprostatic gold seeds and an IGRT protocol. FSD measurements were taken on a daily basis pre-intervention and also post-intervention if an isocentre shift was made. Analysis of systematic and random isocentre shifts were made and compared to measured FSDs. An individual case study was carried out assessing the dosimetric impact of multiple isocentre shifts throughout a course of treatment and analysed against measured FSDs. Results: Ten patients received radiotherapy to the prostate (78 Gy/39 fractions). 390 treatment sessions were available for analysis, inclusive of 2340 measured FSDs. Measured FSDs were out of tolerance (greater than 1 cm difference from planned measurement) less than 2% of the total treatment sessions. Of the isocentre shifts made, 66% (160/242) were random and 34% (82/242) were systematic. The individual case study revealed 72% of treatment sessions required an isocentre shift with FSDs being outside tolerance for one session. Conclusions: FSD measurements in the era of intraprostatic gold seed IGRT have been reduced in importance. IGRT has improved the identification of systematic and random errors therefore allowing better visualisation of dosimetric impact these errors may cause. Our data suggest that FSD measurements for men undergoing IGRT for prostate cancer have minimal dosimetric impact.

Keywords: Fiducial markers, focus to skin distance, image guided radiation therapy, prostate cancer.

Introduction

This study analyses the traditional methodology of taking and recording field Focus to Skin Distance (FSD), and their relevance in the age of target based image guided radiation therapies (IGRT). It will discuss the effects that frequent isocentre shifts can impose on dosimetry.1,2 Multiple isocentre shifts, be they systematic or random, throughout a course of treatment can introduce variables into a treatment plan which can affect dosimetry. A systematic error can be defined as persistent geometrical inaccuracies that can lead to differences between theoretical or planned dosimetry and what is actually delivered.3 A random error however, can “…stem from variable processes such as daily alignment of the patient’s skeleton or the internal target position and are unique for each patient and each fraction”.4 These variables and the increased recognition of them via gold seed fiducial markers have made it difficult to continue the traditional workflow practice of measured FSDs.

Intraprostatic gold seed fiducial markers have over the last 10 years become a standard of care for dose escalated radiotherapy for prostate cancer patients. Previous studies have shown that the prostate can displace within the bony pelvic anatomy by 9 mm or more between fractions.5,6 The introduction of gold seed fiducials as a surrogate for prostate position, in conjunction with IGRT, has enhanced the ability to target the prostate on a daily basis with increased accuracy. Negating the effect of this motion has improved both short-term and long-term toxicities.6,7 The experiences at Radiation Oncology Queensland, Toowoomba, have illustrated that this degree of accuracy can impact on traditional workflow methods. Traditionally, FSDs have been used as a mechanism to base potential dosimetric recalculations on. FSDs are one of the most frequently used reference parameters during patient set-up to verify the depth of treatment for each external beam in clinical radiotherapy. The present tool used for this purpose is the optical distance indicator (ODI) mounted inside the linear accelerator.8 The use of gold seed fiducials in conjunction with IGRT has illustrated that the prostate is a moving target within the bony pelvic anatomy, whereas FSDs are effectively a measure of distance from patient contour to set-up point. This set-up point however, in an IGRT setting, may not be the treated isocentre. When there is an anatomical change in the path of a treatment beam, considerable impact on delivered dosimetry can occur.5,6,9,10,11,12

Importantly, throughout the body of this paper it is noted that when FSDs impact on dosimetry it is also the effective path length that is being referred to. The effective path length is simply defined as the treatment beams pathway through patient anatomy, which of course changes in density and inhomogeneities, dependent on the type of tissue passed through. Thus the effective path length can be seen as a true measure of distance through human tissue. FSDs are an indicator of the measure of the radiation focus to the skin and are a quality assurance set-up indicator to assist patient and target positioning and identify changes in size and
shape. While FSDs may measure a change in patient set-up, dose recalculations are done based on the effective path length from target to isocentre of which a change in FSD is an indicator.

Materials and methods

This study received low risk ethics approval from the Toowoomba and Darling Downs Health Services District (TDDHSD) Human Research Ethics Committee (HREC) on 22nd October 2008

A convenience sample of 10 prostate gold seed patients were selected for the study, each undergoing dose escalated IGRT to 78 Gy in 39 fractions. Ten patients were chosen as anecdotal evidence over our department’s first 12 months indicated little consistency between isocentre movement for these patients and subsequent FSD measurements. This study aimed to be conclusive evidence. The gold seed fiducials were positioned in the right prostate base, the left prostate mid gland and the right prostate apex. Patients were positioned head first and supine on the treatment couch. Two foam sponges were placed under the head. The pelvis and legs were positioned in a personalised Vac Pac, which was indexed onto an indexed pelvic board. The 10 patients were planned with a treatment technique consisting of six fields at a variety of gantry angles (240°, 270°, 330°, 30°, 90°, 120°) with weightings optimised to reduce dose to the rectum, bladder and femoral necks. The PTV was an expansion of the CTV of 7 mm. The dose tolerances for the organs at risk followed the guidelines set by the PROstate Fractionated Irradiation Trial (PROFIT).

During the planning and simulation procedures the patients were instructed to follow a rectal and bladder filling protocol, which requires an empty rectum and comfortably full bladder. This process was also enforced during treatment. The patients’ gold fiducial positions were verified daily using an IGRT online correction protocol. This comprised of taking orthogonal (right lateral and anterior) electronic portal images (EPI) of the gold seed fiducial positions. If pre-treatment images were outside a 3 mm action threshold on any of the orthogonal axes an online intervention was made. Importantly, all isocentre moves were tracked enabling detailed analysis of either systematic or random set-up error. The FSDs are commonly recorded on a weekly basis to ensure no change in patient contour, but for the purposes of this study they were taken daily. Generally a tolerance of 1.0 cm is given for FSD; therefore if the FSD recorded differed from the planned FSDs by more than 1.0 cm for three consecutive days then a re-assessment of the treatment would occur.

Data collection

For the purposes of the study FSD measurements were recorded pre- and post-intervention on a daily basis. That is, FSDs would be recorded once the patient set-up position was established prior to leaving the room. If an online correction was made, based on the gold seed fiducial match, the radiation therapists would re-enter the room and re-record the FSDs. These FSDs were then entered into a program specifically written for the study. This allowed the extraction of the information collected as a whole, enabling comparisons to be made between the pre, post and planned FSDs in relationship to any isocentre shift. This allowed the quantification of the relationship between isocentre shifts, systematic and random, and the recording of FSDs. An isocentre shift for the purposes of this study can be viewed as a move made to the planned isocentre due to systematic set-up error or trend, whereas isocentre intervention can be viewed as an online intervention where pre-treatment images are taken and a move to the isocentre made. A simplistic explanation would be an isocentre shift is made in the offline environment after analysis of systematic error, whilst an isocentre intervention is made in the online environment. In this study an isocentre shift was made if three consecutive treatment fractions showed a trend or systematic set-up error.

Included in the analysis was the proportion of treatment sessions that required an intervention and an isocentre shift. Both pre-intervention and post-intervention FSD results were tabulated and a comparison made to the treated isocentre (which was where treatment was actually delivered after online intervention) for each patient each fraction. From this information, the relationship of FSDs to the treated isocentre and potential recalculations could be assessed. Importantly a distinction was made between whether an isocentre shift was systematic or random in nature. Additionally weight measurements were taken on each individual on a weekly basis and accessed via Varian Patient Manager™ (Palo Alto, California USA).

Data analysis

In order to evaluate the magnitude of the dosimetric change from isocentre shifts, the shifts were divided into three separate groupings, less than 0.5 cm, 0.5–0.9 cm and greater than 1.0 cm shifts along the three axes. Each fraction for each patient was placed into one of these groups to determine the frequency of the different isocentre shifts. The shifts were replicated in Varian’s Eclipse™ Treatment Planning System (TPS) (Palo Alto, California, USA) and the plans recalculated. The Monitor Units (MU) were recalculated for the variety of shifts and compared to the original planned MU.

Systematic and random components of total error (diagnosed by the gold seed match) were analysed for the data set utilising the Newcastle Model. Additionally, using the Newcastle Model a distinction was made between the percentage of systematic and random errors occurring. Internal organ motion was calculated by subtracting the set-up error from the total error. The data used to calculate the internal organ motion was from the raw data (lateral, longitudinal and vertical directions), obtained from matching the daily portal images on Varian’s ARIA Offline Review™. The total error was established from the gold seed match (taking into account organ motion). To determine the set-up error an anatomy template, based on the bony anatomy, was outlined from the computerised tomography (CT) planning digitally reconstructed radiographs (DRRs) and used to then template match (overlay the drawn template over the EPI) for each fraction. The same raw data as the total error was then exported. These data were tabulated and the internal organ motion calculated.

Case study

A case study was undertaken on one patient. The systematic isocentre shifts for this patient were entered into the Eclipse™ Treatment Planning System (TPS) and analysed. A hypothetical situation was proposed to justify dose recalculations based on traditional methods whereby dose recalculations are performed if the FSDs were out of tolerance for three consecutive days. The potential monitor units (MU) were recalculated on an in-house FSD change program, created on Excel 2003 (Microsoft, Seattle, Washington, USA) and were based on FSDs which were out of tolerance. This program simply performs a correction of the tissue maximum ratio (TMR) from the new FSDs. The isocentre shift for the relevant fraction was recreated by relocating the isocentre and the beam weight point in Eclipse™ TPS. Based on the recalculations the geometric and effective path lengths were analysed and compared to the assumed path lengths based on FSDs. The
The geometric path length is defined as the actual distance the beam travels from the patient’s contour to the isocentre along the central axis of the field. Whereas the effective path length refers to the distance the beam travels taking into account the different homogeneities the field encounters along the central axis. The resulting dosimetry and MU were also analysed and compared to potential recalculations that were undertaken using the daily recorded FSDs as the recalculation flag.

Results
Sample
A total of 390 treatment fractions were available for analysis, inclusive of 2340 recorded FSDs and a total of 242 isocentre shifts. Table 1 indicates the magnitude of internal organ motion, both systematic and random.

For the 10 patients studied, the FSDs were only out of tolerance a total of 26 out of the possible 2340 recorded FSDs (less than 2%). This differed greatly to the number of isocentre and systematic isocentre shifts made which totalled to 62% (242/390) and 34% (82/242) respectively. Figure 1 illustrates this data in graphical form. From this graph it can be seen that isocentre shifts, whether they be systematic or not, occur at a much higher rate than FSDs being out of tolerance (pre- and post-intervention). This is most evident in Patient 5 where the FSDs were out of tolerance less than 1% of the total treatment period. In contrast isocentre shifts were made 85% (33/39) of the time and 57% (22/39) of the time a systematic move resulted.

The MUs which were recalculated in Eclipse™ TPS after performing the variety of shifts (0.5 cm, 1.0 cm and 1.5 cm), indicated no significant dosimetric change unless the shift was greater than 1.0 cm. That is, an MU change of greater than 2 MU on 2 or more fields was noticed. An isocentre shift greater than 1 cm was noticed to have occurred 11% (41 out of 390 fractions) of the time.

Table 2 shows the magnitude of the systematic and random components of the total error (gold seed match) diagnosed by our study. The X, Y and Z components represent the left to right (LR), anterior to posterior (AP) and superior to inferior (SI) shifts respectively. From the table it is evident that a reduction exists for the random error in the post-intervention figures compared to the pre-intervention. The weight measurements taken on a weekly basis for each patient showed no large decreases or increases in the total body weight.

Case study
The case study undertaken focused on a prostate patient who received 78 Gy in 39 fractions in one phase given over an...
Table 3: FSDs recorded for fraction 26 to represent the hypothetical situation derived

<table>
<thead>
<tr>
<th></th>
<th>Planned (cm)</th>
<th>Pre (cm)</th>
<th>Difference (cm)</th>
<th>Post (cm)</th>
<th>Difference (cm)</th>
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</thead>
<tbody>
<tr>
<td>Left lateral</td>
<td>82.5</td>
<td>81</td>
<td>1.5</td>
<td>81.5</td>
<td>1</td>
</tr>
<tr>
<td>Left anterior oblique</td>
<td>90.8</td>
<td>89</td>
<td>1.8</td>
<td>90.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Right anterior oblique</td>
<td>90.6</td>
<td>89.5</td>
<td>1.1</td>
<td>90.5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Pre – Recorded FSD Pre-Intervention (prior to isocentre shift)
Post – Recorded FSD Post-Intervention (after isocentre shift)

Table 4: Comparison of geometric depth and effective path length changes for the case study between the original plan and the 26 treatment fraction

<table>
<thead>
<tr>
<th></th>
<th>Geometric depth</th>
<th>Effective path length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original (cm)</td>
<td># 26 (cm) Difference (cm)</td>
</tr>
<tr>
<td>Left lateral</td>
<td>18.6</td>
<td>18.4</td>
</tr>
<tr>
<td>Left anterior oblique</td>
<td>10.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Right anterior oblique</td>
<td>10.2</td>
<td>9.6</td>
</tr>
</tbody>
</table>

Geometric depth – actual distance from skin surface to isocentre along the central axis of the field
Effective path length – distance from skin surface to isocentre along the central axis of the field taking into account the changes in heterogeneity

Table 5: Comparison of the recalculated monitor units in the case study

<table>
<thead>
<tr>
<th></th>
<th>Original</th>
<th>SSD</th>
<th>Eclipse</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left lateral</td>
<td>72</td>
<td>76</td>
<td>72</td>
<td>4</td>
</tr>
<tr>
<td>Left anterior oblique</td>
<td>23</td>
<td>24</td>
<td>22</td>
<td>2</td>
</tr>
<tr>
<td>Right anterior oblique</td>
<td>19</td>
<td>20</td>
<td>18</td>
<td>2</td>
</tr>
</tbody>
</table>

Difference – the difference in monitor units calculated from the FSD change program and Eclipse treatment planning system (taking into account internal organ motion and isocentre shifts)
NB: No monitor units were required to be re-calculated for the right lateral, right post oblique and left post oblique fields as the FSDs taken (pre and post intervention) were within the 1 cm tolerance.

eight-week period. For this patient, isocentre shifts were made 72% (28 out of 39 fractions) of the time. Of these isocentre shifts 29% (eight out of the 28 isocentre shifts) resulted in a systematic move. The FSDs were only out of tolerance for a single fraction (fraction 26). The planned FSDs for the left lateral (LL), left anterior oblique (LAO), right lateral (RL) and right anterior oblique (RAO) were 82.5 cm, 90.8 cm, 81.5 cm and 90.6 cm respectively. The pre-intervention FSDs recorded were 81 cm, 89 cm, 81 cm and 89.5 cm. For three out of the four fields the FSDs were out of tolerance. However, the post-intervention FSDs recorded were within tolerance. This data is presented in Table 3.

The change in effective path length was assumed to be the same as the change in FSDs, that is, within the range of 1–1.5 cm for the fields where the FSDs were out of tolerance. The geometric and effective path lengths calculated from the Eclipse™ TPS yielded a maximum difference of the effective path lengths between the original and the 26th fraction of 0.8 cm on the RAO field. All other fields had a difference less than 0.8 cm, and this data is presented in Table 4.

The re-calculated MU values based on the out of tolerance pre-intervention FSDs were 76, 24 and 20 MU for the LL, LAO and RAO respectively. The MUs calculated by Eclipse™ TPS, once the isocentre shift was recreated and internal motion taken into account, were 72, 22 and 18 MU respectively. A comparison was made between the different MU values that were calculated. The difference calculated for the LL, LAO and the RAO were 4, 2 and 2 MU respectively, with the FSD Change program MU being the higher of the two. This is presented in Table 5.

Discussion

This study aimed to assess the dosimetric impact of IGRT and implications of FSD measurement in the image guided era. Our data suggests that daily FSD measurements in the presence of IGRT have minimal dosimetric impact for men being treated for prostate cancer. Previous studies have quantified that isocentre shifts for these prostate patients can occur on a relatively regular basis. A systematic error has the potential to occur every fraction and is more difficult to account for. Random errors are unpredictable and are viewed as a one-off event implying that any dosimetric impact is assumed to even out during the course of treatment. A systematic error has the potential to occur every fraction and therefore, suggests that the treated isocentre would differ significantly from the theoretical plan derived from a TPS. It has been noted previously that random variations lead to a blurring of the dose distribution, while systematic deviations can lead to changes in the dose distribution with respect to the clinical target volume (CTV).

A dynamic, moving isocentre will consequently affect other elements when treating gold seed fiducial prostate patients.
Traditionally, FSDs are recorded during the set-up of a patient and do not take into account any subsequent isocentre shifts made based on IGRT. This can be viewed as pre-intervention as opposed to post-intervention whereby the FSDs would be taken after isocentre shifts. If an isocentre shift is made, the pre-intervention FSD will not reflect the treated isocentre and hence any subsequent recalculations made could be inaccurate. This is an irresolute method to base dose re-calculations on.

**Sample**

The standard deviations of prostate motion relative to bony anatomy presented by Langan, *et al.* gave a range of LR motion of between 0.7 to 1.9 mm standard deviations (SDs), SI motion a range of 1.7 to 4.5 mm SDs and for AP motion 1.5 to 4.1 mm SDs. The data from this study draws a parallel with these findings.

Data presented indicate that a potential dosimetric change, large enough to warrant a re-calculation, occurred when the treated isocentre differed from the original set-up point by a magnitude greater than 1.0 cm in any direction. If this was to occur for three consecutive days (i.e. a systematic change) then a dosimetric impact could occur. That is the recalculated MU differed from the original planned MU enough to indicate a clinically significant change. Therefore a systematic isocentre shift greater than 1.0 cm in any direction could justify a re-assessment of the plan. Previous studies have also indicated that a similar magnitude would affect the Dose Volume Histogram (DVH) parameters and therefore affect the dose to critical organs. It can be hypothesised that the significant change could be due to organ motion of the prostate and the varying volumes of the bladder and rectum on a daily basis. The occurrence of daily prostate movement is clinically important as it is a main component when determining the CTV to planning target volume (PTV) margin and such motions could lead to overdosing of the surrounding critical structures.

Previous results suggest that a CTV-PTV margin of 10–13 mm allowed for satisfactory dosimetric outcomes regardless of systematic or random isocentre shifts. However, with dose escalation and smaller margins the influence of both systematic and random isocentre shifts are increased and therefore must be considered, with a view to determining an appropriate response to such occurrences.

It is important to make the distinction between systematic and random isocentre shifts in relation to dosimetry. Previous studies have noted that the amount of underdosing or overdosing would be less if the isocentric shift was considered random, due to it being in a different location for each treatment and thus tending to even out over a course of treatment. However if the shift was systematic, with the prostate in an extreme position overdosing or underdosing could occur for the duration of treatment.

Traditionally, FSDs are recorded on a daily basis to monitor any alterations in the patient’s contour due to weight loss or gain. It was found that for the ten patients in the study, none had FSDs out of tolerance consecutively to suggest a change in the contour. In addition, each patient’s weight was monitored on a weekly basis and no patient was measured to have had noticeable decreases or increases. Analysis of the data shows the FSDs being out of tolerance for less than 2% of the overall treatment and showing little consistency with the systematic isocentre shifts made. By their very nature, systematic isocentric shifts suggest a potential dosimetric impact. However, the recording of FSDs did not reflect this potential for dosimetric change. Therefore the use of FSDs to flag recalculations for patients with intraprostatic markers is problematic which is further investigated in the aforementioned case study.

**Case study**

For the patient in the case study, recorded FSDs were only out of tolerance for 1 out of 39 fractions, suggesting that the patient contour was consistent during the course of treatment. However, the hypothetical situation derived assumed that the FSDs which were out of tolerance for the 26th fraction occurred for three consecutive days. Traditionally this would indicate a dosimetric recalculation based on the recorded FSDs. These calculations are based on the assumption that the change in the FSDs equals the change in the effective path length for the relevant field. This in turn alters the equivalent field size at depth. It is noted that this may not be completely accurate due to organ movement and a change in the set-up point will imply the field will be travelling through different densities from that of the original plan. The new MUs calculated from the FSD change program indicated the MU needed to be increased from the original plan for three of the six fields.

It was noted that a systematic isocentre shift had been made previous to the 26th fraction. This isocentre shift signified a potential dosimetric change. Initial analysis of the new geometric and effective path lengths showed, as expected, a change. However, this change (based on the systematic moves and the resultant effective lengths in the treatment planning program) differed to what would be assumed by the FSD program (based calculations on the FSDs measured during treatment). In addition, the newly calculated MUs differed from those calculated from the Eclipse TPS. Although a difference of 4 and 2 MU respectively for each field seems small, with 13 fractions remaining of the treatment course an extra 104 MU could be potentially delivered. On face value an extra 104 MU or just over 1 Gy extra dose contribution from this field may seem small, but with tight margins and DVH constraints on these patients it is a concern. Importantly of course it would be a deviation from the prescribed dose. The recording of FSDs and their subsequent purpose must be considered carefully during a treatment course of a patient with intraprostatic fiducials. It has been previously noted that precise targeting of prostate cancer is mostly dependent on careful daily set-up and on random changes in rectal geometry, therefore the role of FSDs for this group of patients is diminished. Importantly this case study illustrates that it is indeed possible to perform recalculations that may or may not be necessary and lends weight to the argument that FSD measurements are unreliable sources of recalculations in the era of IGRT.

**Resultant actions at Radiation Oncology Queensland**

Based on the data presented a variety of steps and new protocols have been undertaken at Radiation Oncology Queensland. Previously, FSDs were recorded on a weekly basis for the prostate gold seed patients. However, as a result of this study it was decided to remove this step. For prostate patients with gold seed fiducials, the FSDs are only recorded on the first day of treatment and when a systematic isocentre shift is made, that is, when a potential dosimetric change may have occurred. These FSDs would also only be taken post-intervention so they represent the treated isocentre. By undertaking these steps, it has been possible to reduce the overall treatment time for these patients. Less time is required to set-up up the patient, therefore reducing the treatment time by at least one minute per patient. Our centre treats approximately 20 prostate gold seed patients a day, hence a saving of 20 minutes per daily workload. In addition, a new protocol was created to flag gold seed prostate patients on treatment if dosimetry needed to be re-assessed. This new protocol is based.
on systematic isocentre shifts. From the data presented and previous studies, it was evident that no significant dosimetric change occurred unless an overall isocentre shift of greater than 1.0 cm was made. Therefore, if a systematic (as previously outlined three consecutive treatment fractions) isocentre shift greater than 1.0 cm occurred in any direction, the patient’s plan would be sent back to planning to be re-assessed. Initially the systematic isocentre shift would be re-created in Eclipse™ TPS to determine the magnitude of change and flag a potential re-CT. It has been noted that there is a distinct need to understand and manage the consequences of anatomic variations within the lower pelvis, and our study supports this.

Conclusion

The traditional workflow practice of basing recalculations on FSDs for patients with intraprostatic fiducials has been shown to be problematic. There are many unknown factors and unpredictable variables in relation to dosimetry within the lower pelvis. Therefore, basing recalculations on systematic isocentre shifts would be a more valid process to accurately depict dosimetric changes than the method of recording FSDs. This is a paradigm shift from the traditional process, but enhanced technology has led to improved recognition of anatomical variances within the lower pelvis. Intraprostatic fiducials in combination with an effective IGRT protocol have allowed us to manage the motion of the prostate on a daily basis. However, the consequences of that motion must be acknowledged, allowing IGRT to make the logistical evolution to dose guided radiotherapy. FSD measurements in the presence of a mature IGRT program for these patients have been reduced in importance due to increased visualisation and understanding of the role of both systematic and random isocentre shifts on dosimetry.

References


