Preoperative Evaluation of Aortic Calcification by Computed Tomography in Thoracic Aortic Disease

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Abstract

Background: Computed tomography (CT) is a useful tool for the identification of calcified lesions in the aorta. However, no quantitative evaluation has been established to assess the applicability of simple anastomosis preoperatively. We conducted this retrospective study to establish a reference range of the maximal CT value for application of simple anastomosis. Methods: 122 consecutive patients underwent replacement of the thoracic aorta between 2007-2011, excluding those with acute aortic dissection. The patients were divided into two groups: those who could undergo simple anastomosis (Simple group:n=105), and those who required endarterectomy prior to anastomosis (Manipulation group:n=17). The maximal CT value at the anastomosis site was calculated by an imaging software. Results: The mean maximal CT value (Hounsfield unit: HU) was significantly higher in the Manipulation group (638.1 ± 269.5 [166-1304]) than in the Simple group (94.7 ± 171.5 [0-790]) ($p<0.0001$). The maximal CT value enabled us to predict the simple anastomosis with the area under the receiver operating characteristic curve of 0.96 ($p<0.0001$). The cut-off value was 325 HU (sensitivity 94.1%, specificity 81.7%). The 10-year survival rate was significant lower in the Manupilation group (11.8%) than in the Simple group (43.2%). In the multivariate analysis, age (Hazard Ratio [HR]:1.073), Hypertension (HR:2.382) and maximal CT value (HR:1.001) were independently associated with long-term mortality. Conclusions: Preoperative evaluation of the maximal CT value is a useful tool in predicting whether simple anastomosis is applicable or not, in the thoracic aortic surgery. Maximal CT value is a risk factor for long-term mortality.

Introduction: An aging society brings with it a wide range of medical problems, one of which is an increasing number of patients with a severely calcified aorta[1]. These patients, who often require thoracic aortic surgery, may encounter numerous obstacles during the surgery. For one, the calcified intima interferes with suturing of the aorta, thereby renders aortic anastomosis to be difficult. Moreover, should the calcified aorta be forcibly sutured, the aortic wall may split and lead to bleeding or rupture. In view of the increased risk of complications that would affect the surgical plan and outcome, it is important to predict the extent of aortic calcification preoperatively. Computed tomography (CT) is a useful device for diagnosis of calcified lesions, but no quantitative evaluation has been established to predict whether simple anastomosis or any additional manipulation such as endarterectomy is required during operation. Here, we conducted this retrospective study to establish the reference value range of the maximal CT value for application of simple anastomosis in thoracic aortic surgery.

Patients and Methods: Between 2007 and 2011, 122 consecutive patients (mean age = 67 ± 14 years) underwent replacement of the thoracic aorta were included in this study. Patients with acute aortic dissection were excluded, though those with chronic aortic dissection were included such as dissecting aortic aneurysm. We divided the 122 patients into 2 groups, 105 patients (mean age = 66 ± 14) underwent simple anastomosis (Simple group), and 17 patients (mean age = 73 ± 6) required endarterectomy before undergoing anastomosis (Manipulation group). Preoperative CT scans were taken and the maximal CT value at the anastomosis site in comparison with postoperative CT was calculated using a diagnostic imaging software (AZE Virtual Place

Raijin, Aze Ltd., Tokyo, Japan), based on the peak Hounsfield unit (HU) of the detected calcified lesions. When it was less than 130 HU, we defined 0 HU at the area. The institutional review board approved this retrospective study. Informed consent was obtained from all patients.

Surgical technique:

In the cases of ascending aorta, aortic arch, and aortic root replacement, the chest was opened via a median sternotomy under general anesthesia. The bilateral axillary arteries were exposed for arterial cannulation. Cardiopulmonary bypass (CPB) was established with bilateral axillary arterial cannulation and bicaval drainage. The patient's body temperature was cooled down to 25°C and measured rectally, followed by implementation of lower body circulatory arrest with moderate hypothermia. Antegrade selective cerebral perfusion was established by axillary perfusion with clamped brachiocephalic and left subclavian arteries and by direct cannulation of the left common carotid artery. Antegrade cold blood cardioplegia was administered to achieve and maintain cardiac arrest. Open distal anastomosis was first performed. The arch vessels were reconstructed individually, and finally, proximal anastomosis was completed.

In the cases of descending aorta and thoracoabodominal aorta replacement, the chest was opened via a intercostal space under general anesthesia.The femoral artery and vein were exposed for cannulation. CPB was established with the arterial cannulation and right ventricular drainage via femoral vein. If possible, anastomosis was performed by aortic clamping with normal temperature. If not possible, the patients' body temperature was cooled down to 25°C, mesured rectally, followed by the implementation of lower body circulatory arrest with moderate hypothermia. Open proximal and distal anastomosis were performed.

Patient follow-up

Complete follow-up data were available for hospital survivors. The mean follow-up period was 83 ± 44 months (median, 98 months). The follow-up rate was 100%.

Statistical analyses: Quantitative data are expressed as mean ± standard deviation (SD). Statistical comparisons between the two groups were performed using an unpaired Student's t test or the Fisher's exact test and a log-rank test using the JMP 14 (SAS Institute Inc., Cary, NC, USA). P values of <0.05 were considered statistically significant. Significance was determined when $p<0.05$. The reference value range of the maximal CT value for simple anastomosis application was determined by the area under the receiver operating characteristic (ROC) curve. Results of quantitative studies are presented as mean ± SD. Survival was analyzed by the Kaplan-Meier method. Multivariable Cox proportional hazard analysis was performed to exclude the confounding factors and identify independent risk factors for long-term survival.

Results: The preoperative characteristics of the two groups are presented in **Table 1** . The number of female, smoker and arteriosclerosis were significantly higher in the Manipulation group ($p<0.05$). The Hemoglobin and eGFR were significantly higher, and the body weight was significantly heavier in the Simple group ($p<0.05$). One patient in the Simple group was a dialysis patient. **Table 2** shows the replacement range of the aorta in each group. Aortic arch replacement was most common in the Simple group (50.5%), while ascending and descending aorta replacement accounted for the majority in the Manipulation group (52.9% and 17.6%, respectively). The JapanSCORE has been devised as the Japanese original risk model for cardiovascular surgery[2]. JapanSCORE was similar between the two groups. The replacement range of the aorta was wider in the Simple group rather than in the Manipulation group ($p<0.01$). The concomintant procedure was not significantly different between the two groups. Perioperative data are summarized in**Table 3** . Operation time and cardiopulmonary bypass time were shorter in the Manipulation group. Hospital death rate was 1.9% (2/105) in the Simple group and 5.9% (1/17) in the Manipulation group. Postoperative bleeding and cerebral infarction were occurred in each group. These complications were not related to the anastomosis site. There were no significant difference in postoperative stay, intensive care unit stay, and the amount of bleeding.

The distribution of maximal CT value is shown in **Figure 1** . The mean maximal CT value (Hounsfield unit: HU) was 94.7 ± 171.5 (0-790) in the Simple group, and 638.1 ± 269.5(166-1304) in the Manipulation group.

The maximal CT value was significantly higher in the Manipulation group than that in the Simple group. The ROC curve revealed that the best cut-off value for the prediction of manipulation was 325 HU (sensitivity 94.1%, specificity 81.7%) (**Figure 2**). The area under the curve was calculated to be 0.96 ($p<0.0001$).

The postoperative 10-year actual survival rates of the patients are shown in **Figure 3** . The 5-year and 10-year survival rate were 69.7% and 38.3% in all patients (**Figure 3A**). The 5-year and 10-year survival rate were 73.3% and 43.2% in the Simple group and 47.6% and 11.2% in the Manipulation group (**Figure 3B**). The postoperative survival rate in the Manipulation group was significantly lower than those in the Simple group ($p = 0.001$). The variables that had p values < 0.10 according to the univariate Cox analyses of age, hypertension, preoperative eGFR, required amount of blood transfusion, preoperative hemoglobin, Japan SCORE, Manipulation, body wight, and maximal CT value. Multivariate Cox proportional hazard analysis determined that age (Hazard Ratio [HR]: 1.073), hypertension (HR: 2.38) and maximal CT (HR: 1.001) were independently associated with long-term mortality.

Comment: Severe calcified lesion of the aorta increases the risk of complications after cardiovascular surgery[3]. Generally, if calcification interferes with anastomosis, it requires root replacement[4] or a larger extent of aortic replacement beyond the planned anastomosis site, which also increases the operative risk. If possible, the extended range of aortic replacement should be reduced by manipulation of the calcified lesion of the aorta. Recently, several papers have reported novel manipulation methods of a calcified aorta, such as endarterectomy[5]and covering with bovine pericardium[6]. If preoperative assessment are able to identify to be needed manipulation of the aorta, well-planned strategies can be established before surgery.

CT is an ideal tool for diagnosis of calcified lesions. It is minimally invasive and can be performed on almost all patients without a history of claustrophobia. In Japan, CT scans are a common preoperative examination for cardiovascular surgery. CT can detect various vascular abnormalities including calcification and anomalies of aorta. Indeed, Lee and colleagues[7] suggested that preoperative CT may help in identifying and avoiding aortic areas known to form emboli and cause a stroke after cardiac operation[8]. In this study, we evaluated whether the maximal CT value could predict the application of simple anastomosis or reqirement of aortic manipulation in patients with thoracic aortic disease. CT values range from -1000 to 1000 HU, depending on the density; air is -1000 HU, water is 0 HU and bone is 1000 HU. The higher the CT value is the more calcified the aorta. We found that a calcified aorta with a maximal CT value of 325 HU or more requires manipulation prior to anastomosis. Therefore, if the maximal CT value of the planned anastomosis site is 325 HU or more, a manipulation method or another anastomosis site should be planned before the operation.

In this study, endarterectomy was used for the manipulation of all severely calcified aortas. We were concerned that endarterectomy may increase the risk of aortic dissection, but no such incident was observed. Svensson and colleagues[5] reported that the intima and media are densely adherent to the adventitia in patients with a calcified aortic wall. If the media was prone to peel at a site distal to the anastomosis, we hypothesized that aortic dissection was prevented by fixing sutures using 5-0 monofilament. The anastomosis site was reinforced by a continuous suture by the 4-0 monofilament suture and a circumferential horizontal matteress suture with 4-0 monofilament sutures with double pledgets. The clinical results were evaluated again one year after the surgery and CT showed no dissection or pseudoaneurysm in any of the patients. Furthermore, the total number of 30-day operative deaths and cerebral infarction amounted to three and one respectively. We concluded that the operative results were satisfactory, even for patients with a severely calcified aorta.

We showed strong evidence that age, hypertension, and maximal CT value are independently associated with long-term mortality. The follow up rate is 100%, and this result is from 10 years actual survival. In generally, age and hypertension are related to long-term mortality, so the results of this study provide the first evidence that maximal CT value may be a useful tool for the increase in late mortality. Furthermore, though Agatston and colleagues[9] reported that CT protocol and coronary calcification score were determined by 20 slices from 3-mm slice CT images. And AZE Virtual Place Raijin, a workstation of medical imaging, played an important role in this study. Calcium scoring is one of the analysis options of the software. This software automatically calculates voxel, volume, minimal CT value, maximal CT value, average CT value, standard deviation, and Agatston score from selection of CT images. We used “maximal CT value” in this study as it was necessary to evaluate the calcification at the anastomosis site. The software was originally set to calculate calcium scoring (Agatston score) of coronary arteries from 3-mm slice CT images, but we changed the setting to 5-mm slices, because this is the normal width under CT imaging. The maximal CT value may not be included at anastomosis site. However, it should be noted that the maximal CT value does not change depending on the slice width and scanner. Furtehrmore, we need only 2 slices CT image at proximal and distal anastomosis site. And either 3 mm or 10 mm CT image is acceptable. In the future, we hope that the maximal CT value becomes one of the standard preoperative assessments to decide the operation plan for thoracic aortic surgery. In conclusion, preoperative evaluation of the maximal CT value can help us to predict whether simple anastomosis is applicable to patients with thoracic aortic disease.

Conclusions : Preoperative evaluation of the maximal CT value is a useful tool in predicting whether simple anastomosis is applicable or not, in the thoracic aortic surgery. If the maximal CT value is 325 HU or more, a manipulation method or another anastomosis site should be planned before the operation. Furthermore, maximal CT value is individual's risk associated with late mortality. Further study is needed to clarify the mechanisms that long-term mortality increases by the CT value.

Author contributions :

Ryo Suzuki : Concept/design, Data analysis/interpretation, Drafting article, Statistics, Data collection

Akihito Mikamo : Concept/design, Data analysis/interpretation, Critical revision of article

Tsubone Sari, Kazumasa Matsunaga, Matsuno Yuutaro, Hiroshi Kurazumi : Data collection

Kimikazu Hamano : Critical revision of article, Approval of article

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Figure legends

Figure 1 . The distribution of the maximal CT value In the Simple group [A], the minimum CT value was 0, the maximum was 790, and the average was 94.7 ± 171.5 In the Manipulation group [B], the minimum CT value was 166, the maximum was 1304, the average was 638.1 ± 269.5.

Figure 2. Receiver operating characteristic curve analysis and area under the curve calculated for manipulation. The maximal CT value enabled us to predict the simple anastomosis with the AUC (area under the receiver operating characteristic curve) of 0.96 ($p<0.0001$). The cutoff value for the maximal CT value to predict manipulation was 325 HU (sensitivity 94.1%, specificity 81.7%).

Figure 3A . Postoperative 10-year acutual survival rate shows by the Kaplan-Meier curve. The 5-year and 10-year survival rate were 69.7% and 38.3% in all patients.

Figure 3B. The 5-year and 10-year survival rate were 73.3% and 43.2% in the Simple group and 47.6% and 11.2% in the Manipulation group.

Table 1. Preoperative characteristics

	Simple group (n=105)	Manipulation group (n=17)	p value
Age (y)	66 ± 14	73 ± 6	*0.07*
Male : Female (n)	75 : 30	7 : 10	*0.02*
Body weight (kg)	61.0 ± 13.3	48.2 ± 7.0	*0.002*
Hemoglobin (g/dl)	11.9 ± 1.7	10.5 ± 1.7	*0.002*
eGFR (mL/min/1.73 m2)	65.9 ± 25.9	48.2 ± 20.1	*0.01*
Hypertension (n, %)	90 (85.7%)	12 (70.6%)	0.14
Dyslipidemia (n, %)	27 (25.7%)	6 (35.3%)	0.39
Smoking (n, %)	75 (71.4%)	5 (29.4%)	*0.002*
Diabetes mellitus	10 (9.5%)	3 (17.6%)	0.39
Arteriosclerosis : Dissection	76 : 29	17 : 0	*0.01*
Main disease			0.33
Aorta	90	9	
Valve	14	6	
Coronary	1	2	
JapanSCORE (%)	6.6 ± 7.5	9.3 ± 10.7	0.24

eGFR: Estimated Glomerular Filtration Rate

CABG: coronary artery bypass grafting

Table 2. Replacement range of the aorta and concomitant procedure

	Simple group (n=105)	Manipulation group (n=17)	p value
Replacement range			*0.004*
Ascending aorta	14 (13.3%)	9 (52.9%)	
Ascending + Arch	53 (50.5%)	2 (11.8%)	
Arch + Descending aorta	6 (5.7%)	0	
Aortic root	5 (4.8%)	0	
Aortic root + Arch	6 (5.7%)	1 (5.9%)	
Descending aorta	13 (12.4%)	3 (17.6%)	

Thoracoabdominal aorta	8 (7.6%)	2 (11.8%)	
Concomitant procedure			0.25
Valve	16	9	
Aortic root	11	1	
CABG	9	4	

Table 3. Perioperative data

	Simple group (n=105)	Manipulation group (n=17)	p value
Operation time (min)	601 ± 157	532 ± 148	*0.09*
CPB time (min)	299 ± 87	256 ± 94	*0.06*
Blood loss (g)	8755 ± 452	609 ± 310	0.20
Hospital death (n, %)	2 (1.9%)	1 (5.9%)	0.37
Stroke (n, %)	1 (1.0%)	0	0.99
Re-exposure for bleeding (n, %)	2 (1.9%)	1 (5.9%)	0.37
ICU stay (day)	4.0 ± 6.7	3.6 ± 4.6	0.71
Postoperative hospital stay (day)	22.3 ± 39.6	20.3 ± 14.7	0.84

CPB: cardioPulmonary Bypass

ICU: Intensive Care Unit

Figure 1

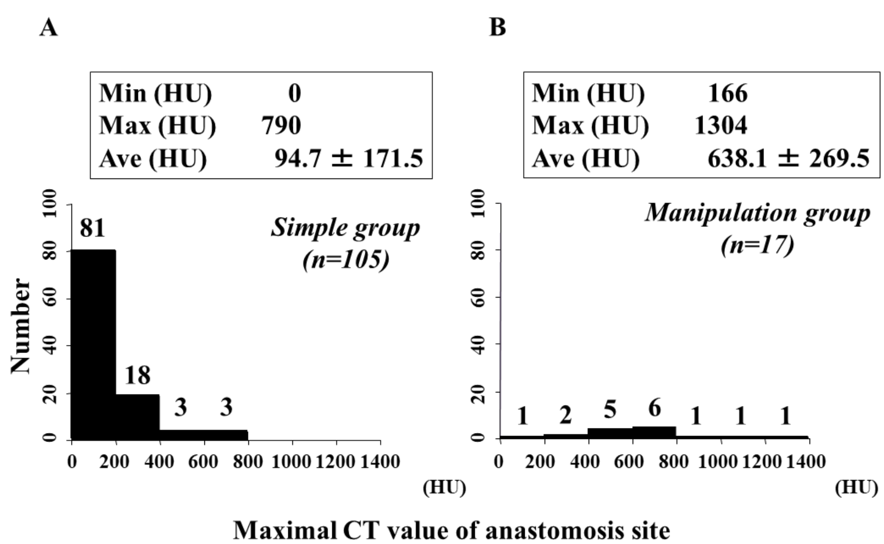
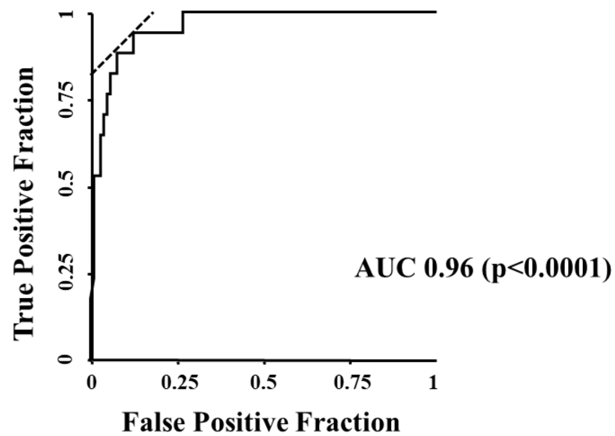


Figure 2



	cut off value	Sensitivity (%)	Specificity (%)
Maximal CT value	**325**	**94.1**	**81.7**

Figure 3A

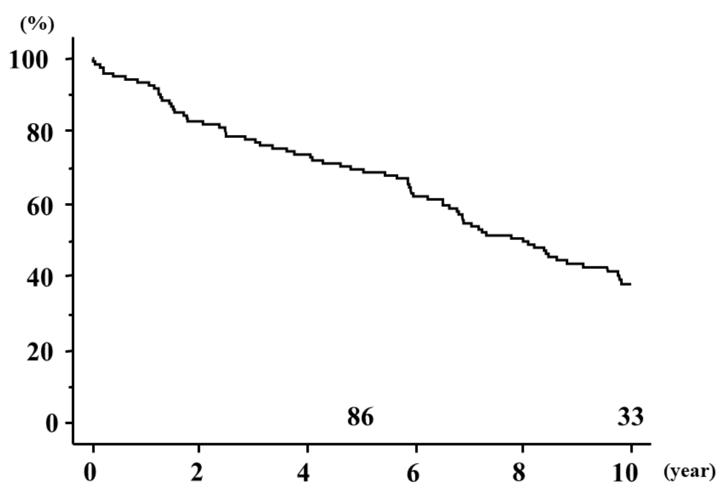
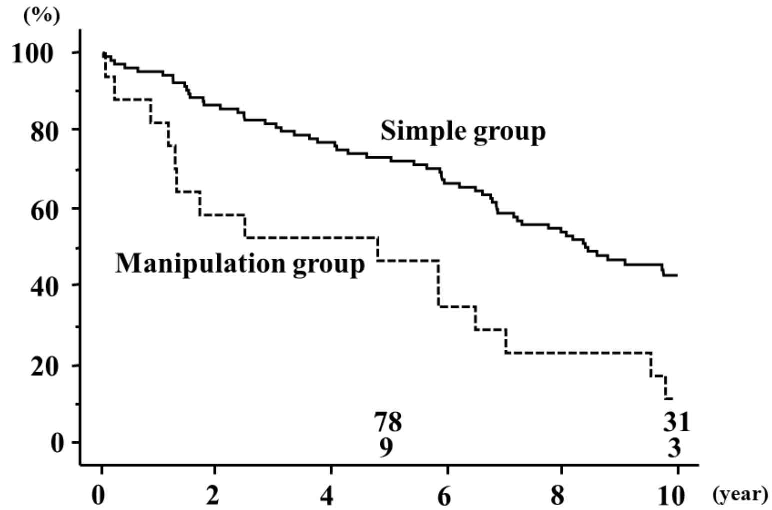


Figure 3B


(%)
100
80
60
40
20
0
Simple group
Manipulation group
78
9
31
3
0
2
4
6
8
10
(year)