89838_Auto_Edited.docx

Name of Journal: *World Journal of Cardiology*
Manuscript NO: 89838
Manuscript Type: ORIGINAL ARTICLE

Observational Study

Evaluation of mitral chordae tendineae length using four-dimensional computed tomography

Mitral valve evaluation by 4D-CT

Takuya Mori, Satoshi Matsushita, Terumasa Morita, Abulaiti Abudurezake, Junji Mochizuki, Atsushi Amano

Abstract

BACKGROUND

Mitral valvuloplasty using artificial chordae tendineae represents an effective surgical approach for treating mitral regurgitation. Achieving precise measurements of artificial chordae tendineae length (CL) is an important factor in the procedure; however, no objective index currently exists to facilitate this measurement. Therefore, preoperative assessment of CL is critical for surgical planning and support. Four-dimensional CT (4D-CT) may be useful for accurate CL measurement considering that it allows for dynamic three-dimensional evaluation compared to that with transthoracic echocardiography, a conventional inspection method.

AIM

To investigate the behavior and length of mitral chordae tendineae during systole using 4D-CT.

METHODS

Eleven adults aged >70 years without mitral valve disease were evaluated. A 64-slice CT scanner was used to capture 20 phases in the cardiac cycle in electrocardiographic synchronization. The length of the primary chordae tendineae was measured from early systole to early diastole using the 3D images. The primary chordae tendineae originating from the anterior papillary muscle and attached to the A1-2 region and those from the posterior papillary muscle and attached to the A2-3 region were designated as cA and cP, respectively. The behavior and maximum lengths (cA [max], cP [max]) were compared, and the correlation with body surface area (BSA) was evaluated.

RESULTS

In all cases, the mitral anterior leaflet chordae tendineae could be measured. In most cases, the cA and cP chordae tendineae could be measured visually. The mean cA (max) and cP (max) were 20.2±1.95 mm and 23.5±4.06 mm, respectively. cP (max) was significantly longer. The correlation coefficients (r) with BSA were 0.60 and 0.78 for cA (max) and cP (max), respectively. Both cA and cP exhibited constant variation in CL during systole, with a maximum 1.16-fold increase in cA and a 1.23-fold increase in cP from early to mid-systole. For cP, CL reached a plateau at 15% and remained elongated until end-systole, whereas for cA, after peaking at 15%, CL shortened slightly and then moved toward its peak again as end-systole approached.

CONCLUSION

The study suggests that 4D-CT is a valuable tool for accurate measurement of both the length and behavior of chordae tendineae within the anterior leaflet of the mitral valve.

Key Words: Mitral Valve; Chordae Tendineae; Computed Tomography; Four-Dimensional; Cardiac Cycle

Mori T, Matsushita S, Morita T, Abudurezake A, Mochizuki J, Amano A. Evaluation of mitral chordae tendineae length using four-dimensional computed tomography. *World J Cardiol* 2024; In press

Core Tip: Mitral regurgitation is one of the most common cardiac diseases. Although mitral valvuloplasty with artificial chordae tendineae is a standard procedure for surgical treatment, it has been difficult to evaluate the length and their motion preoperatively. In this study, we used four-dimensional computed tomography to establish accurate measurement of the length of chordae tendineae in the anterior leaflet of the mitral valve.

INTRODUCTION

Remarkable advancements have occurred in medical CT, and its applications have expanded with the improvement in multi-slice CT scanning. In cardiovascular medicine, CT is particularly useful in diagnosing coronary artery disease[1]. In recent years, its application has expanded through various guidelines and cases in which images of sufficient quality cannot be obtained with other noninvasive diagnostic equipment[2]. The structure of the mitral valve, which comprises the valve leaflet, annulus, chordae tendineae, papillary muscle, and left ventricular wall, can be comprehensively and three-dimensionally evaluated. The introduction of 320-slice CT has improved temporal resolution to levels approaching those of echocardiography. Conversely, degenerative mitral insufficiency, a prevalent condition, involves myxomatous degeneration of the valve leaflet and chordae tendineae, causing the chordae tendineae to elongate or tear. This results in leaflet deviation of the leaflet and mitral regurgitation (MR)[3,4]. Mitral valvuloplasty, a preferred surgical intervention for MR, offers advantages such as avoiding lifelong anticoagulation therapy and maintaining cardiac function. Numerous techniques for this procedure have been reported[5]. For a long time, resection of the deviated leaflet was the primary method; however, this has limited application for the anterior leaflet. Therefore, chordae tendineae reconstruction (CR) using artificial chordae tendineae is a widely used significantly effective treatment modality for MR caused by anterior leaflet deviation[6]. However, whether CR can be successfully achieved depends largely on the surgeon's experience and skill; hence, it lacks reproducibility and objectivity. Although it would be ideal to form the chordae tendineae by taking differences in their location, characteristics, and length into account, determining their length preoperatively is difficult; furthermore, much remains unknown about their behavior inside the body. When conventional echocardiography is used for preoperative evaluation in mitral valvuloplasty, it is difficult to observe the length and behavior of the chordae tendineae owing to the nature of the technique. In contrast with cardiac CT, it is possible to construct a 3D image of the beating heart under electrocardiographic synchronization to obtain images, as needed, that are independent of cross-section and angle, which could allow for the dynamic evaluation of mitral chordae tendineae. Furthermore, dual-energy CT, which has received attention recently, combines images from both low- and high-energy imaging. This could allow for a more detailed evaluation than that with conventional CT[7]. A better understanding of the *in vivo* behavior and geometry of the chordae tendineae is expected to greatly improve the objectivity and reproducibility of surgeries, and could provide very useful preoperative information, especially in surgeries with restricted surgical field, such as minimally invasive cardiac surgery, which is widely being used.

Therefore, our study aims to assess the detectability of mitral chordae tendineae using four-dimensional (4D) CT (4D-CT) and examine variations in their length and behavior throughout the cardiac cycle *in vivo*.

MATERIALS AND METHODS

The participants in this study provided consent for their participation after they receiving detailed information on how their data would be handled. The study protocol was reviewed and approved by the Ethics Committee of Juntendo University School of Medicine (approval #2021080 Juntendo University Medical Ethics).

Eleven adults aged >70 years without mitral valve disease were included in the study. Data from coronary CT scans performed as part of health checks were analyzed. The table presents basic data for all participants. None of the participants had any cardiac disease that required medication.

A 64-slice CT scanner (iQon Spectral CT, Philips Healthcare, Amsterdam, Netherlands) was used to obtain CT images. The contrast agent was iopamidol (370 mg/mL, Bayer Pharmaceuticals, Leverkusen, Germany) administered at 3.5 mL/s for at least 10 s. CT imaging was performed with 600 mA tube current, 120 kV tube voltage, and 0.16 pitch factor. The data were reconstructed with an R-R interval of 0-95% in 5% increments with a thickness of 0.67 mm (Figure 1). Data from 20 phases of the cardiac cycle were sent to a workstation (Aze Virtual Place, Canon Medical Systems, Tochigi, Japan) to create 3D images.

The primary chordae tendineae originating from the anterior papillary muscle (APM) and attached to the A1-2 region were designated as cA, and those originating from the posterior papillary muscle (PPM) and attached to the A2-3 region as cP. The chordae tendineae were measured using the following procedure.

cA or cP was confirmed on the 3D image.

The attachment sites of the valve leaflets and corresponding papillary muscle attachments were identified and marked on the image.

Those marks were confirmed on 2D Multi-Planar Reformatting (MPR) images of the long axis of the heart corresponding to the 3D image.

The angle of the cross-section was fine-tuned so that the two marks appear simultaneously in the 2D-MPR images.

The distance between two points in the 2D-MPR images was measured.

Measurements were taken for 11 phases (0–50%) for cA and cP, respectively. Three measurements were taken per phase in all cases, and the mean value was used as the chordae tendineae length (CL). The maximum CL in the 11 phases for each case was defined as cA (max) and cP (max), and comparisons were made to evaluate the correlation with the body surface area (BSA). The rate of change of CL at each time phase concerning early systole (phase 0%) was graphed to compare the behavior of cA and cP during systole.

Statistical analyses

All data were analyzed with IBM SPSS Statistics version 29 (IBM, Armonk, NY, USA) and presented as mean ± standard deviation. The homoscedasticity of the mean values of each group was confirmed, and an unpaired t-test was used to compare them. Pearson's product-moment correlation coefficient was used to analyze the correlation between CL and BSA. Intra-rater reliability was determined by calculating intraclass correlation coefficients [ICC (1,1) and ICC (1,3)]. The significance level for all statistical tests was <5%.

RESULTS

Evaluation of mitral anterior leaflet chordae tendineae using 4D-CT

The mitral anterior leaflet chordae tendineae could be measured in all cases. In most cases, the cA and cP chordae tendineae could be measured visually, and the leaflets and papillary muscle attachments could be easily identified, even for smaller chordae tendineae that could not be visualized on CT. Individual differences occurred in the number of chordae tendineae originating from the papillary muscles. The number originating from the anterior leaflet of the APM was 3.18 ± 0.60, and that from the anterior leaflet of the PPM was 2.45 ± 0.52, with a significantly higher number originating from the APM. The PPM of Case 10 was smaller than those of the other cases, being displaced toward the apex.

cA and cP measurements and differences

CL exhibited large variations between individuals, with mean cA (max) and cP (max) being 20.2 ± 1.95 mm and 23.5 ± 4.06 mm, respectively. cP was significantly longer than cA (max). The correlation coefficients (r) with BSA were 0.60 and 0.78 for cA (max) and cP (max), respectively, showing significant correlations.

Variation in cA and cP during systole

CL revealed constant variation during systole for both cA and cP, with a maximum 1.16-fold elongation in cA and 1.23-fold elongation in cP from early to mid-systole. For cP, CL reached a plateau at 15% and remained elongated until end-systole. Conversely, for cA, after peaking at 15%, CL shortened slightly and then peaked again as end-systole approached.

DISCUSSION

Evaluation of mitral anterior leaflet chordae tendineae using 4D-CT

We were able to measure the length of the mitral anterior leaflet primary chordae tendineae using 4D-CT. The chordae tendineae are small tissues that move at high speeds, making accurate evaluation challenging. Recently, however, several studies have attempted to measure the length of mitral chordae tendineae with transthoracic echocardiography (TTE), transesophageal echocardiography (TEE), and cardiac CT. TTE measurements have been used for a relatively overtime owing to their simplicity. However, considering that it is challenging to obtain a cross-section that adequately evaluates the 3-dimensional length of the mitral chordae tendineae, this method is somewhat lacking in accuracy[8]. Recently, evaluation by TEE has become widely used, while improvements in techniques such as transgastric echocardiography that produce fewer artifacts have been reported[9]. Although TEE is at present considered the standard method for evaluating CL, this method has some drawbacks, such as the mental and physical stress associated with the examination and the skill needed to perform the technique[10, 11]. Despite these challenges, with the advent of multi-slice CT, evaluation using cardiac CT has garnered attention. With helical CT, the mitral valve structure can be obtained as volume data; following this, MPR and 3D images can be created to reconstruct optimal cross-sections for chordae tendineae assessment. This allows for direct and accurate measurement of CL, and for all chordae tendineae to be assessed in a single imaging session[12]. However, the characteristics of 3D measurements make them prone to error, while creating suitable cross-sections for 2D-MPR image measurements is time-consuming. Therefore, in the present study, we combined both methods to obtain simple, reproducible, and accurate results. We identified the points to be measured in 3D images, and then accurately measured them in 2D-MPR images. In most instances, we could evaluate the anterior leaflet primary chordae tendineae directly, although in some cases they were blurred from timing artifacts.

cA and cP measurements and differences

In previous reports on autopsies, mitral anterior leaflet CL was 15–20 mm[13] and 17.5 ± 0.25 mm[14]. While this study had similar findings, the CLs measured in our study were slightly longer than those measured in previous autopsies. Moreover, CLs measured by the previous studies using TEE tended to be longer than those obtained through autopsies, i.e., 21.3 ± 2.8 mm[9] and 19.3 ± 0.50 mm[11]. The lengths obtained by autopsies were shorter than those obtained by live measurements because the chordae tendineae in the dead bodies lacked proper tension. In the present study, cP (max) was longer than cA (max) and APM had more chordae tendineae origins than PPM. A similar tendency was observed in a study of pig hearts, with cA 16.04 ± 2.16 mm and cP 20.56 ± 3.35 mm (Sengda), suggesting that it is possible to accurately measure cA and cP with 4D-CT[14].

The intraclass correlation coefficients ICC (1,1) and ICC (1,3) in our study were 0.963 and 0.987 for cA and 0.970 and 0.990 for cP, respectively, suggesting very high reproducibility of this method.

cA (max) and cP (max) exhibited large individual differences in the present study, and a significant correlation was found between BSA and CL. It is known that left ventricular end-diastolic diameter correlates with BSA in normal hearts; however, larger bodies and hearts may have longer CL[15, 16]. Although there have been no reports on differences in CL based on body size, it may be necessary to take body size into account, especially when making preoperative predictions. It could be beneficial to investigate the relationship between heart size and CL by comparing various echocardiographic parameters to CL.

Variation in cA and cP during systole

Variation in CL was observed during systole in the present study. Conventionally, the chordae tendineae were thought to be rigid, non-elastic tissues composed mainly of elastin and collagen; however, recent studies have indicated that they have some degree of elasticity[17-19]. In the present study, a maximum 1.16-fold elongation was observed in cA from early to mid-systole and 1.23-fold elongation in cP. This indicates the importance of timing (15-40%) in CL measurement, because measuring CL without specifying the timing on cardiac CT may underestimate it. In the present study, cP exhibited a PV loop-like variation with increasing intracardiac pressure, whereas cA exhibited a slight shortening of CL once it peaked, and then another peak toward end-systole. This may distort the pressure applied to the mitral anterior leaflet during systole. In vitro studies have suggested that in normal hearts, pressure on the mitral valve is uniform, but the displacement of the papillary muscle may result in non-uniform pressure[20]. The left ventricle is also known to undergo torsional movement during systole, which may have some effect on the displacement of the papillary muscle or the length of chordae tendineae[21]. Moreover, a recent analysis found that intracardiac blood flow is not linear but spiral, suggesting the pressure applied to the mitral valve in the body is not uniform[22]. While we were unable to determine the cause of this, dynamic assessments and blood flow analyses of the papillary muscles and left ventricular wall should be performed going forward.

As described above, while 4D-CT was seen as useful for CT measurements, the risks associated with radiation exposure and the use of contrast media in CT imaging should be taken into consideration when using this technique. That said, this imaging method does not require any special treatment or technique and can be performed simultaneously with coronary artery CT. If an institution routinely performs coronary artery CT as a preoperative examination, this method can be simultaneously implemented with no increase in radiation exposure or other burdens on patients. In the present study, we focused on two of the more important and thicker chordae tendineae; however, we believe that relatively thin chordae tendineae close to the commissure could also be evaluated if suitable cross-sections were prepared. Variations in the shape of the papillary muscles were also seen in the cases in this study. In case 10, a smaller PPM than that in the other cases was noticed and resulted in a very long cP. It is very important to take these individual differences into account when performing mitral valvuloplasty, and CT is an excellent tool for evaluating the entire mitral valve apparatus, including the papillary muscles. Using this study as a stepping stone, we would like to pursue further research by evaluating patients with pathological conditions to help make 4D-CT a useful preoperative examination for mitral valvuloplasty.

Limitations

The limitations of this study include a small sample size, a narrow range of participants restricted to older individuals, and the absence of direct measurement of chordae tendineae. The chordae tendineae behavior in older individuals may differ from that in younger patients.

CONCLUSION

This study revealed that the primary chordae tendineae of the mitral valve anterior leaflet can be measured using 4D-CT. The lengths of cA and cP differed among individuals and varied during systole. As 4D-CT can measure the mitral complex in three dimensions and at specific timings, it may provide a more accurate evaluation of mitral CL than other modalities. Further research is warranted to explore the applicability of 4D-CT in various clinical scenarios and pathological conditions, enhancing its role as a valuable preoperative examination tool for mitral valvuloplasty

89838_Auto_Edited.docx

ORIGINALITY REPORT

1 %
SIMILARITY INDEX

PRIMARY SOURCES

1	jtd.amegroups.com Internet	15 words — < 1%
2	discovery.dundee.ac.uk Internet	12 words — < 1%

EXCLUDE QUOTES	ON	EXCLUDE SOURCES	< 12 WORDS
EXCLUDE BIBLIOGRAPHY	ON	EXCLUDE MATCHES	< 12 WORDS