J Cardiol 2005 Oct; 46(4): 149–154

Gorlin Formulas for Aortic Regurgitant and Mitral Regurgitant Orifice Areas: Experimental Studies

Masahide CHIKADA,MD
Takahiro SHIOTA, MD*1
Michael JONES, MD*2

Abstract

Background and Objectives. The measurement of aortic regurgitant and mitral regurgitant orifice areas has recently been pioneered. The present study tried to establish Gorlin formulas for aortic regurgitant and mitral regurgitant orifice areas for evaluating the severity of aortic regurgitation and mitral regurgitation.

Methods. Seventeen stable hemodynamic states for mitral regurgitation and 22 for aortic regurgitation were studied in sheep. Aortic regurgitant and mitral regurgitant orifice areas were determined by dividing regurgitant volume per second by the time integrals of the continuous aortic regurgitant and mitral regurgitant wave velocities. Aortic regurgitant and mitral regurgitant orifice areas calculated by the formulas using echocardiographic data were compared with other measurements by electromagnetic flowmeters.

Results. The Gorlin formulas were aortic regurgitant orifice area = per second valve flow/ $50.7\sqrt{\text{mean pressure gradient}}$, and mitral regurgitant orifice area = per second valve flow/ $27.5\sqrt{\text{mean pressure gradient}}$. Simple linear analysis between aortic regurgitant fractions, regurgitant volume per beat and peak aortic regurgitant flow rates, and aortic regurgitant orifice areas derived from the formula showed moderately good relationships ($r = 0.73$, 0.81 and 0.83). Mitral regurgitant orifice areas calculated by the formula also correlated with mitral regurgitant fractions, regurgitant volume per beat and peak mitral regurgitant flow rates ($r = 0.86$, 0.92 and 0.74).

Conclusions. The Gorlin formulas for aortic regurgitant and mitral regurgitant orifice area may provide an index for evaluating the severity of regurgitation.

J Cardiol 2005 Oct ; 46(4): 149−154

Key Words

■**Valvular disease** ■**Echocardiography, transthoracic** ■**Doppler ultrasound**
■**Experimental medicine** ■**Aortic regurgitation** ■**Mitral regurgitation**

INTRODUCTION

Valve area has been a valuable index of hemodynamic severity in patients with valvular stenosis. Only the stenotic valve area could be calculated by the Gorlin equation[1]. Recently regurgitant valve area has also been considered a valuable index of severity in patients with aortic regurgitation (AR)[2–4] and mitral regurgitation (MR)[5–7]. A few attempts were reported to establish modified Gorlin formulas for AR and MR, but they were not effective. Gorlin formulas for AR and MR could be useful to calculate the regurgitant valve orifice area in catheter examination. In this study, using strictly quantified AR and MR volumes, we tried to establish Gorlin formulas for AR and MR orifice areas for evaluating the severity of AR and MR.

聖マリアンナ医科大学 心臓血管外科：〒216−8511 川崎市宮前区菅生2−16−1；*1Department of Cardiology, The Cleveland Clinic Foundation, Cleveland, Ohio, USA；*2Laboratory of Animal Medicine and Surgery, National Heart, Lung and Blood Institute, National Institutes of Health, Bethesda, Maryland, USA
Department of Cardiovascular Surgery, St. Marianna University, School of Medicine, Kawasaki, *1Department of Cardiology, The Cleveland Clinic Foundation, Cleveland, Ohio, USA；*2Laboratory of Animal Medicine and Surgery, National Heart, Lung and Blood Institute, National Institutes of Health, Bethesda, Maryland, USA
Address for correspondence: CHIKADA M, MD, Department of Cardiovascular Surgery, St. Marianna University, School of Medicine, Sugao 2−16−1, Miyamae-ku, Kawasaki 216−8511；E-mail：chikada-circ@umin.ac.jp
Manuscript received March 22, 2005；revised May 25, 2005；accepted June 30, 2005

SUBJECTS AND METHODS

Subjects

Thirteen juvenile sheep weighing 22 to 43 kg (mean 34 kg) were studied. AR was surgically created in six sheep and MR was surgically created in seven sheep. All operative and animal management procedures were approved by the Animal Care and Use Committee of the National Heart, Lung and Blood Institute. Preoperative, intraoperative and postoperative animal management and husbandry methods are described in detail elsewhere[8).

Methods

A Swan-Ganz catheter was positioned in the main pulmonary artery inserted via the right femoral vein. An electromagnetic flow probe (model EP455, Carolina Medical Electronics) was placed around the ascending aorta distal to the coronary ostia and proximal to the brachiocephalic trunk. For the AR study, another electromagnetic flow probe (model EP455, Carolina Medical Electronics) was placed around the pulmonary artery just above the pulmonary valve sinuses. For the MR study, another electromagnetic flow probe (model EP455, Carolina Medical Electronics) was sutured into the left atrium above the mitral annulus during cardiopulmonary surgery. Aortic and left ventricular pressures were monitored for the AR study. Left atrial and left ventricular pressures were monitored for the MR study. These pressures were obtained from intracavity manometer-tipped catheters (model SPC-350, Miller Instruments Inc.) positioned transmurally.

The integrals of instantaneous flow over time were determined by planimetry of the electromagnetic flow signal recordings. The problem of zero baseline drift on electromagnetic records was managed in the AR study and MR study separately as follows. In the AR study, the pulmonary artery flow zero-level baseline was adjusted according to the contour of its electromagnetic flow probe signal. The baseline for the aortic flow recording was then adjusted until forward flow minus backward aortic flow equaled pulmonary forward flow volume. The correlation coefficient for the regression of pulmonary forward flow versus aortic forward minus regurgitant flow was 0.98 (SEE 0.03 liters/min). In the MR study, the aortic flow zero-level baseline was adjusted according to the contour of its electromagnetic flow probe signal. No animal had physiological important aortic regurgitation. The baseline for the mitral flow record was then adjusted until forward minus backward mitral flow volume equaled aortic forward flow volume. The coefficient for regression of aortic forward flow versus mitral forward minus backward flow was 0.97 (SEE 0.12 liters/min). Regurgitant volumes were calculated from the time integrals of AR and MR flow rates. Regurgitant fraction was calculated as aortic or mitral backward flow volume/min divided by forward aortic or mitral flow volume/min. Once the curves of flows were properly adjusted, instantaneous regurgitation flow rates could be determined.

After baseline measurements were obtained, various degrees of severity of AR or MR were made by altering preload or afterload using blood transfusion and angiotensin infusion alone or in combination. Twenty-two stable hemodynamic states for AR study and seventeen stable hemodynamic states for MR study were observed.

Ultrasound study

A Vigmend 750 system (Vingmed Sound, A/S) using color Doppler flow mapping was employed to image forward flow and regurgitant flow. The 5-MHz ultrasound probe was placed directly near the apex of the heart at a pulse of repetition frequency of 4 kHz. Color gain was adjusted to eliminate random color in areas without flow. The color Doppler filter was selected to de-emphasize velocities $<$ 16 cm/sec. A narrow color sector was chosen to allow frame rates as high as 45 per second.

Guided by the two-dimensional and color Doppler imaging of the regurgitant jet and the valve from the apical transducer location, continuous wave Doppler recordings were obtained, recording the regurgitant flow velocity parallel to the direction of the regurgitant jet. The continuous wave and color Doppler data were matched for each steady state with color Doppler flow mapping images as digital cine loops.

Gorlin formula for aortic regurgitation and mitral regurgitation

Regurgitant volume per second was obtained from electromagnetic flow and mean pressure gradient (mPG) was derived from cardiac catheterization data. AR and MR orifice areas were determined by dividing regurgitant volume per second by the time integrals of the continuous AR and MR wave velocities obtained by ultrasound study. The

Gorlin formula constant (K) of each hemodynamic condition was calculated as follows. K = regurgitant volume per second/valve area × $\sqrt{mPG}$ = the time integral of continuous wave velocity/ $\sqrt{mPG}$. Both mPG were derived from cardiac catheterization. Gorlin formula constants of AR and MR were determined by calculating the average of K. Once the formulas of AR and MR were determined, AR and MR orifice areas were calculated by the formulas using echocardiographic data. The AR and MR orifice areas calculated by the formulas were compared with those obtained by electromagnetic flowmeters. AR and MR orifice areas by the formulas were also compared with regurgitant volumes, regurgitant fractions from electromagnetic flowmeter monitoring and regurgitant peak flow velocities from the ultrasound study.

Statistical analysis

Data are presented as mean ± SD. Correlations between continuous variable data were determined by linear regression analysis. Statistical significance was defined as $p < 0.05$.

RESULTS

The formulas for AR and MR were as follows: AR orifice area = per second valve flow/50.7 $\sqrt{mPG}$; MR orifice area = per second valve flow/27.5 $\sqrt{mPG}$. AR orifice areas calculated by the formula were 0.13 ± 0.09 cm^2, and MR orifice areas were 0.11 ± 0.06 cm^2. The formula was accurate for quantifying AR orifice areas obtained by electromagnetic flowmeters ($r = 0.94$, difference = 0.001 ± 0.029 cm^2), and for quantifying MR orifice areas by electromagnetic flowmeters ($r = 0.92$, difference = 0.002 ± 0.025 cm^2). Simple linear analysis between regurgitant volumes per beat and AR orifice areas derived from the formula revealed a moderately good relationship (**Fig. 1−A**, $r = 0.81$). Analysis between AR fractions and AR orifice areas also showed a good relationship (**Fig. 1−B**, $r = 0.73$). Analysis between peak AR flow rates and AR orifice areas also showed a fairly good correlation (**Fig. 1−C**, $r = 0.83$). Simple linear analysis showed a close correlation between regurgitant volumes per beat and MR orifice area derived from the formula (**Fig. 2−A**, $r = 0.92$), a fairly good correlation between MR fractions and MR orifice (**Fig. 2−B**, $r = 0.86$), and a good correlation between peak MR flow rates and MR orifice areas (**Fig. 2−C**, $r = 0.74$).

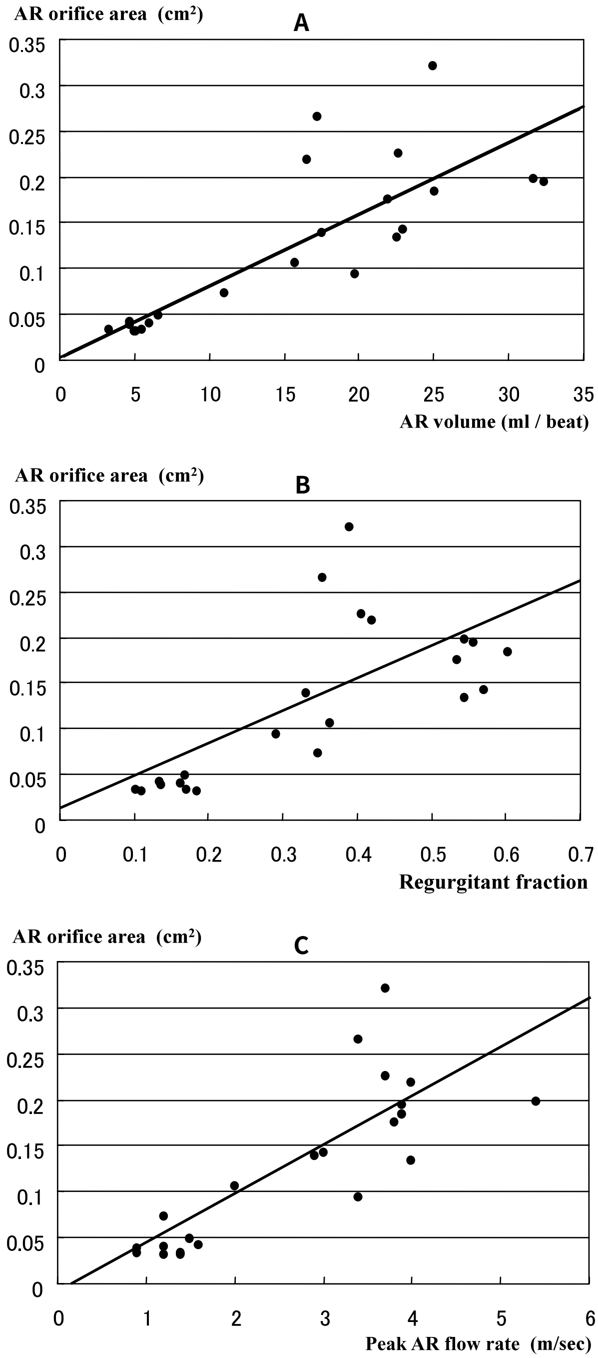

Fig. 1 Correlations between aortic regurgitant orifice area calculated by the Gorlin formula and regurgitant volume per beat obtained by electromagnetic flowmeter (*A*), aortic regurgitant fraction obtained by electromagnetic flowmeter (*B*), and peak aortic regurgitant flow rate obtained by echocardiography (*C*)

Continuous lines are regression lines.
AR = aortic regurgitant.

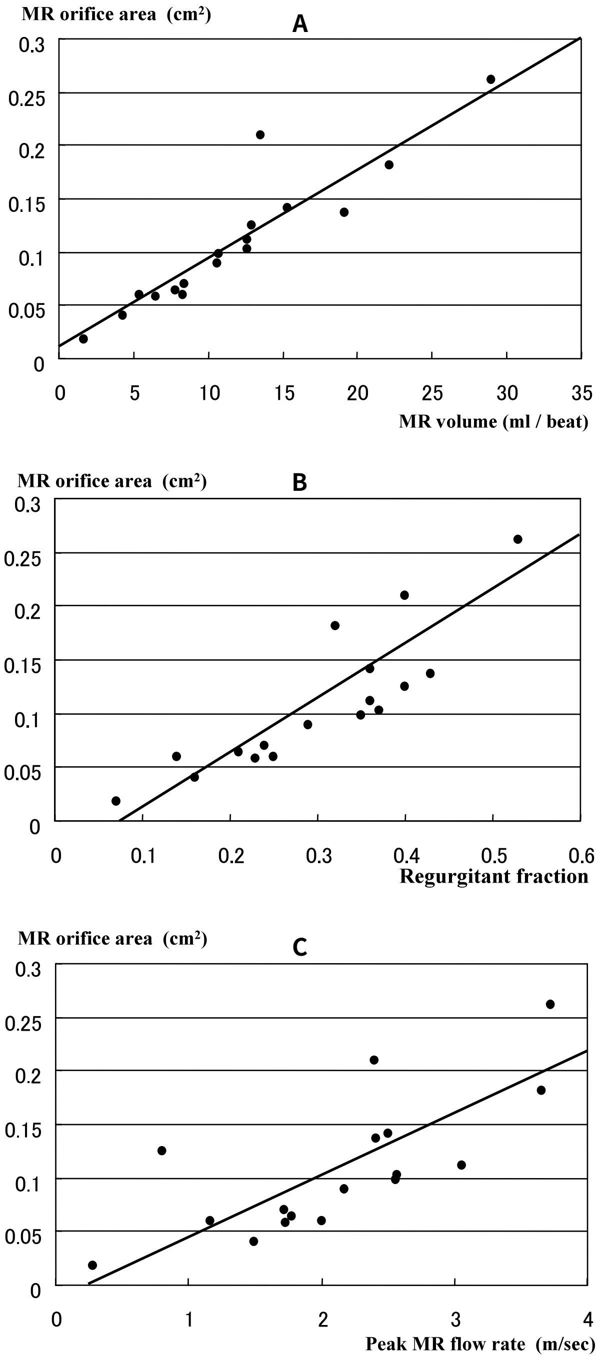

Fig. 2 Correlations between mitral regurgitant orifice area calculated by the Gorlin formula and regurgitant volume per beat obtained by electromagnetic flowmeter (*A*), mitral regurgitant fraction obtained by electromagnetic flowmeter (*B*), and peak mitral regurgitant flow rate obtained by echocardiography (*C*)

Continuous lines are regression lines.
MR = mitral regurgitant.

DISCUSSIONS

The Gorlin formula was proposed in 1951[1]. The Gorlin formula is useful for calculating the valve areas of aortic stenosis[9–11] and mitral stenosis[12–15]. The formulas for the valve areas of AR and MR had not been established[16].This study tried to establish the Gorlin formulas to calculate the valve areas of AR and MR as an index of severity of AR and MR.

Quantification of AR and MR is a common and difficult clinical problem. The severity of AR and MR is a very important issue to determine the surgical indication[17–20]. Recently color Doppler images of AR and MR flow convergence and the vena contracta have been effective for estimating the severity of AR and MR[5,21,22]. However, clinical application of these methods is limited because of the difficulty in clearly imaging the flow convergence and vena contracta[5,21–23]. More recently aortic and mitral regurgitant valve orifice areas have been advocated to evaluate the severity of AR and MR. AR and MR orifice areas have been calculated by using the flow convergence and the vena contracta[5,23]. These methods are effective but complex to perform. The Gorlin formula was previously used to calculate the valve areas of aortic stenosis and mitral stenosis in catheter examination[10,12,15]. In this study, we established the Gorlin formulas for AR and MR by using strictly quantified AR and MR volumes. AR and MR orifice areas calculated by the formulas showed good correlation with regurgitant volumes per beat and regurgitant fractions obtained by electromagnetic flow study. The orifice areas were also correlated with AR and MR peak flow velocities in ultrasound study. AR and MR orifice areas calculated by the formulas are thus useful for estimating the severity of AR and MR.

The measurement of AR and MR orifice areas has recently been pioneered in animal studies[2,5,21–23], clinical data in large series of patients are still not available. In the future, measurement of AR and MR orifice areas will be a prerequisite to surgical decision making. Our established formulas for AR and MR could provide an index for the decision.

Study limitation

In our study, constant K was obtained by using the time integrals of continuous wave velocity.

Therefore, the constant K could be calculated as larger than the correct value. We used epicardial echocardiography and located the best position for the echo transducer to obtain good alignment for Doppler imaging. Under clinical conditions, such alignment may not be possible in some patients with AR and MR. Calcification of aorta and valve in elderly patients may hinder good flow imaging from the apex. In our present study, the apical view, routinely used in clinical practice, rarely provided good flow images. We often moved the echo transducer a little more towards the base to improve flow images. In clinical settings, this method may not be applicable. In this study, regurgitant fraction was less than 0.55 in all MR models and in almost all AR models, so severe regurgitation was not tested, especially in the MR model.

CONCLUSIONS

This study used an animal model with strictly quantified AR and MR volumes to establish the Gorlin formulas for calculating AR and MR valve orifice areas. AR and MR orifice areas obtained from the formulas showed good correlations with other measurements of AR and MR.

要　約

大動脈弁と僧帽弁の逆流弁口面積に対するGorlinの式の実験的検討

近田　正英　　塩田　隆弘　　マイケル・ジョーンズ

背景と目的: 最近，大動脈弁閉鎖不全症や僧帽弁閉鎖不全症で，逆流部の弁口面積が疾患の重症度の指標として用いられている．今回，我々は動物実験において大動脈弁閉鎖不全と僧帽弁閉鎖不全の慢性モデルを作製し，電磁流量計と心エコー図法を用いて計測を行い，逆流の弁口面積を求めるGorlinの式を確立することを試みた．さらに，その式を用いて求めた逆流部弁口面積と弁逆流の他の指標との関連性を検討した．

方　法: ヒツジ13匹で22の状態の大動脈弁閉鎖不全と，7匹で17の状態の僧帽弁閉鎖不全の状態で計測を行った．弁閉鎖不全の弁口面積は，電磁流量計で求めた逆流量を逆流の流速の積分で割ることによって求めた．Gorlinの式の係数Kを，Gorlinらの最初の論文に従って計算し，その平均値を弁逆流のGorlinの式のK値とした．弁逆流の弁口面積を，心エコー図法で得たデータを用いて求めたGorlinの式で計算し，実測された逆流率，1拍の逆流量，逆流の最高流速と比較した．

結　果: 大動脈弁閉鎖不全の式は大動脈弁逆流量/50.7$\sqrt{\text{大動脈左室拡張期平均圧較差}}$であり，僧帽弁閉鎖不全症の式は僧帽弁逆流量/27.5$\sqrt{\text{左室左房拡張期平均圧較差}}$であった．式より求められた大動脈弁逆流弁口面積は逆流率，1拍の逆流量，逆流の最高流速と有意に相関した($r=0.73$，0.81，0.83)．式より求められた僧帽弁逆流の弁口面積も，逆流率，1拍の逆流量，逆流の最高流速と有意に相関した($r=0.86$，0.92，0.74)．

結　論: 動物実験の慢性モデルを使って，大動脈弁不全症と僧帽弁閉鎖不全症に対するGorlinの式を求めた．大動脈弁閉鎖不全と僧帽弁閉鎖不全に対するGorlinの式は，逆流の重症度を示す指標となりうると考えられた．

J Cardiol 2005 Oct; 46(4): 149－154

References

1) Gorlin R, Gorlin SG: Hydraulic formula for calculation of the area of the stenotic mitral valve, other cardiac valves, and central circulatory shunts: Ⅰ. Am Heart J 1951; **41**: 1－29
2) Chikada M, Shiota T, Aida S, Yamada I, Sahn DJ, Jones M: A method for estimating aortic regurgitant orifice area by digital Doppler color flow mapping. J Heart Valve Dis 1998; **7**: 102－107
3) Reinmold SC, Ganz P, Bittl JA, Thomas JD, Thoreau D, Plappert TJ, Lee RT: Effective aortic regurgitant orifice area: Description of a method based on the conservation of mass. J Am Coll Cardiol 1991; **18**: 761－768
4) Veyrat C, Lessana A, Abitbol G, Ameur A, Benaim R, Kalmanson D: New Indexes for assessing aortic regurgitation with two-dimensional Doppler echocardiographic measurement of the regurgitant aortic valvular area. Circulation

1983; **68**: 998−1005
5) Shiota T, Jones M, Teien DG, Yamada I, Passafini A, Ge S, Sahn DJ: Dynamic changes in mitral regurgitant orifice area: Comparison of color Doppler echocardiographic and electromagnetic flowmeter-based methods in a chronic animal model. J Am Coll Cardiol 1995; **26**: 528−536
6) Hoit BD, Jones M, Eidbo EE, Elias W, Sahn DJ: Sources of variability for Doppler color flow mapping of regurgitant area in an animal model of mitral regurgitation. J Am Coll Cardiol 1989; **13**: 1631−1636
7) Yellin EL, Yoran C, Sonnenblick EH, Gabbay S, Frater RWM: Dynamic changes in the canine mitral regurgitant orifice area during ventricular ejection. Cir Res 1979; **45**: 677−683
8) Jones M, Barnhart GR, Chavez AM, Eidbo EE: Experimental evaluation of bioprosthetic valves implanted in sheep. *in* Cardiac Bioprostheses (ed by Cohn LM, Gallucci V). Yoke, New York, 1982; pp 275−292
9) Okura H, Yoshida K, Hozumi T, Akasaka T, Yoshikawa J: Planimetry and transthoracic two-dimensional echocardiography in noninvasive assessment of aortic valve area in patients with valvular aortic stenosis. J Am Coll Cardiol 1997; **30**: 753−759
10) Tardif JC, Rodrigues AG, Hardy JF, LedercY, Petitclerc R, Mongrain R, Mercier LA: Simultaneous determination of aortic valve area by the Gorlin formula and by transesophageal echocardiography under different transvalvular flow conditions: Evidence that anatomic aortic valve area does not change with variations in flow in aortic stenosis. J Am Coll Cardiol 1997; **29**: 1296−1302
11) Teirstein P, Yeager M, Yock PG, Popp RL: Doppler echocardiographic measurement of aortic valve area in aortic stenosis: A noninvasive application of the Gorlin formula. J Am Coll Cardiol 1986; **8**: 1059−1065
12) Gorlin WB, Gorlin R: A generalized formulation of the Gorlin formula for calculating the area of the stenotic mitral valve and other stenotic cardiac valves. J Am Coll Cardiol 1990; **15**: 246−247
13) Riggs TW, Lapin GD, Paul MH, Muster AJ, Berry TE: Measurement of mitral valve orifice area in infants and children by two-dimensional echocardiography. J Am Coll Cardiol 1983; **1**: 873−878
14) Chen CG, Wang YP, Guo BL, Lin YS: Reliability of the Doppler pressure half-time method for assessing effects of percutaneous mitral balloon valvuloplasty. J Am Coll Cardiol 1989; **13**: 1309−1313
15) Rifkin RD, Harper K, Tighe D: Comparison of proximal isovelocity surface area method with pressure half-time and planimetry in evaluation of mitral stenosis. J Am Coll Cardiol 1995; **26**: 458−465
16) Berglund H, Kim CJ, Nishioka T, Luo H, Siegel RJ: Influence of ejection fraction and valvular regurgitation on the accuracy of aortic vlave area determination. Echocardiography 2001; **18**: 65−72
17) Grimm RA, Stewart WJ: The role of intraoperative echocardiography in valve surgery. Cardiol Clin 1998; **16**: 477−489
18) Katz AS, Devereux RB: Timing of surgery in chronic aortic regurgitation. Echocardiography 2000; **17**: 303−311
19) Bonow RO: Asymptomatic aortic regurgitation: Indication for operation. J Card Surg 1994; **9**: 170−173
20) Quinones MA: Management of mitral regurgitation: Optimal timing for surgery. Cardiol Clin 1998; **16**: 421−435
21) Shiota T, Jones M, Yamada I, Russell S, Heinrich RS, Ishii M, Sinclair B, Yoganathan AP, Sahn DJ: Evaluation of aortic regurgitation with digitally determined color Doppler-imaged flow convergence acceleration: A quantitative study in sheep. J Am Coll Cardiol 1996; **27**: 203−210
22) Ishii M, Jones M, Shiota T, Heinrich RS, Yamada I, Sinclair B, Yoganathan AP, Sahn DJ: Evaluation of eccentric aortic regurgitation by color Doppler jet and color Doppler-imaged vena contracta measurements: An animal study of quantified aortic regurgitation. Am Heart J 1996; **132**: 796−804
23) Shiota T, Jones M, Yamada I, Russell S, Heinrich RS, Ishii M, Sinclair B, Holcomb S, Yoganathan AP, Sahn DJ: Effective regurgitant orifice area by the color Doppler flow convergence method for evaluating the severity of chronic aortic regurgitation: An animal study. Circulation 1996; **93**: 594−602