Using volumetric navigators (vNavs) in multi-echo MPRAGE for prospective motion and resonance frequency correction: development progress and lessons learned in routine clinical use.

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INTRODUCTION The volumetric navigators (vNavs) system was initially proposed [1] to enable prospective motion correction in multi-echo MPRAGE (MEMPRAGE) [2], and has subsequently been applied in several other pulse sequences [3,4,5,6]. In the intervening time, the system has seen substantial technical development, in addition to accumulating some "best practices" learned from its routine clinical use. While these results have been incrementally described in abstracts and pulse sequence manuals, here we aim to present a holistic update on the status of the vNavs system and its use.

METHODS The core of the system is the navigator sub-sequence, embedded once per TR during dead-time in the parent sequence (e.g., during the inversion recovery period of the MEMPRAGE). The vNav acquired in the first TR is used as the "reference", and all subsequent TRs are compared back to this one for both motion and frequency tracking.

The vNav consists of a 32^3 isotropic volume 3D-encoded with EPI and requiring roughly 275 ms to acquire. To accelerate the acquisition without complicating reconstruction, only 3/4 of the partitions are acquired and the remainder are zero-filled. In addition to the 24 TRs of 3D EPI, we start each vNav with one TR in which we acquire the center line of k-space 32 times. This serves as both a N/2 ghost correction navigator for the EPI, and a resonance frequency navigator. The resonance frequency is estimated from these 32 lines by applying an inverse-FFT in the readout direction and truncating the data to the imaging FOV, then applying an FFT in the readout direction to return the data to the frequency domain. We then perform sample-wise multiplication with the conjugate of the reference vNav's frequency navigator (canceling out eddy current effects) and fit the phase roll across even and odd echoes of the navigator. This average phase roll, combined with the echo spacing, accurately estimates the resonance frequency shift relative to the reference vNav.

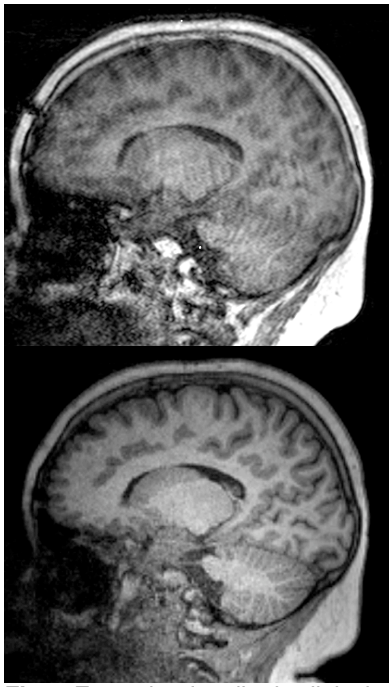

Fig. 1 Example of pediatric clinical subject scanned without (top) and with (bottom) vNavs. *Courtesy: Dr. Ellen Grant, Boston Children's Hospital*

Motion estimation is performed using the PACE [7] library to register each vNav's image back to the reference vNav. Due to the low resolution of the vNav image, this can be performed reliably in under 100 ms on current scanner hardware; this gives a full navigate-and-update block of < 400 ms. Accuracy in human subjects is hard to evaluate due to the inability to distinguish small motions and noise, but in structured phantoms tracking accuracy has been better than 0.5 mm. Three significant sources of error in the motion tracking have been found in practice and addressed individually. First, non-rigid motion of the jaw and neck, which can lead to poor rigid registration estimates from PACE, is addressed by locating the vNav imaging volume over only the brain and skull, and using readout-direction oversampling to prevent other tissues from wrapping into the FOV. Second, resonance frequency drift (due mostly to heating of the shim iron at 3 T, and subject respiration at 7 T) causes a shift if the PE direction of the vNav which will be mistaken for subject motion if not corrected; this is addressed with the prospective frequency correction described above. Finally, a significant source of variability was found to be stimulated echoes in the vNav; ensuring synchronized RF spoiling between parent and vNav, and increasing the gradient spoiling of the vNav by a factor of 4, resulted in more consistent images and less noise in the motion estimates.

RESULTS The vNav MEMPRAGE is now used routinely at several hospitals for scanning pediatric and epileptic patients, in addition to its use in research studies of pediatric autism subjects imaged without sedation (see Fig. 1). The feedback received from these user groups has been invaluable in directing the previously described technical and workflow improvements to the original vNav system. The sequence is now also being distributed on the mMR system, with the goal of allowing the motion-tracking data acquired with vNavs to be used to retrospectively correct the PET acquisition as well.

In addition to its clinical use, the vNav MPRAGE has also been used to produce sub-400 μm isotropic whole-brain images at 3 T [8], enabling the required several hours of averaging by reducing the requirement that the subject remain still.

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