Prospective head motion correction in 3D FLASH using EPI-based volumetric navigators (vNavs)

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Target Audience Users of 3D FLASH-based neuroimaging sequences that are interested in reducing artefacts due to subject motion.

Purpose FLASH [1] (spoiled gradient echo) forms the basis of many 3D neuroimaging sequences, but acquisition times often stretch to several minutes during which the subject must remain motionless. Prospective motion correction using cloverleaf navigators has been previously demonstrated in FLASH, allowing for successful image acquisition even with significant head motion [2]. However, in order to maximize SNR/time efficiency, short TR protocols are often set up with very little dead time, forcing navigators to be very short with limited k-space coverage from which to estimate the subject's head motion. In contrast to these ultra-fast navigators, we have previously described vNavs (EPI-based navigators that acquire a whole-head volume in roughly 275 ms) allow high-accuracy motion tracking [3,4]. However, vNavs have previously only been used in sequences with significant dead time (TI or TR gaps) in which the entire vNav could be inserted. In the present work we demonstrate that vNavs can be inserted in 3D FLASH sequences with only marginal impact on SNR/time. This work demonstrates successful motion correction in 3D FLASH using vNavs.

Methods The vNav sequence is a 3D-encoded EPI with a 32^3 matrix, but is acquired with ¾ partial Fourier encoding in the partition direction and so has 25 3D excitation pulses. On current scanner hardware, the minimum TR (time between excitations) for the vNav is usually 11 ms. We note that if a 3D FLASH scan has a TR that matches the vNavs', and if the pulses of both sequences are matched, we can play a train of 25 vNav TRs (*i.e.,* one vNav) instead of a FLASH TR without disturbing the steady state of the FLASH sequence. Expanding on this, as long as the TR of the FLASH sequence is 11 ms or longer, matching the vNav TR to the FLASH TR is trivial: we simply add TR-filling dead time to the vNav after its readouts. Thus, as long as our 3D FLASH scan meets the minimum TR requirement, we can insert vNav TRs into it at any point (see Fig. 1). Motion estimates are sent back to the scanner as they are generated on the image reconstruction computer, and are immediately applied to the next TR's imaging coordinates, keeping them consistent with the subject's head.

Inserting the vNavs as separate TRs at any time allows a great deal of flexibility, but also increases overall scan time. In previous sequences with vNavs, the navigators were inserted in TR or TI gaps and so did not increase scan time, but in FLASH we are adding 25 additional TRs to the total scan time with every vNav while not gaining any additional FLASH signal. To allow maximum flexibility, the sequence UI allows the user to set how many FLASH TRs will be played between each vNav, and the overall scan time is updated on the UI to inform users of the trade-off between tracking accuracy and scan time.

To test the efficacy of our system, a human volunteer, having given informed consent, was scanned in a 3 T TIM Trio (Siemens Healthcare, Erlangen, Germany) using the product 32-channel head matrix. Our FLASH sequence used a 15° flip angle, 11 ms TR, 3.43 ms TE, 200 Hz/px bandwidth, 256 mm × 256 mm × 176 mm FOV, and 1 mm isotropic resolution, and 2× GRAPPA acceleration for a total scan time of 4:48. We acquired one volume with this protocol while the subject remained still. We then inserted a vNav after every 136 FLASH TRs (approximately 1.5 seconds), increasing the scan time to 5:38, and acquired another volume while the subject remained still. We then acquired two more volumes with the vNavs protocol, during both of which the subject was prompted to change their head position every minute, repeating the same motion pattern in both scans. In the first of these with-motion scans we applied the correction for the subject's motion in real time, while in the second with-motion scan we did not apply the update.

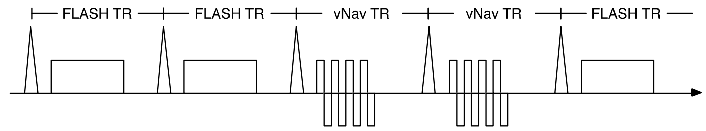

Fig 1. Simplified timing diagram of the vNav FLASH sequence, showing common pulses and TRs, but varied gradients, for interleaved FLASH and vNavs.

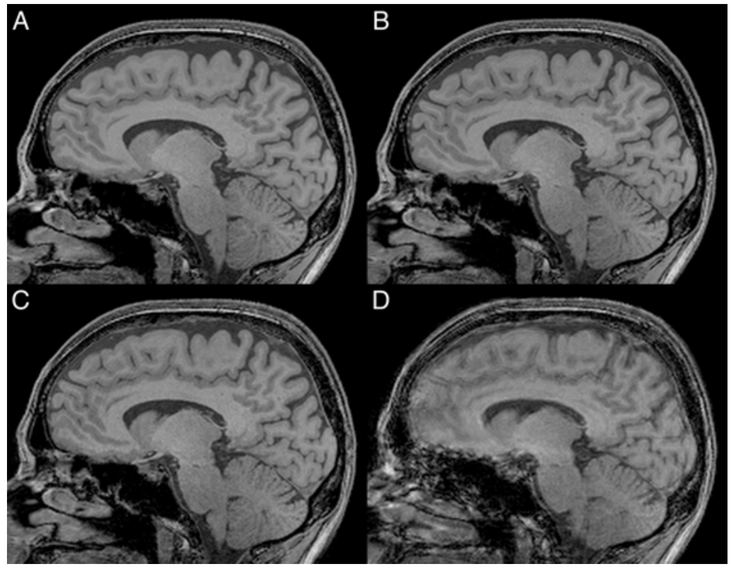

Fig 2. Representative slice from 4 FLASH scans with identical protocols. A) no vNavs, no motion; B) with vNavs, no motion; c) with vNavs, motion every minute; d) no vNavs, motion every minute. Note that introducing vNavs did not compromise contrast (A and B), but did provide significant resistance to motion (C

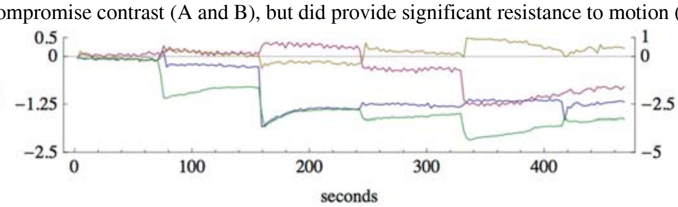

Fig 3. vNav-estimated head motion during the with-motion-correction scan (Fig 2. C). Translations in x (blue), y (red), and z (yellow) are in mm, while rotation (green) is in degrees.

Results and Discussion An equivalent slice from all four volumes is shown in Fig. 2, and the motion of the subject in the with-motion-and-correction condition is shown in Fig. 3. Comparing the FLASH and vNav FLASH with the subject remaining still (Fig. 2 A and B, respectively), we can see that there is no visible change in image contrast or image artefact induced by the introduction of the vNav TRs. Comparing the corrected and uncorrected motion series (Fig. 2 C and D, respectively) we can see the clear improvement in image quality produced by performing prospective motion correction with vNavs.

Conclusions We have demonstrated a novel method for performing prospective motion correction in FLASH. Unlike previous navigator methods, that attempted to insert ultra-fast navigators into the FLASH TR, we insert multiple matched vNav TRs into the FLASH train and thus preserve the steady state. Unlike in previous vNavs applications where there was no scan-time increase, the additional TRs in vNav FLASH did increase overall scan time. However, the benefit of the vNavs method is the high registration accuracy enabled by the whole-head navigator [3]. We note that the additional scan time is still significantly less than what would be required for an MR technologist to request patient compliance and rescan. Additionally, the vNav FLASH sequence allows users the flexibility to trade-off scan time for tracking accuracy based on the needs of their application and the subject population involved.

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