札幌医学雑誌　85（Supplement）85～91（2017）　doi：10.15114/smj.85s.85

ORIGINAL

Novel measurement method for mitral valve anterior leaflet free margin length using 3DTEE

Yasuko MIYAKI[1)], Seiichi FUNAMOTO[1)], Kazutoshi TACHIBANA[1)], Tomohiro NAKAJIMA[1)], Masaki TABUCHI[1)], Nobuyuki TAKAGI[1)], and Tetsuya HIGAMI[1)]

[1)] Department of Cardiovascular Surgery, Sapporo Medical University School of Medicine

ABSTRACT

Background: The aim of our study is to establish an accurate measurement method for anterior mitral leaflet (AML) free margin length, which is a key aspect for prediction of the extent of resection in anterior mitral valve (MV) leaflet repair.

Method: Among the patients who underwent anterior MV leaflet repair between July 2010 and August 2012, we studied 17 patients with data on 3D echocardiography obtained pre- and intra-operatively and intraoperative direct measurements of AML free margin. The AML free margin lengths measured at different frames (early-opening frame of MV and end-opening frame of MV) by using real-time 3D transesophageal echocardiography (RT-3DTEE) were compared with the values directly measured during mitral valvuloplasty (MVP). For acquisition of 3D data during surgery, RT-3DTEE images of MV were obtained by using the Philips iE33 echocardiography system with X7-2 probe before MVP.

Result: The free margin length values measured with Q-LAB MVQ. Regarding the correlation between the measured values with the RT-3DTEE and values directly measured intraoperatively, the measured values at the early-opening frame of MV had no correlation between the actual measured values and r-value = 0.338 (P=0.184). Conversely, the measured values at the end-opening frame of MV had an extremely high significant correlation between the measured values and r-value = 0.980 (P<0.0001).

Conclusion: In conclusion, the novel measurement method enables measurement of anterior mitral leaflet free margin length by using RT-3DTEE. At the end-opening frame of MV, the novel measurement method that reflects more accurate actual measured value was established.

Key words: mitral valve, mitral valve repair, echocardiography, anatomy, rough-zone trimming

1. Introduction

Recently, mitral valvuloplasty (MVP) is one of the standard surgical treatments for Mitral Regurgitation (MR). MVP for lesions on the anterior mitral leaflet, in particular, requires meticulous procedure. There are various valvuloplasties; however, the gold standard has not yet been established. Like Carpenter's French Collection[1)] for MVP, various valvuloplasties for anterior mitral leaflet lesions have been suggested. At present, MVP with the use of artificial chordate tendineae without resection of the mitral valve (MV) prolapsed is becoming the mainstream[2)], but whether or not all anterior leaflet lesions can be treated using this method remains debatable. On the other hand, operative procedures for anterior mitral leaflet that principally involve resection, including triangular resection as a representative procedure, have not yet obtained satisfactory results in terms of durability and long-term outcome[1,3)]. Thus, we developed our own repair procedure which can compensate for the limitations of artificial chordate tendineae implantation and overcome drawbacks of the conventional valve resection in MVP for anterior mitral leaflet lesions. We named it "Rough-zone trimming" procedure, and it has been applied in a clinical setting for almost 12years. In Rough-zone trimming procedure, only the rough zone of the prolapsed surplus leaflet is resected, while the prolapsed leaflet-free margin is retracted toward the left ventricle using a suturing method and matched with the resection-free margin. The operative procedure is based on the concept of pulling the free margin of the prolapsed leaflet into the left ventricle and creating a new and deep coaptation area. The long-term follow-up results are satisfactory. At present, the determination of the extent of rough-zone resection depends heavily on

the surgeon's experience. If the prolapsed anterior mitral leaflet free margin length could be evaluated based on pre-operative echocardiographic findings, the extent of rough-zone resection using Rough-zone trimming procedure can be estimated in advance. Rough-zone trimming is a promising and highly developed procedure. The debut of real-time 3D echocardiography (RT-3DTEE) may enable the measurement of anterior mitral leaflet free margin length. The measurement method, however, has not yet been established. Thus, in this study, we devised a measurement method for free margin length by using RT-3DTEE, which is fundamental to Rough-zone trimming procedure. By using the recently developed Philips iE33 echocardiography system with X7-2 probe that provides real-time 3D transesophageal echocardiography (Phillips Healthcare, Andover, MA) and Q-LAB MVQ software (Phillips Healthcare) installed in the iE33, it assures that detailed description and measurement of the complicated 3D structural MV can be provided in 3D over time. At present, the measurable parameters by RT-3DTEE, however, are antero-posterior leaflet length (Fig.1-a, b) and coaptation length (Fig.1-d) in each domain (A 1-3 and P 1-3 by Carpenter classification[5]) [6-8,10,11]. As far as mitral leaflet parameter is concerned, only the free margin length at the line of closure can be determined (Fig.1-e,)[9]. Anterior mitral leaflet free margin length, which is the most important aspect for Rough-zone trimming procedure, cannot be measured (Fig. 1-c). The aim of our study is to establish the accurate method for measurement of the anterior mitral leaflet free margin length by using the Q-LAB MVQ software for RT-3DTEE.

2. Patients & Methods

2.1. Clinical Characteristics

Among the patients who underwent anterior mitral valve leaflet repair between July 2010 and August 2012, we studied 17 patients with data on 3D echocardiography obtained pre- and intra-operatively and intraoperative direct measurements of the anterior mitral leaflet free margin (Table 1). All patients for MVP underwent Rough-zone trimming procedure for anterior mitral leaflet and McGoon's procedure for posterior mitral leaflet. Thirteen patients underwent annuloplasty (Cosgrove Edwards Artificial valve ring; Edwards, Irvine, CA). Combined surgery included 2 cases of CABG, 2 cases of TAP, and 4 cases of LA MAZE. The anterior mitral leaflet free margin lengths measured at different frames (early-opening frame of MV and end-opening frame of MV) by using real-time 3D echocardiography were compared with the values directly measured during MVP.

This study was approved by the Institutional Review Board of Sapporo Medical University School of Medicine. Each subject received adequate explanation for the informed consent.

2.2. Measurement method for free margin length by using 3D Echocardiography

For intraoperative 3D data acquisition, 3D echocardiographic mitral valve images were obtained by

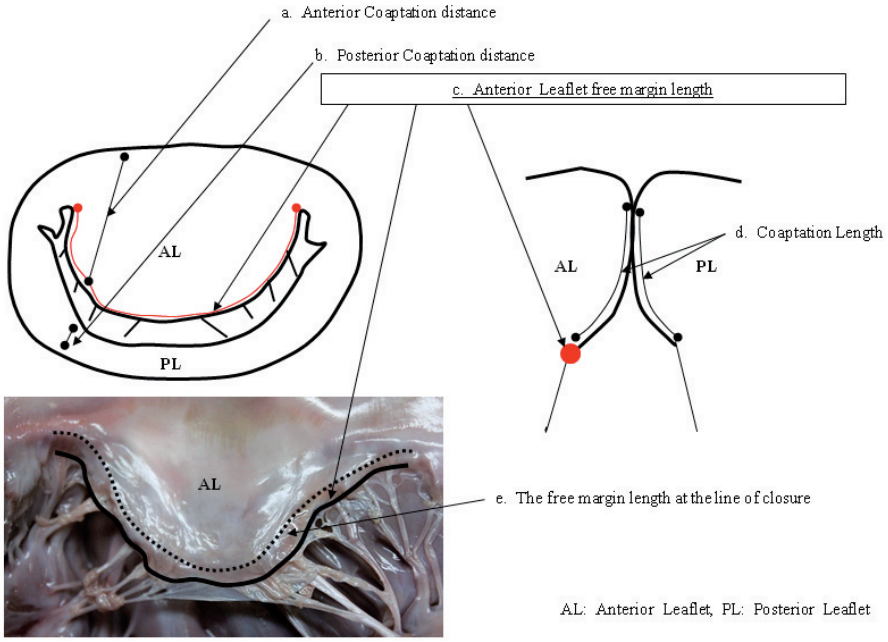

Fig. 1 A definition of measurement parts of the mitral valve

Table 1. Patient Characteristic

Characteristic N = 17	Value
Mean age (years)	46.2 (15-66)
Gender	
Male(n)	10
Female(n)	7
Etiology	
non-ischemic	17
Ischemic	0
Concomitant procedures	
TAP	2
CABG	2
LA MAZE	4
Annuloplasty device size (mean ± SD (mm))	28 ± 1.75

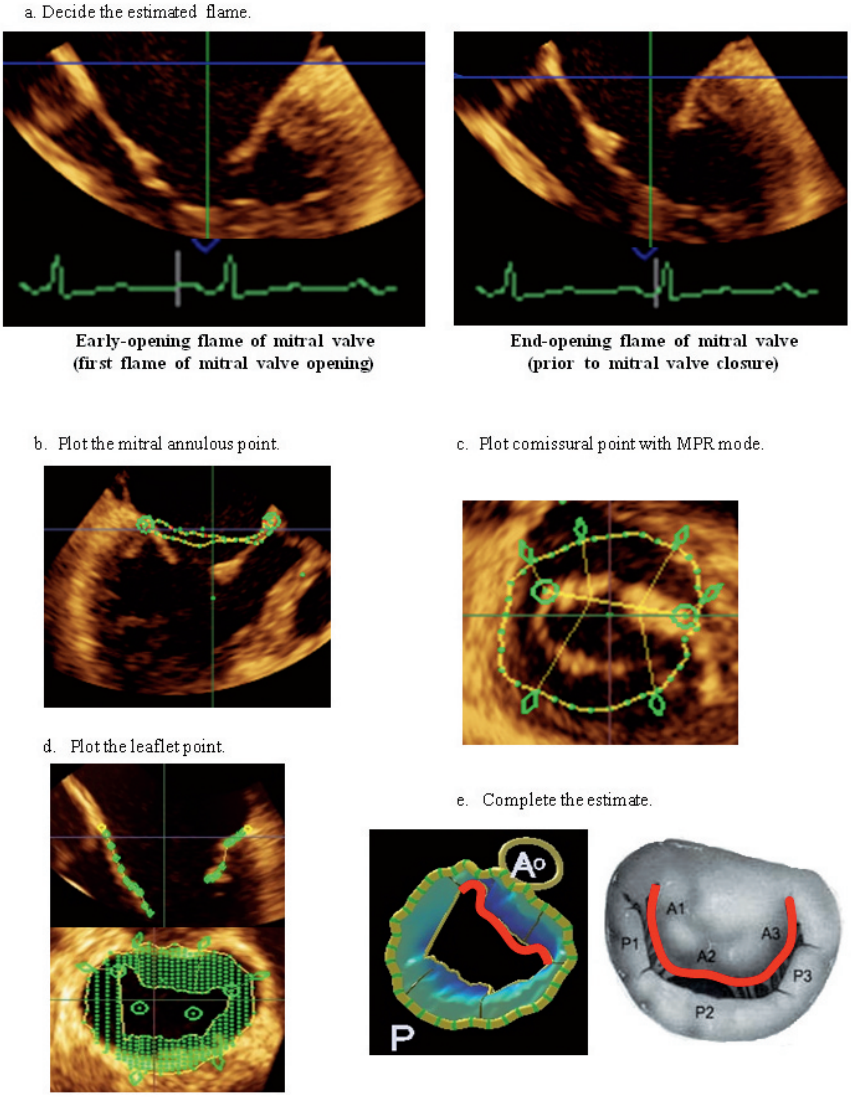

Fig. 2 Measurement method of the free margin length

using the Philips iE33 echocardiography system with X7-2 probe before the MVP. The images for 2 heart beats were recorded with 3D zoom mode. The echocardiographic images of MV obtained in 3D were analyzed by using Q-LAB MVQ off-line. For rendering the two cross-sections of the mitral valve ring, the cross-sections of two frames [(1) early-opening frame of MV and (2) end-opening frame of MV] were set for the measurement of the anterior mitral leaflet free margin length (Fig. 2 -a) and analyzed with 3D images. The measured data of the leaflet were obtained by tracing the whole figure. The measurement procedure using Q-LAB MVQ included the following: (a) determination of the estimated frame, (b) plot of the mitral annular point, (c) plot of commissural point with MPR mode, and (d) plot of the leaflet point (Fig. 2). The anterior mitral leaflet free margin length at each frame was measured.

SPSS (PASW Statistics 18; SPSS Inc, Chicago, IL) was used for the statistical analysis of the data obtained.

3. Result

The free margin length values measured with Q-LAB MVQ and the actual measured values directly measured during MVP are shown in Table 1. Mean value at early-opening frame of MV was 71.3 mm, while mean value at end-opening frame of MV was 59.9 mm. The mean value of the actual anterior mitral leaflet free margin length directly measured intraoperatively was 58.5 mm. The mean value revealed that the measurement values at the end-opening frame of MV were closely related to the actual measured values.

In addition, regarding the correlation between the measured values with the 3D echocardiography and the actual measured values directly measured intraoperatively, the measured values at the early-opening frame of MV had no correlation between the actual measured values and r-value = 0.338 (P = 0.184) (Fig. 4). Conversely, the measured values at the end-opening frame of MV had an extremely high significant correlation between the measured values and r-value = 0.980 (P < 0.0001) (Fig. 5).

4. Comment

We devised our own procedure for anterior mitral leaflet resection without the use of artificial chordate tendineae implants (Rough-zone trimming procedure) in MVP. So far, early and midterm results were satisfactory. The rough-zone trimming procedure is based on the concept of creating a new deep coaptation area and has a very wide range of applications. Only the rough zone of the prolapsed surplus leaflet is resected, and the prolapsed leaflet-free margin is retracted toward the left ventricle using

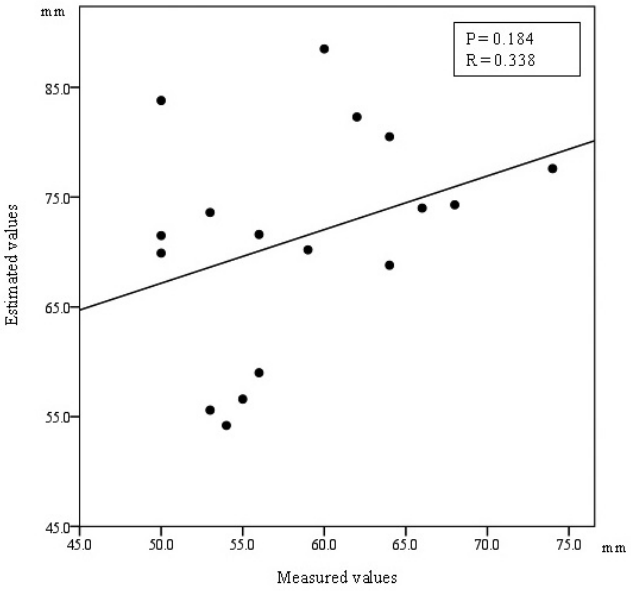

Fig. 4 Comparison of measured and estimated values of Anterior Leaflet free margin (early-opening flame)

Table 2. A average and a standard deviation of measured and estimated values

	Average (mm)	SD (mm)
(1) Estimated values (Early-opening flame of mitral valve)	71.3	10.1
(2) Estimated values (End-opening flame of mitral valve)	59.9	7.53
(3) Measured Values	58.5	7.0
|(3) - (1)|	12.8	10.2
|(3) - (2)|	1.61	1.3

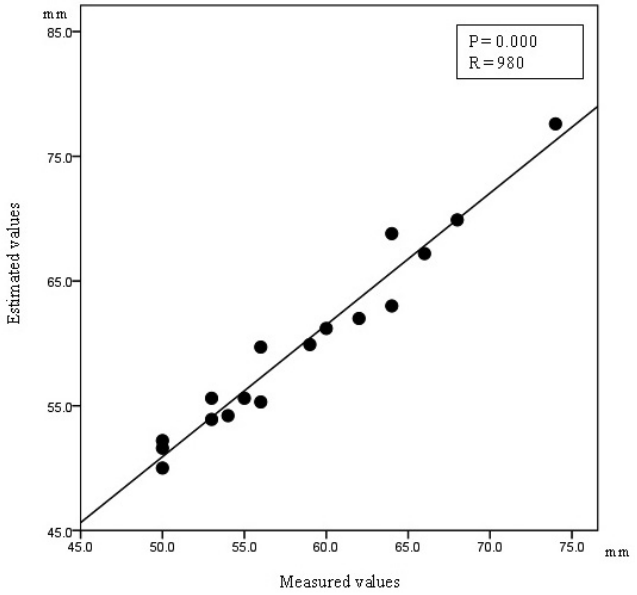

Fig. 5 Comparison of measured and estimated values of Anterior Leaflet free margin (end-opening flame)

a suturing method and matched with the resection-free margin. At present, determination of the extent of rough zone resection, however, depends heavily on the surgeon's experience. If the prolapsed anterior mitral leaflet free margin length could be evaluated based on pre-operative echocardiographic findings, the extent of rough zone resection using Rough-zone trimming procedure can be estimated in advance. Rough-zone trimming is a promising and highly developed procedure.

On the other hand, the debut of real-time 3D echocardiography may enable measurement of anterior mitral leaflet free margin length. The measurement method, however, has not yet been established. The use of Q-LAB MVQ software for real-time 3D transesophageal echocardiography in this study establishes the measurement system for the free margin at the line of closure. However, the measurement system for free margin length has not yet been established. Thus, we devised a measurement method for free margin length by using real-time 3D echocardiography, which is fundamental to Rough-zone trimming procedure.

Determination of the estimated frame is the most important aspect in the accurate measurement of anterior mitral leaflet free margin length. The 3D echocardiographic mitral valve images obtained automatically is divided into eight frames per heart beat. Calculation based on the images of anterior mitral leaflet free margin length in each frame indicated that the free margin length fluctuated with width and was not constant (Fig. 3). In the measurement of the anterior mitral leaflet free margin length based on 3D echocardiographic mitral valve images, the free margin during MV atresia (frames 1-3) was invisible because of the junction between the anterior MV leaflet and posterior MV leaflet, which rendered accurate measurement impossible. Consequently, this measurement was excluded. It was confirmed that different frames during MV opening (frames 4-7) caused different measurement values.

The two points when the MV leaflets can be relatively visible during MV opening are the first frame of MV opening (frame 4) and prior to MV closure (frame 6), which are considered as the optimum estimated frames. Regarding prior to MV closure (frame 6), Greenhouse et al. [6] employed the estimated frame for antero-posterior leaflet length of MV. Onishi et al. [7] also used the frame with R-wave peak time in ECG as end-opening frame of MV. Thus, this study defined the two points for visible MV leaflets during MV opening as the early-opening frame and end-opening frame of MV. The optimum estimated frames were decided by evaluating which measurement of free margin length in the two points reflects the directly measured free margin length values.

The measurement values of the anterior mitral leaflet free margin length in the early-opening frame of MV had a margin of error of 20-30 mm compared with the actual measured values. No correlation between the measurement values and the actual measured values was found, while a significant correlation in the end-opening frame of MV between the measurement values of the anterior mitral leaflet free margin length and the actual measured values was observed. That is, in the anterior mitral leaflet free margin length measurement, the measurement values at the end-opening frame of MV were more accurate and closely reflected the actual measured values.

The reason for the significant correlation between the

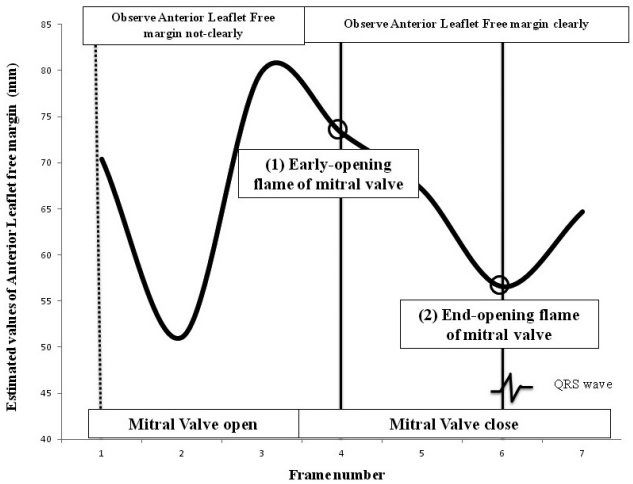

Figure 3. Transition of Anterior Leaflet free margin length in 1-beat

measurement values and actual measured values during the end-opening frame of MV was due to the difference in the opening angle of anterior mitral leaflet between the early-opening frame and end-opening frame of MV and in the leaflet view of MV when analyzed. Tsakiris et al.[12] reported that in a normal MV, the maximum-opening frame of MV was the early-opening frame. The opening-distance of MV in the open-ending frame of MV (left atrial systolic phase) did not correspond to the early-opening frame. In the measurement of anterior mitral leaflet free margin length, it is essential to plot the anterior mitral leaflet free margin after 2D images for correlation with 3D images. When the procedure is conducted, at the early-opening frame when the MV opens maximally, the border between the anterior mitral leaflet free margin and chordate tendinae becomes unclear due to the bending-over of MV and the buffer effect of the subvalvular tissue and left ventricular wall. In many cases, calculation of the anterior mitral leaflet free margin length is overestimated. On the other hand, at the open-ending frame of MV, which shows MV images in the course of MV closure, the anterior mitral leaflet free margin is clearly demonstrated, and it is likely to reflect the area close to the actual anterior mitral leaflet free margin. Therefore, analysis of the open-ending frame of MV will enable calculation of more accurate measured values.

Next, determination of the commissural point was crucial for accurate measurement of the anterior mitral leaflet free margin length. The commissural point was determined by directly observing the MPR images (Fig. 2-c). Determination of the estimated frame at the end-opening frame of MV clarified the border line of the commissural point on the MPR images. Based on these findings, calculation of the measurement values closer to the actual measured values became feasible.

In conclusion, our novel Rough-zone trimming procedure enables measurement of the anterior leaflet free margin length by using 3D echocardiography. Based on the use of the end-opening frame of MV and determination of accurate commissural point, the novel measurement method that dramatically improves accuracy of measurement values and reflects the more accurate actual measured values was established.

5. Disclosures

Yasuko Miyaki, Seiichi Funamoto, Kazutoshi Tachibana, Tomohiro Nakajima, Masaki Tabuchi, Nobuyuki Takagi and Tetsuya Higami have no conflicts of interest or financial ties to disclose.

Reference

1. Carpentier A. Cardiac valve surgery - the “French correction”. J Thorac Cardiovasc Surg 1983; 86: 323-337.
2. Spratt JA. Non-resectional repair of myxomatous mitral valve disease: the “American Correction”. J Heart Valve Dis. 2011; 20: 407-414.
3. Fasol R, Joubert-Hübner E. Triangular resection of the anterior leaflet for repair of the mitral valve. Ann Thorac Surg 2001; 71: 381-383.
4. Foster GP, Isselbacher EM, Rose GA, Torchiana DF, Akins CW, Picard MH. Accurate localization of mitral regurgitant defects using multiplane transesophageal echocardiography. Ann Thorac Surg 1998; 65: 1025-1031.
5. Ender J, Eibel S, Mukherjee C, Mathioudakis D, Borger MA, Jacobs S, Mohr FW, Falk V. Prediction of the annuloplasty ring size in patients undergoing mitral valve repair using real-time three-dimensional transoesophageal echocardiography. Eur J Echocardiogr 2011; 12: 445-453.
6. Greenhouse DG, Dellis SL, Schwartz CF, Loulmet DF, Yaffee DW, Galloway AC, Grossi EA. Regional Changes in Coaptation Geometry after Reduction Annuloplasty for Functional Mitral Regurgitation. Ann Thorac Surg 2012; 93: 1876-1880.
7. Otani K, Takeuchi M, Kaku K, Sugeng L, Yoshitani H, Haruki N, Ota T, Mor-Avi V, Lang RM, Otsuji Y. Assessment of the aortic root using real-time 3D transesophageal echocardiography. Circ J 2010; 74: 2649-2657.
8. Yamauchi T, Taniguchi K, Kuki S, Masai T, Noro M, Nishino M, Fujita S. Evaluation of the Mitral Valve Leaflet Morphology After Mitral Valve Reconstruction with a Concept “Coaptation Length Index”. J. Card Surg 2005; 20: 432-435.
9. Lam JH, Ranganathan N, Wigle ED, Silver MD. Morphology of the human mitral valve. I. Chordae tendineae: a new classification. Circulation 1970; 41: 449-458.
10. Ng AC, Delgado V, van der Kley F, Shanks M, van de Veire NR, Bertini M, Nucifora G, van Bommel RJ, Tops LF, de Weger A, Tavilla G, de Roos A, Kroft LJ, Leung DY, Schuijf J, Schalij MJ, Bax JJ. Comparison of aortic root dimensions and geometries before and after transcatheter aortic valve implantation by 2- and 3-dimensional transesophageal echocardiography and multislice computed tomography. Circ Cardiovasc Imaging 2010; 3: 94-102.
11. Ender J, Eibel S, Mukherjee C, Mathioudakis D, Borger MA, Jacobs S, Mohr FW, Falk V. Prediction of the annuloplasty ring size in patients undergoing mitral valve repair using real-time three-dimensional transesophageal echocardiography. Eur J Echocardiogr 2011; 12: 445-453.
12. Tsakiris AG, Gordon DA, Mathieu Y, Irving L. Motion of both mitral valve leaflets: a cineroentgenographic study in intact dogs. J Appl Physiol 1975; 39: 359-366.

Accepted January 16, 2013

３Ｄ心エコーによる僧帽弁前尖の free margin length 計測法の確立

宮木靖子[1)]，舩本誠一[1)]，橘　一俊[1)]，中島智博[1)]，
田淵正樹[1)]，高木伸之[1)]，樋上哲哉[1)]

[1)] 札幌医科大学医学部心臓血管外科講座

背景：本研究の目的は，僧帽弁前尖形成術において，切除範囲予測のカギとなる，僧帽弁前尖縁長（Anterior leaflet free margin length）の正確な計測方法を確立することである．

方法：2010年７月より2012年８月までに施行した前尖に対する僧帽弁形成術のうち，術前・術中３Ｄ心エコーデータのすべてを収集でき，かつ，手術時に僧帽弁前尖のfree marginを実測し得た17例を対象とした．３Ｄエコー上で，異なる時相（僧帽弁開放早期，僧帽弁開放末期）での前尖のfree margin長を計測し，僧帽弁形成術中に直視下に測定した実測値と比較検討した．
手術中の３Ｄのデータ採取には，僧帽弁形成術の前に，X7-2プローベを設置したiE33システムを用いて３Ｄ僧帽弁エコー画像を採取した．

結果：QLAB定量化ソフトウェアで計測したfree margin length値と，僧帽弁形成術中に直視下に測定した実測値は以下の通りであった．僧帽弁開放早期の計測値の平均値は71.3mmで，僧帽弁開放末期の計測値の平均値は59.9mmであった．手術中の実測僧帽弁前尖free margin長の平均値は58.5mmであった．エコーからの計測値とそれに対応する直視下計測による実測値の相関を見ると，僧帽弁開放早期での計測値は，その実測値とR値＝0.338（P＝0.184）で相関を認めなかったのに対し，僧帽弁開放末期での計測値は，その実測値とR=0.980（P<0.0001）の極めて強い有意な相関関係にあることが判明した．

結論：我々の新しい計測方法により，３Ｄエコーによる僧帽弁前尖縁長の測定は可能となった．僧帽弁開放末期の時相を用いることと，交連部の設定位置を適切に行うことにより，実測値をより正確に反映する測定方法が確立された．