Detectability of MR suitable prostate fiducial markers in an anthropomorphic phantom utilizing the TrueBeam Advanced Imaging Package during VMAT prostate treatment.

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Introduction

SBRT is commonly used for definitive treatment of patients with localized prostate cancer. Prostate fiducial markers' high kV contrast allows them to be used as surrogates to track organ motion during treatment. Measuring organ motion provides for more precise treatment as the patient can be repositioned if the markers move outside a preset tolerance margin. These makers are also useful for MR and CT image co-registration, but this requires that markers be MR safe and visible in both MR and CT images. We compare the detectability of MR suitable gold, platinum and polymer-based fiducial markers as identified by the Varian TrueBeam's Advanced Imaging Package, during a VMAT prostate treatment of a stationary anthropomorphic phantom.

Method

I. Gold-based-segmented Gold Anchor, Naslund Medical AB (0.4x10mm), platinum-coil Visicoil, IBA (0.5x5mm), and polymer-based-cylindrical Polymark, CIVCO radiotherapy (1x3mm) fiducial markers were implanted in a beef prostate phantom placed into a rando phantom. The phantom received (VMAT) therapy utilizing on-board kV imaging. In each image, the Varian software detected the presence and location of each marker within a 3 mm radius of its planned location.

II. The plan was delivered 11 times using different marker detection settings (MDS) to collect 484 kV projection images. MR images were collected to assess MR detectability.

III. Delivery was repeated 43 times using the current clinical detection settings (MDS) while translating the phantom independently along the three orthogonal axes in 1 mm increments, to collect over kV 1680 projection images.

IV. Video frames of the projection images were searched offline to record whether the TrueBeam Advanced Imaging Package found each marker and whether each marker was found within tolerance.

Method (continued)

I. Results were assessed to determine which MDS performed the best for each individual marker type and globally across all markers. The dependence of marker detection on the projection angle was also assessed. Lastly, a study measured marker detectability as a function of known, introduced translational shifts.

Results

Figure 1A. An image of the phantom setup arranged in an HFS orientation.
Figure 1B. A close-up view of the pelvic section of the Rando phantom.
Figure 1C. A close-up view of the beefsteak phantom prostate insert housing the fiducial markers.

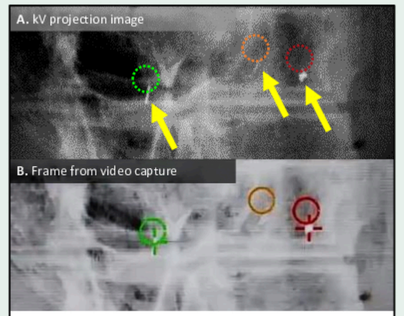

Figure 2A. A kV projection from a 89 degree gantry angle. Overlaid are circles showing the expected marker positions and yellow arrows showing the true marker positions.
Figure 2B. A frame from the video capture of the marker identification. Green indicates that the maker was found within tolerance, red indicates that the marker was found out of tolerance and orange indicates that the system could not find the marker.

The best MDS was dependent on the marker used. The Visicoil and Gold Anchor markers were best identified using the "GoldSeed_1_0x3_0"/"GoldSeed_1_0x2_5" and "GoldSeed_1_0x3_0"/"GoldSeed_1_0x2_0" settings respectively. The best passing rate for the PolyMark marker was achieved using the "GoldSeed_1_0x2_0" or "GoldSeed_1_0x2_5" settings. The Gold Anchor and Visicoil markers were accurately found in 95% of the acquired projection images, using the optimized marker detection settings for each marker type. Polymark markers were found in 80% of the acquired projection images.

Table 1. The effect of the marker detection setting on **Visicoil** (0.5x5mm) fiducial marker identification within the phantom.

Marker Detection Setting	% Passed	% Failed	% Not found
custom (1x5)	20	0	75
Clip_1_5x4_0	79	0	16
Calypso_1_5x5_0	90	0	10
GoldSeed_1_3x3_3	93	0	2
EmbolizationCoil_2_0x2_0	89	0	5
GoldSeed_1_0x3_0	95	0	2
GoldSeed_1_3x5_0	20	0	75
GoldSeed_1_0x2_5	95	0	0
GoldSeed_1_8x3_6	86	0	7
GoldSeed_2_5x5_0	23	0	73
GoldSeed_1_0x2_0	93	0	2

Right three columns show the percentage of kV projection images, in which the marker was found within tolerance (% Passed), found out of tolerance (% Failed), or not found (% Not found).

Table 2. The effect of the marker detection setting on **Gold Anchor** (0.4x10mm) fiducial marker identification within the phantom.

Marker Detection Setting	% Passed	% Failed	% Not found
custom (1x5)	0	5	91
Clip_1_5x4_0	63	5	30
Calypso_1_5x5_0	90	0	10
GoldSeed_1_3x3_3	89	0	7
EmbolizationCoil_2_0x2_0	93	0	2
GoldSeed_1_0x3_0	95	2	0
GoldSeed_1_3x5_0	0	2	93
GoldSeed_1_0x2_5	91	0	5
GoldSeed_1_8x3_6	73	5	18
GoldSeed_2_5x5_0	2	0	93
GoldSeed_1_0x2_0	95	0	0

Right three columns show the percentage of kV projection images, in which the marker was found within tolerance (% Passed), found out of tolerance (% Failed), or not found (% Not found).

Table 3. The effect of the marker detection setting on **PolyMark** (1x3mm) fiducial marker identification within the phantom.

Marker Detection Setting	% Passed	% Failed	% Not found
custom (1x5)	18	2	75
Clip_1_5x4_0	51	5	42
Calypso_1_5x5_0	40	0	60
GoldSeed_1_3x3_3	68	2	25
EmbolizationCoil_2_0x2_0	45	2	48
GoldSeed_1_0x3_0	61	5	32
GoldSeed_1_3x5_0	20	2	73
GoldSeed_1_0x2_5	80	0	16
GoldSeed_1_8x3_6	66	5	23
GoldSeed_2_5x5_0	18	2	75
GoldSeed_1_0x2_0	80	0	16

Right three columns show the percentage of kV projection images, in which the marker was found within tolerance (% Passed), found out of tolerance (% Failed), or not found (% Not found).

Results (continued)

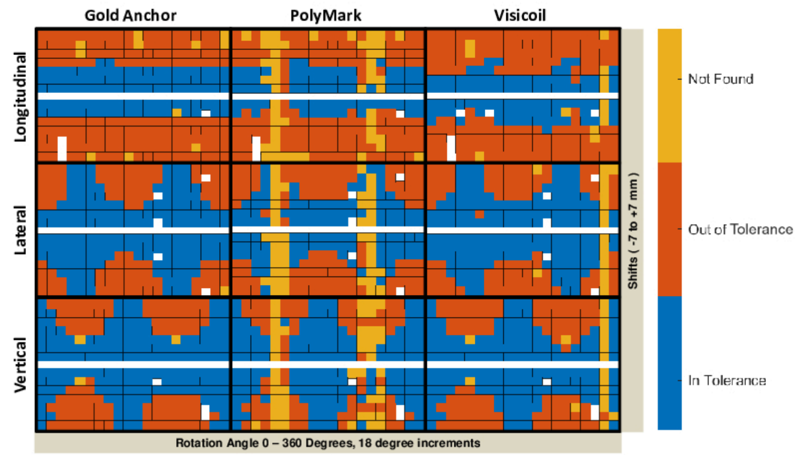

Figure 3. Marker detection status versus projection angle, horizontal shift magnitude, and vertical shift magnitude (+/- 7 mm). This plot is reproduced for each marker type and shift direction.

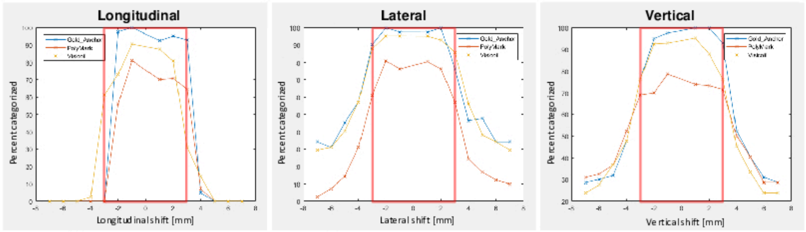

Table 4. Binary classification accuracy of the software's determination of whether or not the marker is within the tolerance margin

Binary Classification Accuracy	Gold Anchor	PolyMark	Visicoil
Longitudinal shift	0.87	0.67	0.82
Lateral shift	0.73	0.67	0.70
Vertical shift	0.76	0.55	0.73

Binary classification accuracy stratified by marker type and shift direction

Figure 4. (Above) Percent "in tolerance" marker detection status versus projection shift magnitude (+/- 7 mm), reproduced for each marker shift direction. The red box indicates the preset 3 mm tolerance margin.

Discussion and Conclusion

When assessing the effect that the marker detection setting (MDS) has on marker detection under static phantom conditions, we observed a 15% drop in accuracy when using the PolyMark fiducial marker compared to both the Gold Anchor and Visicoil markers. This difference is attributable to poor image contrast, particularly at angles of 72 and 288 degrees, where the femoral heads obscure the marker. We found our current clinical MDS is the most favorably suited for use with the Gold Anchor or Visicoil markers. We selected this setting for our future study of the effect of phantom motion on marker detectability. The data indicate the superior accuracy of the Gold Anchor marker for detecting motion in all three directions. Both the Gold Anchor and the Visicoil markers perform better than the PolyMark marker, likely due to its relatively poor contrast. Other authors have demonstrated that the shape a segmented marker takes after insertion effects the Varian system's ability to recognize it.

Conclusions (continued)

The spread of marker "in tolerance" classification seen in the lateral and vertical subplots of figure 4 is attributable to the loss of fiducial marker position information from in plane motion, parallel to the kV detector. For instance, vertical movement is undetectable from an AP projection image of the prostate. The phantom motion data were analyzed to calculate a binary classification accuracy value for each marker and each direction of motion. This value is the ratio of the number of true positive and true negative classifications over the total number of classification. The Gold Anchor marker demonstrates superior sensitivity to motion, particularly along the superior-inferior direction. The effect gantry angle had on marker classification was very small for the high opacity (Visicoil and Gold Anchor) markers. A more substantial effect was seen when using the polymer based marker.

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