Benefits of Time-Correlated and Breath-Triggered MR Acquisition in Treatment Position for Accurate Liver Lesion Contouring in Stereotactic Body Radiotherapy

Soléakhéna Ken, Ph.D.[1]; Richard Aziza, M.D.[3]; Aurélie Tournier, MSc[1]; Michel Rives, M.D.[2]; Françoise Izar, M.D.[2]; Younès Sekkal, BSc[3]; Nicolas Morel, BSc[3]; Laure Parent, Ph.D.[1]

[1] Institut Universitaire du Cancer Toulouse Oncopôle, Engineering and medical physics department, Toulouse, France
[2] Institut Universitaire du Cancer Toulouse Oncopôle, Radiotherapy department, Toulouse, France
[3] Institut Universitaire du Cancer Toulouse Oncopôle, Imaging department, Toulouse, France

Introduction

In stereotactic body radiotherapy (SBRT), high-gradient dose is delivered and target volumes have to be delineated precisely in order to avoid irradiation of healthy tissue. Liver lesions are not always visible on planning CT imaging, even after injection of contrast agent. MR images are therefore necessary for a precise lesion contouring. Accurate registration is thus a crucial step for SBRT planning in order to perform relevant delineation of target volumes.

Prior to imaging, gold fiducials are implanted under echo or CT guidance inside or in the vicinity of the lesions. These fiducials are used both as surrogate to pinpoint the lesion in order to precisely position the patient on the treatment machine, and also as markers to register planning CT and MR images.

Liver imaging is challenging because of movement caused by breathing. This movement has been reported to be up to 2 cm in free breathing [1]. Our institution uses audio coaching for a better breathing pattern reproducibility [2].

In order to account for breathing motion, planning CT is performed on a 4D CT. The planning and treatment are generally made on exhale images as these are more reproducible [3]. MR sequences were thus optimized to match CT images in exhale phase.

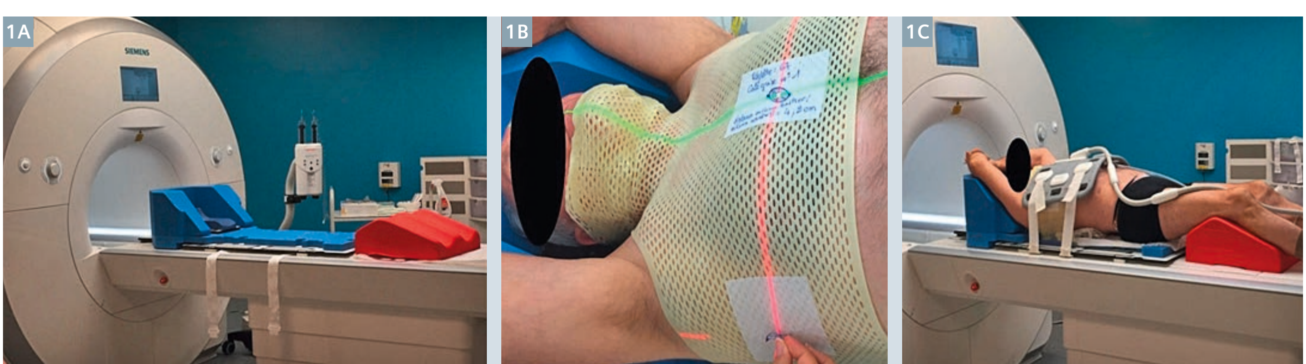
MR imaging

With the aim of improving registration accuracy, MR images were acquired in the same position as for CT planning images using Orfit (Orfit Industries, Wijnegem, Belgium) dedicated thermo-plastic nets, table, supports and cushions and Civco (Civco Medical Solutions, Coralville, Iowa, USA) knee cushion (Figs. 1A, 1B).

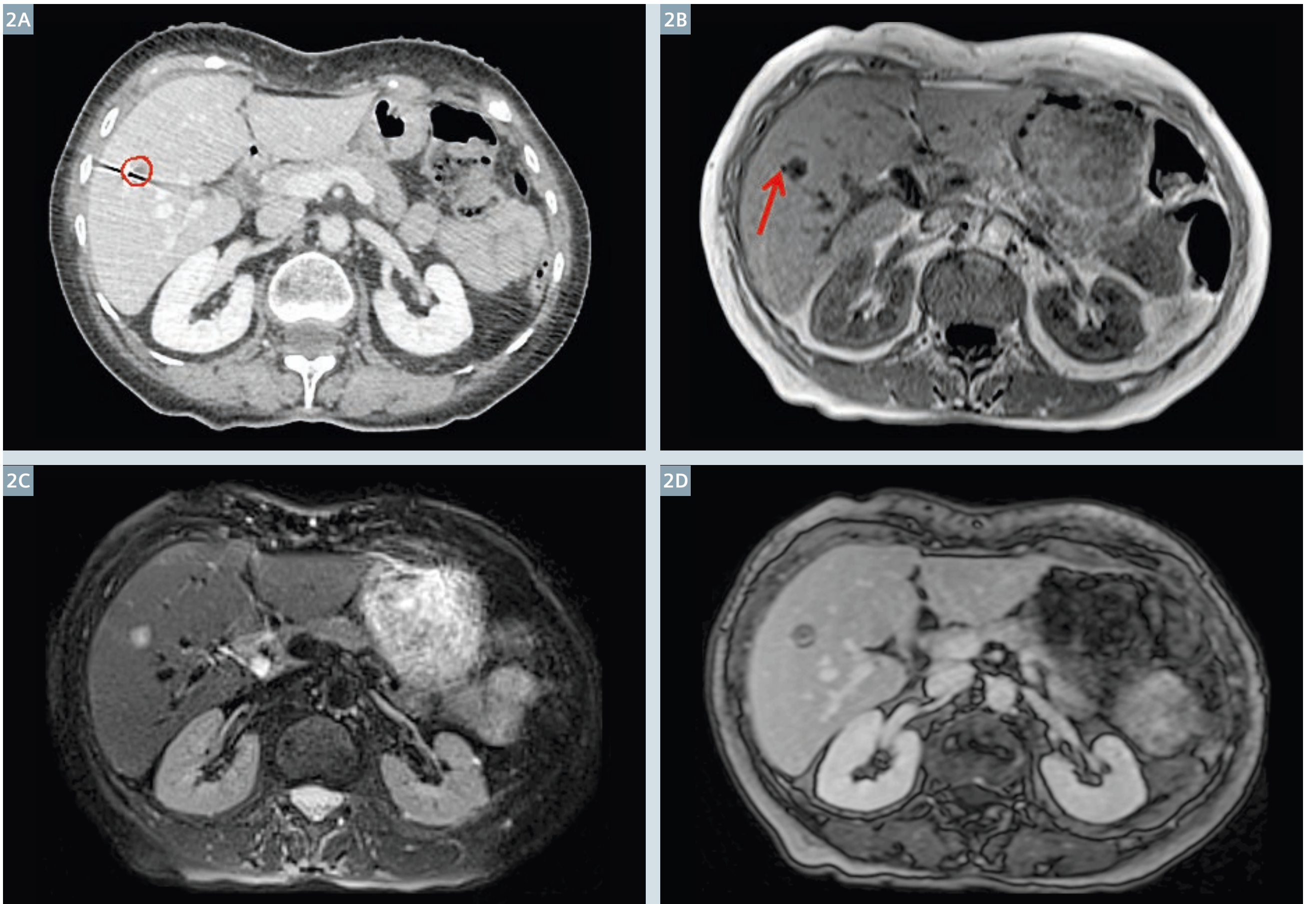
MR imaging series of the liver were acquired at the 1.5T MAGNETOM Aera (Siemens Healthcare, Erlangen, Germany) using the 18-channel body flex coil (Fig. 1C). The optimized MR sequences were able to take into account the support table and immobilization devices, which neither interfered with, nor degraded the images.

A total of three sequences were systematically acquired:

- For T2 lesion visualization, axial series of Single Shot Fast Spin Echo T2-weighted with fat saturation (T2) were used. Image acquisition is triggered on exhale and allows motion artifact reduction. TR and TE are 5248 ms and 73 ms respectively.



1 Dedicated table, supports and cushions for patient's immobilization and positioning at the MR 1.5T Aera scan **(1A)**; patient's thermo-plastic net with laser alignment **(1B)** and final setting with body coil ready for MR acquisitions **(1C)**.



2 Example of registered image for a breast metastasis in liver segment V. Injected CT50 with target contour delineated in red thanks to the MR sequences **(2A)**, T1 Dixon with red arrow identifying fiducial **(2B)**, T2 showing hyper intense lesion **(2C)** and injected T1 TFL **(2D)**.

- The combination of Dixon and ultra-fast gradient echo T1-weighted images with CAIPIRINHA (Controlled Aliasing in Parallel Imaging Results in Higher Acceleration) technique allows performing the acquisition in one exhale breath-hold. Fiducials are visible on Dixon water separation images (T1 Dixon). TR and TE are 6.78 ms and 2.39 ms respectively.
- After injection of gadolinium-based contrast agent, lesion visualization was obtained with a T1-weighted Fast Low Angle Shot imaging sequence (T1 TFL) acquired using GRAPPA (Generalized Autocalibrating Partially Parallel Acquisitions) technique and with breath triggering on expiration phase. Gold fiducials are also visible on this sequence. TR and TE are 835 ms and 2.32 ms respectively.

Slice thickness was set to 2 mm for all series and pixel size was 1.48 x 1.48 mm² for T2 and T1 TFL; and 1.18 x 1.18 mm² for T1 Dixon. All sequences were acquired in the same plane and with the same slice positions in order to ease image registration in the treatment planning software.

The entire MR imaging protocol lasts generally between 15 and 20 minutes, depending on the regularity of the patient's breathing pattern.

Image registration for treatment planning

Radiotherapy planning is based on a 4D CT reconstructed in six phases across the respiratory cycle, CT0 and CT50 corresponding to inhale and exhale phases respectively. The CT50 expiration phase is the image set used for MR image registration.

As the three MR image sets are registered, the T1 Dixon water-only image set is used to register to CT50 images using the gold fiducials and the two other sequences are automatically registered. T1 Dixon is useful to register water separation MR images based on fiducials' position, as they are the most visible on this sequence (see red arrow on Figure 2B). The two breath-triggered (expiration phase) sequences (T2 and injected T1 TFL) provide a motion artifact-free image necessary to accurately delineate the lesion (Figs. 2C, D). An example of lesion delineation is given in Figure 2A.

Target motion range is assessed based on fiducials' displacement. Treatment planning is most frequently performed on expiration phases, but when lesion movement caused by breathing is small, target contouring is done on all breathing phases based on fiducial movements, and treatment planning is achieved in free breathing.

Conclusion

CT and MRI acquisitions in treatment position are performed with the same table and immobilization device. The use of MR imaging sequences optimized to account not only for the dedicated table and immobilization devices but also for fiducial visualization and tumor delineation allow high precision target delineation for treatment planning. The increasing number of patient cases eligible for SBRT and proof of its benefit have stimulated the effort to set up and improve new imaging protocols at our institute for a personalized and optimal SBRT treatment.

Recent developments in 4D MRI have demonstrated the possibility to sort and reconstruct the images according to the different phases of the respiratory cycle [4–7]. The use of 4D MRI acquisition would allow better registration with 4D CT planning over the entire breathing cycle. Delineation accuracy will benefit from significant improvements if the same respiratory phases are registered from both MR and CT modalities.

Acknowledgments

The authors are thankful to Karen Mkhitaryan (Siemens Healthcare) for his help in setting up the MR image acquisition sequences.

References

1 R. B. Case, J. J. Sonke, D. J. Moseley, J. Kim, K. K. Brock, L. A. Dawson, "Inter- and Intrafraction variability in liver position in non-breath-hold stereotactic body radiotherapy," Int. J. Radiat. Oncol. Biol. Phys., vol. 75, no. 1, pp. 302–308, 2009.

2 C. J. Haasbeek, F. O. Spoelstra, F. J. Lagerwaard, J. R. van Sörnsen de Koste, J. P. Cuijpers, B. J. Slotman, S. Senan, "Impact of Audio-Coaching on the Position of Lung Tumors," Int. J. Radiat. Oncol. Biol. Phys., vol. 71, no. 4, pp. 1118–1123, 2008.

3 Y. Seppenwoolde, H. Shirato, K. Katamura, S. Shimizu, M. van Herk, J. V. Lebesque, K. Miyasaka, "Precise and real-time measurement of 3D tumor motion in lung due to breathing and heartbeat, measured during radiotherapy," Int. J. Radiat. Oncol. Biol. Phys, vol. 53, no. 4, pp. 822–834, 2002.

4 M. von Siebenthal, G. Székely, U. Gamper, P. Boesiger, A. Lomax, P. Cattin, "4D MR imaging of respiratory organ motion and its variability," Phys. Med. Biol., vol. 52, no. 6, pp. 1547–1564, 2007.

5 C. Paganelli, P. Summers, M. Bellomi, G. Baroni, M. Riboldi, "Liver 4DMRI: A retrospective image-based sorting method.," Med. Phys., vol. 42, no. 8, pp. 4814–21, 2015.

6 K. B. Bernatowicz, R. L. Perrin, M. Peroni, D. C. Weber, A. J. Lomax, "4D-MRI: Future of Radiotherapy of Moving Targets?," MAGNETOM Flash, 62, vol. 2, pp. 74–76, 2015.

7 Z. Celicanin, O. Bieri, F. Preiswerk, P. Cattin, K. Scheffler, F. Santini, "Simultaneous acquisition of image and navigator slices using CAIPIRINHA for 4D MRI." Magn Reson Med. 2015 Feb;73(2):669-76.

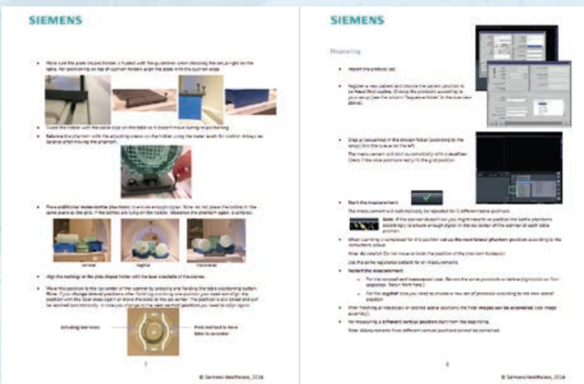
Contact

Soléakhéna Ken
Institut Universitaire du Cancer
Toulouse Oncopôle
1 avenue Irène Joliot-Curie
31059 Toulouse
France
ken.soleakhena@iuct-oncopole.fr

Relevant clinical information at your fingertips

From technology to tips and tricks, you will find the news on all aspects of MRI in Radiation Therapy at

www.siemens.com/magnetom-world-rt

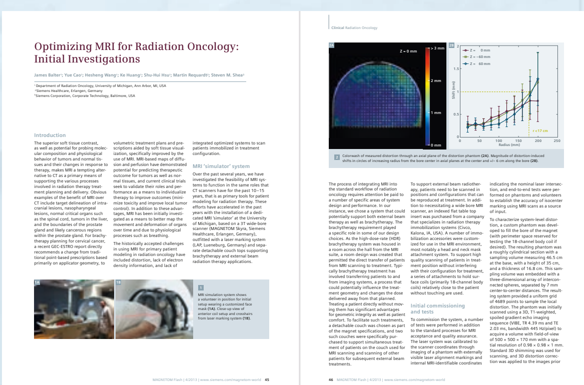


Just a mouse click away you will find application tips allowing you to optimize your daily work.

MRI Geometric Distortion QA

Using the ACR MRI Accreditation Phantom

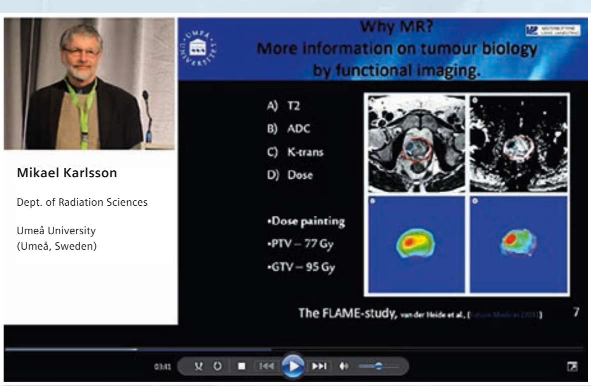
Nina Niebuhr
Siemens Healthcare



The centerpiece of the MAGNETOM World Internet platform consists of our users' clinical results. Here you will find case reports, review articles and clinical methods.

Optimizing MRI for Radiation Oncology

James Balter
Dept. of Radiation Oncology, University of Michigan



Don't miss the talks of international and renowned experts on MRI in RT.

MRI in the Radiotherapy Process. Now and in the Future

Mikael Karlsson
Umeå University Hospital (Umeå, Sweden)