Journal of Cardiovascular Computed Tomography xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Cardiovascular Computed Tomography

journal homepage: www.elsevier.com/locate/jcct

Research paper

Automated quantification of mitral valve geometry on multi-slice computed tomography in patients with dilated cardiomyopathy – Implications for transcatheter mitral valve replacement

Tom Banks[a,*], Orod Razeghi[b], Ioannis Ntalas[a], Waqar Aziz[a], Jonathan M. Behar[a], Rebecca Preston[c], Brian Campbell[a], Simon Redwood[a], Bernard Prendergast[a], Steven Niederer[b], Ronak Rajani[a,b]

[a] Department of Cardiology, Guy's and St Thomas' NHS Foundation Trust, London, United Kingdom
[b] Division of Imaging Sciences and Bioengineering, King's College London, London, United Kingdom
[c] Department of Radiology, Guy's and St Thomas' NHS Foundation Trust, London, United Kingdom

ARTICLE INFO

Keywords:
Mitral valve
Geometry
Computed tomography
Transcatheter mitral valve replacement

ABSTRACT

Objectives: The primary aim of this study was to quantify the dimensions and geometry of the mitral valve complex in patients with dilated cardiomyopathy and significant mitral regurgitation. The secondary aim was to evaluate the validity of an automated segmentation algorithm for assessment of the mitral valve compared to manual assessment on computed tomography.

Background: Transcatheter mitral valve replacement (TMVR) is an evolving technique which relies heavily on the lengthy evaluation of cardiac computed tomography (CT) datasets. Limited data is available on the dimensions and geometry of the mitral valve in pathological states throughout the cardiac cycle, which may have implications for TMVR device design, screening of suitable candidates and annular sizing prior to TMVR.

Methods: A retrospective study of 15 of patients with dilated cardiomyopathy who had undergone full multiphase ECG gated cardiac CT. A comprehensive evaluation of mitral valve geometry was performed at 10 phases of the cardiac cycle using the recommended D-shaped mitral valve annulus (MA) segmentation model using manual and automated CT interpretation platforms. Mitral annular dimensions and geometries were compared between manual and automated methods.

Results: Mitral valve dimensions in patients with dilated cardiomyopathy were similar to previously reported values (MA_{area} Diastole: 12.22 ± 1.90 cm^2), with dynamic changes in size and geometry between systole and diastole of up to 5%. The distance from the centre of the MA to the left ventricular apex demonstrated moderate agreement between automated and manual methods (ρ_c = 0.90) with other measurements demonstrating poor agreement between the two methods (ρ_c = 0.75–0.86).

Conclusions: Variability of mitral valve annulus measurements are small during the cardiac cycle. Novel automated algorithms to determine cardiac cycle variations in mitral valve geometry may offer improved segmentation accuracy as well as improved CT interpretation times.

1. Introduction

The recommended treatment strategy for patients with severe symptomatic mitral regurgitation (MR) is surgical mitral valve repair or replacement. However, a large proportion of patients suffering from MR are unsuitable for surgery owing to co-existing morbidities.[1] Following the success of transcatheter aortic valve replacement (TAVR),[2] there has been similar interest in the development of transcatheter mitral valve replacement (TMVR). Before this approach can achieve a similar acceptance to TAVR it will need to demonstrate similar efficacy outcomes and be proven to be a viable option to bridge this therapeutic gap.[3,4] This will require optimal patient selection and procedure planning to account for the more complex anatomy of the mitral valve and its apparatus.

Although early studies have defined the 3-dimensional (3D) geometry of the mitral valve and its dynamic changes throughout the cardiac cycle in healthy individuals,[12,13] limited data are available in pathological states,[14] especially in patients with MR.[13] Patients with

* Corresponding author. Cardiac Outpatients, North Wing, St Thomas' Hospital, Westminster Bridge Road, London, SE1 7EH, United Kingdom.
E-mail address: Tom.Banks@gstt.nhs.uk (T. Banks).

https://doi.org/10.1016/j.jcct.2018.04.003
Received 5 January 2018; Received in revised form 29 March 2018; Accepted 15 April 2018

Abbreviations list

MR	Mitral regurgitation
CT	Computed tomography
ECG	Electrocardiogram
LCCC	Lin's concordance correlation coefficient
TAVR	Transcatheter aortic valve replacement
TMVR	Transcatheter mitral valve replacement

dilated cardiomyopathy represent a distinct subgroup where dilation of the left ventricle, increased wall stress and systolic dysfunction result in papillary muscle displacement, chordae tendinae traction, mitral valve leaflet tenting and mitral annulus dilatation. One result of these changes is the development of functional mitral regurgitation.[12,14] Furthermore, existing studies are limited by their methodological heterogeneity and applicability to the requirements of TMVR. These namely being: small sample sizes[14,15]; failure to quantify the mitral valve throughout the full cardiac cycle[11,14]; and differences in segmentation models.[5] It has therefore become important to establish a standardised approach to the assessment of the mitral valve to ensure optimal TMVR device design and patient outcomes.[16]

The large reliance on pre-procedural imaging with numerous measurements requires cumbersome and time–consuming processing of large datasets and expert interpretation.[15,17] An automated system may streamline pre-procedural workups as seen with similar semi-automated algorithms applied to other cardiac structures acquired with computed tomography (CT).[11,17]

The aims of the current study were 1) to define the dynamic changes in mitral valve geometry throughout the cardiac cycle in patients with dilated cardiomyopathy and 2) to explore the accuracy of a novel automated tracking algorithm for valve segmentation.

2. Methodology

2.1. Study cohort

This study involved the retrospective evaluation of 17 consecutive patients with dilated cardiomyopathy with permanent pacemakers in situ who were scheduled to have pacemaker upgrades to cardiac resynchronisation therapy. Helical scans with retrospectively ECG-gated image reconstruction were performed in these patients as part of a previous study protocol to evaluate CT dyssynchrony, coronary venous anatomy and delayed enhancement by CT. All patients were > 18 years of age and had no contraindication to cardiac CT. No patient in this the study had undergone prior aortic and/or MV repair/replacement that may have introduced MV apparatus distortion to the planned measurements.[20]

All data sets were evaluated manually at all stages of the cardiac cycle and thereafter automatically using a locally developed mitral valve tracking computer algorithm. Written informed consent was obtained from all patients for the original study, while the local research and governance board further approved the use of the acquired data for the purposes of mitral valve geometry evaluation.

2.2. Cardiac CT acquisition

All cardiac CT scans were performed using a Philips Brilliance iCT 256-slice MDCT scanner (Philips Healthcare, Best, The Netherlands). Intravenous metoprolol was used to achieve a heart rate of < 65 beats/min (< 100 beats per minute for those in atrial fibrillation). A total of 100 mls of intravenous contrast (Omnipaque, GE Healthcare, Princeton, NJ, USA) was injected (5 mL/s) via a power injector into the antecubital vein. Ascending aorta contrast triggered, helical scanning was performed with a single breath-hold technique after a 10–12 s delay. The scanning parameters included a heart rate dependent pitch of 0.2–0.45, a gantry rotation time of 270 ms, a tube voltage of 100 or 120 kVp depending on the patient's body mass index and a tube current of 125–300 mA, depending upon the thoracic circumference. Retrospectively ECG-gated image reconstruction was used to generate 10 data sets per cardiac cycle.

2.3. CT data analysis

Assessment of the mitral valve dimensions was performed in two separate platforms for manual and automatic methods, with both allowing double-oblique multiplanar reformatted reconstructions of the heart.[21] Manual assessment of the mitral apparatus was performed in OsiriX (Pixmeo SARL, Bernex, Switzerland), while automatic tracking was performed in a dedicated platform developed in MatLab (MathWorks, Natick, MA, USA).

Pre-processing of CT datasets was required for the automatic tracking algorithm including cropping of CT images to include only the heart structures, allowing for reduced image processing times.

2.4. Mitral valve anatomy – determination of optimal measuring planes

The mitral annulus is a fibro-muscular junction dividing the left atrium and the left ventricle. Its complex 3D saddle shaped structure is defined by the anterior and posterior horn and inferiorly positioned anterolateral and posteromedial commissures[3,10,12] (Fig. 1). The fibrous region of the annulus is located at the aorto-mitral continuity, between the medial and lateral trigones. The predominantly muscular posterior border predisposes the structure to remodeling unlike its fibrous anterior counterpart.[6] The anterior and posterior mitral leaflet are supported by further sub-valvular structures. All of which play an important role in the function of the mitral valve in healthy and pathological states.[12]

2.5. Segmentation models

A plethora of 2D and 3D segmentation models are apparent in the assessment of the mitral valve. The D-shaped, non-planar model and protocol for mitral annulus assessment has recently been proposed and supported as an applicable and valid model in the context of TMVR.[5,21]

2.6. Mitral valve evaluation

2.6.1. Manual quantification

Prior to assessment of the mitral valve, each CT data set was aligned into 4 chamber, 2 chamber and short axis views at the level of the

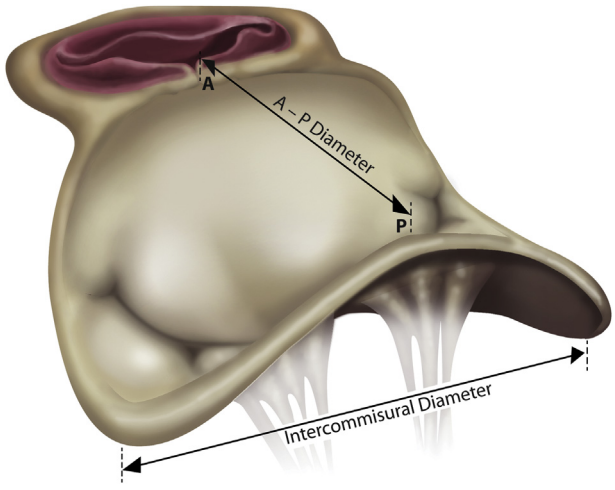

Fig. 1. The saddle shaped mitral valve annulus.