TECHNICAL NOTE

Clinical Application of an Automatic Slice-Alignment Method for Cardiac MR Imaging

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Purpose: We evaluated the usefulness of an automatic slice-alignment method to simplify planning of cardiac magnetic resonance (MR) scans with a 3-tesla scanner.

Methods: We obtained 2-dimensional (2D) axial multislice images using steady-state free precession (SSFP) sequences covering the whole heart at the end-diastole phase with electrocardiography (ECG) gating in 38 patients. We detected several anatomical feature points of the heart and calculated all planes required for cardiac imaging based on those points. We visually evaluated the acceptability of an acquired imaging plane and measured the angular differences of each view between the results obtained by this method and by a conventional manual pointing approach.

Results: The average visual scores were 3.4 ± 1.0 for short-axis images, 3.2 ± 0.9 for 4-chamber images, 3.2 ± 0.8 for 2-chamber images, and 3.3 ± 0.8 for 3-chamber images; average angular differences were 5.8 ± 5.1 (short axis), 7.7 ± 5.7 (4-chamber), 11.5 ± 6.7 (2-chamber), and 9.1 ± 4.6 degrees (3-chamber). Processing time was within 1.8 s in all subjects.

Conclusion: The proposed method can provide planes within the clinically acceptable range and within a short time in cardiac imaging of patients with various cardiac shapes and diseases without the need for high level operator proficiency in performing the examination and interpreting results.

Keywords: *automatic slice-alignment, cardiac, 3T*

Introduction

Cardiac magnetic resonance (MR) imaging is useful for accurate evaluation of the morphology and function of the heart, but precise morphological characterization of cardiac structures requires complex procedures for acquiring the necessary scout scans to obtain suitable views in a short time. In conventional examinations, the heart is typically anchored using a multistep approach that involves the acquisition of double-oblique views to determine its long and short axes.^{1–4} This approach is

operator dependent, time consuming, and demands a high level of proficiency of the medical staff responsible for performing the examination and interpreting the images obtained.

Several recent reports have described a variety of automatic slice location tools to support planning of cardiac MR views and thus minimize the need for operator interaction.^{5–9} However, these methods remain challenging in clinical practice because they require a robust approach to differentiating the heart from other complicated anatomical structures while also taking into account the large variations across populations.

To simplify cardiac scan planning, we have developed a new automatic slice-alignment method

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based on gated breath-hold axial multislice scout images (Fig. 1).¹⁰ This method employs knowledge-based recognition techniques to achieve higher accuracy and greater robustness for differentiating a variety of cardiac shapes, phases, and image patterns due to blood flow. Our previous experience in healthy volunteers using a 1.5-tesla scanner has shown that our proposed method can detect standard cardiac planes quickly and accurately.¹⁰ The purpose of this study is to determine the usefulness of this automatic slice-alignment method for simplifying the planning of cardiac MR scans with a 3T scanner.

Materials and Methods

Subjects were 38 consecutive patients (31 men, 7 women; aged 22 to 84 years, average, 46.3 ± 18.1 years) who underwent cardiac MR examination from November 2011 to April 2012 at our institution. Our institutional review board approved the study, and in accordance with our ethics committee, we obtained written informed consent from all patients. All subjects were scanned using a 3T MR imaging system (Vantage Titan 3T, Toshiba Medical Systems, Otawara-shi, Tochigi, Japan) and Atlas SPEEDER body coil. Steady-state free precession (SSFP) sequences covering the range from the cardiac base to the apex at the end-diastolic phase were used to acquire axial 2-dimensional (2D) multislice images in approximately 20 s during a single breath-hold with ECG gating (repetition time [TR]/echo time [TE], 4.2 ms/2.1 ms; flip angle, 60°; matrix, 256×256 ; slice spacing, 1.17×1.17 ; slice thickness, 7 mm; interslice gap, 7 mm; and number of slices, 16 to 21).

We first used the proposed method combined with several feature recognition techniques to identify the positions of the mitral valve and cardiac apex to determine the left ventricular (LV) long-axis orientation. At the same time, we detected a number of anatomical feature points of the heart to determine the short-axis, 4-chamber, 2-chamber, and 3-chamber views from these series of images using a knowledge-based technique designed to distinguish image patterns around these points. We then calculated all planes required for cardiac imaging based on the extracted features.

Figure 1 shows the procedures employed in our proposed method. There are four steps: (Step 1) conversion of an anisotropic image to an isotropic image based on a cubic convolution interpolation method; (Step 2) detection of the positions of the mitral valve, apex, tricuspid valve, and LV outflow tract in the isotropic image; (Step 3) detection of

the apex point to correct the position from the pilot horizontal long-axis slice; and (Step 4) detection of the right ventricular corner and anterior wall points in the basal short-axis slice.

To detect the positions of the 4 anatomical features of the heart in Step 2, we employ a knowledge-based feature recognition technique to achieve high robustness and accuracy.¹⁰ For example, in the procedure to detect the position of the mitral valve in the isotropic image (Step 2), we construct a 2-category classifier that designates the mitral valve position as either acceptable (positive) or unacceptable (negative) using extremely randomized trees during the learning stage. During the next estimation stage, we use the samples classified as positive to calculate the mitral valve position in the input data.

By consensus, 2 cardiac radiologists (K.Y., R.I.) evaluated the results of slice alignment using this method. They evaluated imaging planes acquired from the dataset of the axial SSFP images but not images acquired after using this method, such as cine or late gadolinium-enhanced images. To assess the clinical acceptability of the images in identifying the standard cardiac axes, we used a 4-point scale to score the detected imaging planes based on the axial SSFP images of each subject (4 points, excellent; 3 points, good; 2 points, marginal but clinically acceptable; 1 point, not clinically acceptable). In addition, we detected imaging planes based on the axial SSFP images by manual annotation on the consensus of the 2 cardiac radiologists and compared the results obtained by our proposal method with those by manual annotation. The angular difference is measured as the angular distance of the normal vectors of the automatically detected results and manually annotated views (Fig. 2):

$$\begin{aligned} \text{angular difference [degrees]} \\ = \frac{180}{\pi} \cos^{-1} \left(\frac{\vec{v}_{\text{man}} \cdot \vec{v}_{\text{aut}}}{|\vec{v}_{\text{man}}| |\vec{v}_{\text{aut}}|} \right), \end{aligned}$$

in which $\vec{v}_{\text{man}}$ are the normal vectors of manually annotated views, and $\vec{v}_{\text{aut}}$ are the normal vectors of automatically detected views.

Results

We successfully performed automatic slice alignment in all 38 subjects for short-axis and 4-, 3-, and 2-chamber views. Processing time from Step 1 through Step 4 was within 1.8 s in all subjects using an AMD Phenom™ II X4 965 Processor 3.39 GHz with 15.7 GB of memory (without the use of multi-threading techniques).

Subjects' diagnoses included various pathologic

Fig. 1. Procedures employed in our proposed method (from reference 10, with modifications). There are 4 steps: (1) conversion of an anisotropic image to an isotropic image; (2) detection of the positions of the mitral valve (red circle), apex (yellow circle), tricuspid valve (sky blue circle), and left ventricular outflow tract (dark green circle) in the isotropic image; (3) detection of the apex point to correct the position from the pilot horizontal long-axis slice; and (4) detection of the right ventricular corner and anterior wall points in the basal short-axis slice.

Fig. 2. Example of the angular difference between the automatically determined result and manually annotated view. The angular difference is measured as the angular distance of the normal vectors of the automatically detected and manually annotated views.

cardiac conditions: myocardial infarction ($n = 13$, 5 cases within 4 weeks after onset and 8 cases more than 4 weeks after onset), angina pectoris ($n = 8$), dilated cardiomyopathy ($n = 9$), hypertrophic cardiomyopathy ($n = 3$), heart failure of unknown cause ($n = 4$), and acute pericarditis ($n = 1$)

(range of left ventricular end-diastolic volume [LVEDV], 75.2 to 354.6 mL; LV end-systolic volume [LVESV], 34.3 to 135.2 mL; ejection fraction [EF], 17.1 to 75.5%; and LV mass [LVM], 73.8 to 230.8 g).

The average scores of visual assessment for clin-

Table 1. Visual assessment scores of the clinical acceptability of the images in identifying the standard cardiac axes for each of the short-axis and 4-, 2-, and 3-chamber views

Visual scores (Scale 1 to 4)	
Short-axis view	3.4 ± 1.0
4-chamber view	3.2 ± 0.9
2-chamber view	3.2 ± 0.8
3-chamber view	3.3 ± 0.8

Table 2. Average angular differences between the proposed automatic slice-alignment method and the operator-dependent manual approach for each image

Angular differences (degrees)		
Short-axis view	5.8 ± 5.1	3.1 ± 1.7*
4-chamber view	7.7 ± 5.7	4.5 ± 3.8*
2-chamber view	11.5 ± 6.7	7.3 ± 4.7*
3-chamber view	9.1 ± 4.6	5.8 ± 3.8*

*Values obtained for healthy volunteers in a previous study¹⁰

Fig. 3. A 42-year-old man with dilated cardiomyopathy. (a) Vertical long-axis view. (b) Horizontal long-axis view. (c) Short-axis view. (d) 4-chamber view. (e) 2-chamber view. (f) 3-chamber view. The detected mitral valve, cardiac apex, their central position, and long axis are superimposed on the results. The crossing lines of the 4-chamber, 2-chamber, and 3-chamber views are superimposed on the results for the short-axis view. The angular differences (and visual scores in parentheses) were 4.9° (3) for the short-axis, 4.2° (3) for the 4-chamber view, 5.7° (3) for the 2-chamber view, and 3.9° (4) for the 3-chamber view.

ical acceptability of planes (mean ± SD) were 3.4 ± 1.0 for short-axis images, 3.2 ± 0.9 for 4-chamber images, 3.2 ± 0.8 for 2-chamber images, and 3.3 ± 0.8 for 3-chamber images (Table 1). All images had scores of 3 (good) or 4 (excellent) points; none received a score of one or two points (not clinically acceptable). The average angular differences between the automatic method and conventional manual scan planning for each type of image were 5.8 ± 5.1 (short-axis), 7.7 ± 5.7 (4-chamber), 11.5 ± 6.7 (2-chamber), and 9.1 ± 4.6 degrees (3-chamber) (Table 2).

Discussion

We obtained images of acceptable planes in all cases in a short processing time using the proposed method. We use the proposed method combined with several feature recognition and image processing techniques to identify the positions of the mitral valve, cardiac apex, LV outflow tract, tricuspid valve, anterior wall of the heart, and right ventricular corner to determine the position of the heart and then calculate all planes required for cardiac imaging based on the extracted features. The initial

Fig. 4. A 24-year-old woman with hypertrophic cardiomyopathy. (a) Vertical long-axis view. (b) Horizontal long-axis view. (c) Short-axis view. (d) 4-chamber view. (e) 2-chamber view. (f) 3-chamber view. The detected mitral valve, cardiac apex, their central position, and long axis are superimposed on the results. The crossing lines of the 4-chamber, 2-chamber and 3-chamber views are superimposed on the results for the short-axis view. The angular differences (and visual scores in parentheses) were 6.9° (4) for the short-axis view, 3.6° (4) for the 4-chamber view, 7.4° (3) for the 2-chamber view, and 6.2° (3) for the 3-chamber view.

results obtained in 23 healthy volunteers using a 1.5T scanner have shown that this method can detect the standard cardiac planes quickly and accurately by combining knowledge-based recognition and image processing techniques. It can also detect the cardiac planes with high reproducibility.¹⁰

The angular differences observed in this study were slightly larger than those obtained in healthy volunteers using a 1.5T scanner as previously reported.¹⁰ We believe this is mainly attributable to the various pathologic cardiac conditions and cardiac shapes of our current subjects that made identification of these differences more difficult than in healthy volunteers (Figs. 3, 4). Additionally, the reduced contrast between the myocardium and ventricular cavity and occurrence of banding artifacts with SSFP sequences at 3T may lead to incorrect results in automatic detection.

We did not expect successful automatic slice alignment in subjects with hypertrophic cardiomyopathy because deformity of the cardiac chambers would make it difficult to determine the planes accurately and marked hypertrophy of the apical myocardium would make it difficult to identify the position of the apex accurately. Nevertheless, we suc-

cessfully performed our proposed method in 3 patients with hypertrophic cardiomyopathy with only a small amount of angular correction needed (Fig. 4). However, if apical hypertrophy becomes so severe that the apex cannot be recognized by conventional visual assessment, the automatic alignment method might also fail to provide accurate results.

The accuracy of automatic slice alignment is expressed in terms of the deviation in the orientation of the imaging plane. Danilouchkine and associates¹¹ reported that variability between 2 operators during manual scan planning amounted to 4.99 degrees of angular LV axis deviation. Based on this criterion, the accuracy of our proposed method is comparable to the limits of interoperator variability. This method is designed to be used under an operator's supervision. However, in this study, we intentionally avoided operator interaction to evaluate the inherent accuracy of the method. The automatic slice-alignment procedure was performed accurately and yielded results comparable to those obtained by conventional manual scan planning used in routine clinical practice. However, this automatic method can also be used in a semiautomatic

manner, with operator interaction implemented by displaying the calculated images in the scout image sets and permitting the radiologist or technologist to intervene if necessary. The use of the proposed method in semiautomatic mode to permit minor corrections in the orientation of the automatically planned slices should be beneficial, although our study results lead us to expect that such operator interaction should not be required in most cases.

This report describes our initial clinical experience; further studies involving larger numbers of subjects are required. Our proposed automatic slice-alignment method employs knowledge-based recognition techniques to achieve higher accuracy and greater robustness for identifying a variety of cardiac shapes, phases, and image patterns due to blood flow. Knowledge-based recognition is expected to provide even more accurate setting results after a larger number of subjects have been examined.

Conclusion

We developed a new automatic slice-alignment method to simplify planning of cardiac scans and used this method to examine actual patients with a 3T scanner in the clinical setting. Our results show that this method can provide planes within the clinically acceptable range and within a short time and that it is useful by avoiding the need for high level operator proficiency for performing cardiac MR of patients with various cardiac shapes and diseases and interpreting examination results.

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