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대한영상의학회지

Extent of Subprosthetic Pannus after Aortic Valve Replacement: Changes Over Time and Relationship with Echocardiographic Findings

대동맥판막치환술 후 발생한 판막하 판누스(Pannus): 시간에 따른 변화 및 심초음파 소견

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Purpose This study aimed to evaluate changes of subprosthetic pannus on cardiac CT and determine its relationship to echocardiographic findings in patients with mechanical aortic valve replacement (AVR).

Materials and Methods Between April 2011 and November 2017, 17 AVR patients (56.8 ± 8.9 years, 12% male) who showed pannus formation on CT and had undergone both follow-up CT and echocardiography were included. The mean interval from AVR to the date of pannus detection was 10.5 ± 7.1 years. In the initial and follow-up CT and echocardiography, the pannus extent and echocardiographic parameters were compared using paired *t*-tests. The relationship between the opening angle of the prosthetic valve and the pannus extent was evaluated using Pearson correlation analysis.

Results The pannus extent was significantly increased on CT ($p < 0.05$). The peak velocity (3.9 ± 0.8 m/s vs. 4.2 ± 0.8 m/s, $p = 0.03$) and mean pressure gradient (36.4 ± 15.5 mm Hg vs. 42.1 ± 15.8 mm Hg, $p = 0.03$) were significantly increased. The mean opening angles of the mechanical aortic leaflets were slightly decreased, but there was no statistical significance (73.1 ± 8.3° vs. 69.4 ± 12.1°, $p = 0.12$). The opening angle of the prosthetic leaflets was inversely correlated with the pannus extent ($r = -0.57$, $p < 0.001$).

Conclusion The pannus extent increases over time, increasing transvalvular peak velocity and the pressure gradient. CT can be used to evaluate the pannus extent associated with hemodynamic changes that need to be managed by surgical intervention.

Index terms Aortic Valve Disease; Aortic Valve Stenosis; Computed Tomography, X-Ray; Echocardiography

INTRODUCTION

Aortic valve disease is one of the most common valvular heart diseases that require surgical or interventional treatment (1, 2). Subvalvular, fibrotic soft-tissue formation in the prosthetic heart valve, i.e. pannus formation, has recently been recognized as a postoperative complication. Considering the aging population, the number of people who live long after valve surgery increases and pannus formation has been an increasing problem that requires redo-valve surgery. Traditionally, mechanical valve dysfunction is evaluated with fluoroscopy and transthoracic echocardiography (TTE). However, the cause of prosthetic valve dysfunction is difficult to determine using the conventional methods (3), and transesophageal echocardiography (TEE) is recommended in the current guidelines (4-6). Several studies have demonstrated that the extent of pannus is related to the hemodynamic disturbance detected on echocardiography. However, as it is often difficult to visualize the exact cause of prosthetic valve dysfunction even by TEE, cardiac CT can be used as a complementary method to more clearly evaluate the dysfunction of the prosthetic aortic valve (2, 7-16).

Cardiac CT can demonstrate prosthetic valve motion using multiphase reconstruction (13, 15, 17-19). Several studies have shown the use of cardiac CT for evaluation of pannus (13, 20, 21) and these studies suggest the correlation of the pannus extent seen on CT with TTE parameters (7, 10). In a previous study, the extent of pannus seemed larger as the time after aortic valve replacement (AVR) became longer, although it was not measured in the same patients (8). Therefore, it can be assumed that the pannus extent will gradually increase as time progresses. There is no published manuscript on this topic because this disease has only recently received attention and the evaluation of the valve using multiphase-reconstructed images of CT scans with an adequate time interval is limited, considering that pannus is usually seen approximately 10 years after AVR (8). In addition, when there is severe hemodynamic disturbance caused by pannus of the prosthetic aortic valve, the prosthetic aortic valve is usually surgically removed and therefore these patients do not undergo follow-up CT. In this study, we analyzed the interval changes of the pannus extent and the hemodynamic parameters among patients with subprosthetic pannus, by evaluating multiphasic CT scans after pannus detection and with all echocardiographies done at the same time as the CT scan.

MATERIALS AND METHODS

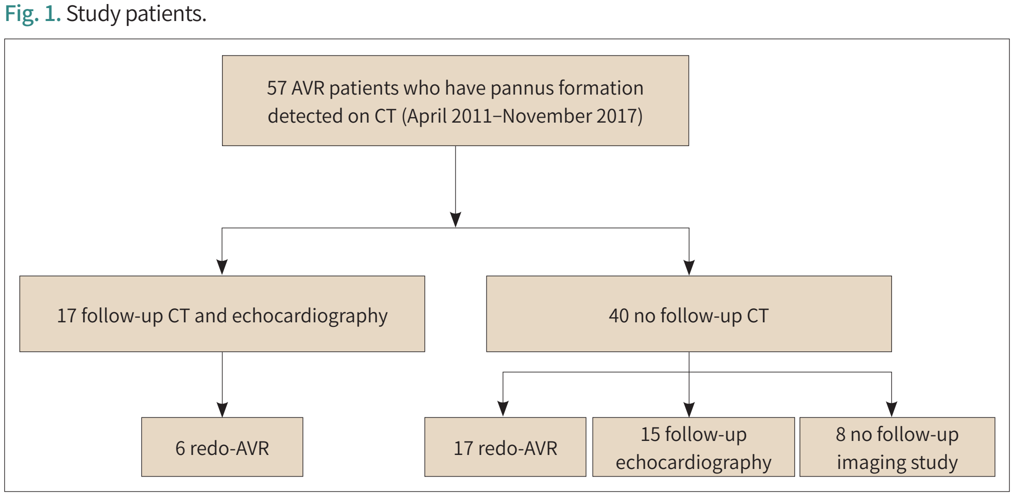
STUDY POPULATION

This study was approved by the Institutional Review Board of our institution (approval number. 2016-0482) which waived the requirement for informed consent due to the retrospective nature of this study. Between April 2011 and November 2017, we found 57 patients who underwent AVR and suspected pannus formation on CT scanning. Among them, 17 had both follow-up CT and echocardiography without any intervention, 17 underwent redo-AVR, and 15 had only follow-up echocardiography except eight patients with medical follow-up without follow-up imaging studies (Fig. 1). To evaluate whether the characteristics of 17 patients with follow-up CT scans are different from the others, clinical and echocardiographic findings of the 17 patients were compared with the 40 patients without follow-up CT scans. Also, the interval changes of the pannus extent on CT and the echocardiography parameters were evaluated in the 17 patients who had both follow-up CT and echocardiography. Of the 57 patients, 10 were included in a previous study (8). The previous study centered on the relationship of the pannus extent and the hemodynamic dysfunction of the prosthetic aortic valve. On the other hand, our study focused on the change of the pannus extent and its relationship with hemodynamic changes in the same patients. Electronic medical records, echocardiography findings and CT images were thoroughly reviewed.

IMAGE ACQUISITION

Cardiac CT scans were performed using a second-generation, dual-source CT scanner (Somatom Definition Flash; Siemens Medical Solutions, Forchheim, Germany). After a bolus of 60–80 mL of iomeprol-400 (Iomeron; Bracco Imaging SpA, Milan, Italy) followed by 40 mL of a saline chaser was injected at a rate of 4 mL/s using a power injector, images were acquired. CT scans were performed using a bolus tracking method (eight seconds after the attenuation of the ascending aorta reached 100 Hounsfield unit). Retrospective electrocardiogram-gated data acquisition was done with automatic tube current modulation. The tube voltage and tube current-time were adjusted according to the patients' body sizes. For all patients, 10 sets of reconstructed data were acquired every 10% of the cardiac cycle. The scanning parameters were as follows: tube voltage 80–120 kV; tube current-time product 240–450 mAs; pitch 0.17–0.38; detector collimation 128 $\times$ 0.6 mm; and gantry rotation time 280 ms. The mean dose–length product for cardiac CT was 1141.7 $\pm$ 458 mGy·cm, and the mean estimated effective dose was 16.2 mSv. Since multi-phase images were obtained for valve evaluation and CT scans included thorax and abdomen for a whole aorta evaluation to prepare for surgery in a part of patients,

Fig. 1. Study patients.



AVR = aortic valve replacement

the mean radiation dose is higher than normal cardiac CT.

IMAGE ANALYSIS

All reconstructed images were analyzed by using dedicated, three-dimensional software (Aquarius iNtuition, TeraRecon, San Mateo, CA, USA). Using multiplanar image reconstruction, the in-plane views (en-face view) of the prosthetic aortic valve were obtained in order to evaluate the extent of the subprosthetic pannus. For more accurate analyses, the images from the phases that showed the least motion artifact were chosen. CT analyses were performed in consensus by two expert radiologists who were blinded to the clinical information and echocardiographic results. The presence of subprosthetic pannus was defined as a low-attenuation or calcified lesion protruding into the valvular strut beneath the prosthetic valve. The geometric orifice area (GOA), pannus extent, and pannus involvement angle were measured on the in-plain views using the open source software (https://itk.org/) for lesion segmentation. The effective orifice area (EOA) was determined by subtracting the area of pannus from the GOA. The encroachment ratio was defined as [(GOA - EOA)/GOA × 100]. The average opening angle of the valve leaflets was also measured in a fully opened position. The analysis method used was described in a previous study (8).

ECHOCARDIOGRAPHY

TTE, including two-dimensional and Doppler imaging, was performed by clinically experienced cardiologists. Ultrasonographic equipment with a 3–5 MHz, real-time, echocardiographic transducer (Sonos 7500; Philips Healthcare, Andover, MA, USA; or Vivid 7, GE Healthcare, Waukesha, WI, USA) was used in all patients. The transvalvular pressure gradient, transvalvular velocity (peak and mean value), left ventricular ejection fraction, end-diastolic volume index, end-systolic volume index, and left ventricular mass index were measured.

STATISTICAL ANALYSIS

Continuous variables were expressed as the means ± standard deviations, and categorical variables as numbers and percentages. The initial and follow-up echocardiographic findings of the 17 patients who had follow-up CT were compared with those who did not undergo follow-up CT using the Student's *t*-test. In patients who had both follow-up CT scans and echocardiographies, the echocardiographic and CT-derived parameters were compared using the paired *t*-test. Pearson correlation analysis was performed to evaluate the relationship between the opening angle of the prosthetic valve and the pannus extent. If the Pearson correlation coefficient (*r* value) is positive, it signifies that the variables are directly related. Alternatively, if the *r* value is negative, the variables are inversely related. The absolute value of the *r* value indicates strength of association: 0.81–1.00, very strong; 0.51–0.80, strong; 0.21–0.50, fair; and 0–0.20, poor correlation. A p value < 0.05 was considered statistically significant. Statistical analysis was performed using SPSS statistical software (version 21.0, IBM Corp., Armonk, NY, USA) and MedCalc Statistical Software version 18.2.1 (MedCalc Software bvba, Ostend, Belgium; http://www.medcalc.org; 2018).

RESULTS

PATIENTS' CHARACTERISTICS

The mean time interval from AVR surgery to the date of pannus detection on CT scan was 10.9 ± 7.1 years in all patients (*n* = 57). The commercial names of the prosthetic aortic valves are as follows: St Jude (*n* = 34); Sorin (*n* = 7); ATS (*n* = 5); CarboMedics (*n* = 5); Edwards MIRA (*n* = 5); and On-X (*n* = 1).Comparisons of clinical and echocardiographic findings between 17 patients who had follow-up CT scans and those without follow-up CT scans are demonstrated

Table 1. Patient Characteristics

Character	Total (*n* = 17)		
Male:female	2 (11.8):15 (88.2)		
Age, years	56.8 ± 8.9		
BSA, kg/m^2	1.57 ± 0.13		
Interval between AVR and pannus formation, years	10.5 ± 7.1		
Hypertension	4 (23.5)		
Diabetes mellitus	0 (0.0)		
Replaced aortic valve type			
St. Jude	10 (58.8)		
Carbomedics	2 (11.8)		
Sorin	2 (11.8)		
ATS	2 (11.8)		
Edwards MIRA	1 (5.9)		
Replaced aortic valve diameter, mm	21.4 ± 2		
Preoperative diagnosis of aortic valve			
Aortic stenosis	10 (58.8)		
Aortic regurgitation	12 (70.6)		
Aortic aneurysm	2 (11.8)		
Combined surgery for mitral valve disease during follow-up			
Mitral valve annuloplasty	1 (5.9)		
Mitral valve replacement	11 (64.7)		
Concomitant valvular disease during follow-up			
Tricuspid regurgitation	6 (35.3)		
Mitral regurgitation or stenosis	11 (64.7)		
Echocardiography Parameter	**Initial**	**Follow-Up**	***p*-Value**
Peak velocity, m/s	3.9 ± 0.8	4.2 ± 0.8	0.03
Peak pressure gradient, mm Hg	63.4 ± 24.4	72.4 ± 23.2	0.02
Mean pressure gradient, mm Hg	36.4 ± 15.5	42.1 ± 15.8	0.03
LVEF, %	63.9 ± 5.3	63.5 ± 4.1	0.82
EDVI	55.8 ± 10.9	57.0 ± 15.7	0.74
ESVI	20.2 ± 5.2	20.9 ± 6.8	0.64
LV mass index	97.0 ± 29.1	101.8 ± 28.3	0.10

Data are demonstrated as numbers and percentages in parenthesis or mean ± standard deviation.
AVR = aortic valve replacement, BSA = body surface area, EDVI = end-diastolic volume index, ESVI = end-systolic volume index, LV = left ventricle, LVEF = left ventricular ejection fraction

in Supplementary Table 1 (in the online-only Data Supplement). The intervals from AVR surgery to the date of pannus detection were not statistically different between the two groups. Also, the initial echocardiography parameters, including peak velocity and pressure gradient did not differ. To compare the follow-up echocardiography parameters, 17 patients with redo-AVR and eight patients who did not undergo follow-up echocardiography were excluded. The follow-up echocardiographic parameters of the 17 patients with CT scans were higher, and thus suggestive of severe aortic stenosis, although the interval between the two echocardiographies was longer in those patients without follow-up CT (26.3 ± 11.4 months vs. 39.0 ± 14.6 months, $p = 0.01$).

The baseline characteristics of the 17 patients who had both follow-up CT and echocardiography are summarized in Table 1. The mean time interval between the AVR and the pannus formation was 10.5 years. In this group, prosthetic aortic valves were included as follows: St Jude ($n = 10$); Sorin ($n = 2$); ATS ($n = 2$); CarboMedics ($n = 2$); and Edwards MIRA ($n = 1$). Of the 17 patients, six underwent redo-AVR after obtaining follow-up CT scans.

PANNUS EXTENT AND ECHOCARDIOGRAPHY PARAMETERS

The comparison between the initial and follow-up CT and the echocardiography parameters in the 17 patients are summarized in Table 2. Echocardiographic parameters were significantly increased on follow-up echocardiography. However, in 15 (88%) patients, echocardiography failed to detect pannus formation (Fig. 2). All of the CT-derived parameters of the pannus extent were significantly increased on follow-up CT. Although there was no statistically significant change, the mean opening angle of the prosthetic aortic valve was slightly decreased on follow-up CT (73.1 ± 8.3° vs. 69.4 ± 12.1°, $p = 0.12$). The changes of the EOA, pannus area, encroachment ratio, and involved angle of the pannus for each patient are shown in Fig. 3, respectively. The EOA of the prosthetic aortic valve measured on both initial and follow-up CT

Table 2. Comparison of the Pannus Extent and Echocardiography Parameters between the Initial and Follow-Up Studies ($n = 17$)

	Initial	Follow-Up	*p*-Value
Mean pannus width, mm	2.2 ± 1.1	2.5 ± 1.2	0.03
Maximal pannus width, mm	3.6 ± 1.6	4.0 ± 1.6	0.01
Mean pannus width/valve diameter × 100, %	12.7 ± 6.5	14.4 ± 7.0	0.02
Maximal pannus width/valve diameter × 100, %	20.7 ± 9.0	23.2 ± 9.3	0.01
Pannus area, mm^2	52.3 ± 39.9	79.9 ± 36.7	< 0.001
EOA, mm^2	197.1 ± 54.4	166.6 ± 53.3	< 0.001
Encroachment ratio, %	20.5 ± 13.3	32.7 ± 13.4	< 0.001
Involved pannus angle, °	178.1 ± 80.5	253.8 ± 75.0	< 0.001
Peak velocity, m/s	3.9 ± 0.8	4.2 ± 0.8	0.03
Peak pressure gradient, mm Hg	63.4 ± 24.4	72.4 ± 23.2	0.02
Mean pressure gradient, mm Hg	36.4 ± 15.5	42.1 ± 15.8	0.03
Opening angle, °	73.1 ± 8.3	69.4 ± 12.1	0.12

Data are demonstrated as mean ± standard deviation. The EOA was determined by subtracting the area of the pannus from the GOA. The encroachment ratio was defined as [(GOA – EOA)/GOA × 100].
EOA = effective orifice area, GOA = geometric orifice area

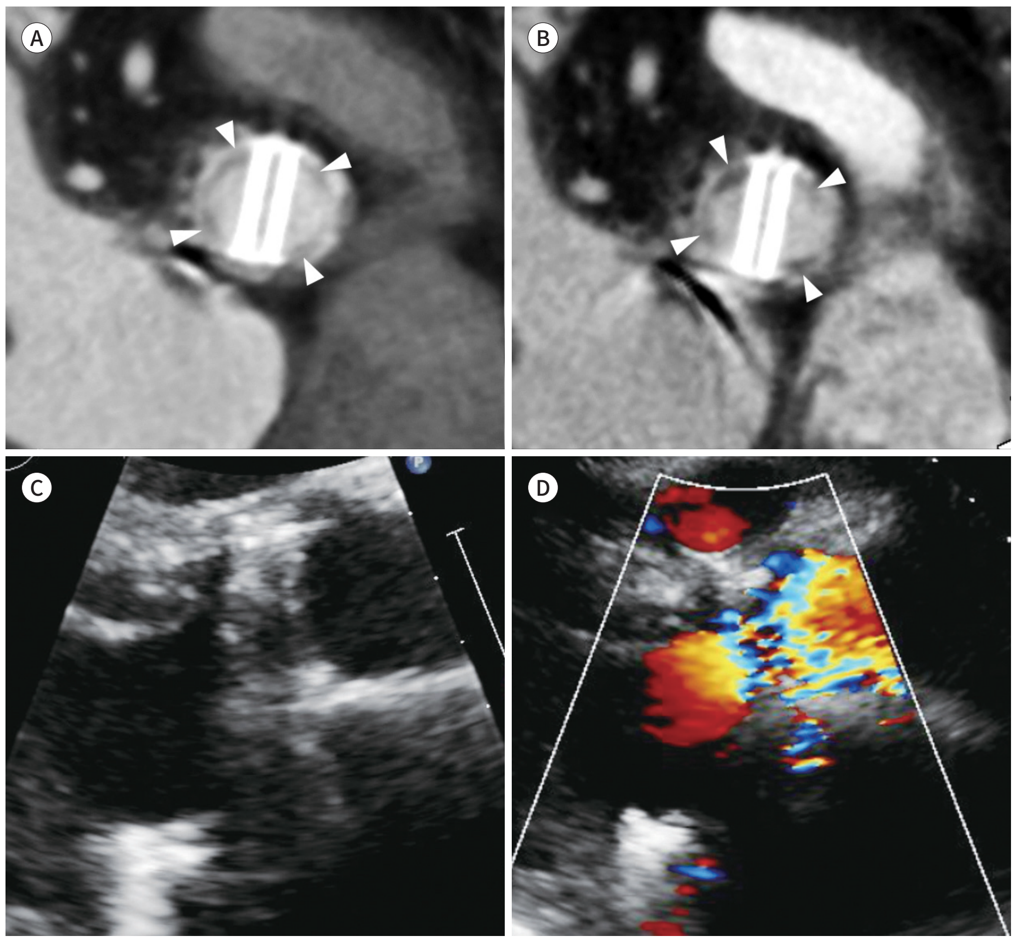


Fig. 2. A 42-year-old female who underwent aortic valve replacement using a 21-mm St. Jude valve 5 years ago.
A. Initial CT image shows pannus formation (arrowheads); maximal width, 2.7 mm; pannus area, 40.16 mm^2; and effective orifice area, 275.84 mm^2.
B. After 3 years, the pannus extent (arrowheads) has increased to 3.8 mm, 103.12 mm^2, and 204.86 mm^2, respectively.
C. Transthoracic echocardiography can not demonstrate the subvalvular pannus because of a poor sonic window.
D. Doppler echocardiography shows flow acceleration. The peak and mean transvalvular pressure gradients changed from 34 to 67 mm Hg and 18 to 37 mm Hg, respectively.

scans showed a significant inverse correlation with the transvalvular peak velocity and mean pressure gradient (r = -0.50, p = 0.003 and r = -0.47, p = 0.005, respectively).

RELATIONSHIP BETWEEN THE OPENING ANGLE OF THE PROSTHETIC VALVE AND THE PANNUS EXTENT

CT-derived pannus extent showed significant correlations with opening angles of the prosthetic valves when evaluating all initial and follow-up CT scans together (Table 3). Pannus width, the ratio of pannus width and the valve diameter, the pannus area, encroachment ratio, and the involved angle of the pannus were inversely correlated with the opening angle (Fig. 4). The EOA was directly proportional to the opening angle. The parameter showing the highest correlation with the opening angle was the encroachment ratio (r = -0.57, p < 0.001). In addition, correlation analysis was performed with the same parameters in the initial CT scans and the follow-up CT images, respectively. In the initial CT images, none of the CT-derived pannus parameters showed a significant correlation with the opening angle. However, in the follow-up CT images which show increased pannus extent, all of the pannus parameters, except for the EOA and the

Fig. 3. Graphs demonstrate interval changes of the pannus extent.
A. In general, the effective orifice area is seen to be decreased on follow-up CT.
B-D. The pannus area (B), encroachment ratio (C), and pannus (D) involvement angle are increased.

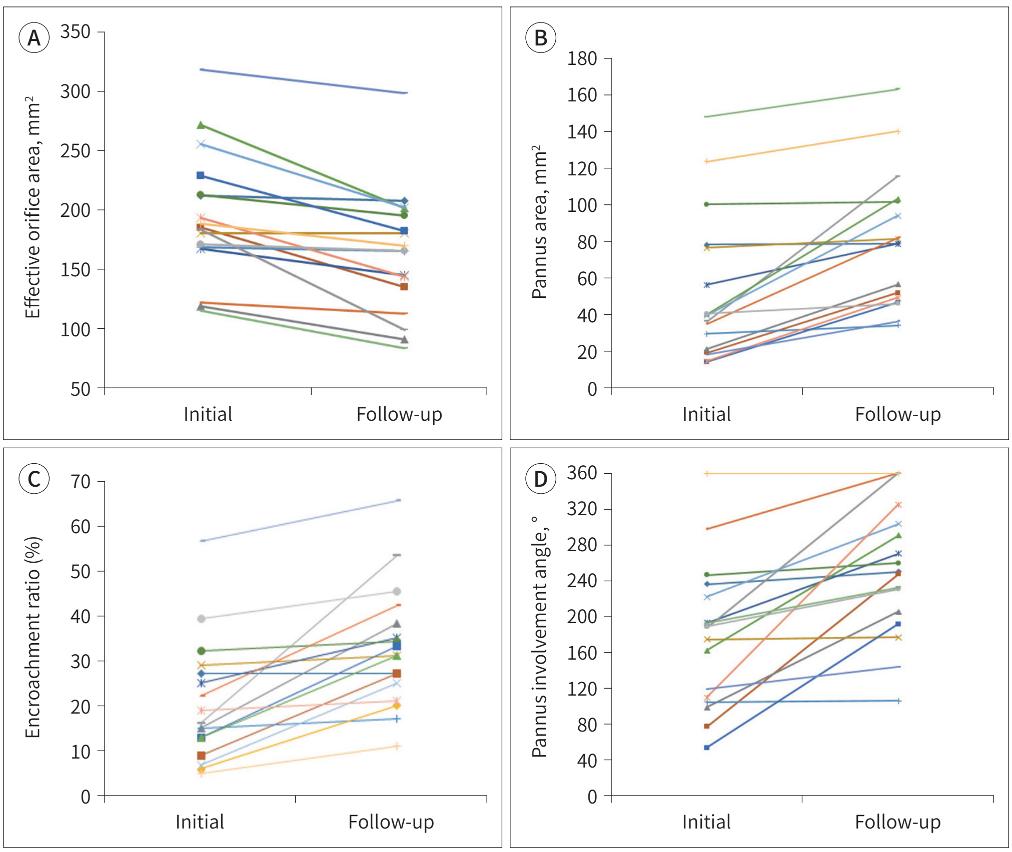
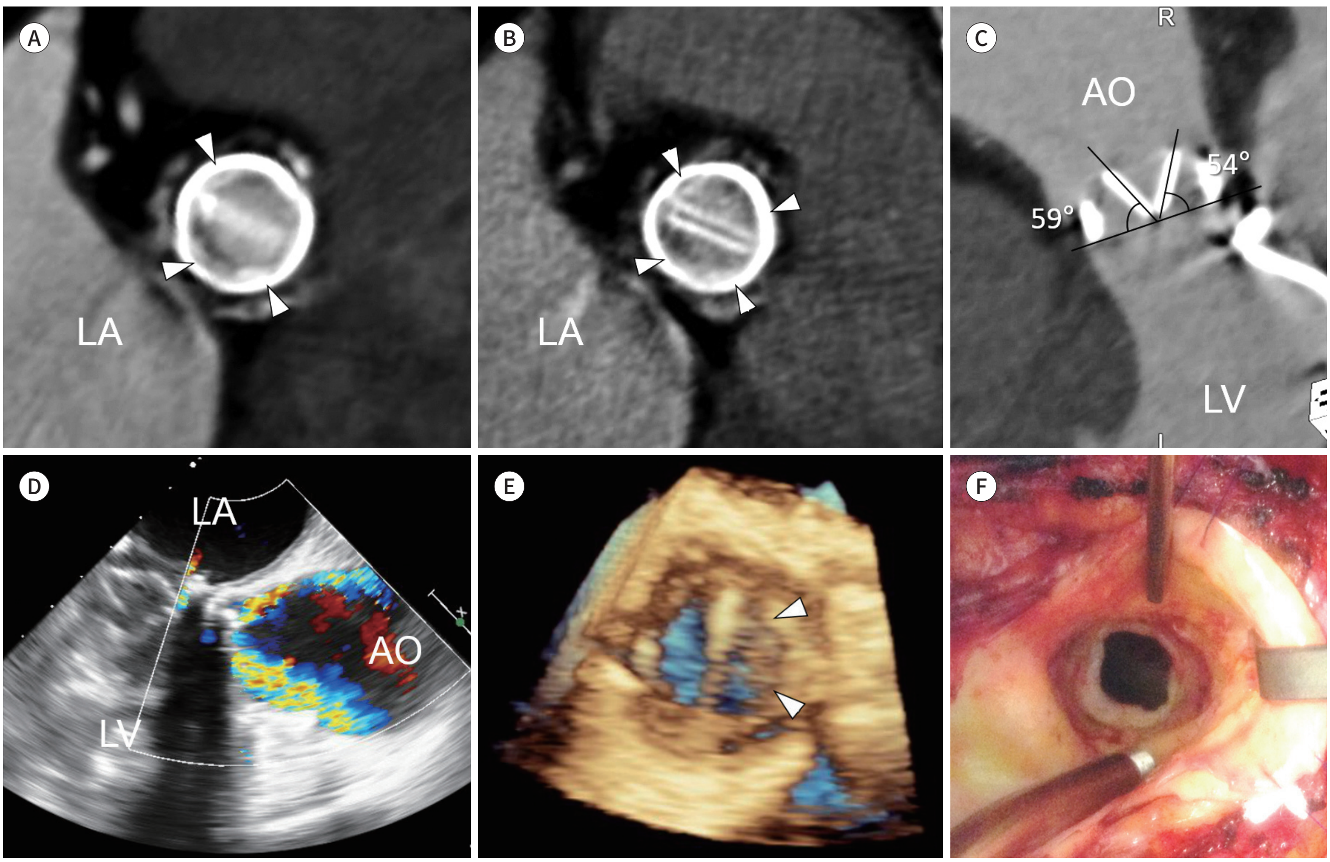


Table 3. Correlation between the Opening Angle of the Prosthetic Valve and Pannus Extent

	All CT Scans		Initial CT		Follow-Up CT	
	r	*p*-Value	*r*	*p*-Value	*r*	*p*-Value
Mean pannus width, mm	-0.45 (-0.69– -0.14)	0.007	-0.01 (-0.49–0.47)	0.97	-0.73 (-0.90– -0.38)	0.001
Maximal pannus width, mm	-0.47 (-0.70– -0.15)	0.005	-0.07 (-0.53–0.43)	0.79	-0.71 (-0.89– -0.35)	0.001
Mean pannus width/valve diameter	-0.42 (-0.66– -0.09)	0.014	0.01 (-0.47–0.49)	0.96	-0.68 (-0.87– -0.29)	0.003
Maximal pannus width/valve diameter	-0.44 (-0.68– -0.12)	0.010	-0.05 (-0.52–0.44)	0.84	-0.67 (-0.87– -0.29)	0.003
Pannus area, mm^2	-0.52 (-0.73– -0.22)	0.002	-0.23 (-0.64–0.28)	0.38	-0.71 (-0.89– -0.35)	0.001
EOA, mm^2	0.38 (0.05–0.64)	0.026	0.27 (-0.24–0.67)	0.29	0.42 (-0.08–0.75)	0.098
Encroachment ratio	-0.57 (-0.76– -0.29)	< 0.001	-0.28 (-0.67–0.24)	0.28	-0.76 (-0.91– -0.44)	< 0.001
Involved angle of pannus, °	-0.35 (-0.62– -0.02)	0.041	-0.45 (-0.77–0.04)	0.07	-0.22 (-0.63–0.29)	0.403

Data are Pearson *r* correlation values. Numbers in parentheses are 95% confidence intervals. The EOA was determined by subtracting the area of the pannus from the GOA. The encroachment ratio was defined as [(GOA – EOA)/GOA × 100].
EOA = effective orifice area, GOA = geometric orifice area

Fig. 4. A 56-year-old female who had undergone AVR using an 18 mm ATS valve 14 years earlier.
A. The initial CT scan shows subvalvular pannus formation (arrowheads). The maximal pannus width is 3 mm, the pannus area is 36.2 mm², and the effective orifice area is 186.9 mm².
B. Two years later, the pannus extent (arrowheads) increases to 5 mm, 115.5 mm², and 101.9 mm², respectively.
C. The prosthetic aortic valve shows limitation of motion (mean opening angle 56.5°).
D. On Doppler echocardiography, eccentric flow acceleration is observed along the wall of the aortic root.
E. 3D transesophageal echocardiography shows eccentric pannus formation (arrowheads). The peak and mean transvalvular pressure gradients are changed from 84 to 88 mm Hg and 52 to 57 mm Hg, respectively.
F. During the redo-AVR, subvalvular pannus entirely involving the valve is confirmed.
AO = aortica root, AVR = aortic valve replacement, LA = left atrium, LV = left ventricle



involved angle of the pannus, significantly correlated with the opening angle. The Pearson *r* correlation values obtained from the follow-up CT images were higher than those obtained by using both initial and follow-up CT images.

DISCUSSION

The pannus extent gradually increased during the follow-up period in the patients who had AVR and the hemodynamic dysfunction measured on echocardiography also aggravated as the extent of pannus grew. The mean opening angle of the prosthetic leaflets was inversely correlated with the pannus extent. This phenomenon was more markedly noted when we compared the pannus extent and the opening angle measured on follow-up CT scans.

TTE is a first-line tool used to evaluate mechanical valves and their dysfunction because it is cost-effective, easy to access, and able to assess functional information without radiation exposure (22). TEE, which shows clearer images than TTE, should also be used to evaluate prosthetic valve dysfunction (23, 24). However, TTE and TEE are operator-dependent and small pannus formations are usually not visible on echocardiography (13, 25). A co-existing, mechanical mitral valve can also hinder an accurate diagnosis due to the acoustic shadowing and ring-down artifact (11). In addition, even in patients with pannus formation, echocardiographic hemodynamic parameters may not be increased due to low cardiac output or low blood flow. In those patients, these parameters are unreliable for evaluating prosthetic valve function (8).

Cardiac CT has rapidly improved over the past 10 years, and enables us to evaluate cardiac diseases, including aortic valve dysfunction, although not with real-time imaging. Using beta-blockers to reduce the heart rate before performing a CT scan makes it possible to overcome the problem of temporal resolution. Post-processing methods of cardiac CT provides complementary information for assessing the dysfunction of prosthetic valves (13-16, 20, 21, 26), and CT-derived pannus parameters are known to correlate with the hemodynamic parameters measured on echocardiographies (7, 8, 10, 12). However, the previous studies did not evaluate the interval changes of pannus extent in the same patients, and they could not clearly demonstrate whether the pannus formation developed suddenly, or would be enlarged over time. It can be postulated that the extent of pannus will gradually increase, from a previous study which showed a larger pannus extent as the time after AVR becomes longer (8). To date, it has been difficult to compare the changes of the pannus extent in the same patients due to lack of patients undergoing follow-up CT scans. Therefore, we compared the initial CT and echocardiographic parameters with the follow-up parameters in the same patients.

Our study found that in the same patients the pannus extent, including the pannus area, EOA, encroachment ratio, and the involved angle of the pannus was gradually increasing on the follow-up CT scan and that the echocardiographic hemodynamic parameters were also worsened with the increased pannus extent. Among the parameters, the EOA, which was calculated by subtracting the pannus area from the GOA, showed significant correlation with the hemodynamic parameters measured on echocardiography. In other words, the area of the aortic valve narrowed by pannus would be the best parameter for predicting the hemodynamic change in each patient.

The mean opening angle of the prosthetic aortic leaflets showed a negative correlation with all of the CT-derived parameters of the pannus extent, in other words, the mean opening angle decreases as the pannus extent increases. Especially in follow-up CT scans, the correlation was stronger; that may indicate the opening angle is decreased more when the pannus extent is larger.

This study had several limitations. First, it is a retrospective study performed at a single institution. Not all of the AVR patients who showed high transvalvular peak velocity and pressure gradient underwent cardiac CT to evaluate the pannus. Moreover, a follow-up CT scan after pannus formation is uncommon as only 30% (17/57) of the patients underwent follow-up CT scans in this study. Patients who underwent follow-up CT scans without redo-AVR may have a small pannus extent which could cause less significant hemodynamic changes. However, compared with the initial echocardiography parameters of those patients who had follow-up CT scans and those who did not, there was no significant difference in echocardiographic findings between the two groups. Moreover, transaortic peak velocity and pressure gradient measuring on follow-up echocardiography were higher in patients with follow-up CT compared to those without follow-up CT. This may suggest that we performed a follow-up CT scan when we encountered patients with significant aortic stenosis, to confirm the interval changes of the pannus extent detected on the initial CT scan. Also, treatment options such as watchful waiting or redo-surgery were varied based on clinical presentation, and made by clinician's decision. Second, although 23 (40%) patients underwent redo-AVR surgery, pathological confirmation of pannus formation was unavailable in the others. Due to lack of established guidelines for surgical treatment of subvalvular pannus, the management methods in this study were varied. Nevertheless, we showed that the pannus is growing with time rather than being decreased or removed without surgical intervention. Because there is not a high prevalence of pannus formation, our study included as many patients as possible and we discovered interval changes of the pannus extent in the same patients. Pannus formation should be suspected when a gradually increasing transvalvular peak velocity or pressure gradient is detected on echocardiography after AVR. Alternatively, when subvalvular pannus formation is detected on a CT scan, it is necessary to perform hemodynamic evaluation using echocardiography, and surgical management will be necessary, considering the interval growth of pannus formation without regression. Lastly, because most patients in our study had AVR over 10 years ago, we could not obtain the electronic medical records and echocardiography results of all patients at the time of AVR. As a result, the immediate postoperative echocardiography data for evaluating patient-prosthesis mismatch, such as EOA and indexed EOA, were not available in some patents. Further studies about the significance of patient-prosthesis mismatch in pannus formation would be needed.

In conclusion, in our patient population, the extent of pannus increases over time, which increases the transvalvular peak velocity and pressure gradient, and may induce opening dysfunction of prosthetic leaflets. CT can demonstrate the exact extent of pannus formation and this allows us to predict hemodynamic changes which need to be managed by surgical intervention.

Supplementary Materials

The online-only Data Supplement is available with this article at http://dx.doi.org/10.3348/jksr.2019.0124.

Author Contributions

Conceptualization, K.H.J., Y.D.H.; data curation, all authors; formal analysis, P.M.Y., K.H.J., H.H.; investigation, P.M.Y., K.H.J., H.H., Y.D.H.; methodology, K.H.J., P.M.Y., Y.D.H.; project administration, K.H.J.; resources, K.J., Y.D.H.; software, K.H.J., H.H., K.J.; supervision, K.H.J., K.J., Y.D.H.; validation, K.H.J., P.M.Y.; visualization, K.H.J., P.M.Y.; writing—original draft, K.H.J., P.M.Y.; and writing—review & editing, all authors.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

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대동맥판막치환술 후 발생한 판막하 판누스(Pannus): 시간에 따른 변화 및 심초음파 소견

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목적 본 후향적 연구는 심장 CT를 이용하여 대동맥판막치환술 후 발생한 판누스(pannus)가 시간 경과에 따라 증가하는지를 평가하고 심초음파 결과와 비교하는 것을 목적으로 한다.

대상과 방법 2011년 4월부터 2017년 11월까지 CT에서 판누스가 발견되어 follow-up 심장 CT와 심초음파를 촬영한 17명의 환자를 포함하였다. 대동맥판막치환술 후 판누스 발견까지의 시간은 평균 10.5 ± 7.1년이었다. 처음 판누스가 발견된 CT와 이후 CT에서 판누스의 변화를 확인하고, 심초음파 결과의 변화를 paired *t*-test를 이용하여 분석하였다. 인공판막의 열리는 정도와 판누스의 크기는 Pearson 상관관계분석을 이용하여 평가하였다.

결과 판누스의 크기는 follow-up CT에서 증가하였다($p < 0.05$). 대동맥판막을 지나는 최고 혈류속도(3.9 ± 0.8 m/s vs. 4.2 ± 0.8 m/s, $p = 0.03$)와 평균 압력차(36.4 ± 15.5 mm Hg vs. 42.1 ± 15.8 mm Hg, $p = 0.03$)는 심초음파상 의미 있게 증가하였다. 인공판막의 열리는 정도는 약간 감소하였으나 의미 있는 변화는 아니었다(73.1 ± 8.3° vs. 69.4 ± 12.1°, $p = 0.12$). 인공판막의 열리는 정도와 판누스의 크기는 음의 상관관계를 보였다($r = -0.57$, $p < 0.001$).

결론 판누스는 시간이 지남에 따라 커졌고, 이에 따라 인공판막을 지나는 혈류속도와 평균 압력차가 증가하였다. 심장 CT는 판누스의 크기를 평가할 수 있고, 이는 혈역학적 변화와 관련이 있으며 추후 수술 여부 결정에 도움을 줄 수 있다.

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