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Influence of the short-axis cine acquisition protocol on the cardiac function evaluation: A reproducibility study

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ABSTRACT

Purpose: To define the optimal cardiac short-axis cine acquisition protocol for the assessment of the left and rightventricular functions.
Materials and methods: 20 volunteers were recruited and breath-hold CINE images were acquired on a Siemens Prisma 3T MRI. Four short-axis acquisition planes were defined from the 4-chamber view. *AV Junctions*: short-axis slices parallel to the plane that cuts through the external right and left atrioventricular junctions. *Left AV Junctions*: short-axis slices parallel to the plane that cuts through both left atrioventricular junctions. *Septum*: short-axis slices perpendicular to the septum with one cutting through the septum junction. *LongAxis*: short-axis slices perpendicular to the long axis with one cutting through the septum junction. Intra and inter reproducibility was assessed using Bland-Altman coefficient of variation (CV) and Lin's concordance correlation coefficient (CCC). The influence of the protocol on the ejection fraction (EF) and stroke volume (SV) was quantified statistically using pair-wise CV and Pearson's correlation coefficient R^2.
Results: All protocols led to high reproducibility for the LV EF (mean intra CV = 3.83%, mean inter CV = 4.81%, lowest CV = 4.20% (AV junctions) and highest CV = 5.24% (Left AV Junctions)). Reproducibility of the RV measurements was lower (mean intra CV = 7.84%, mean inter CV = 9.17%). Septum protocol led to significantly lower variability compared to the other 3 protocols for RV EF (CV = 7.62% (Septum), CV = 8.42% (Long Axis), CV = 9.54% (Left AV Junctions) and CV = 11.08% (AV Junctions) with Lin's CCC varying from 0.4 (AV Junctions) to 0.69 (Septum) for inter-observer reproducibility). No differences in group average for clinical parameters was found for both LV and RV clinical measurements. However, patient-specific RV EF evaluation is dependent on the chosen protocol (CV = 9.95%, R^2 = 0.52).
Conclusion: Based on the results of the study cine mode short-axis acquisitions should be planned perpendicular to the septum in order to guarantee optimal RV and LV measurements.

1. Introduction

The diagnosis and follow up of cardiovascular diseases are very challenging. Choosing the appropriate test to perform as well as measuring accurately the desired quantities is of high importance to make reliable, relevant clinical decisions. Cardiovascular Magnetic Resonance (CMR) imaging has proven to give more reproducible and accurate evaluation of the left and right ventricular functions compared to other modalities [1–4], mainly due to its high temporal resolution combined with a high spatial resolution which allow to cover the entire heart and the entire cardiac cycle [5]. Analysing these images with accuracy is challenging and requires specific training [6]. In particular, reproducibility of the measurements for the right ventricle (RV) seems to be adequate only with long processing times (45 min) [7,8] not compatible with routine practice. Therefore, current clinical studies on RV function must include a large data sample [9] for the group differences to be significant. This reproducibility issue is mainly due to the choice of the basal slice to include in the segmentation, for the left ventricle (LV) and the RV [10], in spite of precise guidelines to perform this selection [11]. Consistency in the imaging protocols is essential to compare results over different studies and for multi-center trials. The standard CMR protocol for the assessment of the left and right ventricular function includes 3 long axis slices (2-chamber view, 3-chamber view and 4-chamber view) and 10–14 contiguous short-axis slices. Each of these slices is a 2-dimensional (2D) image over 20–25 time frames, in order to represent the full

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cardiac cycle. Although, axial plane assessment of RV function has been shown to be more robust [12], the standard protocol still consist of the short-axis slices in order to evaluate both ventricles without increasing scanning time, as described by the SCMR guidelines [13]. The orientation of the short-axis stack is ambiguous and variation in clinical protocols exists. Conventionally, the short-axis slice orientation is defined from the 4-chamber view at end-diastole. It then varies from being perpendicular to the septum [14], or perpendicular to the long axis (defined as the axis passing through the apex and the center of the mitral valve) as prescribed by the SCMR 2008 guidelines [13]. Another definition commonly used forces the first slice to be placed across the atrioventricular valve plane. For a specific evaluation of the RV function, an acquisition plane from the outflow tract to increase accuracy can also be defined [15]. In this study, since the accuracy of the segmentation cannot be assessed by comparison with a true value, the optimal acquisition protocol will be defined as the one leading to the most reproducible results. Intra and inter observer variability will be measured for several short-axis orientation protocols as well as the influence of these protocols on the clinical parameters. Therefore, this studies aims at defining the optimum imaging protocol alignment for simultaneous measurement of RV and LV function using short-axis cine CMR imaging.

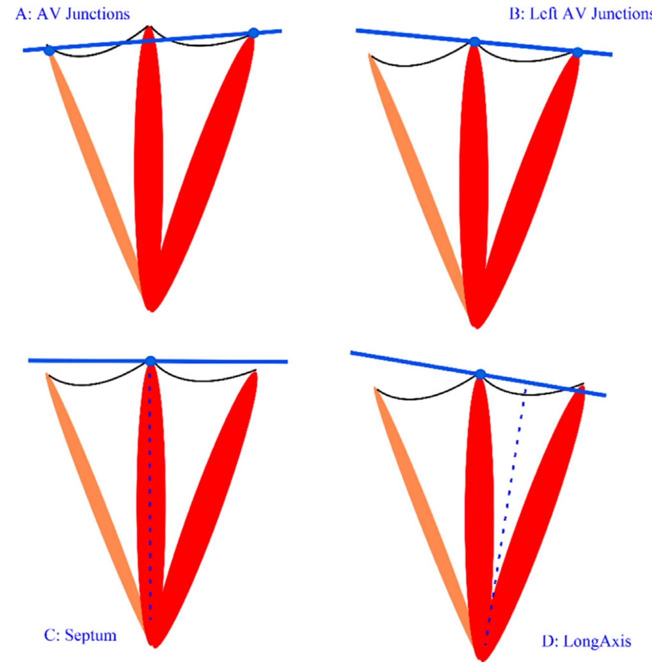

Fig. 1. Definition of the 4 protocols. (A) *AV Junctions*: short-axis slices parallel to the plane that cuts through the right and the left atrioventricular junctions. (B*) Left AV Junctions*: short-axis slices parallel to the plane that cuts through the left atrioventricular junction. (C) *Septum*: short-axis slices perpendicular to the septum with one cutting through the septum junction. (D) *Long Axis:* short-axis slices perpendicular to the long axis with one cutting through the septum junction.

2. Methods

2.1. Study population

The study population consisted of 20 healthy volunteers without known cardiovascular diseases (mean age 33, range 22–69, mean weight 67.9 kg, range 46–120 kg, 10 males). Exclusion criteria were standard for MRI studies (no metallic device, no pregnant woman, claustrophobia). Ethical approval was obtained and all subjects gave written consent. The sample size was limited by the acquisition time of approximately 20 min more than one standard cine protocol. This protocol was therefore limited to healthy volunteers not undergoing other CMR imaging sequences [16].

2.2. CMR acquisition

The study was performed using a 3T MR system (MAGNETOM Prisma, Siemens, Erlangen, Germany) equipped with an anterior 18-element matrix coil and a posterior 32-element spine matrix coil. Images were obtained with ECG-gating and breath-holding. The scanning protocol was as follows: 1) Transverse True fast imaging with steady state precession (TrueFISP) single-shot sequence of the whole heart was performed for the localization, 2) left ventricular 2-chamber TrueFISP cine, 3) 4-chamber TrueFISP cine, 4) 4 sets of contiguous short-axis TrueFISP cine stack of the two ventricles in which the orientation of each short-axis stack varies (Fig. 1). The short-axis stacks were obtained by aligning the imaging plane parallel to both right and left atrioventricular junctions with one slice cutting through both atrioventricular junctions (*AV Junctions* protocol), aligning the imaging plane parallel to the left AV junction only (*Left AV Junctions* protocol), aligning the plane perpendicular to the septum with one slice acquired through the septal junction (*Septum* protocol) and aligning the imaging plane perpendicular to the long axis of the LV with one slice cutting through the septal junction (*Long Axis* protocol). The contiguous short-axis TrueFISP cine stack parameters were as follows: TR = 45.15 ms, TE = 1.37 ms, slice thickness = 8 mm, FOV = 300 $\times$ 300 mm, matrix = 192 $\times$ 192, flip angle = 55, parallel imaging factor = 3 and inter-slice gap = 25%, as per SCMR latest acquisition guidelines. The four sequences were acquired in the following order: *Septum*, *Left AV Junctions*, *AV Junctions* and *Long Axis*.

2.3. CMR image analysis

The segmentation of both the RV and LV was performed on Segment, Medviso software version 3949 [17] which has been 510 k FDA approved.

For LV function assessment, epicardial and endocardial borders were automatically contoured and calculated by selecting the basal and apical short-axis slices. Basal slice was defined as the slice with more than 50% myocardium around the blood during diastole (Fig. 2) as described by the SCMR analysis guidelines [11]. Apical slice was selected as the last slice of the stack with visible ventricular cavity. Manual adjustment of the contours was performed if required. Papillary muscles were estimated and excluded from the LV volume calculation. The adjustment for systolic atrioventricular ring descent was performed automatically by the software with manual selection of the basal descent. The basal descent was estimated by identifying the basal plane at end-systole (ES) and end-diastole (ED) with the inclusion of the slice thickness and inter-slice gap. (Fig. 3). From the delineated contours, the end-diastolic volume (EDV) and end-systolic volume (ESV) were computed using the summation of disc method. Both stroke volume (SV) and ejection fraction (EF) were determined for LV function assessment. SV was computed by subtracting the ESV from EDV while EF was determined by dividing the SV by the EDV.

Endocardial borders were manually contoured at end-systole and end-diastole for RV function assessment from the most basal to the most apical slices. RV end-systolic and end-diastolic frames were selected based on LV end-systolic and end-diastolic frames which were determined by the software after LV segmentation. RV basal slice was defined as the first RV slice not superior to the level of the tricuspid valve (Fig. 4) [11]. Trabeculations and papillary muscles were included in the determination of the RV volumes. Similar