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Assessment of left ventricular myocardial deformation by cardiac MRI strain imaging reveals myocardial dysfunction in patients with primary cardiac tumors

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ABSTRACT

Background: To assess left ventricular myocardial deformation in patients with primary cardiac tumors.
Methods: MRI was retrospectively performed in 61 patients, including 31 patients with primary cardiac tumors and 30 matched normal controls. Left ventricular strain and function parameters were then assessed by MRI-tissue tracking. Differences between the tumor group and controls, left and right heart tumor groups, left ventricular wall tumor and non-left ventricular wall tumor groups, and tumors with and without LV enlargement groups were assessed. Finally, the correlations among tumor diameter, myocardial strain, and LV function were analyzed.
Results: Left ventricular myocardial strain was milder for tumor group than for normal group. Peak circumferential strain (PCS) and its diastolic strain rate, longitudinal strains (PLS) and its diastolic strain rates, and peak radial systolic and diastolic velocities of the right heart tumor group were lower than those of the left heart tumor group (all $p < 0.050$), but the peak radial systolic strain rate of the former was higher than that of the latter ($p = 0.017$). The corresponding strains were lower in the left ventricular wall tumor groups than in the non-left ventricular wall tumor group ($p < 0.050$). Peak radial systolic velocities were generally higher for tumors with LV enlargement than for tumors without LV enlargement ($p < 0.050$). Peak radial strain, PCS, and PLS showed important correlations with the left ventricular ejection fraction (all $p < 0.050$).
Conclusion: MRI-tissue tracking is capable of quantitatively assessing left ventricular myocardial strain to reveal sub-clinical abnormalities of myocardial contractile function.

1. Introduction

Primary cardiac tumors are uncommon; most are benign and over 50% of these tumors are myxomas. More than half of all primary cardiac tumors occur in the endocardium and myocardium [1–2]. Clinical courses vary and may be serious, ranging from postural syncope embolism to sudden death. As a strong outcome predictor, myocardial contractility is a major consideration in medical decisions [3–4]. Regional myocardial systolic dysfunction could be quantified by changes to the left ventricular wall, changes in stress, or fiber stretching. Left ventricular functions are responsible for systemic circulation perfusion and provide the body with oxygen and nutrition; thus, these functions represent the overall state of cardiac function. Considering the importance of the left ventricle, an accurate and quantitative method to evaluate left ventricular myocardial contractility is imperative.

Global left ventricular ejection fraction (LVEF) has been demonstrated to be poorly sensitive and late markers of contractile dysfunction. Thus, measurement of left ventricular strain abnormalities by cardiac magnetic resonance imaging (CMR) has been proposed [5–7]. CMR can accurately and clearly delineate the inner and outer membranes of the heart because it allows excellent myocardial blood pool contrast. Recent developments in technology have led to the introduction of CMR tissue tracking, which enables tissue voxel motion tracking of the whole myocardium via routine cine images [8]. CMR tissue tracking can quantitatively measure segmental myocardium functions via several parameters, including strain, from the radial, circumferential, and longitudinal directions. The technology is similar to ultrasound speckle

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tracking, which does not require complex post-processing or image acquisition techniques, and can be applied to previously acquire cardiovascular MRI images [9–10].

Previous studies on left ventricular myocardial strain mainly focus on coronary heart disease, cardiomyopathy, heart failure, and valve disease [11–14]. Measurement of myocardial strain using a myocardial tagging technique to distinguish the boundary of the cardiac tumor tissue and the adjacent normal myocardium has also been reported [15–16]. Despite the importance of these studies, however, knowledge of the effect of left ventricular myocardial strain on primary cardiac tumors is limited. Thus, the purpose of this study is to evaluate left ventricular strain abnormalities in primary cardiac tumor patients. The results of this study can provide important evidence for the early detection of subclinical systolic dysfunction and guide clinical strategies aiming to avoid or reduce the risk of irreversible complications.

2. Methods

2.1. Study population

A total of 86 consecutive subjects who underwent CMR, including 56 patients with clinical suspected cardiac tumors and 30 matched normal controls, were enrolled. Patients with suspected cardiac tumors were admitted for further diagnosis or surgery at our hospital from November 2011 to February 2016. Patients with a pathologic diagnosis of tumor after operation were finally included in the study. The exclusion criteria included the presence of other diseases influencing cardiac strain, such as cardiac metastatic tumors, cardiomyopathy, congenital heart disease, pulmonary heart disease, hypertension, diabetes, myocardial infarction, valvular malformation, valvular stenosis, moderate valvular regurgitation, cardiac tamponade, and pericardial tumors. Patients with serious liver, kidney, and lung dysfunction or inadequate image quality for imaging analysis were also excluded from this work. Finally, 31 patients with primary cardiac tumors were recruited. Another 30 age- and gender-matched patients with suspected heart disease who underwent CMR during the same period but were finally diagnosed to be normal condition served as the control group.

2.2. Cardiac MRI technique

All patients and normal controls were examined in the supine position using a 3.0 T whole-body scanner (Trio Tim; Siemens Medical Solutions, Erlangen, Germany) with a dedicated two-element cardiac phased array coil. An electrocardiographic gating device and breath-holding technique were used when feasible. The continuous data collections were got in the end inspiratory breath hold time for patients. Following local transverse, coronal, and sagittal scanning, cine images were acquired in double-angulated long-axis two- and four-chamber views using a segmented ECG-gated FLASH 2D cine sequence (TR/TE 37.66/1.2 ms, slice thickness 8 mm, flip angle 50°, field of view 278 × 330 mm, matrix size 130 × 192). For functional and strain measurement, short-axis images from the base to the apex were acquired via 8–12 images with TurboFLASH sequences (repetition time, 154.38; flip angle, 10°; echo time, 1.07; inversion time, 90; slice thickness, 10 mm; spacing between slices, 0 mm; acquisition matrix, 106 × 192; field of view, 270 × 460 mm).

2.3. Imaging analysis

Cine MRI data were analyzed offline using commercially available software (cmr42, version 5.2.2; Circle Cardiovascular Imaging Inc., Calgary, Canada) to measure left ventricular strain and cardiac functions. There are about 20–30 images acquired in a cardiac cycle for the patients. According to the common division for left ventricular myocardial strain with 16 segmentations [17], the apical cap was not included in the range of strain analysis. Myocardial cells contain longitudinal and circular muscle fibers called circular bundles in the middle layer and spiral bundles in the outer and inner layers, of which about 70% are longitudinal muscle fibers and 30% are circular muscle fibers [18–19]. Longitudinal muscle fibers play a major role in long-axis motion [20], while circular muscle fibers are mainly responsible for movement in the short-axis and circumferential directions. As such, myocardial strain may occur in three spatial directions, including longitudinal, circumferential, and radial.

Strain in physics is defined as the relative deformation observed between any two points on an object subjected to stretching. Myocardial strain is calculated as the percentage of changes in the length of the myocardium (i.e., the difference between final length and initial length divided by initial length). The strain rate (SR) refers to the rate of myocardial deformation and is defined as the velocity difference between two points divided by their distance. Regional tissue tracking variables included radial, circumferential, and longitudinal strain (RS, CS, LS, respectively), SR, and velocity. LS develop as a result of segmental ventricular wall elongation or shortening along longitudinal fibers; in the systolic phase, myocardial cells are shortened and the myocardial strain presents a negative value. By contrast, LS is positve in value when myocardial cells are elongated. CS develops from circular motion in the direction of the short axis of the heart, i.e., the myocardial wall of each segment is stretched or shortened along the annular direction of the left ventricular short axis of the left ventricle. Thus, CS is negative during the systolic shortening. RS reflects the degree of cardiac wall thickening, and its value is positive when the chamber wall contracted.

A set of short-axis (perpendicular to the ventricular long-axis plane on the basis of previous four-chamber images), four-chamber (horizontal long axis), and long-axis two-chamber (vertical long axis) slices were loaded into the tissue tracking module, and all endocardial and epicardial borders were traced manually. Extension of the LV was defined in the long-axis series. The strain parameters of the 16 LV segments, including six zones at the basal level, six zones at the middle level, and four zones at the apical level, were then automatically determined by the software. In addition, the corresponding polar maps and curve graphs of different strain were obtained.

Cardiac functions, including LVEF, end-diastolic volume (EDV), and end-systolic volume (ESV), were generated automatically by the cmr42 short-3D nodule. According to standard AHA segmentation protocols, it was constructed on the basis of the short-axis slices. As the left ventricular basement exerts a great influence on the overall function of the left ventricle, measurement included the left ventricular outflow tract of the basal part and up to the aortic valve level.

2.4. Statistical analysis

All statistical analyses were performed using SPSS software (Version 16; Chicago, IL, USA). All strain data were confirmed to normal distribution by the Q-Q chart test. The data were recorded as mean values and the corresponding standard deviations. Independent *t*-tests were performed to obtain strain differences between the tumor group and normal controls, the left and right heart tumor groups, the left ventricular wall tumor and non-left ventricular wall tumor groups, and the tumors with and without LV enlargement groups. Pearson's correlation was utilized to evaluate the relationships among tumor diameter, myocardial strain, and LV function parameters. In comparisons of basic clinical data between tumor patients and normal controls, the baseline data were analyzed by *t*-tests; sex differences were compared using the χ^2 test. Intra- and inter-observer variability for reproducibility was evaluated using intraclass correlation coefficients (ICCs). Statistical tests were two-tailed, and $p < 0.05$ was considered to indicate statistical significance.

3. Results

3.1. Baseline characteristics

MRI scanning was successfully performed in all 61 subjects, and cardiac tumors and structures were clearly delineated in the images. In