Addressing Patient Motion in 3D Imaging

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Patient motion has endured as one of the most common barriers to achieving reliable diagnostic quality imaging, frequently requiring rescans or even callback examinations. The most common causes of motion in medical imaging include respiratory, cardiac, and bulk motion. The first two types of motion are often addressed using some type of physiological gating, triggering, or optimization of the standard MR parameters such as frequency and phase encoding direction. The third, bulk motion, is more difficult to predict or prevent and can be categorized into voluntary and involuntary bulk motion. Voluntary motions can often be mitigated by instructing the patient to remain still during the scan and by using immobilization techniques that may reduce patient comfort. In some situations sedation may be a means of addressing patient compliance; however, this may be undesirable. Involuntary motions, such as the hypnic jerk that so often occurs when the patient is falling asleep, or more devastating causes, such as neurodegenerative processes like Parkinson’s disease, are more difficult to address and can severely degrade the diagnostic quality of the MR exam.

The issue of patient motion is of particular concern when using high-resolution three-dimensional (3D) imaging, which is becoming a preferred technique for imaging of the brain for structural anomalies and disease due to the increased detail and potential diagnostic confidence that it can offer radiologists. Unfortunately, 3D imaging techniques are more sensitive to patient motion because the spatial information is encoded over the full acquisition rather than on a slice-by-slice manner as is done in 2D imaging. Because of this, any motion that occurs during the acquisition results in artifacts that are propagated throughout all of the resulting images.
PROMO

A promising approach towards addressing patient motion is to modify the pulse sequence in real-time to follow the patient’s movements during the acquisition—commonly known as prospective motion correction. A general assumption made for motion correction of the brain is that it moves in a rigid fashion; that is, all portions of the brain move in the same manner or that it does not deform as it moves. The jaw and neck are examples of other anatomical features of the head that do not move rigidly, but rather stretch or rotate differently depending on which portion or how much of that anatomy is moving. Rigid body motion can be corrected for by adjusting the position and orientation, or pose, of the field of view (FOV) of the acquisition.

In MR prospective motion correction, the FOV is adjusted by modifying the gradients and radiofrequency (RF) to correct for the position and orientation of the brain. Based on this principle, GE Healthcare, collaborating with researchers at the University of California, San Diego, has developed a motion correction technique called PROspective MOtion correction (PROMO) that is optimized for 3D imaging and is currently available in the Cube T2 and T2 FLAIR sequences. PROMO adjusts the FOV during the scan to maintain anatomical correspondence to the original prescription.

Cube T2 and T2 FLAIR sequences are based on 3D fast spin echo and permit high resolution 3D volumetric imaging through the use of a variable flip angle refocusing echo train that reduces RF power. Cube T2 and T2 FLAIR sequences both have a longer repetition time (TR), 3 to 7 seconds, to permit signal relaxation. PROMO incorporates the collection of three-plane spiral navigator images during the inherent dead-time of the pulse sequence to detect any changes in patient position (Figure 1). The low flip angle spiral navigators have no discernable effect on the imaging and can be used to effectively measure subject motion with a high degree of accuracy. The navigator data is reconstructed and analyzed using an extended Kalman filter, a processing algorithm that can be performed in approximately 10 msec. The patient pose information produced by this processing is sent back to the pulse sequence which corrects for the computed patient movement in near real-time.

Because PROMO uses image-based navigators, the motion estimation can be focused on the brain itself. K-space based techniques can be corrupted by non-rigid body motion in the navigator’s FOV, such as jaw or neck movement. By narrowing the motion estimation to movement of only the brain, common motions, such as swallowing or the bending of the neck, do not affect the quality of the motion correction.

Figure 1. Graphical depiction of the CUBE T2 or T2 FLAIR PROMO technique. Three-plane spiral navigators are inserted in the inherent dead-time of the pulse sequence and processed in real-time. The field of view is adjusted after each navigator to maintain anatomical correspondence to the original prescription.
Bulk motion related artifacts are caused by a number of mechanisms but for 3D brain imaging these artifacts are typically due to discontinuities in k-space, i.e., large signal changes between adjacent k-space lines. If prospective motion correction is used, and motion corrupted data acquired over the detection period (for Cube, a TR) is not reacquired, k-space discontinuities will likely exist and still result in ghosting artifacts or blurring in the images. To address this, a scan using PROMO can be configured to re-acquire data that was severely corrupted by motion using the Maximum Rescan Time field. This field provides the user the flexibility to specify the maximum amount of additional scan time they want to use to acquire the most severely motion-corrupted data, although if no or minimal motion occurred then no additional scan time will be necessary. Re-acquisition of the motion corrupted data will improve the resulting image quality as compared to performing the real-time FOV correction alone.

The main limitation encountered when performing any prospective motion correction is that there is no way to know a priori the magnitude of patient motion that the scan will have to correct. When a scan is prescribed, some MR parameters are internally optimized based on the orientation of the scan FOV with respect to the physical gradients of the MR scanner. To account for the unknown motion, the pulse sequence must usually optimize these parameters using a worst case condition. Therefore, when PROMO is used the echo spacing will be slightly longer than a scan without PROMO. The increased echo spacing will typically result in perceived blurring due to an increased T2 decay over the echo train but a slight loss of SNR is also expected. This effect can be mitigated by appropriately adjusting the scan parameters of a standard Cube T2 or T2 FLAIR protocol (Figure 2). To address the blurring, it is recommended that the echo train length be reduced by about 15, increasing bandwidth by ± 20 kHz, and increasing TR by 500 ms near original image quality can be duplicated (PROMO with subject motion, right). The Maximum Rescan Time field (arrow) may be used to control the amount of additional scan time to add for reacquiring severely motion corrupted data, if necessary.

With the release of the DV25.0 Continuum Pak™, there is a significant improvement to Cube T2 FLAIR, which now permits the use of the T2 preparation (T2 Prep) imaging option for enhanced visualization of white matter/gray matter contrast. In addition, the increased contrast to noise afforded by the use of T2 preparation enables even more flexibility in the optimization of the imaging parameters (e.g. the TR can be lowered by about 1 sec, reducing scan time). When T2 Prep is used with Cube T2 FLAIR and PROMO a high-contrast volumetric motion-robust scan can be achieved (Figure 3).
Patient motion is a problem for everyone, and GE Healthcare is working hard to help customers obtain the best diagnostic image quality possible. Customers incorporating PROMO into their protocols are realizing the benefits and the possibilities for improving the efficiency of their practice. A motion-robust scanning protocol may be used to help reduce sedation rates in young or motion-prone subjects. Reducing rescans by incorporating PROMO in protocols for elderly or severely sick populations is certainly imaginable (Figure 4). A comprehensive portfolio for motion-robust imaging of the brain is an important goal for GE. With techniques like PROPELLER (T2, T2 FLAIR, T1 FLAIR and PD) for 2D motion-robust imaging and now Cube T2 and T2 FLAIR with PROMO for 3D prospective motion corrected imaging, we are helping our customers make the most of their MR scanners.

References