Med. J. Cairo Univ., Vol. 92, No. 2, Accepted 2/4/2024
DOI: 10.22608/MJCU. 497-504, June 2024
www.medicaljournalofcairouniversity.net

Automated MDCT Post-Processing Software for Aortic Annulus Parameters before Surgical Aortic Valve Replacement: Correlation with Operative Details

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Abstract

Background: A comparative study between the automated MDCT post-processing to measure the aortic annulus parameters before surgical aortic valve replacement and intra-operative aortic annulus sizing was done.

Aim of Study: To compare the accuracy of pre-operative automated Fuji software synapse 3D tools with the surgical details of aortic valve replacement, regarding the aortic annulus parameters and distance between the aortic annulus and the coronary ostia.

Patients and Methods: Our study included 168 patients who presented with significant aortic valve disease. Surgical aortic valve replacement was the treatment of choice. The CT images were post-processed using automated Fuji software synapse 3D tools . Intraoperative aortic valve annulus sizing was done.

Results: The mean age of our patients was from 28 to 72 years (mean 54.6±7.2 years). There was a statistically significant positive correlation between aortic calcification grading and AVA by CT examination. There was excellent agreement for annulus effective and mean diameters (ICC: 0.939 & ICC: 0.881 respectively), good agreement for maximum diameter (ICC: 0.751, 95% CI: (0.479-0.850), poor agreement for minimum diameter & annulus area. The correlation of left coronary artery ostium height and right coronary artery ostium height was considered acceptable with a *p*-value of 0.182 and 0.617 respectively.

Conclusion: MDCT is used as a complementary method in pre-procedural planning of aortic valve surgery as it is more accurate in the assessment of aortic valve anatomy, calcification, and aortic annulus sizing. The automated post-processing software tools provide important clinical application in the management of patients undergoing surgical aortic valve replacement with reliable and reproducible aortic annulus measurements, thus reducing the post-procedural complications.

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Key Words: *Aortic valve disease (AVD) – Aortic valve area (AVA) – Aortic valve calcification (AVC) – Computed Tomography Angiography (CTA) – Aortic stenosis (AS) – Automated MDCT post-processing.*

Introduction

AORTIC valve disease is considered the most prevalent cardiovascular disease after hypertension and coronary artery disease. Surgical aortic valve replacement remains the mainstay of treatment for advanced disease **[1].**

Meticulous and proper measurement of the aortic annulus dimensions is necessary for choosing the correct prosthesis size **[2].**

Echocardiography is of low cost and widely available, thus considered the first line of imaging for the detection of valvular heart disease (VHD). However, it is often limited by the patient's acoustic window and has an inter-observer variation **[3].**

MDCT angiography (CTA) has developed an increasingly essential role before surgical aortic valve replacement. It can provide detailed information regarding the anatomical geometry of the aortic root structures and left ventricular outflow tract, as well as the measurement of the distance between the aortic annulus and coronary ostia **[4].**

List of Abbreviations:

AVR : Aortic valve replacement.
AVA : Aortic valve area.
VHD : Valvular heart disease.
AHA/ACC : American Heart Association/ American college of cardiology.
LM : Left main coronary artery.
RCA : Right coronary artery.

Novel automated post-processing imaging software as Fuji software synapse 3D tools may provide an accurate preoperative evaluation by standardizing all image post-processing and may help to increase the preoperative utility of this technique for a wider clinical community **[5]**.

Aim of the work: Was to compare the accuracy of pre-operative automated Fuji software synapse 3D tools with the surgical details of aortic valve replacement, regarding the aortic annulus parameters and distance between the aortic annulus and the coronary ostia.

Patients and Methods

Patients:

The study was conducted on over 168 patients who were admitted to the cardiothoracic surgery department with echocardiography reports of significant aortic valve disease. Their ages ranged from 28 to 72 years (mean 54.6±7.2 years). Surgical aortic valve replacement was the treatment of choice according to the decision made by the cardiac team based on AHA/ACC **[6]**.

Written consent was taken from all the patients according to the ethical committee. The patients underwent CTA in the radiology unit at a tertiary hospital over period from May 2023 to January 2024.

1- *Inclusion criteria:*

• Patients were referred with echocardiographic reports of aortic valve diseases and indicated for aortic valve replacement according to AHA/ACC guidelines for aortic valve replacement (AVR).

2- *Exclusion criteria:*

- Bad general condition e.g. orthopnea.
- Patients with renal failure (relative contraindication).
- Known contrast hypersensitivity reaction.

3- *Patient preparation:*

The patient was instructed to fast for 4-6 hours. An 18-20 gauge cannula was inserted into the antecubital vein. All patients received beta-blocking agents (metoprolol 50-100mg) to lower heart rate to reach 65-70 beats per minute to improve the acquisition scan.

Methods:

CTA technique:

CT machine: High speed 256 MDCT machine using Ingenuity Core TM, Philips, Netherlands.

Technique: Non-contrast scan was done first for subjective assessment of the aortic valve calcification. It was followed by a post-contrast study using the timing bolus technique with localization of the region of interest (ROI) at the proximal descending thoracic aorta with ECG retrospective gating.

CT parameters: Slice thickness was 1.25mm, slice interval was 0.625mm, and matrix size was 512 x 512 with pitch number 1.75:1. The rotation time used was 0.5 seconds with tube speed 35mm/rotation. The Kv was 120 while the mA was ranging from 120 to 400 according to the body weight.

Contrast media: 80-100ml non-ionic contrast media at a rate of 4-5ml/sec.

Image processing: The axial images were transferred to the Fuji automated software synapse 3D tools for specific calculation of the aortic annulus parameters.

A- *Post-processing automated Fuji software synapse 3D tools:*

First, subjective assessment of the aortic valve calcifications was conducted as follows:

- Grade I: No calcifications.
- Grade II: Mildly calcified (small isolated spots).
- Grade III: Moderately calcified (Multiple large spots).
- Grade IV: Heavily calcified (extensive calcification of all cusps).

Then, we have selected the 30% phase from the R-R interval using the Fuji software 3D tools as such phase had maximum valve opening (similar to echocardiography) **[7]**. The software extracted the heart and aortic regions from the CT input images. The automated results concerning the aortic root have included aortic annulus, aortic circumference, major and minor diameters, as well as the distances between the aortic annulus and the LM/RCA origin (Fig. 1).

B- *Aortic valve replacement surgery (AVR):*

Aortic valve replacement surgery was performed within two weeks from the last CTA examination and was considered the gold standard for our study.

Intraoperative aortic valve annulus sizing:

- Aortic annulus size was assessed intra-operatively after resection of the aortic valve cusps and after decalcification of the aortic annulus in patients with aortic valve calcification. Aortic valve sizers were inserted in the aortic annulus.
- After metric sizing, the annulus was sized using the prosthesis manufacturer's sizers and an appropriate valve prosthesis was implanted.

Results

The present study was carried out on 168 cases with their mean age from 28 to 72 years (mean 54.6 ±7.2 years), 57.1% of them were males and 42.9% were females.

The aortic valve disease has included AR (52.3%), AS (37%), and mixed aortic valve disease (10.7%).

The subjective assessment of the aortic valve calcifications into four grades (Table 1).

Table (1): Distribution of the studied cases according to calcification grades.

Calcification grade	N	%
GI	22	13.2
GII	34	20.2
GIII	78	46.4
GIV	34	20.2
Total	168	100.0

Correlation of aortic annulus size between CT and intra-operative direct sizing (CT max/CT min / CT mean / CT area) by interclass correlation (Table 2):

Mean annulus maximum diameter (CT max), minimum diameter (CT min), mean diameter (CT mean), effective diameter (CT eff) & annulus area (CT area) by CT are 23.18±3.84 mm, 29.93±6.51mm, 26.55±4.73mm, 22.1±2.62 & 576.68±224.68mm^2 respectively that were assessed for agreement with surgery mean valve size 22.19±2.12. There was excellent agreement for annulus effective and mean diameters (ICC: 0.939 & ICC: 0.881 respectively), good agreement for maximum diameter (ICC: 0.751, 95% CI: (0.479-0.850), poor agreement for minimum diameter & annulus area as shown in (Table 2&3), (Figs. 2,3).

Correlation and level of agreement between the CT measurements of the distance from the aortic annulus to the origin of both LM and RCA and intraoperative sizing by Bland-Altman analysis and interclass correlation:

The CT measurement of the distance between the aortic annulus and both LM and RCA were 13.27±2.9 mm, and 15.56±2.8m respectively that were assessed for agreement with surgery. There was excellent agreement for both distances (ICC 0.720 & ICC: 0.689 respectively) (Table 4).

Statistical analysis:

Data from MDCT examination using Fuji automated software synapse 3D tools specific calculation of the aortic annulus as well as intraoperative direct sizing were collected, tabulated, and subjected to appropriate statistical test.

Table (2): Correlation of aortic annulus size between CT and intra-operative direct sizing (CT max/CT min / CT mean / CT area) by interclass correlation.

	CT	Intraoperative sizing	ICC	(95% CI)
CT max	23.18±3.84 (12-31.6)	22.19±2.12 (19.0-25.0)	0.751	(0.479-0.850)
CT min	29.93±6.51 (19.1-47.8)	22.19±2.12 (19.0-25.0)	0.428	(-0.066-0.693)
CT mean	26.55±4.73 (17.4-29.7)	22.19±2.12 (19.0-25.0)	0.881	(0.274-0.991)
CT eff	22.1±2.62 (16.8-27.9)	22.19±2.12 (19.0-25.0)	0.939	(0.886-0.967)
CT area	576.68±224.68 (219.0-1119.1)	22.19±2.12 (19.0-25.0)	0.022	(-0.819 -0.476)

ICC: Interclass correlation.

Table (3): Agreement between CT annulus (maximum, minimum & mean diameter and surface area) and intraoperative sizing by Bland-Altman analysis.

	Mean diameter of CT versus mean diameter of surgery	*p*-value of difference mean	Mean difference (range)/mm	Limits of agreement/mm
CT max	23.18±3.84Vs 22.19±2.12	<0.001*	0.79 (-9.0, 9.1)	-17.06 to 18.63
CT min	29.93±6.51Vs 22.19±2.12	<0.001*	7.73 (-6.1, 24.8)	-3.8 to 19.15
CT mean	26.55±4.73Vs 22.19±2.12	<0.001*	4.38(-3.1, 16.6)	-3.4 to 12.07
CT eff	22.1±2.62Vs 22.19±2.12	0.344	-0.17(-2.1, 5.1)	2.07 to 2.5
CT area	576.68±224.68Vs 22.19±2.12	<0.001*	-554.51 (-1096.3, -198.1)	-1.618 to 532.26

Table (4): Correlation and level of Agreement between the CT measurements of distance from the aortic annulus to the origin of both LM and RCA and intraoperative sizing by Bland-Altman analysis and interclass correlation.

	CT Measurement	Intraoperative sizing	ICC	*p*-value of difference mean
Distance between annulus and LM	13.27+2.9	14.61±2.19	0.720	0.182
Distance between annulus and RCA	15.56+2.8	15.02±2.8	0.689	0.617

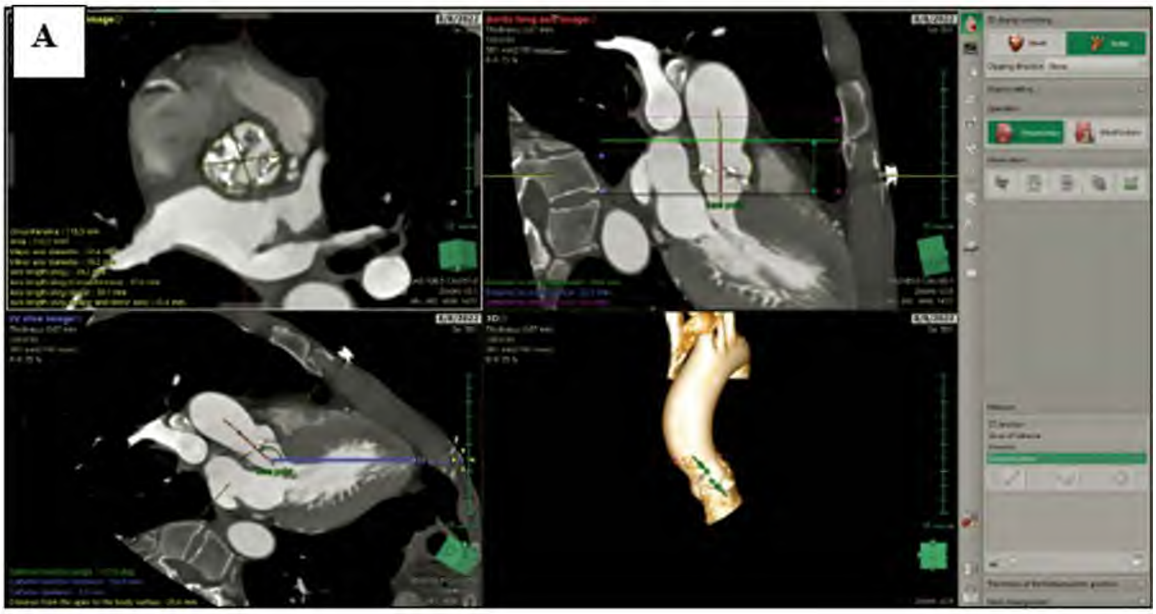

Fig. (1-A)

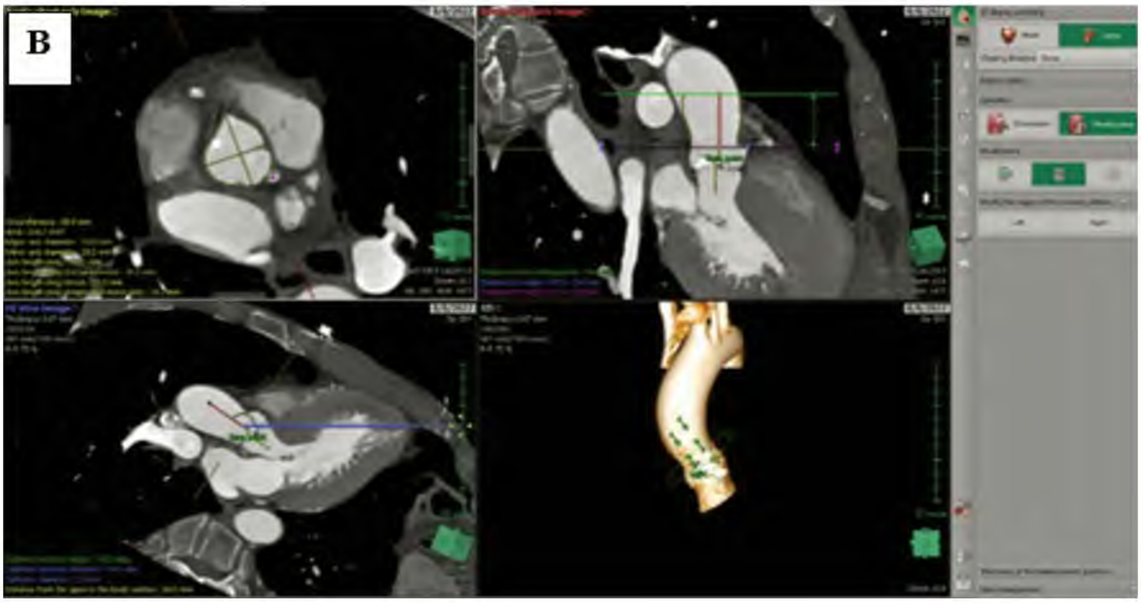

Fig. (1-B)

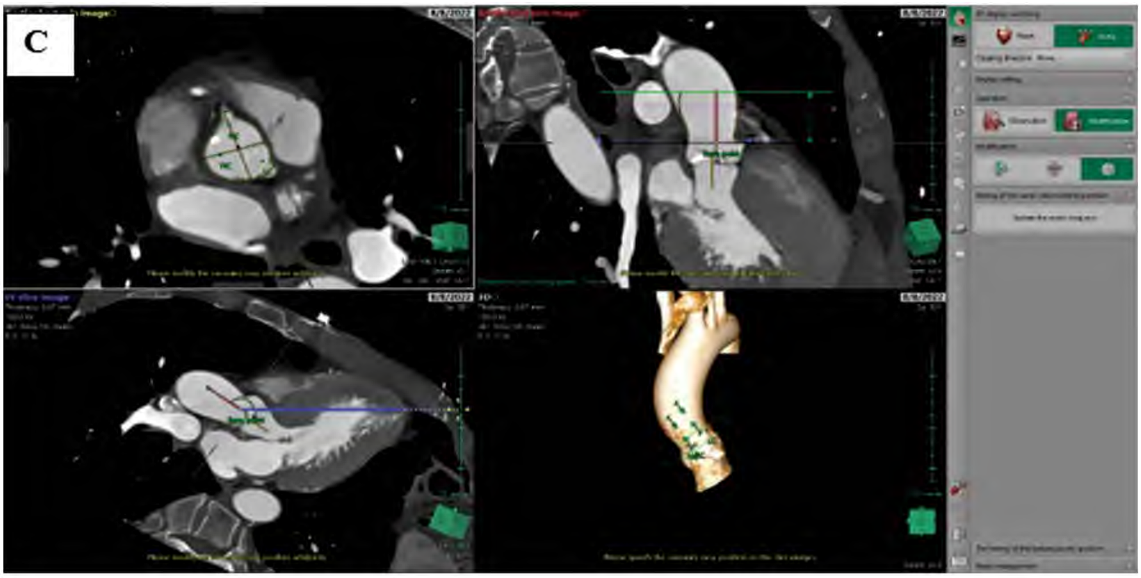

Fig. (1-C)

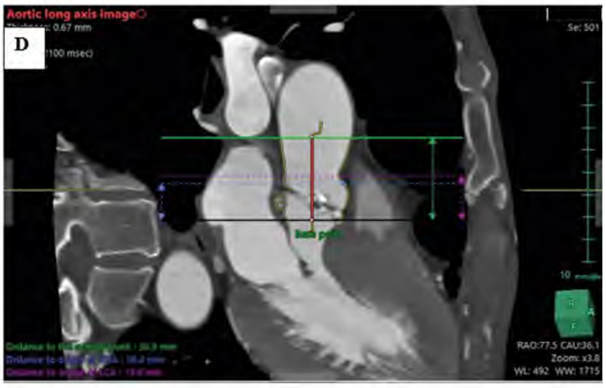

Fig. (1-D)

Fig. (1): Steps of the calculation of the aortic annulus parameters. (A) The automated Fuji 3D synapse software started byshowing the left ventricular outflow tract and the ascending aorta in the three orthogonal planes with 3D simulation. (B) The second step was to identify the location of the right coronary cusp (RC), left coronary cusp (LC), and non-coronary cusp (NC). (C) The third step is to identify the ostium of the right coronary artery and left coronary artery. (D) The fourth step was the oblique coronal CT image showing the distances between the aortic annulus and the ostium of the right coronary as indicated by the blue color; as well the distance between the aortic annulus and the LM as indicated by purple color.

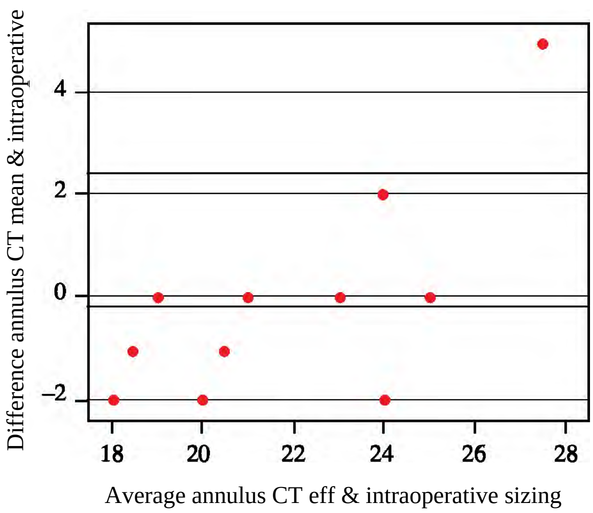

Fig. (2): Bland-altman analysis for agreement between CT & direct intraoperative sizing for CT effective. The middle line represents the mean; the upper line and the lower line represent ±1.96 standard deviation (SD).

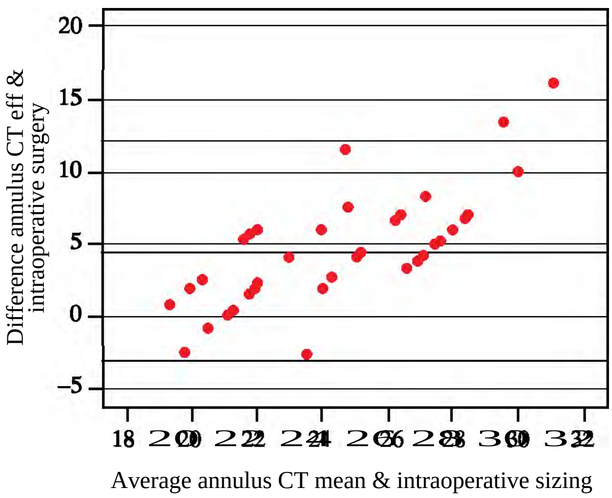

Fig. (3): Bland-altman analysis for agreement between CT & direct intraoperative sizing for CT mean. The middle line represents the mean; the upper line and the lower line represent ±1.96 standard deviation (SD).

Discussion

This study reports the first correlation between the pre-operative MDCT assessment using the post-processing Fuji software tools in the evaluation of aortic annulus parameters and comparing these measurements with the intra-operative annular sizing.

The automated Fuji software synapse 3D tool is a software program for a specific analysis of the aortic root measurement. It can provide accurate automated measurement of the aortic annulus in patients undergoing surgical aortic valve replacement by automatically constructing an orthogonal image of the aortic root.

Echocardiography (TEE) has been used as a primary imaging modality for preoperative evaluation to measure aortic annulus diameter and for valve sizing before surgical intervention ***[8]***.

MDCT appeared to be more reproducible across multiple readers and can offer valuable information in clinical scenarios compared to echocardiography ***[9]***.

MDCT is used as a complementary method in pre-procedural planning of the aortic valve surgery as it is more accurate in the assessment of aortic valve anatomy, calcification, and aortic annulus sizing ***[10]***.

This study included 168 patients indicated for aortic valve replacement surgery. Their ages ranged from 28 to 72 years (mean 54.6±7.2 years) and 57.1% were males. This is consistent with Wang et al who stated that aortic valve replacement surgery showed higher incidence in old age and male patients compared to females, especially in developing countries ***[11]***.

The most common systemic disease associated with valve heart disease is RHD which constituted 51.2% of the cases in this study. This is similar to Coffey et al., who stated that rheumatic valve disease is the most common risk factor for AVD in developing countries. However, degenerative valve calcification in the old population is the leading cause of valve dysfunction in developed countries ***[12,13]***.

There was a positive correlation between AVA and grade of calcification detected by CT and the severity of aortic valve stenosis (AS) (r=0.881) which was matching with a previous study done by Paulsen et al., ***[14]***.

We found that the best agreement between CT annulus measurement and direct intraoperative sizing was CT effective diameter and CT mean diameter ((ICC: 0.939 & ICC: 0.881 respectively). This was similar to a study done by Kempfert et al, who compared the echocardiography versus computed tomography using conventional manual measurements with the direct surgical data and found that the best agreement was with CT effective diameter [15].

On the other hand, George et al., had performed a study comparing the intra-operative aortic valve annular size versus preoperative multi-detector computed tomography with the traditional manual post-processing technique. The MDCT measurements of the aortic annulus were different from intraoperative direct measurements, and most of the cases had smaller intraoperative aortic root dimensions. This can be explained by some reasons. First, the left ventricle is arrested during the surgical intervention with deformation of the geometry of the aortic annulus. Second, the nature of the surgical AVR valve sizing may exacerbate annular under-sizing as valve sizes are typically provided in sizes 19 to 29mm with valves available every 2mm [16].

The automated MDCT post-processing software (Fuji 3D synapse) can provide reliable and reproducible aortic annulus measurements in patients undergoing surgical aortic valve replacement, with comparable results to real aortic valve sizing. We think that (Fuji 3D synapse) will be a promising application that can standardize all MDCT images post-processing. In addition, it is rapid, time-saving and can be performed by junior staffs.

Conclusion:

MDCT is more accurate in the assessment of aortic valve anatomy, calcification, and aortic annulus sizing than echocardiography. The automated MDCT post-processing software provides important clinical applications for patients undergoing surgical aortic valve replacement with reliable and reproducible measurements. Moreover, it is rapid, time-saving, and can be performed by junior staff.

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برنامج ما بعد المعالجة الآلى لـ MDCT لأبعاد الحلقة الأورطى قبل استبدال الصمام الأورطى جراحيًا: والارتباط بالتفاصيل الجراحية

الخلفية: يعتبر مرض الصمام الأورطى من أكثر أمراض القلب والأوعية الدموية انتشارًا بعد ارتفاع ضغط الدم ومرض الشريان التاجى. يظل استبدال الصمام الأورطي جراحيًا الدعامة الأساسية لعلاج المرض المتقدم. يعد القياس الدقيق والسليم لأبعاد حلقة الأورطي ضروريًا لاختيار حجم الصمام الصناعي الصحيح.تصوير الأوعية باستخدام الاشعة المقطعية MDCT (CTA) له دورًا أساسيًا بشكل متزايد قبل استبدال الصمام الأورطى جراحيًا. يمكن أن يوفر معلومات مفصلة فيما يتعلق بالهندسة التشريحية لهياكل جذر الأورطي ومسالك تدفق البطين الأيسر، بالإضافة إلى قياس المسافة بين حلقة الأورطى وفوهة الشريان التاجى. ويوفر برنامج التصوير الآلى الجديد بعد المعالجة مثل أدوات 3D Fuji Software Synapse تقييمًا دقيقًا قبل الجراحة من خلال توحيد جميع معالجة الصور بعد المعالجة وقد يساعد فى زيادة فائدة هذه التقنية قبل الجراحة لمجتمع كلينيكى أوسع.

الهدف من البحث: مقارنة بين المعالجة اللاحقة لـ MDCT الآلية لقياس ابعاد الحلقة الأورطى قبل استبدال الصمام الأورطى جراحياً وتغيير حجم الحلقة الأورطى أثناء العملية.

المرضى و طرق الدراسة: شملت دراستنا ١٦٨ مريضاً يعانون من مرض الصمام الأورطي الكبير. كان استبدال الصمام الأورطي جراحيًا هو العلاج المفضل. تمت معالجة الصور المقطعية بعد المعالجة باستخدام أدوات المزامنة ثلاثية الأبعاد لبرنامج Fuji الآلي. وتم إجراء تحجيم حلقة الصمام الأورطي أثناء العملية.

النتائج: كان متوسط عمر مرضانا من ٢٨ إلى ٧٢ عاماً (يعنى ٥٤,٦ ± ٧,٢ عامًا). كان هناك علاقة إيجابية ذات دلالة إحصائية بين درجات تكلس الأورطى وAVA بواسطة الفحص المقطعى. كان هناك اتفاق ممتاز للحلقة الفعالة والأقطار المتوسطة (ICC: ٠,٩٣٩ وICC: ٠,٨٨١ على التوالى)، اتفاق جيد للقطر الأقصى (ICC: ٠,٧٥١، ٩٥٪ CI: (٠,٤٧٩-٠,٨٥٠)، اتفاق ضعيف على الحد الأدنى للقطر ومنطقة الحلقة. تم اعتبار العلاقة بين ارتفاع فتحة الشريان التاجى الأيسر وارتفاع فتحة الشريان التاجى الأيمن مقبولة بقيمة p تبلغ ٠,١٨٢ و٠,٦١٧ على التوالى.

الخلاصة: يُستخدم MDCT كوسيلة تكميلية فى التخطيط المسبق لجراحة الصمام الأورطى لأنه أكثر دقة فى تقييم تشريح الصمام الأورطى والتكلس وتحجيم حلقة الأورطى. يمكن لأدوات برامج ما بعد المعالجة الآلية أن توفر تطبيقًا سريريًا مهمًا في إدارة المرضى الذين يخضعون لاستبدال الصمام الأورطى جراحيًا بقياسات حلقة الأورطى الموثوقة والقابلة للتكرار، وبالتالى تقليل مضاعفات ما بعد الإجراء الجراحى.