Combining 3T, SENSE and k-space segmentation for robust coronary sinus flow quantification

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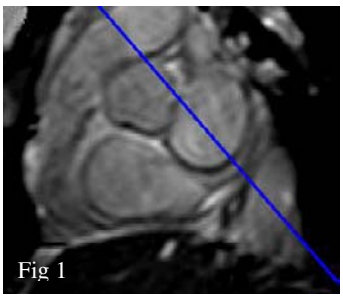
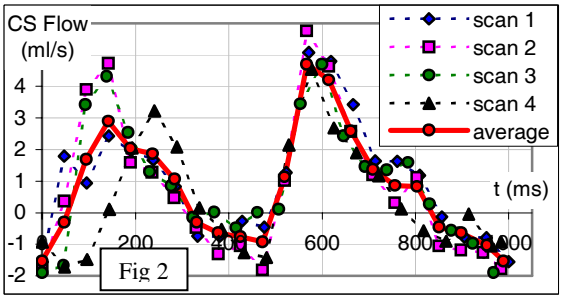
Introduction

Cardiac perfusion is an important physiological parameter, especially when measured both in rest and in stress, when the coronary flow reserve can be assessed. Furthermore, MR phase contrast (PC) measurements have the potential to quantify perfusion (1). To avoid respiratory motion, breath-hold PC sequences, using segmentation as well as SENSE, have been developed and evaluated (2-4). As the coronary sinus drains ~95% of the venous flow from the left ventricle (LV), flow in this vessel is a good representation of the total LV perfusion. However, the long acquisition windows that result from segmented techniques may lead to blurring and erroneous velocity measurements in the moving coronary sinus (CS). In this work, we demonstrate that the combination of high field strength (3T), parallel imaging and segmented gradient echo sequences allow for robust measurements of the coronary sinus flow within one breath-hold. Subsequent measurements of the left ventricular mass allow for deduction of the perfusion of the left ventricle.

Material and Methods

All scanning was performed on a Philips Intera 3.0 T system with a 6-element phased-array cardiac coil. For the phase mapping, a retrospectively triggered segmented GRE sequence was used (TE/TR= 3.5/5.4 ms, $\alpha = 10^{o}$, k-space segmentation factor=10, 21 heart phases, acquisition window~44 ms, BW~800 Hz/Pix, resolution=1.3x1.3 mm^2, slice thickness=8mm, v_{enc} =50-70 cm/s, total acquisition time ~20 seconds, SENSE reduction factor=2.0). Validation of the sequence was done by in-vitro measurements in a flow phantom (tube diameter: 4.8 mm, wall thickness<0.1 mm, background medium: agarose gel). For in-vivo validation, the CS flow was measured in 12 healthy volunteers. A built-in cardiac simulator was used to trigger the phantom study, while vector ECG was applied in vivo. To assess reproducibility, the phase mapping was performed three-four times in each volunteer. In addition, left ventricular (LV) mass was determined from a stack of short-axis slices acquired in breath-hold using balanced SSFP, $\alpha=60^{o}$. Software provided by the manufacturer (ViewForum) was used for region-of-interest based flow evaluation and for wall mass determination.





Results

In-vitro studies show the flow measured by MR and by timer and beaker to agree well over the measured range of flow rates (slope=0.94, R^2=0.997). The in-vivo studies show a bi-phasic flow pattern in the CS (fig. 2), as reported in the literature (5). Further, reproducibility of the flow values is demonstrated (Fig. 2). The average value for the deduced perfusion was found to be 0.59 ml/(min·g), in agreement with literature values (6,7).

Fig. 1. The slice for CS flow measurement was placed perpendicular to the vessel. **Fig. 2.** The reproducibility of the measurement is shown for one volunteer. The dotted lines indicate the four separate measurements, and the full-drawn curve shows the average of the four measurements.

	vol. 1	vol. 2	vol. 3	vol. 4	vol. 5	vol. 6	vol. 7	vol. 8	vol. 9	vol. 10	vol. 11	vol. 12	average
Flow (ml/min)	132	55	54	110	126	38	86	109	43	87	90	124	**88**
LV mass (g)	194	183	181	156	138	142	85	123	133	150	147	170	**153**
Perf. (ml/(min·g))	0.68	0.31	0.3	0.73	0.9	0.27	1.03	0.88	0.32	0.58	0.61	0.74	**0.59**

Table 1. The table summarizes the results from the volunteer studies. The derived value for perfusion is in accordance with literature values.

Discussion

For flow measurements in the CS, positioning of the imaging slice is crucial. It should be placed perpendicular to the CS lumen, and as close as possible to the right atrium, so that all venous branches have emptied into the CS, but must not lie inside the atrium during any part of the cardiac cycle. The planning can for examples be done on cine-images in short-axis orientation, see Fig 1. The low flow values for some volunteers (Table 1) can hence be a result of suboptimal slice positioning. As for all flow measurements, ROI placement is also crucial for a good result. Delineating the coronary sinus requires simultaneous examination of both magnitude and phase images, since confounding signal patterns may arise in the magnitude images, both from surrounding tissue and coronary arteries.

Conclusion

This study demonstrates that a segmented k-space PC sequence, designed for breath-hold studies, gives accurate and reproducible results in the coronary sinus using parallel imaging (R=2) at 3T, in vitro as well as in vivo. In vivo, mean flow was 88 ml/min, and mean perfusion was 0.59±0.22 ml/(min·g). Future development includes the use of the sequence for stress perfusion, and assessment of coronary flow reserve in a clinical setting.

References

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