Clinical Evaluation of a Receiver Coil Custom Designed for MR Simulation of Immobilized Patients

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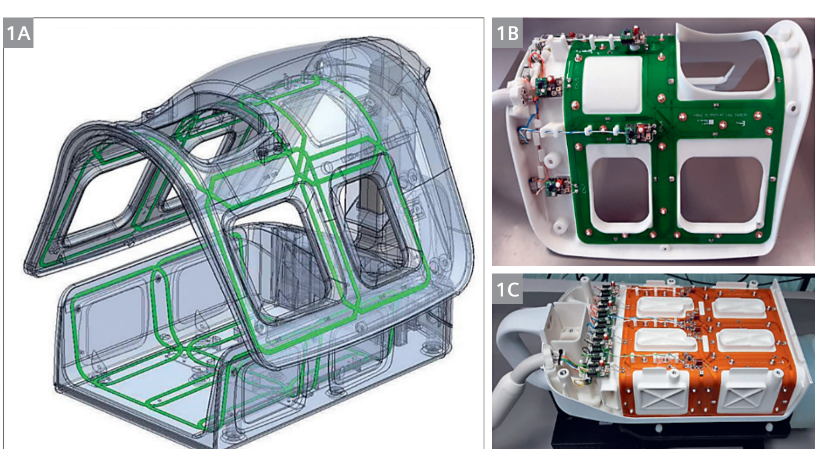
Introduction

There has been significant adoption and/or adaptation of MR scanners to support the needs of Radiation Oncology treatment simulation. A plethora of MR-compatible immobilization devices and phantoms have been developed and imaging sequences have been customized to better suit the needs of supporting planning and guidance of precision radiation treatments. In addition, a number of synthetic CT generation tools have been released commercially. To date, however, little has been done to customize RF coils to better suit the needs of scanning patients immobilized for radiation therapy treatment. This issue was noted as one potential concern for maintaining consistent image quality for scanning certain body sites, most notably the head and neck region. Most existing coil combinations suffer from challenges including increased claustrophobia due to placing coils in high proximity to the patient's eyes, poor SNR due to contributing coil elements being placed distal to the anatomy being scanned, image intensity non-uniformities and technical challenges for reproducibly and conveniently assembling coil combinations around the patient [1].

While a few attempts have been made at customizing existing coil combinations and/or building unique holders for use of existing coils [2], very little effort has been placed in truly optimizing receiver coils for radiation therapy simulation purposes. The introduction of a flexible coil that can be integrated into an immobilization mold has demonstrated the promise of such technology for radiation therapy simulation [3]. To date, however, no such coils have been developed with intracranial radiation



1 Schematic diagram of Encompass receiver coil **(1A)**, as well as pictures of the compositions of the anterior **(1B)** and posterior **(1C)** structural elements.

therapy in mind. This report describes a novel coil that was designed to be conveniently integrated with a commonly used commercially available immobilization system. The performance of this coil on phantom as well as patient images, as well as utility to support MR-only simulation for precise treatment of intracranial tumors, is reported.

Methods

The Encompass coil[1] was developed in partnership with two companies (Qfix and NORAS), with specifications developed specifically to support scanning of patients immobilized using the Encompass™ line of cranial immobilization equipment. The coil consists of two separate components, an anterior 7-channel coil and a posterior 8-channel coil. A design diagram and internal images of the coil are shown in Figure 1. The coil was designed to minimize B_0 and B_1 distortions, and incorporate low-noise preamplifiers, active and passive decoupling, and a safety fuse in each channel. The patient is positioned with the posterior component in place, and the anterior section is then attached via a height-adjustable stand. To reduce noise and increase comfort, patients are given ear plugs prior to being placed in their immobilization masks. Figure 2 shows an example image of a patient being positioned in the coil for MR Simulation.

To evaluate the performance of this coil, a series of patient and phantom scans were performed. The ACR standard phantom was scanned using the Encompass coil on a 3T MRI Simulator (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany), and resulting images compared to those acquired using a standard 20-channel head and neck coil as well as a combined anterior 18-channel surface coil and 8 elements of a posterior spinal coil in a configuration compatible with scanning patients immobilized in masks for Radiation Oncology treatment [4], referred to herein as RTCombo.

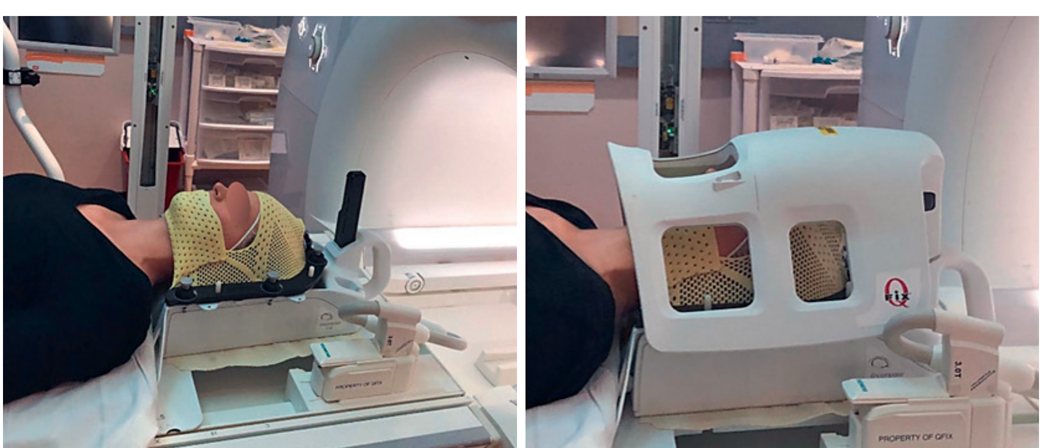
Under an institutional review board-approved protocol, a series of 10 patients with intracranial tumors who were scheduled for stereotactic treatment were scanned using the Encompass coil following conventional CT-based simulation for intracranial stereotactic treatment planning. Standard T1-weighted post-contrast, T2 FLAIR, diffusion-weighted (using an echo planar sequence), and T1 VIBE Dixon images (in support of synthetic CT generation for MRI-only treatment planning and positioning support) were acquired. A subset of these patients were further scanned, without immobilization, using the 20-channel head and neck coil.

Diffusion-weighted images (at b = 0 s/mm^2) were analyzed to estimate the relative signal to background ratio, which was compared to measurements of equivalent images from other subjects scanned using the 20-channel head and neck coil under different research protocols.

Synthetic CT image volumes were generated using a Unet architecture previously trained on 6500 MR-CT image pairs, from T1-weighted (in-phase) images acquired using the VIBE Dixon sequence [5]. These images were compared to simulation CT scans acquired for radiosurgical treatment planning for intensity similarity, accuracy of dose calculation, and accuracy of supporting alignment to Cone Beam CT (CBCT) scans used for patient positioning. The synthetic CT scans were spatially aligned to the treatment planning CT scans using rigid body transforms. Using a previously reported comparison method [4], treatment plans were generated using the synthetic CT scans for attenuation mapping. These plans were then re-calculated using attenuation mapped from the treatment planning CT scans, and the resulting differences in dose recorded.

The cone beam CT (CBCT) image volumes used to support patient positioning for treatment for these subjects were spatially aligned to the CT as well as synthetic CT scans, and the differences in the transformations were recorded.

[1] *While this study has been performed using the prototype coil, the Qfix Encompass 15-channel Head Coil is released and available for sale.*



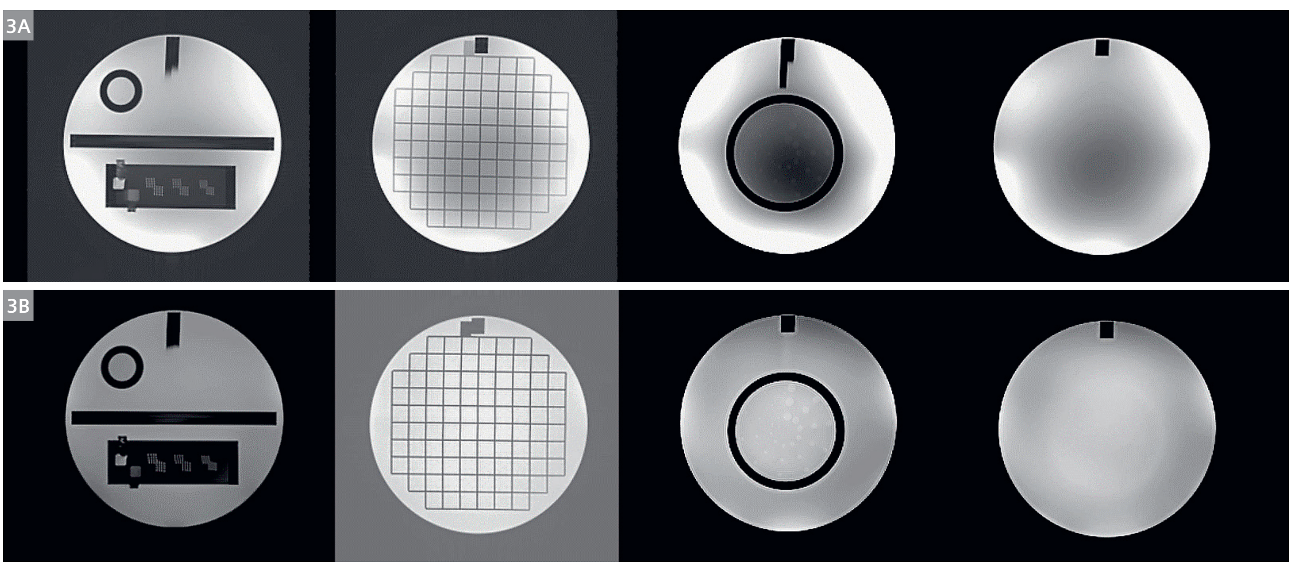
2 Example patient positioning using the Encompass coil. The immobilization frame is indexed to the posterior coil section, and the anterior coil is subsequently attached via a height-adjustable connection.

Results

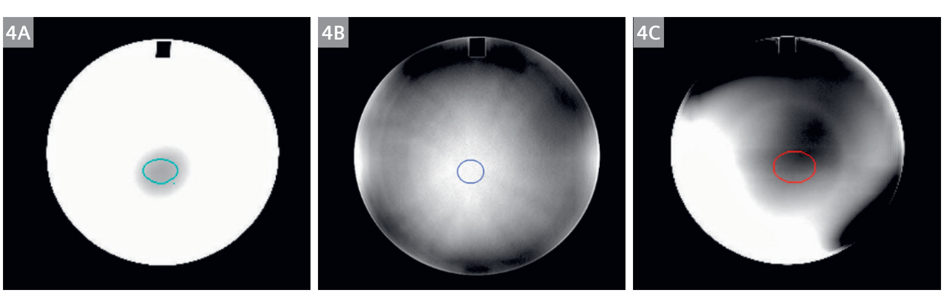
Figure 3 shows images from the various sections of the ACR phantom from the Encompass coil as well as the 20-channel coil. All tests passed successfully. Figure 4 shows images from the uniform section of the phantom scanned with the Encompass, 20-channel head and neck, as well as combined anterior surface and posterior spine coils. The prototype coil passed all ACR phantom test criteria. SNR values, measured in the center of the uniform section of the phantom, were 88.5, 89.9 and 44.4 for the prototype, 20-channel and RTCombo coils, respectively.

Human subject images (examples shown in Figure 5) were qualitatively reviewed by a physician specializing in intracranial treatment and deemed to be of sufficient quality for clinical use. Analysis of ADC maps from DWI showed higher signal to background ratio for the prototype coil (20.7) versus the 20-channel coil (15.6). Figure 6 shows a comparison of a synthetic CT scan, generated from the T1 VIBE images, to the corresponding clinical CT scan acquired for simulation.

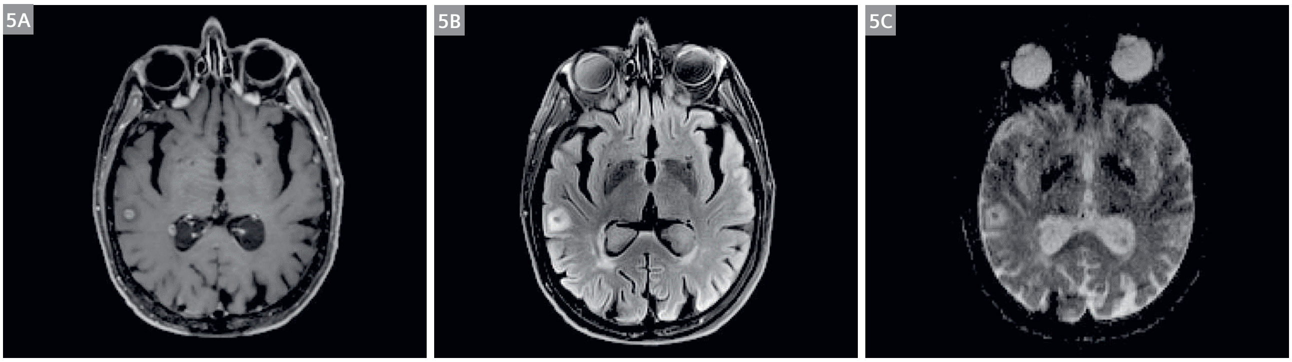
The synthetic CT image volumes compared well with simulation CT scans, with average Mean Absolute Error values of 4.7, 180.5 and 5.7 HU in regions of brain parenchyma, skull, and ventricles across the 10 patients studied, similar to those reported using a 20-channel head and neck coil for non-immobilized patients [5]. Figure 7 shows an example of a treatment plan generated using the synthetic CT from the Encompass coil-acquired VIBE images, as well as that plan with dose re-calculated using the attenuation map generated from the treatment planning CT scan. Treatment plan comparisons across the 10 patients showed dose differences of 2.3 +/-0.9% of the mean dose to the planning target volumes, with the systematic mean dose variation primarily due to the lack of the immobilization frame in the synthetic CT image volumes.



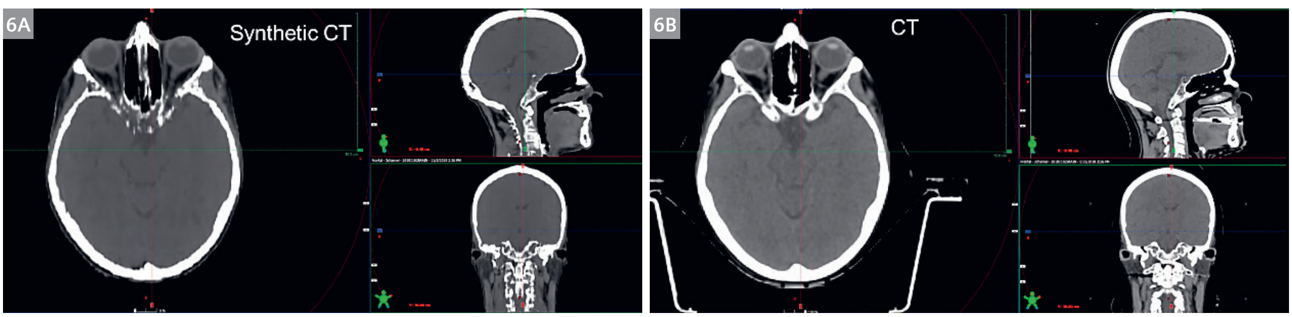
3 Sections of the ACR QA phantom scanned with the Encompass coil **(3A)** and 20-channel conventional Head and Neck coil **(3B)**.



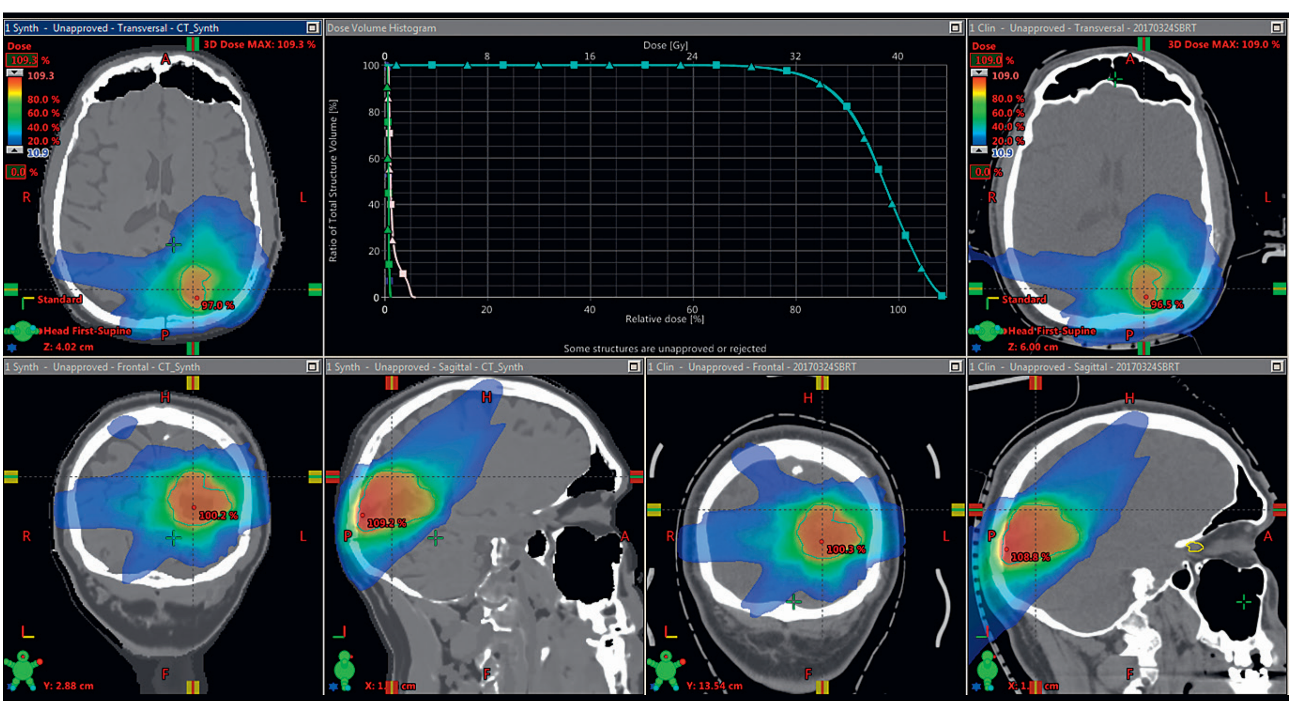
4 Uniform sections of the ACR phantom and regions of interest (contours) used to assess SNR from the **(4A)** Encompass, **(4B)** 20-channel head and neck coil, and **(4C)** RTCombo coil combination.



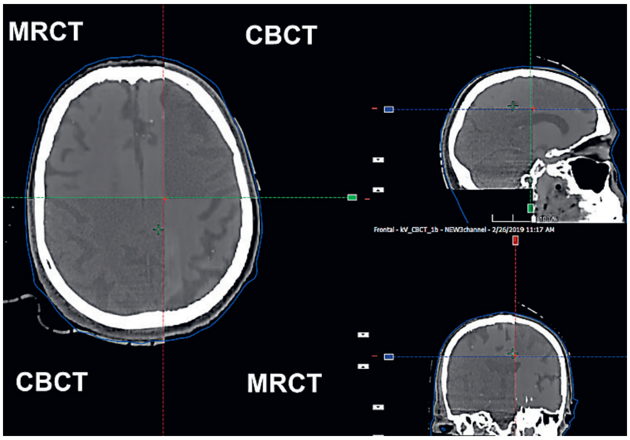
5 Example T1-weighted post contrast **(5A)** and Fluid Attenuated Inversion Recovery **(5B)** images, along with a map of Apparent Diffusion Coefficients **(5C)** for a subject acquired using the Encompass coil.



6 Example synthetic CT image volume **(6A)** generated from images acquired with the Encompass coil and actual CT **(6B)** acquired for treatment planning.



7 Comparison of dose distributions for a plan generated using the synthetic CT from the Encompass coil simulation (left, plan "1 Synth") with that from the treatment fluences used to recalculate dose using the attenuation map from the clinical CT scan (right, plan "1 Clin"). Dose volume histograms are shown for the synthetic CT (squares) and clinical (triangles) plans for the treatment target (blue), brainstem (white) and optic chiasm (green).



8 Example alignment of a synthetic CT (MRCT) generated from VIBE Dixon images acquired using the Encompass coil with a cone beam CT (CBCT) scan acquired for patient positioning.

	Left-Right	Ant-Post	Inf-Sup
mean	-0.04	0.00	0.07
σ	0.14	0.20	0.23
min	-0.3	-0.5	-0.3
max	0.3	0.4	0.5

Table 1: Differences between CBCT-CT and CBCT-synthetic CT alignments applied to target centers (mm)

Figure 8 shows an example alignment of synthetic CT with CBCT from a treatment. Table 1 summarizes the differences between CBCT-CT and CBCT-synthetic Alignment. A mean difference between CT and Synthetic CT of 0.1 mm (standard deviation of 0.3 mm) was observed across all patients.

Conclusion

Tests performed on the Qfix Encompass coil[1], designed to support MR simulation for immobilized patients, demonstrated image quality comparable to commercial general purpose coils for clinical use for precision radiation therapy of intracranial stereotactic treatment targets. Synthetic CT images generated using this coil are sufficiently similar to CT scans to support MR-only treatment planning and image guided patient positioning for radiosurgery.

Acknowledgments

Supported by NIH R01EB016079 and Qfix.

References

1 Glide-Hurst CK, Paulson ES, McGee K, et al. Task Group 284 Report: Magnetic Resonance Imaging Simulation in Radiotherapy: Considerations for Clinical Implementation, Optimization, and Quality Assurance. Med Phys. 2021.
2 Paulson ES, Erickson B, Schultz C, Allen Li X. Comprehensive MRI simulation methodology using a dedicated MRI scanner in radiation oncology for external beam radiation treatment planning. Med Phys. 2015;42(1):28-39.
3 Tyagi N, Zakian KL, Italiaander M, et al. Technical Note: A custom-designed flexible MR coil array for spine radiotherapy treatment planning. Med Phys. 2020;47(7):3143-3152.
4 Paradis E, Cao Y, Lawrence TS, et al. Assessing the Dosimetric Accuracy of Magnetic Resonance-Generated Synthetic CT Images for Focal Brain VMAT Radiation Therapy. Int J Radiat Oncol Biol Phys. 2015;93(5):1154-1161.
5 Gupta D, Kim M, Vineberg KA, Balter JM. Generation of Synthetic CT Images From MRI for Treatment Planning and Patient Positioning Using a 3-Channel U-Net Trained on Sagittal Images. Front Oncol. 2019;9:964.

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