Complete or partial flow compensation for improved arterial depiction in multi-echo susceptibility-weighted imaging

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Target audience: Physicists, engineers and radiologists with an interest in susceptibility-weighted imaging.

Purpose

3D multi-echo gradient-echo sequences are being increasingly used for susceptibility-weighted imaging as a way to increase signal-to-noise ratio (SNR) over conventional single-echo acquisitions[1]. However, while single-echo susceptibility-weighted imaging is generally performed using a gradient-echo sequence with first-order flow compensation in all three directions, conventional multi-echo gradient-echo sequences generally offer the possibility for flow compensation of the later echoes only in the readout direction[1, 2]. Recently, a sequence design for 3D flow compensation of all echoes of a multi-echo gradient-echo sequence has been proposed in the context of venous oxygenation assessment using quantitative susceptibility mapping[3]. The purpose of this work is to illustrate the benefits arising from the use of such sequence with flow compensation for all echoes for susceptibility-weighted imaging. A concept for partial flow compensation is also extended to multi-echo imaging and evaluated.

Methods

All experiments were performed on a clinical 3T system. Complete 3D first-order multi-echo flow compensation was implemented by adding bipolar moment-nulling gradients between the echoes in the two phase encoding directions of a 3D multi-echo gradient-echo sequence[3]. First-order flow compensation in the readout direction was performed as usual by using a flyback gradient. Additionally, in order to counterbalance the echo spacing increase arising from the inclusion of the flow compensation bipolar gradients, the concept of partial moment-nulling[4] was extended to a 3D multi-echo acquisition by limiting the duration of the bipolar gradients to the targeted echo spacing and by performing moment-nulling as far out in k-space as possible. A direct comparison between multi-echo flow compensation in the readout direction only (commercial sequence, 4 echoes, ΔTE = 5.8 ms), partial 3D multi-echo flow compensation (4 echoes, ΔTE = 5.8 ms or 7.0 ms) and complete 3D multi-echo flow compensation (3 echoes, ΔTE = 9.8 ms) was performed on 4 healthy adults subjects. Magnitude and phase images from all echoes were independently combined using respectively a root sum-of-squares combination and a weighted linear combination[2] and phase masking was applied using the phase difference enhanced imaging algorithm[5].

Results and Discussion

Figure 1 presents magnitude images for the last echo from acquisitions performed with multi-echo flow compensation in the readout direction only (a), partial 3D multi-echo flow compensation with minimum echo spacing (b), partial 3D multi-echo flow compensation with intermediate echo spacing (c) and complete 3D multi-echo flow compensation (d). It can be observed that a substantial reduction in flow-induced displacement artifacts can be achieved even with minimum echo spacing by using partial flow compensation and that increasing the echo spacing leads to further improvements.

All flow induced artifacts in the uncombined magnitude and phase images will propagate to the combined susceptibility-weighted images. These effects can be visually assessed on Figure 2, which display the same slice of the combined susceptibility weighted images for all sequences. It can be observed that the use of a sequence with flow compensation in the readout direction only leads to blurring of the time-of-flight signal from thin arteries in the combined susceptibility-weighted image (a). This blurring comes from the fact that images with different amounts of flow induced displacement artifacts are combined. Complete 3D flow compensation leads to a geometrically accurate depiction of arteries (d), while partial flow compensation also provides a substantial gain over the case with flow compensation in the readout direction only (b and c) while allowing shorter echo spacing as opposed to complete flow compensation.

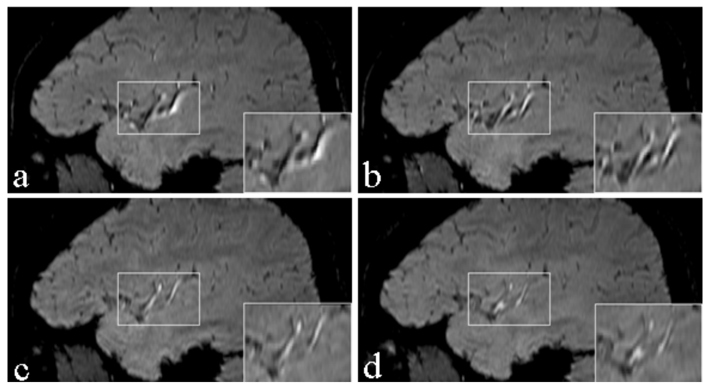

Figure 1: Images from the last echo of each sequence. a) Multi-echo flow compensation in the readout direction only (ΔTE = 5.8 ms, TE = 23.9 ms). b) Partial 3D multi-echo flow compensation (ΔTE = 5.8 ms, TE = 23.9 ms). c) Partial 3D multi-echo flow compensation (ΔTE = 7.0 ms, TE = 27.5 ms). d) Complete 3D multi-echo flow compensation (ΔTE = 9.8 ms, TE = 26.1 ms).

Conclusion

3D flow compensation improves arterial signal depiction in multi-echo susceptibility-weighted imaging. The use of partial flow compensation provides flexibility in the selection of the best compromise between flow compensation and minimum echo spacing for a given application.

References

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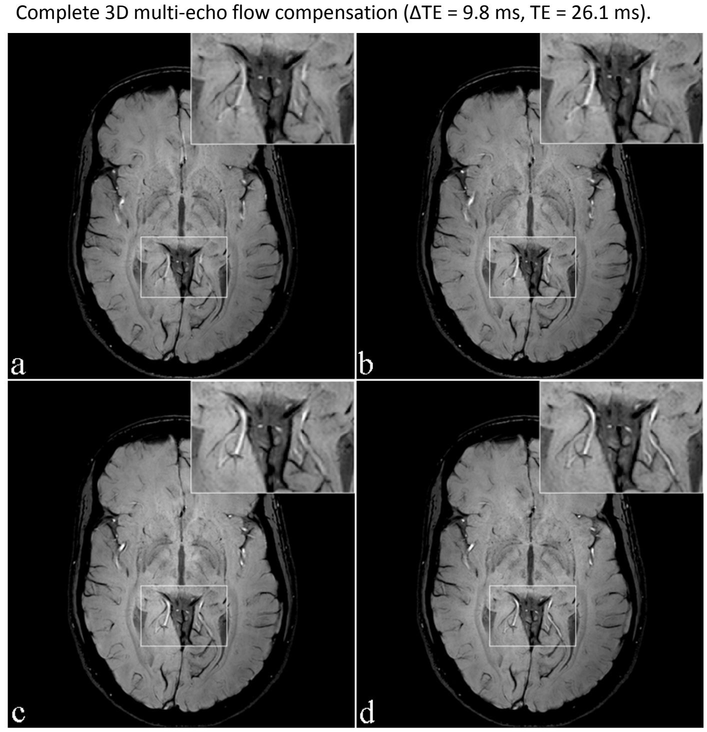

Figure 2: Combined multi-echo susceptibility-weighted images. a) Multi-echo flow compensation in the readout direction only (ΔTE = 5.8 ms). b) Partial 3D multi-echo flow compensation (ΔTE = 5.8 ms). c) Partial 3D multi-echo flow compensation (ΔTE = 7.0 ms). d) Complete 3D multi-echo flow compensation (ΔTE = 9.8 ms). Note the increase in sharpness and geometrical accuracy of the arteries from A to D.