# Time-resolved, three-dimensional brain motion measurements using 3D-DENSE

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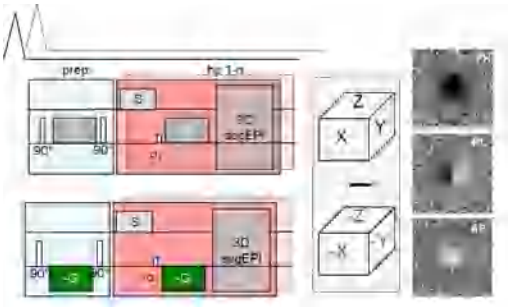
**Introduction** Cine DENSE [1,2] has been successfully used for obtaining insight into brain dynamics by measuring pulsatile brain motion driven by the blood circulation [3]. For measuring not only in-plane motion components of single slices a modified 3D sequence allowing displacement encoding in all three spatial directions is proposed in this work. Three-dimensional brain motion data in healthy volunteers are demonstrated.

**Methods** Cine DENSE (Displacement Encoded Echoes) [1] was implemented on a 3T Achieva system (Philips Medical Systems, Best, The Netherlands). The sequence was modified to allow inversion of the displacement encoding/decoding gradients in consecutive measurements, yielding an inverted displacement encoded phase [2,3]. Using a sufficiently strong spoiling gradient, artifacts of residual undesired echoes are eliminated. Additionally, the spoiling gradient direction was locked in both scans to the direction of the segEPI gradients, which reduced time dependent eddy-current effects, allowing the phase images to capture brain motion throughout the entire RR-interval. Sequence parameters were: spatial resolution: 2x2x4 $mm^3$, temporal resolution: 30 ms, displacement encoding frequency: 3 cycles/mm, spoiling frequency: 10 cycles/mm, EPI factor: 7, TE: 6.3 ms, ramped flip angles [4].




A total of three 3D stacks was acquired. The first two stacks were aligned with a relative rotation of 90° in-plane to map displacement values in two orthogonal directions applying the encoding/decoding gradients in measurement direction. For motion encoding in through-plane direction a third 3D stack with the encoding and decoding gradients in slice selection direction was added. About 120% of the cardiac cycle were acquired for evaluation of the displacement periodicity. In Figure 1 the schematic of the preparation sequence is given. It is followed by a three-dimensional readout scheme with two-dimensional echo-planar sampling and conventional phase-encoding along the z direction. In post-processing the two data sets from the two measurements sampling the echo and the anti-echo were combined by complex division, thereby canceling unwanted phase terms [2,3]. For evaluation, time series of displacements in several brain areas were examined. The software tool Flowtrack (Gyrotools, Zurich, Switzerland) was adapted and phase-unwrapping was included.

**Figure 1:** *Preparation scheme. For the first stack (x) a cine-DENSE acquisition scheme with a positive encoding gradient (G) in measurement direction and a spoiling gradient (S) in slice selection direction is applied after the cardiac trigger. For each cardiac phase the same gradient (G) is applied before the readout. For the second stack (y) the sequence coordinate system is rotated by 90 degrees and repeated to encode the second in-plane direction. For the third stack (z) the gradients (G) are switched to the slice encoding direction. The measurement of the three stacks is then repeated with inverted gradients (-G).*

**Results** Using the proposed acquisition scheme, motion encoded data of the brain were successfully acquired. Figure 2 displays typical displacement time series of four different anatomical regions in a healthy volunteer. A decrease of feet-head (FH) peak displacements towards the upper brain areas can clearly be observed (Pons → Corpus callosum) and the additional centric motion of the thalamus becomes evident. The displacement values also show the periodic characteristics of pulsatile motion (Figure 2, Figure 3). Figure 4 shows the motion differences in two close regions, having different elastic properties.

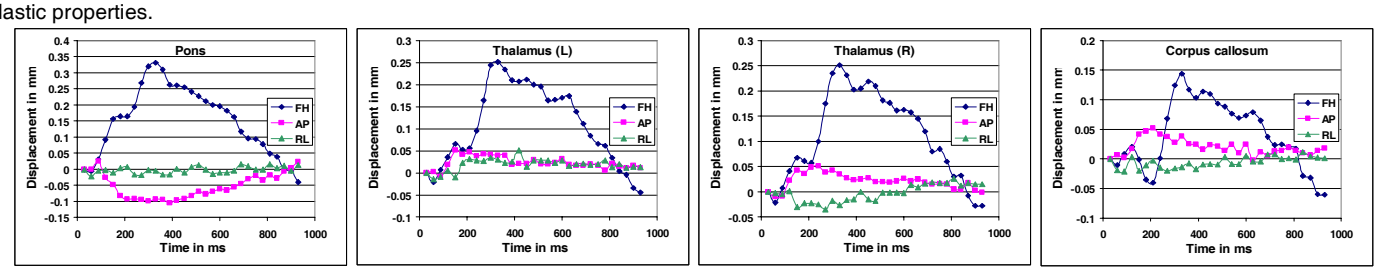



**Figure 2:** *Time series of displacement in feet-head (FH), anterior-posterior (AP) and right-left (RL) directions of the pons the left (L) and right (R) thalamus and the corpus callosum (rostrum).*

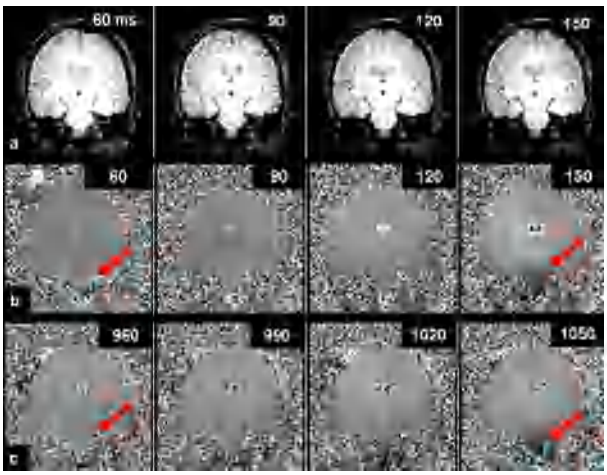



**Figure 3***: Assessment of periodicity of displacement. Combined, coronal, through-plane (AP) encoded images from the same healthy volunteer as presented in Figure 1.* ***a)*** *Magnitude images of the heart phases, 60 to 150 ms after the triggered R-wave.* ***b)*** *Phase images of the corresponding heart phases.* ***c)*** *Phase images 960 to 1050 ms after the triggered R-wave, which correspond to heart phases 90 to 150 ms after the second R-wave. The average RR-interval was 900 ms. Displacement values range from +0.2 to -0.2 mm.*

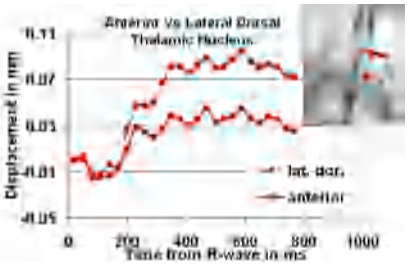



**Figure 4:** *Time series of motion towards the 3rd ventricle during the first 70% of a healthy volunteer. The anatomically different anterior and lateral dorsal thalamic nuclei can be distinguished by the displacements, in spite of their close proximity.*

**Discussion** In this work a technique has been demonstrated enabling mapping of displacement in the brain in three spatial dimensions. With this technique it is possible to assess the motion over the whole cardiac cycle within one scan. Although the deviation of the displacement after 100% of the cardiac cycle is very small, a slight drift is still apparent and has to be further investigated. This drift becomes particularly evident in FH direction, the one with the highest displacement values. Separate encoding sensitivities for the different encoding directions might lower this effect. Respiratory triggering additionally lowers the effect, but prolongs the scans significantly.

**References** **1** Aletras AH et al, JMR 1999; 137(1):247-252 **2** Gilson W et al, MRM 2004 51(4) **3** Soellinger M et al, Proc ISMRM 2006; 3203 **4** Fischer SE et al, MRM 1993; 30