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Research Article

New Automatic Slice-Alignment Method for Cardiac Magnetic Resonance Imaging -Clinical evaluation with a 1.5T scanner-

Kenichi Yokoyama[1*], Rieko Ishimura[1], Masamichi Imai[1], Toshiya Kariyasu[1], Toshiaki Nitatori[1], Shigehide Kuhara[2], Shuhei Nitta[3], Tomoyuki Takeguchi[3], Nobuyuki Matsumoto[3]

[1]*Department of Radiology, Kyorin University, School of Medicine*

[2]*Clinical Application Research Center, Toshiba Medical Systems Corporation*

[3]*Multimedia Laboratory, Corporate Research & Development Center, Toshiba Corporation*

**Corresponding author: Dr. Kenichi Yokoyama, Department of Radiology, KyorinUniversity, School of Medicine, 6-20-2 Shinkawa, Mitaka-shi, Tokyo 181-8611,Japan, Tel: +81-422-47-5511; E-mail: yokoyama@ks.kyorin-u.ac.jp*

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Abstract

We evaluated the clinical feasibility of a prototype automatic slice-alignment method for cardiac MR scan planning with a 1.5T scanner.

Steady-state free precession (SSFP) sequences covering whole heart were used to acquire 2D axial multislice images. A number of anatomical feature points of the heart were detected from these series of images using knowledge-based recognition and image processing techniques, and short-axis, 4-chamber, 2-chamber, and 3-chamber planes were calculated based on them. The subjects of this study were 40 consecutive patients. The acceptance as an acquired imaging plane was visually evaluated, and the angular differences of each view between the results obtained by this method and by a conventional manual pointing approach were measured.

This method was performed in all subjects and there were no undetectable subjects. The average angular differences for each of the images were 4.13±2.80, 7.32±4.06, 10.88±7.82, and 6.57±4.56 degrees, respectively. The positional differences for each of the images were 5.45±3.82 (short-axis, base), 3.08±3.00 (short-axis, apex), 2.03±1.86, 1.45±1.24, and 2.05±2.52 mm. The processing time was about 1.8 seconds.

This method is useful because of unnecessary of proficiency for performing cardiac MR of patients with various cardiac shapes and diseases.

Keywords : Slice Alignment; Clinical Experience; Automatic Processing; MRI; 1.5T; Heart

Abbreviations
LV: Left Ventricular

Introduction

Cardiac magnetic resonance (CMR) imaging is an excellent tool for obtaining accurate morphological and functional measurements of the heart, which are essential for diagnosis, prognosis, and therapeutic decision-making in the clinical setting. The precise morphological characterization of cardiac structures requires complex procedures for acquiring the necessary scout scans to obtain suitable views in a minimal amount of time. In conventional CMR examinations, anchoring of the heart is typically performed using a multistep approach involving the acquisition of double-oblique views in order to determine the long and short axes of the heart. This approach is both operator-dependent and time consuming. Moreover, it requires detailed knowledge of the heart on the part of the operator as he or she plans the views in each step during this long process, which must be carried out while the patient is in the scanner.
Various image analysis tools have recently been introduced to support automated planning of the CMR views and thus minimize the need for operator interaction [1-9]. However, these methods remain challenging in clinical practice because they require a robust approach to differentiating the heart from other complex anatomical structures while also taking into account large variations across populations and minimizing the response time.

We have proposed a new automatic slice-alignment method based on gated breath-hold axial multislice scout images and employing knowledge-based recognition combined with image processing techniques to simplify cardiac scan planning [10]. Our proposed method can detect six views in about 1.8 seconds (using a 3.39-GHz CPU).

The experimental results obtained in healthy volunteers and actual patients with a 3T scanner have shown that our proposed method is able to detect the standard cardiac planes quickly and accurately [10, 11]. Furthermore, this method employs knowledge-based recognition techniques in order to achieve higher accuracy and greater robustness for a variety of cardiac shapes, phases, and image patterns due to blood flow. In this study, we have used this method to examine actual patients and have evaluated its usefulness in clinical practice with a 1.5T scanner.

Materials and methods

The subjects in the present study were 40 consecutive patients (27 men and 13 women, average age = 60 years, age range = 22-84 years) who underwent CMR examination. Our institutional review board approved the study, and we obtained written informed consent from all patients. Their diagnoses included various pathologic cardiac conditions: myocardial infarction (n = 17, 8 cases within 4 weeks after onset and 9 cases more than 4 weeks after onset), angina pectoris (n = 5), dilated cardiomyopathy (n = 5), hypertrophic cardiomyopathy (n = 4), heart failure of unknown cause (n = 4), apical ballooning (n = 2), cardiac tumor (n = 1, malignant lymphoma), pericardial tumor (n = 1, metastatic tumor), and acute pericarditis (n = 1). All subjects were scanned using a 1.5-T MRI system (Excelart Vantage™ powered by Atlas, Toshiba Medical Systems, Otawara-shi, Tochigi, Japan) equipped with a pair of body array coils, each of which consisted of 4 x 4 arrays. The arrays were placed at both the front and back of the chest. Two top rows were used for both the front and back coils to cover the entire heart, resulting in 16 active coil elements connected to 16 receiver channels.

Steady-state free precession (SSFP) sequences covering whole heart at the end-diastole phase using ECG gating were used to acquire 2D axial multislice images in approximately 20 seconds during single breath-hold (matrix = 256×256, slice spacing = 1.17×1.17, slice thickness = 7 [mm], interslice gap = 7 [mm], number of slices = 16-21).

In our proposed method [10], first, the positions of the mitral valve, cardiac apex, left ventricular outflow tract, tricuspid valve, anterior wall of the heart and right ventricular corner are identified to determine the short-axis, 4-chamber, 2-chamber, and 3-chamber views using the method combined with several feature recognition and image processing techniques. The clinical datasets are included in learning stage for applying this method for patients. All of the planes required for cardiac imaging are then calculated based on the extracted features.

The procedures employed in our proposed method are shown in Fig.1. 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 left ventricular 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.

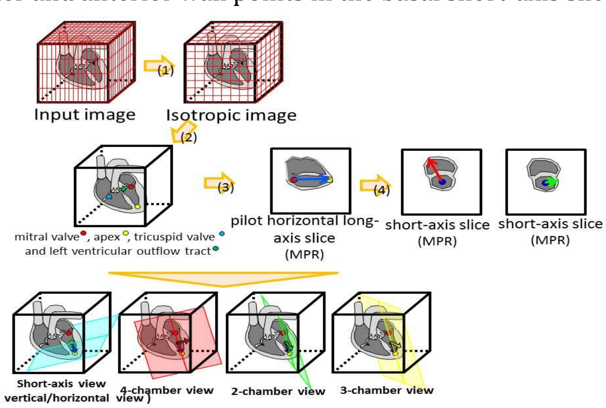


Figure 1. Procedures employed in our proposed method (from ref-

erence 10, with modifications). There are four 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.

To detect the positions of the four anatomical features of the heart in step 2, we employ knowledge-based feature recognition technique to achieve high robustness and accuracy [10]. For example, in the procedure for the position of the mitral valve in isotrophic image (step2), a 2-class classfier that classifies the mitral valve position as acceptable (positive) or unacceptable (negative) is constructed using extremely randomized trees during the learning stage. During the next estimation stage, the mitral valve position in the input data is calculated using the samples that have been classified as positive.

The results of slice alignment using this method were evaluated based on the consensus of two cardiac radiologists (K.Y. and M.I.) In this study, we evaluated imaging planes acquired from the dataset of these axial SSFP images, and the acquired images after using this method such as cine images or late gadolinium enhanced image were not evaluated. The detected imaging planes based on the axial SSFP images of each subjects were scored using a 4-point scale (4 points = excellent, 3 points = good, 2 points = marginal but clinical acceptable, 1 point = not clinically acceptable) to assess the clinical acceptable in identifying the standard cardiac axes. In addition, imaging planes based on the axial SSFP images by manual annotation on the consensus of two cardiac radiologists were detected, and the results obtained by our proposal method and by manual annotation were compared. The angular difference is measured as the angular distance of the normal vectors of the automatically detected and manually annotated views ($\vec{v}_{est}$ and $\vec{v}_{man}$) for the evaluation of directional accuracy (as shown in Fig.2).

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

The positional difference is measured as the point-to-plane distance from a landmark in the automatically detected view plane ($\vec{p}_{est}$) to the manually annotated view plane ($\vec{p}_{man}$) for the evaluation of positional accuracy (as shown in Fig.2). The landmarks in the short-axis view plane are the base position (center of the mitral valve) and the apex position. The landmark in the 4-chamber, 2-chamber, and 3-chamber view planes is the central point between the base and apex positions.

$$positional\ difference[\text{mm}] = \left|\frac{\vec{v}_{man}}{|\vec{v}_{man}|}\cdot(\vec{p}_{est}-\vec{p}_{man})\right|$$

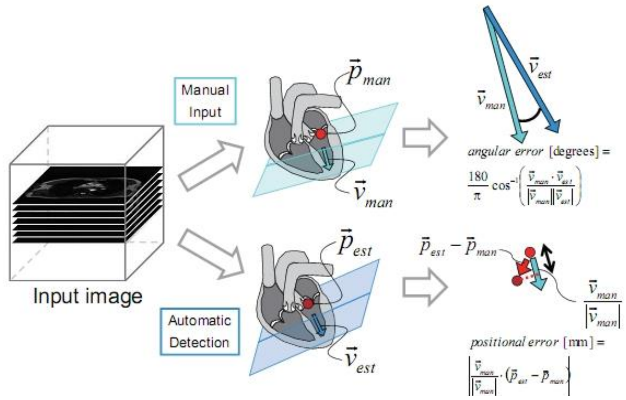


Figure 2. Example of the angular and positional differences between the proposed method and manual annotation.

Results

This method was performed in all subjects and there were no undetectable subjects. Processing time from step 1 to step 4 was about 1.8 seconds in all subjects using an AMD Phenom TMⅡ×4 965 Processor 3.39 GHz with 15.7GB memory (without the use of multithreading techniques).

For all subjects, the average visual assessment scores were 3.74 ± 0.70 for short-axis images, 3.60 ± 0.79 for 4-chamber images, 3.73 ± 0.62 for 2-chamber images, and 3.76 ± 0.61 for 3-chamber images (Table 1). There were no subjects with a score of 1 point (not diagnostically useful) and only 1 subject with a score of 2 points (marginal but diagnostically useful). All of the remaining subjects had scores of 3 points (good) or 4 points (excellent). The weighted kappa statics of the scores which is a statistical measure of inter-rater agreement were 0.992 for short-axis, 0.989 for 4-chamber images, 0.989 for 2-chamber images, and 0992 for 3-chamber images. The average angular difference [degrees] between the proposed automatic method and conventional manual scan planning was 4.13 ± 2.80 for short-axis images, 7.32 ± 4.06 for 4-chamber images, 10.88 ± 7.82 for 2-chamber images, and 6.57 ± 4.56 for 3-chamber images (Table 2). The average positional difference [mm] between the proposed automatic method and conventional manual scan planning was 5.45 ± 3.82 for short-axis images (base), 3.08 ± 3.00 for short-axis images (apex), 2.03 ± 1.86 for 4-chamber images, 1.45 ± 1.24 for 2-chamber images, and 2.05 ± 2.52 for 3-chamber images (Table 2). The lowest score was observed in the subject with a pericardial tumor.

Table 1. Visual assessment scores for each of the short-axis, 4-chamber, 2-chamber, and 3-chamber views.

	Visual scores (scale 1-4)
Short-axis	3.74±0.70
4-chamber	3.60±0.79
2-chamber	3.73±0.62
3-chamber	3.76±0.61

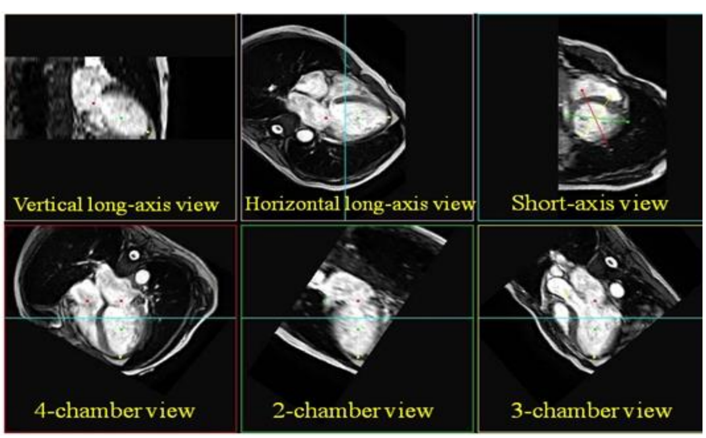
Table 2. Average angular differences and positional differences between the proposed automatic slice-alignment method and the operator-dependent manual approach for each image.

	Angular differences (degree)	Positional differences (mm)
Short-axis	5.8±5.1	5.45±3.82(base) 3.08±3.00(apex)
4-chamber	7.7±5.7	2.03±1.86
2-chamber	11.5±6.7	1.45±1.24
3-chamber	9.1±4.6	2.05±2.52

Discussion

The results of this study show that our proposed automatic slice-alignment method is able to accurately determine the imaging planes for evaluation of the left ventricle in patients with various cardiac shapes and diseases (Fig.3). It was also found that this method is able to provide the clinical acceptable with a 1.5T scanner as well as with a 3T scanner [11]. Good agreement was observed in actual patients between automatic slice alignment and conventional manual scan planning, with results within the clinically acceptable range for the short-axis, 4-chamber, 2-chamber, and 3-chamber views. We did not evaluate the actual examination times in this study. However, we consider that this method significantly can reduce the whole examination time (the examination times for both manual and automated scans in some volunteers were measured [10]).

Figure 3. A 68-year-old man with an old myocardial infarction (inferior wall). The required planes for cardiac MR examination were accurately determined by our proposed automatic slice-alignment method based on multislice scout images acquired using a steady-state free precession(SSFP) sequence.



The accuracy of automatic slice alignment is expressed in terms the deviation of the orientation of the imaging plane. Danilouchkine et al. [9] reported that the interoperator variability that occurred during manual scan planning by two different operators amounted to 4.99 degrees of angular left ventricular axis deviation. Based on this criterion, the accuracy of this method is comparable to the limits of interoperator variability.

In the subjects with hypertrophic cardiomyopathy, we expected that automatic slice alignment would not be performed successfully, because it would be difficult to accurately determine the planes due to the deformity of the cardiac chambers, with marked hypertrophy of the apical myocardium making it difficult to accurately identify the position of the apex (Fig. 4). Four subjects with hypertrophic cardiomyopathy were included in this study, and the proposed method was performed successfully in all subjects, with only a small amount of angular correction needed. However, if apical hypertrophy becomes so severe that the apex cannot be recognized by the conventional visual assessment method, it is possible that this method may also fail to provide accurate results.

Figure 4. A 72-year-old woman with hypertrophic cardiomyopathy. Automatic slice alignment was performed successfully despite the presence of cardiac deformity due to regional myocardial hypertrophy.

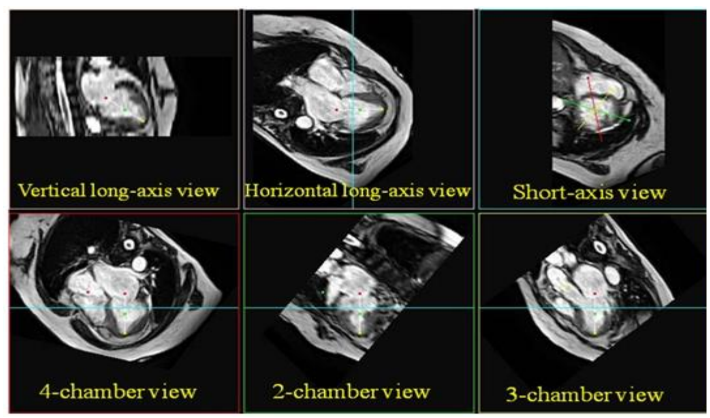
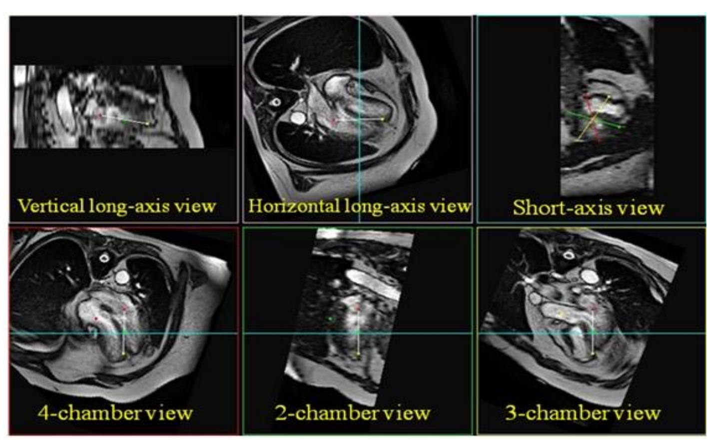


Figure 5. A 58-year-old man with a pericardial tumor. Automatic slice alignment was not performed successfully, and a large amount of correction was needed to obtain suitable planes. There is a substantial overlay of pericardial fat, and it is thought that this fat could not be distinguished from the high-signal areas of the cardiac chambers.



The subject with a pericardial tumor had the lowest visual score and the largest angular difference (Fig. 5). Automatic slice alignment was not performed successfully in this subject, and a large amount of correction was needed to obtain suitable planes. In this subject, there was a substantial overlay of pericardial fat, and it is thought that this fat could not be distinguished from the high-signal areas of the cardiac chambers. Further technological development involving the use of a new sequence with fat suppression techniques may potentially overcome this problem.

In another subject, detection of the right ventricular angle was slightly incorrect due to enlargement of the right ventricle. It is assumed that this pattern had not been learned by the system and therefore could not be identified by the knowledge-based recognition process.

This method is designed to be used under an operator's supervision. However, in this study, we intentionally avoided operator interaction in order to evaluate the accuracy of this method. The automatic slice-alignment procedure was performed accurately, with results comparable to those obtained by conventional manual scan planning in routine clinical practice. However, this 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 to be made in the orientation of the automatically planned slices should be beneficial, although, based on the results of this study, we expect that such operator interaction should not be required in the majority of cases.

The proposed method has been developed to work with current standard MR imaging hardware. A recent advance in MR acquisition technology is the development of real-time MR imagers, which allow interactive scan planning of the planes [1]. This may substantially reduce the time needed to obtain suitable planes. However, the main advantage of this method over real-time planning is that it is not subjective and does not require specialized knowledge on the part of the operator to determine the optimal views.

The present study is based on our initial clinical experience. Our proposed method employs knowledge-based recognition techniques in order to achieve higher accuracy and greater robustness for a variety of cardiac shapes, phases, and image patterns due to blood flow. It is expected that knowledge-based recognition will provide even more accurate setting results after a larger number of cases have been examined.

Conclusions

We have developed a new automatic slice-alignment method to simplify cardiac scan planning and have used this method to examine actual patients in the clinical setting with a 1.5T scanner. The results show that this method is able to provide the planes within the clinically acceptable range and within a short time, and is useful because of unnecessary of proficiency for performing CMR of patients with various cardiac shapes and diseases.

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