Simultaneous Multi-Slice (Slice Accelerated) Diffusion EPI

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Simultaneous multi-slice (SMS) accelerated diffusion-weighted echo planar imaging employs an innovative acquisition and reconstruction scheme that allows multiple slices to be acquired simultaneously. The approach offers a substantial decrease in image acquisition time, or alternatively improved spatial/diffusion resolution. The advent of this technique is analogous to that years ago of 2D multi-slice, and as such may represent one of the major innovations in this decade with widespread clinical utility. This educational exhibit covers briefly the theory behind the approach, advantages and limitations, and applications in brain imaging using clinical source material.
Approach/Methods

The breadth of capabilities, and current limitations, with simultaneous multi-slice diffusion EPI in brain imaging are illustrated at 3T. In this scan approach, multiple slices are acquired simultaneously using blipped CAIPIRINHA technique with the individual slices then reconstructed using a slice GRAPPA method. Slice acceleration with axial imaging, as applied, requires a phased array coil with sufficient elements in the z-direction, which in this instance was accomplished by use of a 32 channel head coil. Eight different scan techniques were compared, with single shot non-accelerated and readout segmented EPI serving as reference standards.
The specific sequence parameters used both for volunteer and patient scans are detailed. Acceleration factors (Sl. Acc.) from 1 (none) to 4 were evaluated.

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<th>Scan Parameters</th>
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The 8 different scan sequences are compared in a normal volunteer. On a brief overview, there appears to be little difference, at this anatomic level, other than less blurring with the readout segmented (Resolve) scan.
In single shot EPI, the entirety of k-space is traversed after one shot (excitation).

Readout-segmentation acquires k-space in multiple shots for reduced TE and encoding time.

Real-time reacquisition of unusable shots is also supported.
Sequence Basics – Slice Acceleration

• The rf excitation is modified, to excite multiple slices simultaneously, and during readout, phase-blips are applied to shift/alias simultaneously excited slices.
• Aliased slices are separated during reconstruction using a slice-Grappa approach, with a high-quality slice separation requiring an appropriate multi-element coil.
• Simultaneous multi-slice acceleration allows more slices per TR or TR to be reduced with the same slice coverage.
• Potentially there is no SNR loss due to under-sampling, and the g-factor penalty is reduced by employing gradient based CAIPIRINHA.
Simultaneous Multi-Slice Acceleration with blipped CAIPIRINHA

- Multiple slices excited simultaneously
- Blipped CAIPIRINHA applied during echo train
  - Minimization of g-factor related SNR loss
- Slice GRAPPA based unaliasing
- Inplane GRAPPA based unaliasing
Choice of TR (DWI)

TR is typically ≈ 6000 msec for 2D DWI, however a reduction to 3500 does not impact substantially image quality or SNR.

This approach expands the potential of SMS accelerated imaging, whether slice thickness is maintained (as illustrated) or reduced.
Examining the 8 scans that were compared more closely, a difference in bulk susceptibility artifact is evident (here caused by the frontal sinus, anteriorly). This is less with thinner sections (2 mm), and with Resolve.
Note also the improved depiction of cortical gray matter on the 2 mm sections, due to less through-plane partial volume imaging. At this level, there is a slight loss in SNR with both 3 and 4 bands, in part due to slice thickness.
SNR

Depending upon level, the SNR results varied. Near the vertex, SNR was essentially equivalent for all scans. At the level of the lateral ventricles, mild decreases in SNR were seen that could be attributable not only to the decrease in TR and slice thickness, but also to the number of bands (g factor of the coil). When comparing the standard 4 mm single shot scan, to the three band 2 mm short TR scan, the decrease in SNR was 27% (likely primarily due to the thinner slice).
In this example, a small pinpoint infarct (arrow) is seen on two adjacent 2 mm slices using the accelerated DWI sequence, and on only one slice on the other two scans. Note the intrinsic blur in single shot epi when compared to the readout segmented scan.

Image blur is reduced in the accelerated scan, due to use of a smaller voxel with less through plane partial volume effects.
Motion artifact is least on the accelerated (simultaneous multi-slice) DWI exam.

In this example, the patient (with multiple punctate, acute, left MCA distribution infarcts) was combative and moved throughout the exam, degrading image quality.

Motion artifact is greatest on the readout segmented DWI exam, due both to the long scan duration (3:26 min:sec) and the acquisition scheme.
Is it real?

The large left MCA distribution infarct is obvious. But is the small lesion in the left caudate head real, and of the same time frame?
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The large left MCA distribution infarct is obvious. But is the small lesion in the left caudate head real, and of the same time frame?

Yes it is! Two adjacent 2 mm sections (simultaneous multislice accelerated) show this small infarct (arrows) well.

The value of being able to acquire quickly thin sections!
Do we have good depiction of this medullary infarct?
Do we have good depiction of this medullary infarct?

No! Not nearly as well as with 2 mm sections, where the infarct is more sharply defined on each section and we have an additional slice (in between)
Not evaluated, but extremely simple, would be the use of slice acceleration to acquire a higher number of b values in the same scan time.

The application of slice acceleration to readout segmented epi (with its long scan time) would find widespread clinical applicability, more closely approaching theoretical gains due to the lower impact of the time required for preparation pulses.
Other Avenues for Improvement

The result – of combining the readout segmented approach with slice acceleration – would be a scan with markedly reduced bulk susceptibility effect as well as image blur, with 2 mm slices through the entire brain, in a relatively short scan time.
Implementation of Slice Acceleration with Readout Segmentation (Resolve)

Once again, slice acceleration can be used to either achieve a shorter scan time, or to permit thinner sections with coverage of the entire brain.
Implementation of Slice Acceleration with Readout Segmentation (Resolve)

The longer scan time of the 2 mm sequence was due to doubling the number of acquisitions. Note the improved visualization of cortex (arrows) due to the thinner slice.
Slice Acceleration with Resolve for Decreased Scan Time

With an acceleration factor of 2, the scan time is reduced by 1 minute (from 3:08 to 2:06 min:sec), with no loss in image quality. Indeed, the resultant image has less blur.
Slice Acceleration with Resolve to Achieve a Thinner Axial Section

By moving to a 2 mm slice (not possible without slice acceleration due to the long scan time), some small pinpoint infarcts are better seen (black arrows), and some revealed for the first time (white arrow).
Bulk susceptibility artifacts (black arrow, from the frontal sinus) on DWI are less, and small pinpoint lesions (white arrows) with restricted diffusion are better seen.
AND, in certain instances small pinpoint lesions can be visualized only on the thinner sections, such as this small cortical infarct (arrow) in the left middle frontal gyrus.
Findings/Discussion

With the highest acceleration factors (4), a slight decrease in SNR was observed, together with some image artifacts. The utility of SMS accelerated diffusion EPI is demonstrated in cerebral ischemia, by allowing - with equivalent image quality - scan acquisition time to be shortened or slice thickness to be reduced. A SMS acceleration of 2 led to a scan time reduction from 1:23 (min:sec) to 0:50, with the required reference scan acquisition preventing a true factor of 2 reduction in scan time. Combining a SMS acceleration of 3 with a reduction in slice thickness, 2 mm sections through the entire brain could be acquired, with scan time, image quality and SNR comparable to the 4 mm single slice standard diffusion EPI acquisition.
Simultaneous multi-slice accelerated imaging offers a marked reduction in the time required for data acquisition (scan time). Using this approach, thin section (2 mm) DWI of the entire brain can also be acquired in a scan time and with image quality equivalent to 4 mm imaging with conventional single slice, single shot DWI. Applicability also exists relative to shortening the scan time of longer, higher image quality scans, such as readout segmented DWI. The technique can also be extended to T2-weighted imaging.