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Original research article

Impact of papillary muscles on ventricular function measurements in 3 T cardiac magnetic resonance

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ABSTRACT

Background: Prior studies revealed, that left and right ventricular (LV, RV) volume, mass and function differ significantly, depending on trabeculae papillary and papillary muscles (TPM) have been included or excluded in LV and RV calculations.

Methods: A cohort of 101 patients underwent CMR. It constituted of 26 patients without pathological findings in CMR (reference group), patients with ischemic cardiomyopathy (ICM), dilated cardiomyopathy (DCM) and patients with left ventricular hypertrophy (25 per group). Left and right ventricular parameters were determined using previously established methods: Method 1 inclusion and method 2 exclusion of TPM in cavity volume.

Results: Compared with inclusion of TPM, exclusion of TPM in the LV and RV cavity volume resulted in significantly lower end diastolic and systolic volume (EDV, ESV) and myocardial mass, and larger stroke volume and ejection fraction (SV, EF) (p0.001). The fraction of the TPM on the LV and RV mass was highest in DCM (18.4 ± 3.8%,) and in ICM (17.8 ± 3.2%) compared to the reference group (15.2 ± 2.5%, both $p < 0.05$), which resulted in a significant larger difference between the two methods (method 1- method 2) in calculating ESV, EDV, SV, EF and myocardial mass among DCM and ICM patients vs. reference group.

Conclusion: Global CMR LV parameters are significantly affected by whether TPM are considered as part of the LV blood pool or as part of LV mass. Therefore, a consistent method of LV cavity delineation may be crucial during longitudinal follow-up to avoid misinterpretation and erroneous clinical decision-making.

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Introduction

Studies have shown that ventricular ejection fraction, volumes and masses are strong therapeutic and prognostic parameters which play decisive roles in the classification of cardiac diseases [1–3]. Echocardiography is a wide-spread tool for the assessment of ventricular function in clinical practice due to its quick and economical availability. However, disadvantages lie in the high inter-observer variability, cases of insufficient acoustic window and error-prone calculations of functional parameters due to difficulty in visualizing the endocardial border and delineation. In echocardiography, essential myocardial parts such as ventricular lumen protruding trabeculae and papillary muscles (TPM) were excluded from ventricular measurements and regarded as additional blood volume [4,5]. Cardiovascular magnetic resonance (CMR) provides high temporal and spatial resolution and has emerged as a diagnostic and clinical standard for the assessment of ventricular function being more superior to echocardiography [6–8]. CMR is capable of distinguishing reliably between myocardium, trabeculae and papillary muscles, raising the question how these structures are rated for the calculation of cardiac function parameters [9,10]. The influence of the incorrect definition to include them into blood volume is discussed controversially and in particular concerning clinical consequences. Literature remains controversial. On the one hand, significant differences between in- and exclusion of papillary muscles were described. On the other hand only small differences were found, thereby leading to the recommendation for exclusion these structures in order to conserve time for CMR analysis [11,12]. Nevertheless, the correct determination of cardiac volumes and ejection fractions remains a time consuming procedure. Semi-automatic evaluation algorithms which allow an exact contour detection of epi- and endocardial borders with consideration to trabeculae and papillary muscles are still unknown [13]. Commercial evaluation software must be corrected manually [10]. In clinical TPM are not consequently in- or excluded in analysis of cardiac function, neither in CMR nor in echocardiography by hand and semi-automatic. Even normal values of cardiac function parameters were created without uniform handling of the inclusion of trabeculae and papillary muscles into ventricular volume [14–20]. Standardized recommendations are missing even though CMR is declared being golden standard of cardiac volumetry [21–28]. Therefore, the present study aims to analyze the importance of trabeculae and papillary muscles for the calculation of ventricular function parameters in 3 T CMR with results leading to recommendations on a uniform approach for a daily routine.

Methods

Study population

101 consecutive patients were prospectively enrolled. All were referred to our institution for cardiac CMR with question of myocarditis or relevant coronary artery disease to perform perfusion CMR. Patients were divided into four groups: (1) subjects without pathological findings in CMR, who constituted the reference group (RF), (2) ischemic cardiomyopathy (ICM, patients with known coronary artery disease assessed by coronary angiography and impaired left ventricular ejection fraction (LVEF) $< 50\%$), (3) dilated cardiomyopathy (DCM, missing relevant coronary artery disease, LVEF $< 50\%$ and dilated cardiac cavities with an end diastolic volume/body surface area of 57–105 ml/m^2 in men and 56–96 ml/m^2 in women), and (4) patients with left ventricular hypertrophy (LVH, normal LVEF and myocardial mass > 85 g/m^2 in men and 81 g/m^2 in women) based on the TPM inclusion method [14,17]. The exclusion criteria included the following contraindications for CMR (claustrophobia, intracranial clips, pacemaker, defibrillator, ferromagnetic prosthesis, clips, foreign particles, cochlea implants, subcutaneous metalliferous injection systems, pregnancy in first trimester and permanent makeup) and intolerance to lying supine, non rate-controlled atrial fibrillation with a heart frequency of $>$100 beats per minutes. Before undergoing CMR, all subjects gave written informed consent and the study was approved by the institutional ethical board.

Cardiac magnetic resonance

CMR was performed on a 3.0 T magnetic resonance system (Signa HDxt 3.0T, General Electrics, USA) using an 8-channel cardiac coil. Real time scout images in sagittal, axial and coronal planes were obtained to localize cardiac position in the thorax. Balanced steady-state-free-precession sequences from the ventricular apex to the base were assessed in the short axis view triggered by electrocardiogram during breath-hold. Parameters were as follows: echo time: 1.5 ms, repeat time = 3.8 ms, slice thickness: 8 mm, slice distance 2 mm, acceleration factor: 2, bandwidth 125 kHz, field of view: 38 cm $\times$ 38 cm, matrix (frequence $\times$ phase): 224 $\times$ 224, frames: 16 (typical temporal resolution of 46 ms), flip angle: 45°, phase encode grouping: 6–10, 8–12 short-axis slices were needed to encompass the left right ventricle. Manual tracing of epi- and endocardial borders of the left and right ventricle in the contiguous short-axis slices at the end diastole (first cine phase of the R-wave triggered acquisition) and the end systole (image phase with smallest cavity area) were carried out for calculation of the ventricular end diastolic volumes and ventricular end systolic volumes using the slice summation method, from which ventricular ejection fractions and masses were derived. Two different methods were applied. In method 1, trabeculae and papillary muscles were included to ventricular volume (Fig. 1) and excluded in method 2 (Fig. 2). Both methods were compared concerning end diastolic and end systolic left and right ventricular volumes, ejection fractions, stroke volumes and masses. All measurements were performed with commercially available software (Report CARD 4.0, General Electric Healthcare, Waukesha, Wisconsin, USA). Cardiac risk factors were also matched within the patient groups were also matched.

Statistical analysis

Statistical analysis was completed with Microsoft Excel 2010 and Stata 11.2. Categorical characteristics were presented in

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