16 Months of Exercise – A Case Study of Automated CMR with Cardiac Dot Engine

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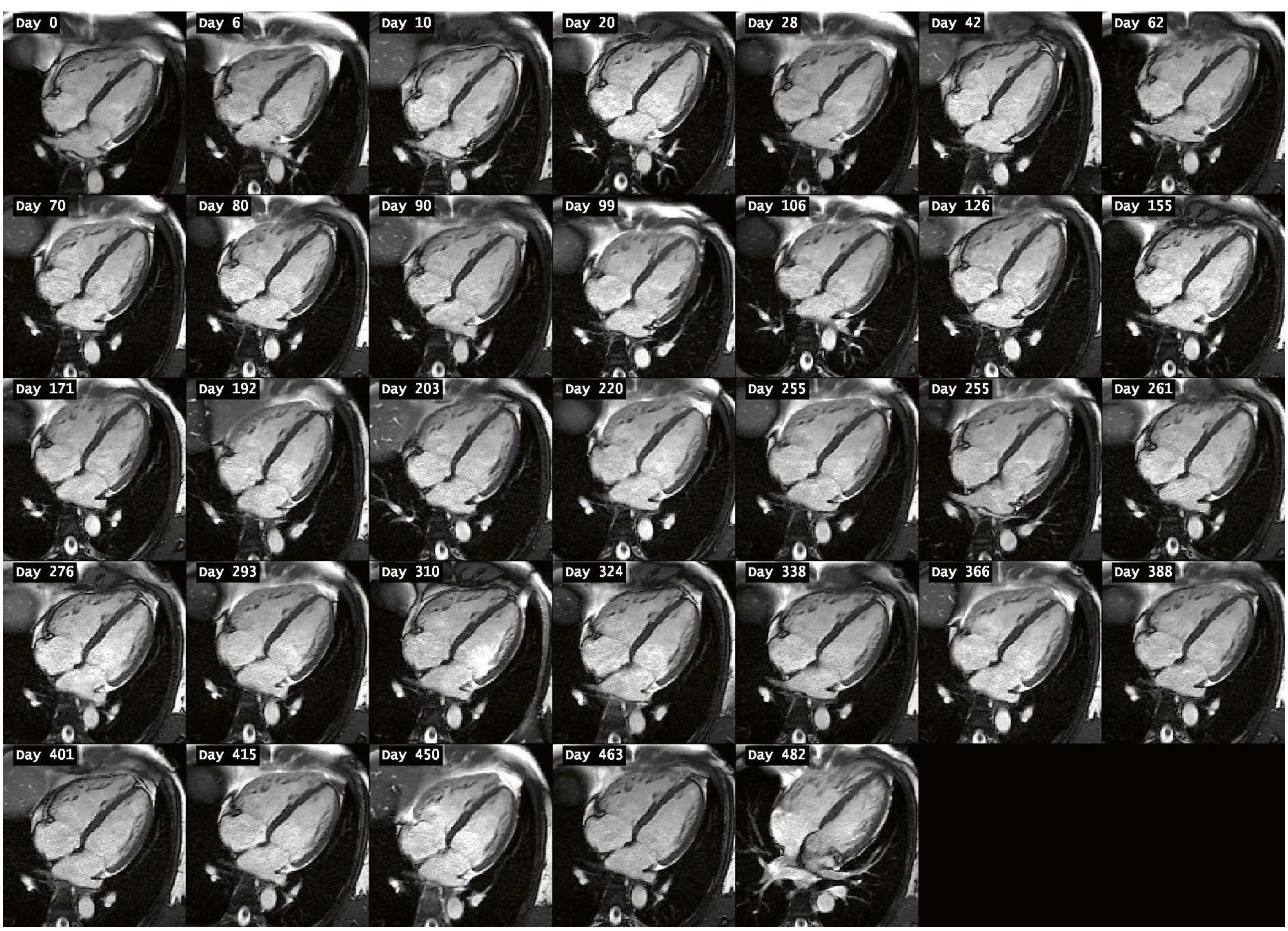
Introduction

Cardiovascular magnetic resonance imaging (CMR) provides valuable information for the clinical management of patients and is widely accepted as the gold standard for functional and viability imaging. However, CMR is a demanding imaging modality and it can be challenging to avoid inter-operator variability in both acquisition and interpretation. Positioning of standardized views such as the long axis views and short axis stack can be challenging for less experienced operators, and numerous sequence adjustments to optimize image quality require significant effort, all resulting in inconsistency between scans. Manual contouring of the myocardium for functional analysis is time consuming and can also be a significant source of variability for less experienced readers. Variability in both slice planning and manual contouring performed by different operators can negatively affect longitudinal studies where a high degree of reproducibility is required.

Aerobic exercise is well regarded as beneficial for cardiovascular health. The American Heart Association recommends at least 150 minutes of moderate-intensity



1 Automated slice prescription of a 4-chamber view using the AutoAlign component of the Cardiac Dot Engine over 16 months.

aerobic activity per week [1]. In this study, we sought to monitor and assess the effects of a high-intensity exercise training program on a healthy subject using CMR due to its potential for quantifying small changes in cardiac function. The exams were carried out using Cardiac Dot Engine technology (Siemens Healthcare, Erlangen, Germany) to minimize variability in this longitudinal study.

The Cardiac Dot Engine available on Siemens Healthineers MRI scanners provides a suite of guidance technologies designed to improve workflow by reducing operator burden during CMR acquisition and interpretation. The AutoAlign component of the Cardiac Dot Engine uses a machine learning based algorithm trained on 517 patient datasets to identify five anatomical landmarks – the base of the left atrium, aortic root, acute margin of the right ventricle, base of the left ventricle, and left ventricular apex [2–5]. From these landmarks, the standard 2-, 3-, and 4-chamber long axis views as well as the short axis stack are planned. The operator has the option to accept or adjust the position of the landmarks or view orientations if needed. The AutoTiming feature can be used to automatically adjust sequence parameters such as segments, phase resolution, and partial phase Fourier in a user configurable algorithmic manner to reduce scan duration for patients with diminished breath-hold capacity.

The InlineVF module automates the contouring of the endocardium and epicardium of the left ventricle and detection of the mitral valve basal plane. The left ventricular blood pool is segmented using an isoperimetric clustering algorithm [6]. Greyscale analysis with a shortest path algorithm is used to segment the endocardium and epicardium with inverse consistent deformable registration used to apply segmentation to all cardiac phases [7, 8]. A machine learning based cardiac anchoring technique is used to determine the basal and apical landmarks [5]. Together, the various automations in the Cardiac Dot Engine can reduce operator variability and is well suited for longitudinal studies where high reproducibility is required.

Methods

A single healthy 33-year-old male subject was enrolled in a high-intensity exercise program consisting of >150 minutes/week of high intensity aerobic exercise at >75% of age-predicted maximum heart rate (MHR). Exercise activity and heart rate were measured using an Apple Watch Series 3 (Apple Inc., Cupertino, CA, USA). CMR imaging was performed approximately every 2 weeks on a 1.5T MAGNETOM Aera (Siemens Healthcare, Erlangen, Germany). Cine imaging was performed with the following typical sequence parameters: 340 × 280 mm field of view, 1.5 × 1.5 mm^2 in-plane resolution, 6 mm slice thickness, 50° flip angle, 1.16/2.81 ms TE/TR, 13 views per segment, 36.5 ms temporal resolution. The AutoAlign feature of the Cardiac Dot Engine was used to automatically prescribe the 2-, 3-, and 4-chamber views as well as the short axis stack. The Cardiac Dot Engine was also used to automatically start and stop each scan by giving breath-hold instructions with an operator-defined rest interval between scans. InlineVF was used to calculate the ejection fraction, end-diastolic volume, end-systolic volume, stroke volume, cardiac output, and myocardial mass, with results reported inline during each CMR exam. Linear regression was used to evaluate potential trends.

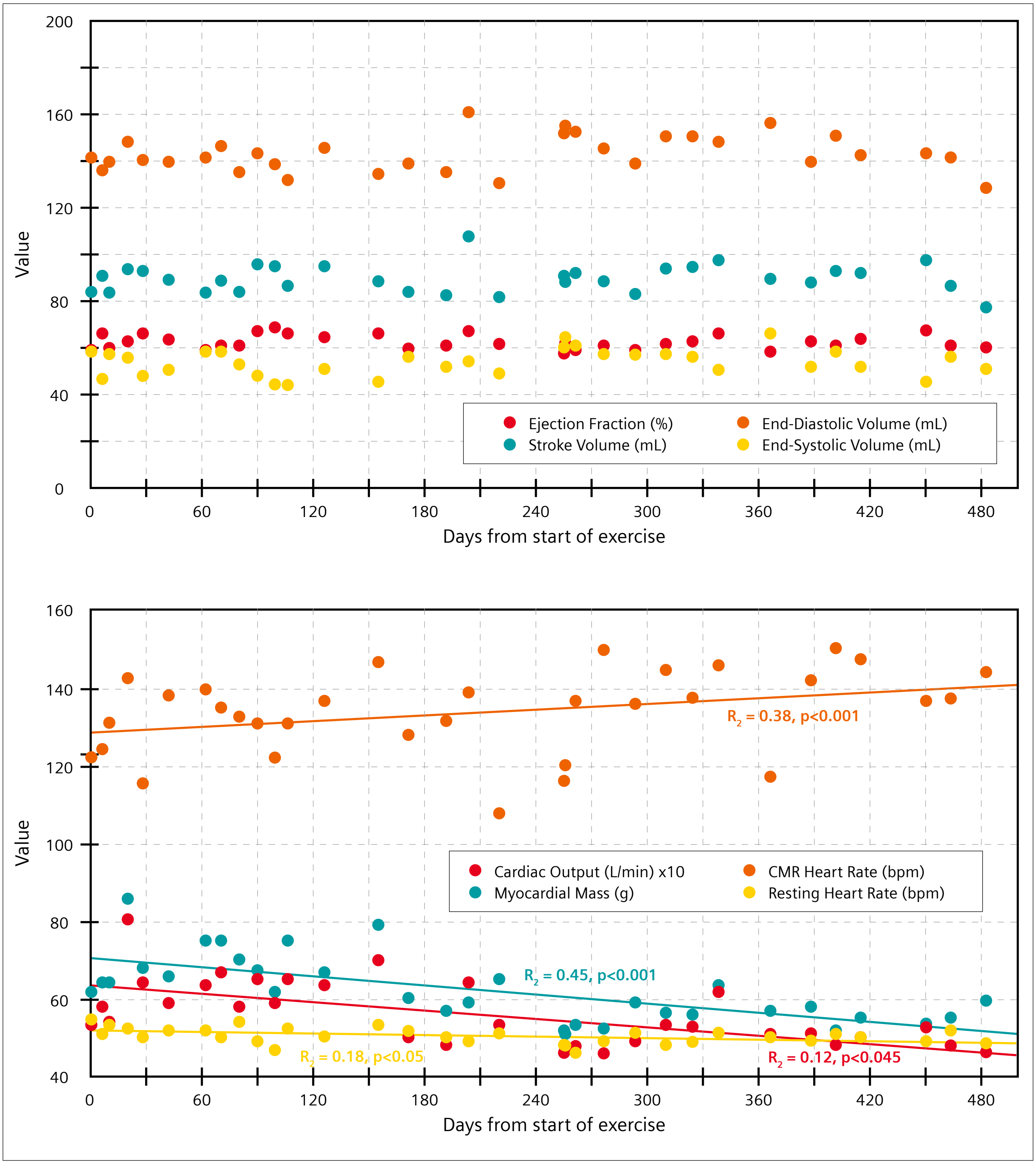
Results

The exercise program was well tolerated throughout the 16-month study duration, with an average of 154±5 minutes per week of high-intensity exercise. Daily "exercise minutes" categorized by the Apple Watch increased from 38±8 minutes in the 7 months prior to the start of the study to 58±6 minutes during the study. During exercise, the mean average heart rate was 159±6 bpm (85±3% of MHR) with a mean peak heart rate of 178±6 bpm (95±3% of MHR). Subject's weight remained unchanged over the course of the study. A total of 33 CMR exams were performed with a mean follow-up interval of 15±8 days.

	Overall	First 60 days	Last 60 days
Ejection Fraction (%)	62.6 ± 3.1		
End Diastolic Volume (mL)	143.7 ± 7.7		
End Systolic Volume (mL)	53.8 ± 5.6		
Stroke Volume (mL)	89.9 ± 6.0		
Cardiac Output (L/min)*	5.6 ± 0.8	6.1 ± 1.0	4.9 ± 0.4
Myocardial Mass (g)*	134.2 ± 10.9	129.3 ± 10.3	139.7 ± 4.2
CMR Heart Rate (bpm)*	62.2 ± 8.6	68.3 ± 8.9	56.0 ± 2.6
Resting Heart Rate (bpm)*	50.3 ± 1.9	52.0 ± 1.4	49.7 ± 2.1

* indicates a linear trend with $p < 0.05$. Resting heart rate was measured with an Apple Watch, and all other parameters are from Siemens Healthineers Inline VF.

Table 1: Cardiac structure and function over 16 months of exercise.



2 Trends of cardiac structure and function over 16 months of high-intensity exercise.

Automated slice planning with AutoAlign required no user intervention in 32/33 cases, where manual identification of a landmark was required in a single case. Slice orientation was highly consistent between studies (Fig. 1). Automated InlineVF analysis was successful in all cases (Table 1, Fig. 2). Ejection fraction and all volumetric measurements were unchanged over the course of the study. Myocardial mass increased 8% from the first 60 days to the last 60 days ($p<0.05$). Cardiac output dropped by 20%, coincident with an 18% decrease in heart rate during CMR and a 4% decrease in resting (sleeping) heart rate ($p<0.05$). Inter-study consistency was good for all parameters, with <10% coefficient of variation for all parameters in which there was no statistical change over the course of the study.

Conclusions

Automated CMR acquisition and analysis techniques were successfully applied to 33 CMR serial exams and used to quantify changes in cardiac function during a high-intensity exercise program. Increased myocardial mass was consistent with a previous study on exercise training [9], although previously reported changes in chamber volumes [10] were not found. Individual responses to exercise training may vary and subjects with >30 "active minutes" as measured by an Apple Watch may have less cardiovascular benefit from an additional high-intensity exercise program. The automated tools in the Cardiac Dot Engine reduce the burden of scanning and interpretation of CMR and reduce overall variability. High inter-study reproducibility of the imaging slice orientations is beneficial for direct comparison of images in serial follow-up studies and in more accurately quantifying small changes in cardiac structure and function.

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