Optimizing Fiducial Markers for MRI-based Radiotherapy

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Introduction

Radiotherapy treatment planning has in the past largely been based on information from CT images, but MR images provide a better basis for target delineation for several diagnoses, e.g. prostate, rectum, cervix, brain, and skin/throat.

A CT scan is, however, typically still required since most radiotherapy dose distribution calculations are based on the radiation absorption information extracted from the CT images.

Image registration of MRI and CT is therefore needed in order to transfer delineated structures to the CT. This, however, introduces geometric uncertainties into the treatment, since image registration seldom provides perfect results.

A reliable point of reference is needed

Implanted fiducial markers can provide reliable reference points for the registration, if they are visible on both CT and MR images.

These markers are also very valuable for the positioning of the target volume when the patient shall receive each fraction of radiotherapy, using on-board imaging with X-ray or the megavoltage treatment beam.

The first application of gold markers for tumor positioning was published in 1995 by James Balter et al. [1]. Gold markers of sufficient mass where required to be visible on the megavoltage images. The needles used to implant the markers were therefore relatively thick.

Flat-panel X-ray detectors based on amorphous silicon were developed rapidly in the early 2000s, resulting in lower dose requirements and improved image quality. By June 2004, the radiotherapy research institution Radiumhemmet at the

Figure 1: Gold Anchor to the left compared to traditional marker.

Figure 2: A piece of pork loin, a salted (cured) and slightly smoked cut of pork with several Gold Anchors with different percentage contents of iron.

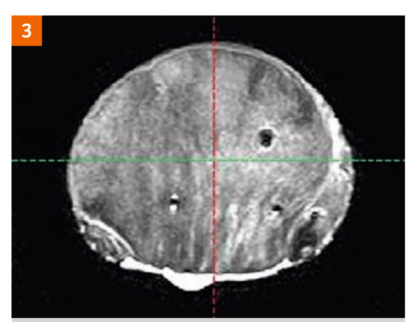

Figure 3: MRI of the pork loin with two markers of 0.5% and one of 2.5% iron content.

Karolinska University Hospital in Stockholm had already begun using On-Board Imaging with gold markers after installing Varian's very first linear accelerators with an integrated X-ray (kV) imaging system.

Modern kV imaging allows smaller gold markers to be used for patient positioning. This led to the development of the Gold Anchor® marker *(www.GoldAnchorMarker.com)*.

Traditional fiducial markers:

- are preloaded in relatively thick needles, typically 17 or 18 gauge (outer diameter of 1.5 and 1.3 mm respectively), which can cause patient discomfort and complications related to the implantation such as pneumothorax, bleeding, infection, and seeding of cancer cells; and
- can move in the needle tract after implantation since the marker diameter is smaller than that of the needle tract caused during implantation – many medical teams therefore wait approximately 1–2 weeks after the implantation of the marker before proceeding, e.g. with CT or MRI for dose planning, to allow time for the marker to settle in and stabilize in the tissue.

In comparison, the Gold Anchor fiducial markers:

- are made of an alloy of pure gold and 0.5% pure iron, which improves the MRI visibility;
- are preloaded in industry leading thin needles, 20, 22 or 25 gauge (outer diameter of 0.9, 0.7, and 0.5 mm respectively), which reduce the risk of patient discomfort and complications related to the implantation; and
- are very stable in the tissue immediately after implantation since the marker can expand to a slightly larger size than the needle diameter after implantation and anchor directly.

Development through collaboration

More and more radiotherapy clinics are acquiring their own MR systems, adapted to their needs, providing them with new possibilities to develop tailored cancer treatments and follow-ups of treatment results. The patient needs to be scanned in treatment position with any relevant fixation devices, and image sequences are chosen to minimize geometric distortion. Plotted tumor areas are transferred to CT images which are used as a basis for treatment planning. Registering the images and daily setup is made easier and safer by using fiducial markers that are visible on both the CT and the MRI images. Currently the markers are clearly visible on MR gradient echo based T1-weighted images, but not on T2-weighted images, which are turbo spin echo based and used for tumor delineation. Thus, a total of three image series are needed for the treatment planning.

Today, most Swedish university hospitals have MRI scanners dedicated to radiotherapy and more purchases are planned. There is thus a great need to optimize this modality for use in radiotherapy.

A national initiative, *Gentle Radiotherapy*, is currently developing methods to plan radiotherapy based solely on MRI images. The idea is also that companies involved should be able to commercialize the technology.

In this presentation we focus on a collaboration between Karolinska University Hospital in Stockholm, Sahlgrenska University Hospital in Gothenburg, Siemens Healthcare and Naslund Medical in Stockholm regarding an iron-containing gold fiducial marker. The aim was to adapt the iron content of the marker on the one hand, and the MRI sequence on the other, for reliable visualization of the markers on T2-weighted images. If successful, this would limit the number of image series needed in treatment planning, and the associated image registration uncertainties.

Visualization of markers with MRI

A range of markers of different sizes (diameter 0.28 – 0.40 mm, length 10–40 mm) and compositions (iron content 0.5–5.0%) were inserted in a piece of pork loin and imaged on a 1.5T MAGNETOM Aera and a 3T MAGNETOM Skyra (Siemens

"Gentle Radiotherapy" – Increase the chance of cure without harming the patient.
http://www.gentleradiotherapy.se

New research shows that magnetic resonance imaging (MRI) can describe tumor biology. This is a tool that radiologists normally use for diagnostic purposes rather than treatment plans.

Our project aims to integrate these research findings into clinical processes at all Swedish university hospitals. We also keep strict focus on efficiency to avoid increasing the costs of health care.

The consortium consists of all teaching hospitals associated with academia and 7 important industrial companies. The project is partly funded by the Swedish Innovation Agency – Vinnova.

The long-term goal is to create a large-scale national world class platform for cancer treatment.

	Aera T1	Aera T2	Skyra T1	Skyra T2
Field strength (T)	1.5	1.5	3	3
Sequence	3D VIBE	2D TSE	2D VIBE	2D TSE
Coil	Body 18*	Body 18*	Body 18	Body 18
TE (ms)	4.77	94	2.46	104
TR (ms)	7.46	12940	4.57	15990
FOV (mm)	420 x 420	448 x 448	390 x 390	220
Slice thickness (mm)	2.0	3.0	2.0	3.0
Pixel size (mm)	1.1 x 1.1	0.7 x 0.7	1.2 x 1.2	0.7 x 0.7
Bandwidth per pixel (Hz)	335	200	450	460
Slice orientation	trans	trans	trans	trans

*With coil support

Healthcare, Erlangen, Germany). All markers were inserted collapsed into a ball shape. The chosen sequences are listed in the table.

As seen in figures 4–7, showing markers with 0.5% iron contents, the markers were much more clearly visualized with T1 than with T2-weighted imaging. A greater iron content was required to reliably visualize the marker with T2, but the larger artifacts constituted a problem for image registration with markers as control points. Six members of staff assessed the performance of the markers on the T2w images with respect to visibility and artifact size/shape and found the best marker to be of 2.5% iron with a diameter of 0.28 mm and 40 mm in length.

Summary

The collaboration platform of Gentle Radiotherapy developed jointly by healthcare and industry has brought clinicians, researchers, inventors and entrepreneurs together from different places in Sweden in a stimulating collaboration.

Fiducial markers need to fulfill many, sometimes competing, criteria when used for MRI based radiotherapy treatment planning. The Gold Anchor markers are exceptionally small and are best visualized with T1 weighted gradient echo based imaging.

References

1 James M Balter, Howard M Sandler, Kwok Lam, Robert L Bree, Allen S Lichter, Randall K Ten Haken. Measurement of prostate movement over the course of routine radiotherapy using implanted markers. International Journal of Radiation Oncology *Biology* Physics,31, 1, 113-118.

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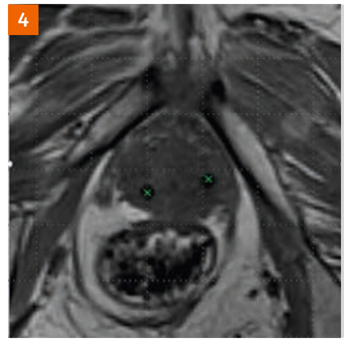

Figure 4: T1-weighted prostate 3T MRI from Karolinska with Gold Anchor 0.28 mm x 20 mm.

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Figure 5: T2-weighted prostate 3T MRI from Karolinska with Gold Anchor 0.28 mm x 20 mm.

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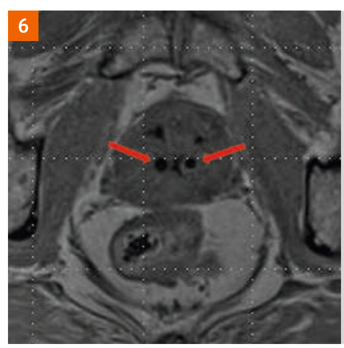

Figure 6: T1-weighted prostate 1.5T MRI from Gothenburg with Gold Anchor 0.40 mm x 20 mm.

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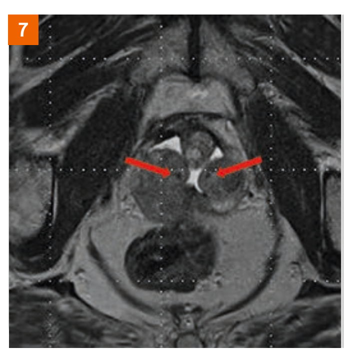

Figure 7: T2-weighted prostate 1.5T MRI from Gothenburg with Gold Anchor 0.40 mm x 20 mm.

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