Single breath-hold cardiac volumetry: a faster new approach by sliding slice cine imaging

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Introduction In difficult patients, real-time cine balanced SSFP (bSSFP) imaging is a final option for measuring cardiac function. Real-time imaging may be obtained without breath-hold or even without cardiac gating if necessary, unlike 2D-segmented or 3D cardiac imaging. Conventionally, for rapid assessment of cardiac function, real-time imaging acquires a cine of a short-axis slice in one cycle, and is repeated for the stack of short-axis slices as required to completely cover the left-ventricle. Real-time cine stack imaging often also uses two cardiac cycles per slice, because the first cycle is required for bSSFP stabilisation and to develop blood:myocardium contrast ready for the start of data acquisition at the second R-wave.
Aim Describe a sliding-slice method for cardiac function measurement which avoids the need for stabilisation delays, compare it with existing methods and also against simply omitting stabilisation on alternate cycles.
Methods Four methods (Table 1) for cardiac function were compared in each of 5 normal subjects, at 1.5T (Siemens Avanto). To avoid the interruptions caused by stepping to the next slice of the stack, real-time cine bSSFP imaging was modified to run continuously and shift the slice gradually during each image (sliding-slice real-time imaging). The shift was calculated so that the slice moved 10mm along the ventricle in a time calculated from the average RR interval found before starting the sequence. There was therefore no need for stabilisation cycles between the slices, so each slice cine required only one cycle to acquire. The image slice moved steadily along the entire ventricle during the breath-hold. For comparison, real-time cine imaging was acquired unmodified (2-cycle real-time imaging), and repeated without stabilisation of each slice (1-cycle real-time imaging). For a "gold-standard" reference, conventional multiple breath-hold cine bSSFP images were obtained (conventional cine imaging). For each cine, the left ventricular chamber area was measured at diastole and systole, and the areas were summed, subject to valve-plane motion, for end-diastolic volume (EDV) and end-systolic volume (ESV). Ejection fraction (EF) and stroke volume (SV) were calculated.

	Sliding-slice real-time	2-cycle real-time	1-cycle real-time	Conventional
Resolution (mm)	2.2FE x 3.4PE	2.2FE x 3.4PE	2.2FE x 3.4PE	1.4FE x 1.4PE
R-R intervals /slice	1	2	1	8
Shared-frame	Y	Y	Y	N
Frame time (ms) incl. sharing	68ms	68ms	68ms	37ms
Parallel imaging	GRAPPA x 1.7	GRAPPA x 1.7	GRAPPA x 1.7	TSENSE x 2

Table 1: Pulse sequence parameters

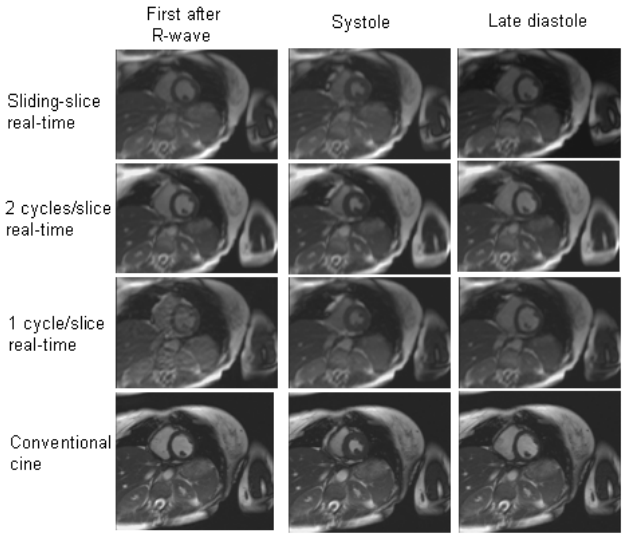

Figure 1

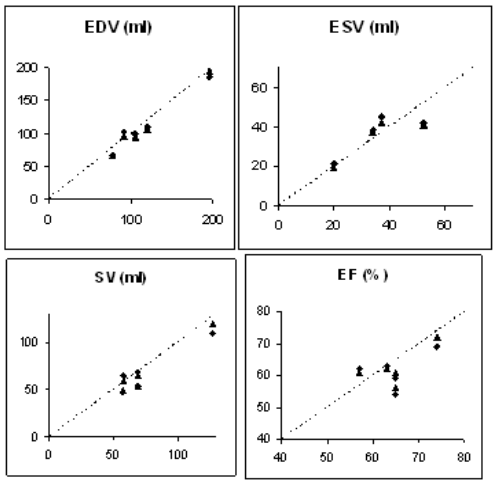

Figure 2: Triangle = 2-cycle real-time, Diamond= sliding-slice. compared with conventional cine on horizontal axis.

Results and Discussion Example images for the four approaches are shown in Figure 1. With no stabilisation, the 1-cycle real-time imaging method showed artefacts and low contrast in the first few cine frames. The end-systolic frame was reasonably clear of stabilisation artefact, but blood:myocardium contrast did not reach that of the 2-cycle approach. Diastolic volume could be measured more accurately from the last frame of the cine because the first frame already contained some cardiac contraction (due to the shared-phases), but the 1-cycle approach was discontinued. For the sliding-slice method, image contrast between myocardium and blood was reduced for some cardiac phases, and it is unclear how much stabilisation / magnetisation transfer, which usually darkens myocardium, occurs in this technique. A modified form of the sliding-slice idea might pause the motion after 10mm waiting for the next R-wave (if ECG is available). Figure 2 compares real-time ventricular function measurements against the conventional cine, showing considerable scatter for both real-time approaches. (One subject was at the upper limit of normal range). The lower resolution of real-time imaging reduces its accuracy, in both temporal and spatial resolutions. Both the conventional 2-cycle real-time approach and the sliding-slice approach performed similarly, at half the breath-hold time for the sliding-slice method. The continuous cine of the sliding-slice was limited to 128 phases by software, obstructing its use in subjects with slow heart-rates. As a last resort in difficult cases, it seems unfortunate that multislice cine real-time image normally spends alternate cycles stabilising the steady-state. The sliding-slice cine approach sought to circumvent this inefficiency, but the gradual change in slice contents may challenge the shared-phase and parallel imaging methods. Surprisingly, this only sometimes caused FOV/2 artefacts.
Conclusion The sliding-slice continuous cine enables more rapid cardiac volume acquisition, but some reduction of blood:myocardium contrast and artefacts would require further investigation.