Spatial Distortion Due to Field Inhomogeneity in 3.0 Tesla Intraoperative MRI

ASIM F. CHOUDHRI¹⁻⁴, ERIC M. CHIN⁵, PAUL KLIMO^{2,4}, FREDERICK A. BOOP^{2,4}

¹Department of Radiology, ²Department of Neurosurgery, ³Department of Ophthalmology, ⁵College of Medicine, University of Tennessee Health Science Center; Memphis, TN, USA

⁴Le Bonheur Neuroscience Institute, Le Bonheur Children's Hospital; Memphis, TN, USA

Key words: magnetic resonance imaging, intraoperative MRI, brain tumor, artifact

SUMMARY – We describe a 14-year-old boy with a pilocytic astrocytoma of the left caudate head. Preoperative localization MR imaging (MRI) was performed in the operating room, and spatial distortion was noted felt to be related to head positioning relative to the isocenter of the magnetic field. The distortion artifact was subtle enough to be difficult to detect, but large enough to change the location of the lesion potentially leading to a non-diagnostic stereotactic biopsy. Repeat imaging after changing the head position to allow scanning closer to the isocenter of the magnetic field showed decreased distortion, an improvement greater than that using the manufacturer's distortion correction algorithm on the initial images. Intraoperative MRI, and its requisite limitations in positioning, requires vigilance to detect possible distortion that could alter surgical outcomes if not identified and corrected prospectively.

Introduction

Intraoperative magnetic resonance imaging (iMRI) is an emerging technology that allows assessment of tumor resection prior to completion of a surgical procedure^{1,2,3}. The benefits include the ability to immediately resect residual tumor, and identify complications such as infarctions or hematomas. This may also obviate the need for an immediate postoperative scan, eliminating the need to transport a postoperative patient from the intensive care unit to the MRI scanner, and in children eliminates the need for an additional iteration of anesthesia. iMRI also allows preoperative stereotactic localization imaging to be performed immediately prior to surgery, performed with the head in the surgical position possibly improving the accuracy of the surgical navigation system⁴.

As the iMRI scans are performed with the head in the position used for the surgical procedure, often with a surrounding stabilization frame and intraoperative support equipment, the positioning of the patient with regard to the isocenter of the B₀ magnetic field of the scanner is not standardized. Heterogeneity of magnetic

fields can induce spatial distortion in the computation of MR images⁵, which can alter the accuracy of stereotactic navigation systems⁶. We describe a case where preoperative localization scanning performed in the intraoperative setting introduced a non-uniform spatial distortion that altered the apparent location of a tumor lesion that was to be biopsied.

Case Report

This HIPAA-compliant report was performed after IRB approval. A 14-year-old boy underwent placement of a shunt at six years of age for an unknown reason at an outside facility. Eight years later, the patient had new onset disconjugate gaze and double vision. MRI was performed showing a multilobular heterogeneously enhancing mass centered in both thalami, the midbrain, and left caudate head (Figure 1). Endoscopic biopsy was attempted at an outside institution, but the specimen was non-diagnostic.

Stereotactic biopsy of the left caudate head lesion was planned. Due to the small size of

Figure 1 Axial T1W post-contrast image at the level of the deep gray nuclei showing a multilobular enhancing lesion in both thalami with an additional discrete lesion in the left caudate head.

Figure 2 Sagittal reformat of axially acquired [FSPGR T1-weighted] post-contrast iMRI imaging (A) shows prolongation of the forehead and a vertical orientation of the nose, which was not present on preoperative imaging (B) performed using a routine diagnostic protocol.

the lesion, approximately 11 mm in diameter, iMRI was utilized to allow immediate postoperative assessment of the location of the biopsy tract and assist in further biopsy or resection if warranted.

The patient was placed on the operating table in a supine position with the neck flexed and the head fixated using an MRI-compatible pin-fixation device (IMRIS-neuro, Winnipeg, Canada). After following safety protocols to en-

Figure 3 Axial and sagittal images with corresponding mapping of displacement by feature detection and tracking for the axial and sagittal images. *Columns (left to right):* preop diagnostic scan (baseline); initial intraoperative scan; initial intraoperative scan with distortion correction algorithm post-processing; rescan after repositioning closer to the isocenter; rescan with distortion correction algorithm post-processing. *First row:* axial images centered on the lesion from each scan. *Second row:* Displacement maps of distortion on axial images relative to baseline. *Third row:* Midline sagittal images. *Fourth row:* Displacement maps of sagittal images relative to baseline. Background shows baseline scan subtracted from the above image. Lines superimposed on the image connect the position of a control point in the baseline scan with its position in the above scan. Line color indicates the direction of displacement: red indicates distortion moving the control point toward the top of the image ($0^\circ < \theta \leq 180^\circ$); turquoise indicates movement toward the bottom of the image ($180^\circ < \theta \leq 360^\circ$; also indicates fixed points).

sure MRI safety, the MRI scanner (Verio 3.0 Tesla, Siemens AG, Munich, Germany) was brought into the operating room via a ceiling-mounted track system (IMRIS-neuro, Winnipeg, Canada). A split array (two part) eight-

channel head coil (HC-300, IMRIS-neuro, Winnipeg, Canada) was used with one four-channel component of the coil placed anterior to the patient's head and one four-channel component placed posterior to the patient's head.

Figure 4 Sagittal T1 post-contrast imaging performed after reducing the amount of neck flexion and lowering the operating table shows resolution of the previously seen distortion of the frontal bone and nose.

Figure 5 Axial T2W iMRI image shows punctate areas of signal hypointensity within the left caudate head lesion, not present preoperatively, indicative of successful localization of this lesion.

Scanning was performed using an axially acquired volumetric gradient T1-weighted sequence after the administration of 0.1 mmol/kg gadopentetate dimeglumine intravenous con-

trast (Magnevist, Bayer Healthcare, Wayne, NJ, USA). Imaging resolution was 0.49 mm×0.49 mm×1.0 mm; phase encoding direction was right-to-left.

The target lesion was confirmed on stereotactic planning MRI. Imaging showed an 11 mm ovoid enhancing lesion in the left caudate head (volume 0.48 cm³) (Figure 1). Images were then loaded into a surgical navigation system (StealthViz, Medtronic Inc., Minneapolis, MN, USA). During quality-assurance evaluation of the dataset, it was noted on sagittal images that there was elongation of the forehead and flattening of the nose (Figure 2A). These findings were not present on preoperative imaging performed using a sagittally acquired volumetric gradient T1 -image performed using a routine diagnostic coil at the isocenter of the MRI scanner (Avanto 1.5 Tesla, Siemens AG, Munich, Germany).

The head was repositioned in the stereotactic frame with less neck flexion, and the operating table was lowered with respect to the bore of the MR scanner. Following repositioning, repeat scanning was performed with a significant qualitative improvement in the distortion (Figure 4). After consultation between the neurosurgeon and the neuroradiologist, the data were felt to be diagnostically accurate, with qualitative resolution of the distortion, and the surgical procedure commenced. The left caudate head lesion was successfully biopsied on the first attempt. Post-biopsy iMRI showed air and blood products within the targeted lesion (Figure 5) and the biopsy showed pilocytic astrocytoma.

While qualitative assessments showed distortion on the initial stereotactic planning scan which decreased on subsequent scanning, we subsequently performed a quantified digital image correlation (DIC) analysis to better understand the phenomenon. In DIC, salient points are “tracked” between two images; the apparent motion of many such points then reflects the overall transformation. All image processing was done in MATLAB R2011a (MathWorks, Natick, MA, USA)⁷. First, iMRI scans were coregistered using AMIDE (GNU General Public License, amide.sf.net) and SPM8 (FIL methods group, University College London) to remove rigid rotations and translations. A previous 3D T1-weighted image acquired in a conventional MRI scanner was used as the reference. Next, control points were identified using the Noble modification of the Horner corner detector^{8,9}; 2D image correlation was then

performed between corners identified on both images⁶: a high level of correlation between two corners indicates a match. Filtering was then performed to remove false matches; displacements that vary greatly from the displacements of neighbors were removed.

Analysis of the distortion showed displacement differences of up to 22 mm across the image. In particular, the anterior calvarial margin was displaced roughly 12 mm anteriorly in the horizontal plane of the lesion and the posterior calvarial margin was displaced roughly 3 mm posteriorly in the plane of the lesion. The lesion was in an area of relatively little displacement (est. 2.5 mm anteriorly, 1.6 mm superiorly). However, this makes apparent distance to anterior and posterior calvarial margins 9.5 mm greater and 5.5 mm greater, respectively. For a lesion with 11mm diameter this could have resulted in a non-diagnostic biopsy.

The MRI manufacturer provides distortion correction algorithms within the post-processing workstation. The distortion correction al-

gorithm was applied to both the initial intra-operative scan and the subsequent scan after re-positioning (both scans performed prior to the biopsy). The volume of the lesion was calculated using an edge detection algorithm on the volumetric dataset^{7,8}. The AP and transverse dimension of the calvarium on an axial image through the center of the left caudate head lesion was also calculated (Table 1).

The images obtained after repositioning the head closer to the isocenter of the magnetic field (Figure 3, columns 4 and 5) showed less distortion in the region of the frontal bone than the initial scan performed away from the isocenter without (Figure 3, column 2) and with (Figure 3, column 3) application of the manufacturer's distortion correction algorithm. It is noted that the initial images where the distortion was noted (Figure 2A and Figure 3 column 2), while performed away from the isocenter of the magnetic field, was close enough to the isocenter for MR scanning software not to prevent the scan taking place.

Table 1 Volume dimensions of the left caudate head lesion in each scan as calculated by edge-detection algorithms on the volumetric datasets, as well as the maximum AP and transverse dimensions of the calvarium on an axial image through the center of the left caudate head lesion.

	<i>Lesion Volume (cc)</i>	<i>AP calvarium (cm)</i>	<i>Transverse calvarium (cm)</i>
Preoperative (diagnostic) scan	0.478	20.2	14.9
Initial iMRI scan	0.458	21.7	15.1
Initial iMRI scan + distortion correction	0.490	20.7	14.9
Rescan iMRI	0.474	21.2	15.3
Rescan iMRI + distortion correction	0.409	20.5	14.9

Discussion

iMRI is an important technology in modern neurosurgery, in particular in surgical neurooncology. The variable scanning conditions often required due to patient positioning and the required head-stabilization frame and other intraoperative supportive devices often preclude scans from being performed directly at the isocenter of the magnetic field of the MR scanner.

Image reconstruction assumes a uniform B_0 over the field of view. If the patient is too far from the isocenter, parts of the field of view enter the fringe field and experience decreased B_0 . As a result, the Larmor frequency of protons in that area is decreased; as field varia-

tions are assumed to be due to gradient coils, reconstruction displaces the signal obtained along the frequency-encoding direction.

We have demonstrated that deviation from the isocenter can cause distortion of an order of magnitude that could have resulted in a non-diagnostic biopsy in this case, despite the scanning parameters being within the manufacturer's specifications. In-scanner distortion correction algorithms decreased the degree of distortion, but were not as accurate as scans performed closer to the isocenter of the scanner. Neurosurgeons and neuroradiologists need to be aware of this potential artifact, and a visual quality assurance evaluation of images performed in an iMRI setting is warranted to ensure accuracy of images.

References

- 1 Pamir MN, Peker S, Ozek MM, et al. Intraoperative MR imaging: preliminary results with 3 tesla MR system. *Acta Neurochir.* 2006; 98 (Suppl): 97-100.
- 2 Tronnier VM, Wirtz CR, Knauth M, et al. Intraoperative diagnostic and interventional magnetic resonance imaging in neurosurgery. *Neurosurgery.* 1997; 40 (5): 891-900. doi: 10.1097/00006123-199705000-00001.
- 3 Choudhri AF, Klimo P, Auschwitz TS, et al. 3 Tesla intraoperative MRI for management of pediatric CNS neoplasms. *Am J Neuroradiol.* 2014. doi: 10.3174/ajnr.A4040.
- 4 Hill DLG, Maurer CR, Wang MY, et al. Estimation of intraoperative brain surface movement. *CVRMed-MRCAS '97 Proceedings of the First Joint Conference on Computer Vision, Virtual Reality and Robotics in Medicine and Medical Robotics and Computer-Assisted Surgery.* 1997; 449-458.
- 5 Huang H, Ceritoglu C, Li X, et al. Correction of B0 susceptibility induced distortion in diffusion-weighted images using large-deformation diffeomorphic metric mapping. *Magn Reson Imaging.* 2008; 26 (9): 1294-1302. doi: 10.1016/j.mri.2008.03.005.
- 6 Sumanaweera TS, Adler JR, Napel S, et al. Characterization of spatial distortion in magnetic resonance imaging and its implications for stereotactic surgery. *Neurosurgery.* 1994; 35 (4): 696-703. doi: 10.1227/00006123-199410000-00016.
- 7 Kovesi P. MATLAB and octave functions for computer vision and image processing. (<<http://www.csse.uwa.edu.au/~pk/research/matlabfns/>>. Accessed February 2, 2013)
- 8 Harris CG. A combined corner and edge detector. *Proceedings of the Fourth Alvey Vision Conference.* Manchester. 1988; 147-151.
- 9 Noble A. Descriptions of Image Surfaces, In: 1989 ed. PhD thesis, Department of Engineering Science, Oxford University. 1989. p. 45.

Asim F. Choudhri, MD
Associate Professor of Radiology,
Ophthalmology, and Neurosurgery
University of Tennessee Health Science Center
Le Bonheur Children's Hospital
848 Adams Ave - G216
Memphis, TN 38103
Tel.: 901-287-6938
Fax: 888-203-4741
E-mail: achoudhri@uthsc.edu