Comparison of 3DQRS and VCG Approaches for MR Gating in 1.5T, 3T & 7T MRIs

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Target Audience: Scientists and physicians interested in cardiac MRI and methods for accurate QRS complex detection and MR gating.

Purpose: During cardiac MR imaging, blood plasma electrolytes ejected into the aorta during early systole interact with the strong magnetic field of the MR scanner to produce a Magnetohydrodynamic (MHD) effect. Electrocardiograms (ECG) recorded in the presence of this magnetic field are overlaid with a MHD-induced voltage (VMHD)[1]. Intermittent QRS detection and MRI gating are resulted, despite the use of Vectorcardiogram (VCG) based gating approaches in most MRI scanners[2], especially at high field strengths[3]. A multiple channel ECG-based cross-correlation algorithm, the 3DQRS, has been developed to achieve increased sensitivity in QRS detection at high field strengths[4]. 3DQRS utilizes a 3-D ECG representation, whereas the third dimension, in addition to voltage and time, is deemed a channels axis, formed from concurrent viewing of the precordial leads V1-V6 (Fig.1). A quantitative comparison of the 3DQRS method and a VCG-based approach at 1.5T, 3T and 7T field strengths was performed on 15 human subjects as an assessment of robustness.

Methods: 12-lead ECG data was recorded using a prototype MRI-conditional 12-lead ECG recorder[5] from 2 Premature Ventricular Contraction (PVC) patients, 2 Atrial Fibrillation (AF) patients, and 8 healthy exercising athlete at 1.5T and 3T[4] (Fig.2). A Halter recorder was used in 2 healthy volunteers at 7T[6](Fig.2). QRS detection was performed using a VCG-based approach (V1-V6,I,II)[2] and 3DQRS (V1-V6) using standard 12-lead ECG chest positioning[4]. Assessments of 3DQRS robustness relative to variations in field strength and cross-correlation kernel temporal length were performed (Fig.3). False Positive (FP) and False Negative (FN) counts were recorded (total of 1,262 beats) in order to assess the sensitivity in QRS detection for each method at 1.5T, 3T, and 7T.

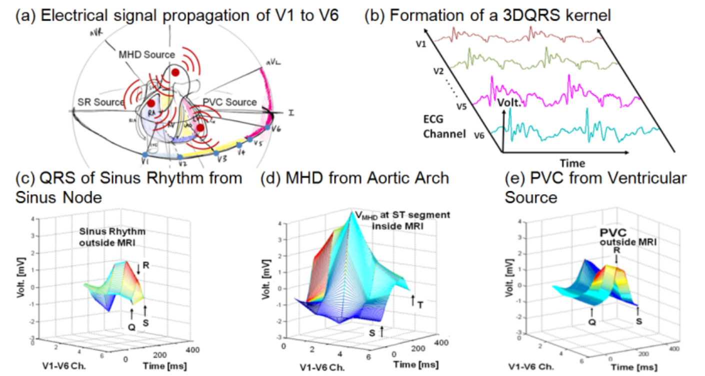

Figure 1: The 3DQRS detection principle; (a) geometric representation of cardiac voltage sources observed within the MRI bore relative to the position of the surface leads V1-V6, (b) formation of a typical 3DQRS complex, (c) QRS of sinus rhythm outside the MRI in an Idiopathic Outflow Tract (IOT) PVC patient, (d) V_{MHD} at 3T, (e) PVC outside the MRI in an IOT PVC patient.

Results (Table1): 3DQRS subject-averaged accuracy levels in QRS detection (Percent False Negative), relative to VCG, were: 1.5T (100% vs. 96.6%), 3T (98.1% vs. 87%), 7T (96% vs. 71.2%). In PVC patients (1.5T), 3DQRS separated between the SR and PVC beats with 100% accuracy, whereas VCG falsely detected PVC beats with only 37.3% accuracy. Sensitivity (Se) and positive predictive (+P) value analyses were included.

Discussion and Conclusion: Higher sensitivity and positive predictive values in QRS detection was achieved using the 3DQRS method when compared to the VCG-based approach in ECGs acquired within 1.5T, 3T and 7T MRI. VCG falsey detected PVC beats, which were of a similar temporal length and magnitude to beats generated from the sinus rhythm (SR), while 3DQRS was able to consistently differentiate from SR beats.

References: [1] Gupta, IEEETrans.BioMed.Eng. 2008. [2] Fischer, MRM 1999. [3] Krug, JCMR 2013. [4] Tse, JCMR 2013. [5] Tse, MRM 2013. [6] Krug, Comp.InCardiol. 2012.

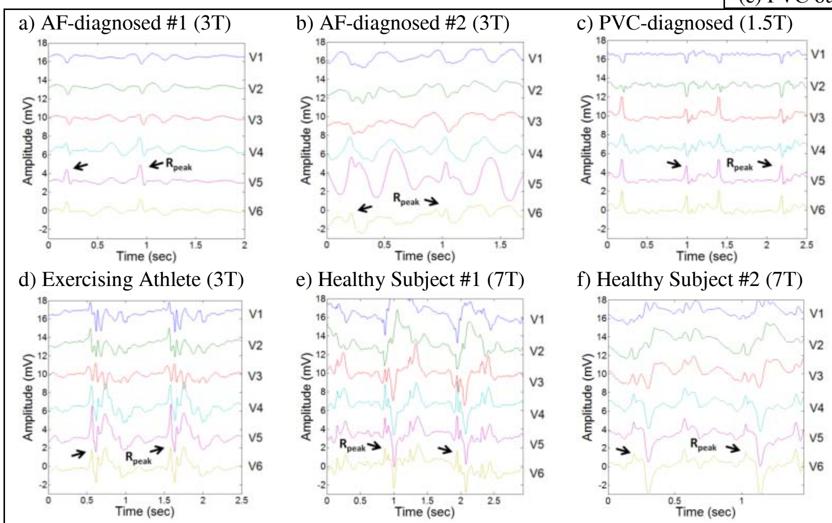

Figure 2: Representative 2 cardiac cycles for patients and volunteers at various field strengths, with the detected R-wave peak positions denoted.

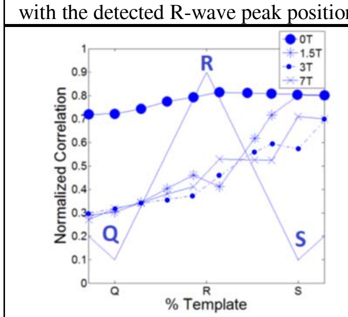

Figure 3: Variation of 3DQRS for multiple field strengths with the temporal length of the QRS complex kernel utilized. A shorter length kernel allows for faster processing time

Table 1: Results of 3DQRS Efficacy Test at 1.5T, 3T, and 7T

		3DQRS		VCG-based		Marked
		False Negative	False Positive	False Negative	False Positive	Total Beats
Section 1	AF-Diagnosed #1 at 3T	3	1	3	6	45
	AF-Diagnosed #2 at 3T	1	1	34	18	169
	Exercising Athlete at 3T	2	2	4	22	102
	8 Healthy Volunteers	4	4	39	33	635
	Total Count	10	8	80	79	951
	Sensitivity (Se)	98.9%		92.2%		--
	Positive Predictive (+P)	99.2%		92.3%		--
Section 2	PVC #1 at 1.5T	0	0	1	21	24
	PVC #2 at 1.5T	0	0	1	16	35
	Total Count	0	0	2	37	59
	Sensitivity (Se)	100%		96.7%		--
	Positive Predictive (+P)	100%		61.5%		--
Section 3	Healthy Subject #1 at 7T	6	6	175	156	382
	Healthy Subject #2 at 7T	29	30	80	56	505
	Total Count	35	36	255	212	887
	Sensitivity (Se)	96.2%		77.7%		--
	Positive Predictive (+P)	96.1%		80.7%		--