Is Phonocardiogram Gating a Reliable Alternative to ECG Gating in Clinical Routine for CINE and Velocity-Encoded Phase Contrast Imaging?

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Introduction:

Similar to other applications of clinical MRI, cardiac MR (CMR) is moving toward imaging at ultrahigh field strengths (≥ 7 Tesla) due to potential gains associated with increasing field strengths. Beside the well-known challenges intrinsically tied to all imaging at ultrahigh field strengths, CMR is additionally hindered by the fact that magneto-hydrodynamic (MHD) effects [1] cause artificial modifications of the ECG trace to such an extent that ECG gating or triggering fails in a large number of cases at 7 T [2].

To overcome this problem, an acoustic gating approach using the heart tones as a trigger impulse has been introduced for cardiac imaging at ultrahigh field strengths [3]. The principle advantages of this so-called phonocardiogram (PCG) gating are its intrinsic insensitivity to MHD effects as well as its use of a well-defined trigger impulse – the first heart tone S_1. So far, this triggering approach had only been evaluated in a rather small number of healthy volunteers [4] for cine imaging of the left ventricle (LV) and not at all for phase contrast flow measurements, which form an additional integral part of many CMR examinations [5].

Therefore, our study aimed to validate the diagnostic accuracy of acoustic triggered cine imaging for the assessment of LV global and regional function (Part A) as well as for velocity-encoded phase contrast MRI for flow quantification (Part B) in a clinical routine protocol at 1.5 T.

Materials and Methods:

For acoustic triggering an in-house developed phonocardiogram (PCG) gating device was used. For auscultation of the heart tones, an optoacoustic microphone (Optimic 4135S, Optoacoustics, Israel) containing no conductive parts was placed close to the left sternal border toward the apex of the heart on top of or beneath the patients' clothes. The microphone was fixed to the chest with an elastic strap to minimize the displacement during the examination. For extraction of the important heart tones (S_1, S_2) from the acoustic noise (MR system, patient, …), a low-pass filtering algorithm was used. To differentiate S_1 from S_2, a threshold-based algorithm was employed and S_1 was then used to generate a TTL trigger signal which was directly fed into the external trigger input of the MR scanner.

In this prospective study, 147 patients were enrolled. (Part A) cine imaging of the LV was performed twice in random order by using a retrospectively PCG- / ECG-gated cine SSFP sequence in 79 consecutive patients (known or suspected coronary heart disease (n=53), suspected myocarditis (n=11), valvular heart disease (n=4), and various cardiomyopathies (n=11)); (Part B) phase contrast imaging for flow quantification above the aortic valve was performed twice in random order by acquiring a retrospectively PCG- / ECG-gated velocity-encoded phase contrast gradient echo sequence in 68 consecutive patients (known or suspected coronary heart disease (n=44), suspected myocarditis (n=7), valvular heart disease (n=10), and various cardiomyopathies (n=7)), both parts on a 1.5 T MRI (Avanto, Siemens Healthcare, Erlangen, Germany).

The quantitative image analyses for clinically relevant parameters were performed using the ARGUS™ software (Siemens Healthcare). For Part A the end-diastolic volumes (EDV), end-systolic volumes (ESV), stroke volumes (SV), ejection fraction (EF), muscle mass (MM), as well as regional wall motion and for Part B the peak velocity (PV), average velocity (AV), forward volume (FV), reverse volume (RV), net forward volume (NFV), as well as the regurgitant fraction (RF) were assessed for the ECG- and PCG-gated datasets. For an improved analysis of the flow data with ARGUS™, the inherent PCG trigger delay was compensated by resorting the data. Additionally, gating artifacts were qualitatively assessed for both gating approaches.

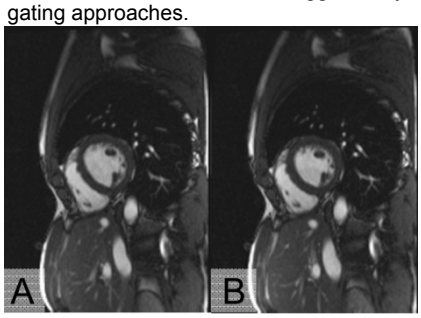

Figure 1:
Mid-ventricular short-axis cine SSFP scans of a 51-year-old male patient with suspected coronary heart disease acquired with ECG (A) and PCG (B) gating: visually comparable image quality for both gating approaches.

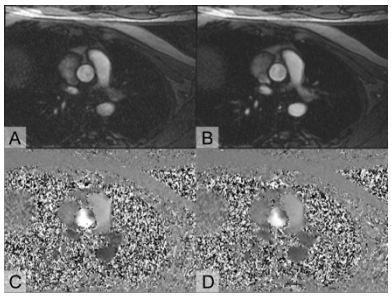

Figure 2:
For quantitative flow measurements, velocity-encoded phase contrast gradient echo (A,C: magnitude; B,D: phase) images were acquired just above the valve level to transect the aortic root with ECG (A, C) and PCG (B, D) gating: visually comparable image quality for both gating approaches.

Results:

PCG-gated imaging was feasible in 139 (95%) patients (75 (95%) for cine measurements and 64 (94%) for flow quantification measurements), whereas the ECG gating worked well in all 147 (100%) patients. Part A: Excellent correlations were observed for all volumetric parameters (r>0.98 for all variables analyzed). EDV (-0.24±3.14 mL, p=0.5133), ESV (-0.04±2.36 mL, p=0.8951), SV (-0.20±3.41 mL, p=0.6083), EF (-0.16±1.98%, p=0.4910), and MM (0.31±4.2 g, p=0.7067) showed no significant differences for the study cohort. Furthermore, PCG- and ECG-gated cine imaging revealed similar results for regional wall motion analyses (115 vs. 119 segments with wall motion abnormalities, p=0.3652). PCG-gated cine images showed a non-significant trend to more gating artifacts compared to ECG-gated images (15.5% vs. 10.2%, p=0.0975). Part B: Before compensation of the PCG inherent trigger delay, significantly different values where observed for PV (121.0±33.9 cm/s vs. 117.3±29.9 cm/s; *p*=0.0367), FV (77.8±27.0 ml vs. 82.7±23.7 ml; *p*=0.0154), and NFV (74.0±27.9 ml vs. 78.5±24.7 ml; *p*=0.0329) when comparing PCG- and ECG-gated flow quantification. After compensation, significantly different values were observed only for PV (121.0±33.9 cm/s vs. 117.3±29.9 cm/s; *p*=0.0367). Nevertheless, wide limits of agreement between PCG- and ECG-gated flow quantification were observed for all variables analyzed (PV: -23.9 to 31.4 cm/s; AV: -4.5 to 3.9 cm/s; FV: -35.6 to 25.9 ml; RV: -8.0 to 7.2 ml; NFV: -36.8 to 27.8 ml; RF: -10.4 to 10.2%). PCG-gated phase contrast images showed significantly more gating artifacts compared to ECG-gated images (25% vs. 3%, *p*=0.0009).

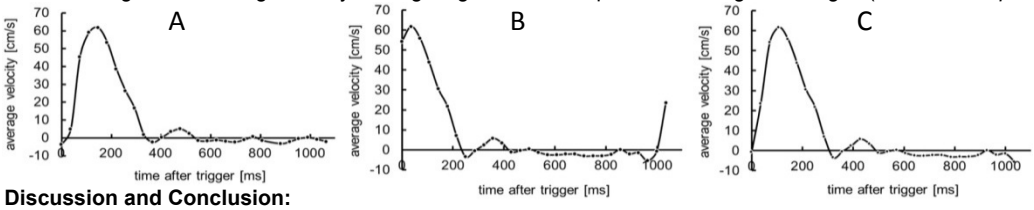

Figure 3:
Average velocity over time curves as derived from ECG-gated (A), PCG-gated (B), and PCG-gated velocity-encoded images after compensation of the PCG trigger delay (C) in a 56-year-old male patient with suspected myocarditis.

Discussion and Conclusion:

The present study demonstrates the great potential of PCG gating. In conjunction with cine imaging it enables accurate assessment of global and regional LV function in most patients in clinical routine, whereas in its current form it is not reliable enough for flow quantification based on velocity-encoded phase contrast gradient echo sequences. Therefore, further refinements of the post processing algorithm such as matched filtering will be necessary to enable widespread use of PCG gating.

References:

[1] Schenck JF, Prog Biophys Mol Biol2005;87(2-3):185-204. [2] Frauenrath T, et al. J Cardiovasc Magn Reson 2010;12:67. [3] Frauenrath T, et al. Invest Radiol 2009;44:539-547. [4] Becker M, et al. Eur Radiol 2010;20(6):1344-1355. [5] Kramer CM, et al. J Cardiovasc Magn Reson 2008,10:35.