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FULL PAPER

Comparison of MRI visualization between linearly placed iron-containing and non-iron-containing fiducial markers for prostate radiotherapy

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Objective: Visualizing the gold marker (GM) in CT and MRI is critical, especially for registration in high-precision radiotherapy. GM sizes vary. Large markers are easily visualized in MRI. Small GMs show fewer artefacts in CT but are harder to detect in MRI because the signal is influenced by metal in MRI. Therefore, we compared MRI visualization between linearly placed new iron-containing marker and non-iron containing marker.
Methods: 27 patients underwent CT/MRI fusion-based intensity-modulated radiotherapy. The gold markers were placed by urologists. An iron-containing Gold Anchor™ (GA) marker (diameter, 0.28 mm; length, 10 mm) was placed by using a 22 G needle on one side of the prostate linearly. A non-iron-containing VISICOIL™ (VIS) marker (diameter, 0.35 mm; length, 10 mm) was placed by using a 19 G needle on the opposite side linearly. T_2* weighted MRI was mostly performed. Two Radiation Oncologists and one Radiation Technologist evaluated and assigned visual quality scores (GA shape, CT artefacts, MRI signal voids).
Results: The mean visualization scores of artefacts were similar between GA and VIS in planning CT. GM visualization in MRI of the prostate was better for GA than for VIS. The visibility of the linear shape of the GA was 3.4–4.1 points when the VIS was 5 points (1 is worst and 5 is best).
Conclusion: Visualization quality was similar between GA (iron-containing marker) and VIS (non-iron-containing marker) in planning CT, but was better for GA than for VIS in MRI. To achieve high-precision radiotherapy, an iron-containing gold marker was useful for CT and MRI registration.
Advances in knowledge: An iron-containing fiducial marker was useful for CT and MRI registration, especially in high-precision radiotherapy, such as stereotactic body radiotherapy and intensity-modulated radiotherapy.

INTRODUCTION

Radiation therapy aims to deliver a high radiation dose to the tumour while minimizing the dose to normal tissues. Gold marker (GM) can reduce margins around CTV. GM has been used to overcome two uncertainties in imaging. First, CT and MRI registration has been performed by placing GM in the prostate.[1] Prostrate margins were clearly depicted by MRI, and the contoured prostate outline was superimposed on the planning CT images using GM guidance. Stereotactic body radiotherapy/intensity-modulated radiotherapy planning was performed using GM. Second, daily radiotherapy has been performed using conebeam CT (CBCT). To recognize the prostate on CBCT, registration was performed using GM in planning CT combined with MRI.[2] Many GM types are used in different countries.[2,3] One unique GM is the Gold Anchor™ (GA) (Naslund Medical AB Vassvagen 21 14139 Huddinge, Sweden), which is an iron-containing marker. GMs are usually placed in spherical or linear shapes; however, GA can be placed in spherical, zigzag or linear (stretched) shapes (Figure 1). In contrast to GA, VISICOIL™ (VIS) (RadioMed Corporation, Bartlett, TN) can be placed in a linear shape only. We compared the use of a spherically shaped GA with that of a linearly shaped VIS. MRI using spherical GM may be more likely to become highly visible, which may not provide suitable comparisons.[3] Three points are necessary to grasp 3D (three-dimensional) space. The two ends of a linear structure can be recognized as points. If one marker is placed linearly, the other point is recognized as a point whether placed spherically or linearly. Herein, we compared MRI visualization of GA with VIS under similar conditions with linear placement for both.

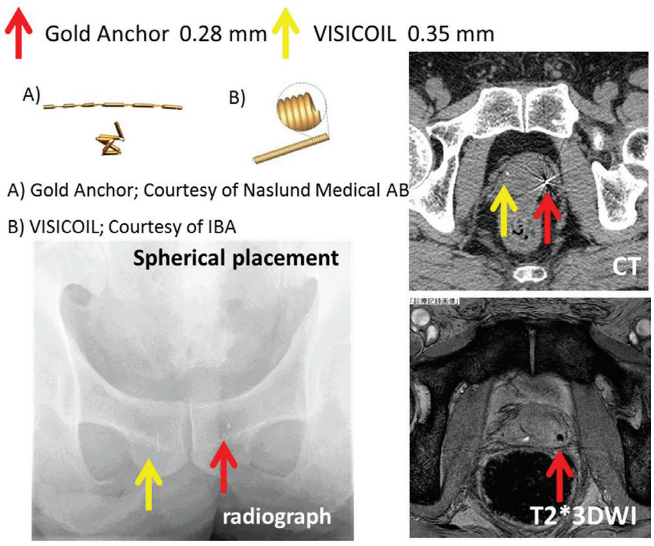


Figure 1. Left upper: The characteristics of each marker. The Gold Anchor (GA) can be placed either linearly or spherically even by using a thin 25-gauge needle. GA contains 0.5% iron, and marker visualization is high in MRI. The VISICOIL (VIS) is a coiled straight flexible line marker that can be placed by using a 22-gauge needle, and there is little migration. Left lower: Visibility by plain radiography: GA: 0.28 mm diameter; VIS: 0.35 mm diameter. Marker visualization is equally good. Right upper and lower: Example of CT and MR images.

METHODS AND MATERIALS

GM was placed by two urologists using the transperineal approach with the patient under local anaesthesia. GA and VIS were placed on opposite sides of the prostate. It is necessary to align markers at a minimum of three positions to perform precise 3D CT and MRI registration. Both ends of the marker detained linearly were used as two points for registration. If linear placement could be achieved, one or two more points on GM were placed both spherically and linearly because registration is possible with three points. Figure 1 (Left upper) shows GA characteristics. Representative CT and MRI images of GA with spherical shape placement and of VIS with linear shape placement are shown in Figure 1 (Right upper and lower, respectively). CT artefacts for GA and the MRI signal voids are also clearly shown.

GA placement was performed using a 22 G needle with syringe and VIS using a 19 G needle with syringe. Both GMs were placed linearly (Figure 2). This method has been easy to use for the urologists. GA and VIS recognition was easily achieved on pelvic plain radiography 1 day after insertion (Figures 1 and 2). 3 weeks after placement, registration of planning CT and MRI was performed.

Image acquisition

All patients were placed in the supine position on a fixed vacuum cushion. The patients drank 200 ml of water 1 h before CT and MRI examinations to increase bladder capacity. MRI (Intera 1.5 Nova; Philips Medical Systems, Eindhoven, Netherlands) was performed within 20 min after planning CT (Optima CT580; GE Medical Systems, Milwaukee, WI).

The following T_2 weighted (T_2WI) fast spin-echo conditions were used: repetition time (TR)/echo time (TE), 4000/80 ms; number of averages (NA), 4; number of phase-encoding steps (PES), 205; number of frequency-encoding steps (FES), 256; typical spatial resolutions (TPR); frequency/phase, 0.63/0.80. The following T_2* weighted (T_2*WI) gradient echo conditions were used: TR/TE, 700/18; NA, 2 times; PES, 205; FES, 256; TPR; frequency/phase, 0.63/0.78. The following T_2* three-dimensional weighted (T_2*3DWI) gradient echo conditions were used: TR/TE1/deltaTE, 37/14/7.3; NA, 2 times; PES, 218; FES, 272; TPR; frequency/phase, 0.55/0.54. The following parameters were used for planning CT: Slice thickness, 1.25 mm; field of view, 40 × 40 cm, 460 mA, 120 kV. The following parameters were used for CBCT: Slice thickness, 2.5 mm; Number of pixels, 384 × 384, 80 mA, 125 kV.

We performed an image evaluation by using T_2WI, T_2*WI and T2*3DWI (mainly T_2*WI was used). We evaluated the degree of artefacts in CT and the visualization of GMs in MRI of the prostate primarily. Novalis Tx system was used (Varian Medical Systems, Inc., Palo Alto, CA). Both GA and VIS were well recognized visually by CBCT in all patients.

Evaluation of images

Two radiation oncologists and one radiation therapist measured the achievement of linear placement in the radiographs after GM placement, as follows: (1) poor, (2) slightly poor, (3) neutral, (4) marginally better and (5) excellent. VIS was always placed linearly; therefore, the state of VIS was assigned 5 points as a baseline. For example, an FM as shown in Figure 1 placed in a spherical shape was 1 point. On the other hand, 5 points were assigned for linear placement, as shown in Figure 2.

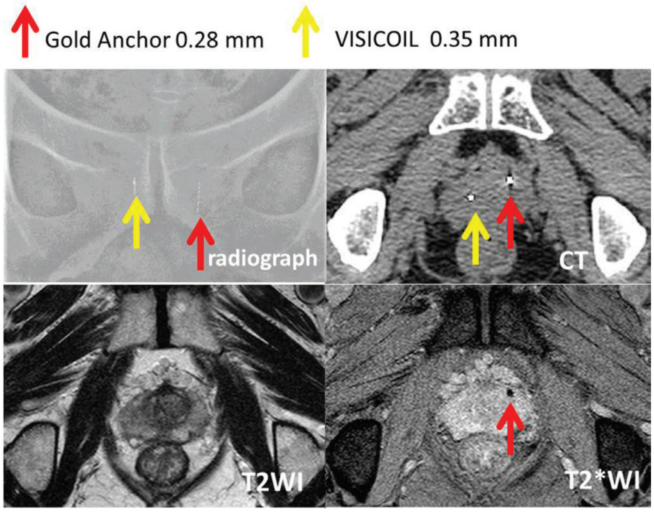
We also assigned a score for the degree of recognition of GM itself in the prostate on MRI as follows: (1) poor, (2) slightly poor, (3) neutral, (4) marginally better and (5) excellent. Images with fewer CT artefacts were assigned higher scores. In Figure 2, for example, the CT artefact scores were 5 points and 3 points for VIS and GA, respectively. The MRI signal void scores were 2 points and 5 points for VIS and GA, respectively.

The differences in observers' scores between GA and VIS were assessed using the Wilcoxon signed-rank test. p-values < 0.05 were considered to be significant. All statistical analyses of recorded data were performed using the Excel statistical software package (Excel-statistic 2015; Social Survey Research Information Co., Ltd., Tokyo, Japan).

RESULTS

Table 1 summarizes the comparison of GA and VIS. The mean visualization scores and artefacts were similar between GA and VIS in planning CT. The visualization of GM in the prostate in MRI was better for GA than for VIS ($p < 0.05$) (Figures 1 and 3). Although GA was placed on the prostate capsule, GA was well depicted by MRI (Figure 3). Conversely, VIS (0.35 mm diameter) was sometimes not depicted by MRI. The linear placement of GA was easy for both urologists. The radiation oncologists were able to recognize

Figure 2. Left upper: both markers are well visualized on the radiograph. Right upper: recognition by CT. Lower images: T_2 weighted and T_2* weighted MR images.



both ends of GA most of the time. The visibility of the linear shape of GA was 3.4–4.1 points when VIS was 5 points (1 is worst and 5 is best).

DISCUSSION

Interobserver variations significantly affect estimated prostate volume and shape.[4–13] Various markers are used worldwide, with diameters of 0.28–2.0 mm. The aim of using GM was to make registration of CT and MRI on radiotherapy planning and minimizing

Figure 3. The Gold Anchor is placed on the capsule of the prostate and is well recognized by MRI. Right upper: CT image. Right lower: T_2* weighted MR image. Left upper: T_2 weighted MR image. Left lower: T_2* three-dimensional weighted MR image (3DWI).

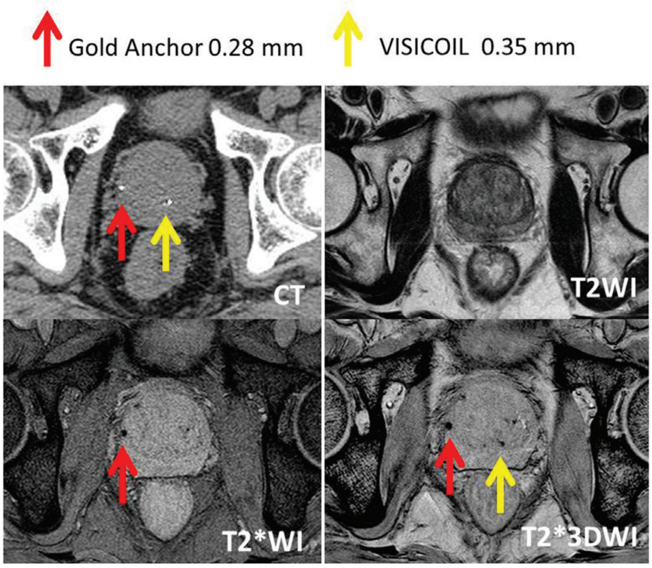


Table 1. Comparison of the iron-containing marker with linearly shaped placement (0.28 mm diameter; Gold Anchor) and non-iron-containing marker (0.35 mm diameter; VISICOIL). Both markers were 10 mm in length. (mean ± SD)

	Technical linear placement quality of GA	Artefacts in CT	Signal voids in MRI
Observer 1			
Gold Anchor	3.4 ± 1.3	3.8 ± 0.6	4.4 ± 0.5
VISICOIL	5	4.2 ± 1.1	2.7 ± 1.0
p value		0.05	**<0.01**
Observer 2			
Gold Anchor	3.8 ± 1.3	3.8 ± 0.6	5.0 ± 0.0
VISICOIL	5	4.9 ± 0.2	2.2 ± 1.2
p value		**<0.01**	**<0.01**
Observer 3			
Gold Anchor	4.1 ± 1.1	3.9 ± 0.9	4.6 ± 0.4
VISICOIL	5	4.2 ± 0.7	2.4 ± 0.8
p value		0.12	**<0.01**

GA, Gold Anchor. We measured linear indwelling acuity on the images after placement of the FMs as follows: (1) poor, (2) slightly poor, (3) neutral, (4) marginally better and (5) excellent. The VIS was always placed linearly; therefore, the state of VIS was assigned 5 points as a baseline of technical linear placement quality for the GA. We also evaluated a score for the degree of recognition of FM itself in the prostate by MRI as follows: (1) poor, (2) slightly poor, (3) neutral, (4) marginally better and (5) excellent. Fewer CT artefacts were assigned higher scores. The difference in the observers' scores between the GA and VIS were assessed using the Wilcoxon signed-rank test. A p value of < 0.05 was considered as indicating a significant difference.

interfraction daily variation. Our results revealed no significant differences between GA and VIS in planning CT artefacts. However, there were significant differences in marker visualization of signal voids in MRI between GA and VIS. GA contains 0.5% iron, and the signal voids are larger than the real GA size. It was reported that when marker detection is desired, markers containing iron and in folded configurations are preferred, but this choice can render diffusion-weighted MRI unreliable close to the marker.[4] However, this was mainly a phantom study and included some patients with pancreatic cancer. Chan et al reported results similar to those of Gurney–Champion.[5] We previously reported the visualization of the spherical shape of GA.[3] To more accurately compare GA and VIS, it is important to place GMs in the same linear shape. We mainly evaluated signal voids in MRI when GA was linearly placed were similar to those when spherically placed.

Subjective evaluation is a limitation of our study. As quantitative analysis is difficult, we invited three observers. We had planned a blinded study, but plain radiography was used to judge the extent to which GA was placed in a linear shape because it was easier to assess the GA placement by the observers. Because of the visualization of GA in MRI, GA is useful in CT and MRI registration for high-precision radiotherapy, such as stereotactic body radiotherapy and intensity-modulated radiotherapy, in daily practice. According to urologists, linear placement was easy in our team, but it depended on urological techniques. Complications, such as infection, bleeding and migration may decrease from three GMs if GM gets off with two.

CONCLUSION

We found that the visualization of an iron-containing marker (GA) was superior to that of a non-iron-containing marker (VIS) on MRI despite its linear placement. Artefacts on CT were almost similar between GA and VIS. For urologists, placing GA linearly was easy, and GA and VIS were visualized in radiographs.

INFORMED CONSENT

The research was approved by institutional review board and national clinical trial registry. Written Informed consent was obtained from all patients.

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