The Heart Surgery Forum #2008-1147
12 (2), 2009 [Epub April 2009]
doi: 10.1532/HSF98.20081147 Online address: http://cardenjennings.metapress.com

Cardioscopic Tricuspid Valve Repair in a Beating Ovine Heart

Dr. Chen

Ramanan Umakanthan,[1] Ravi K. Ghanta,[1] Aravind T. Rangaraj,[1] Lawrence S. Lee,[1] Rita G. Laurence,[1] John A. Fox,[1] Tomislav Mihaljevic,[2] Ralph M. Bolman III,[1] Lawrence H. Cohn,[1] Frederick Y. Chen[1]

[1]Division of Cardiac Surgery, Brigham and Women's Hospital, Harvard Medical School, Boston, Massachusetts; [2]Department of Thoracic and Cardiac Surgery, Cleveland Clinic Foundation, Cleveland, Ohio, USA

ABSTRACT

Background: Open heart surgery is commonly associated with cardiopulmonary bypass and cardioplegic arrest. The attendant risks of cardiopulmonary bypass may be prohibitive in high-risk patients. We present a novel endoscopic technique of performing tricuspid valve repair without cardiopulmonary bypass in a beating ovine heart.

Methods: Six sheep underwent sternotomy and creation of a right heart shunt to eliminate right atrial and right ventricular blood for clear visualization. The superior vena cava, inferior vena cava, pulmonary artery, and coronary sinus were cannulated, and the blood flow from these vessels was shunted into the pulmonary artery via a roller pump. The posterior leaflet of the tricuspid valve was partially excised to create tricuspid regurgitation, which was confirmed by Doppler echocardiography. A 7.0-mm fiberoptic videoscope was inserted into the right atrium to visualize the tricuspid valve. Under cardioscopic vision, an endoscopic needle driver was inserted into the right atrium, and a concentric stitch was placed along the posterior annulus to bicuspidize the tricuspid valve. Doppler echocardiography confirmed reduction of tricuspid regurgitation.

Results: All animals successfully underwent and tolerated the surgical procedure. The right heart shunt generated a bloodless field, facilitating cardioscopic tricuspid valve visualization. The endoscopic stitch resulted in annular plication and functional tricuspid valve bicuspidization, significantly reducing the degree of tricuspid regurgitation.

Conclusion: Cardioscopy enables less invasive, beating-heart tricuspid valve surgery in an ovine model. This technique may be useful in performing right heart surgery without cardiopulmonary bypass in high-risk patients.

INTRODUCTION

The concept of cardioscopy, or endoscopy of the heart, dates back to the early 20th century with the first cardioscope developed by Rhea and Walker in 1913 [Rhea 1924]. The first article on cardioscopy was published in 1922 by Allen and Graham [1922]. Since then, several attempts have been made to design the ideal cardioscope [Murray 1950; Butterworth 1951; Bolton 1954; Reuthebuch 1999]. Cardioscopy, however, has not advanced as rapidly as other forms of endoscopic surgery because of problems with visualization through blood within the beating heart. During the last several years, there has been a revival of interest in cardioscopy, owing to increased interest in performing less invasive forms of cardiac surgery [Reuthebuch 1999].

Current applications of cardioscopy are limited. A small number of previous studies described several useful applications [Kawai 1987; Okada 1989; Uchida 1990; Laborde 1993; Burke 1994, 1995; Oshima 1994; Mazza 1998; Reuthebuch 1999; Inoue 2003]. These applications have included visualization of intraventricular pathology during cardiac surgery, visualization of intracardiac structures during repair of congenital heart defects, obtaining endomyocardial biopsy samples for the diagnosis of myocarditis, and enhancing other surgical procedures [Kawai 1987; Okada 1989; Uchida 1990; Laborde 1993; Burke 1994, 1995; Oshima 1994; Mazza 1998; Reuthebuch 1999; Inoue 2003]. Although such applications are not currently standard procedure, they do suggest the possible benefits that cardioscopy may offer by enabling less invasive forms of cardiac surgery.

The obvious limitations of traditional cardiac surgery are the common use of cardiopulmonary bypass and diastolic arrest to generate the bloodless immobile field required for satisfactory visualization. Cardiopulmonary bypass is associated with well-known complications, such as cerebrovascular accident, neurologic dysfunction, hemorrhage, and low cardiac output syndrome. Diastolic arrest of the heart entails cross-clamping of the proximal ascending aorta, which poses the risk of cardiac ischemia during the cross-clamp period, as well as embolic complications.

Our hypothesis is that cardioscopy may be able to facilitate less invasive forms of cardiac surgery that do not require cardiopulmonary bypass and diastolic arrest in selected situations. As a first step, we examined this concept in the right heart. We induced tricuspid regurgitation in an ovine model and used cardioscopy to perform endoscopic tricuspid valve bicuspidization without cardiopulmonary bypass to correct tricuspid regurgitation in the beating heart.

Received December 9, 2008; received in revised form February 3, 2009; accepted March 3, 2009.

Correspondence: Frederick Y. Chen, MD, PhD, Division of Cardiac Surgery, Brigham and Women's Hospital, 75 Francis St, Boston, MA 02115, USA; 1-617-732-7678; fax: 1-617-732-6559 (e-mail: fchen@partners.org).

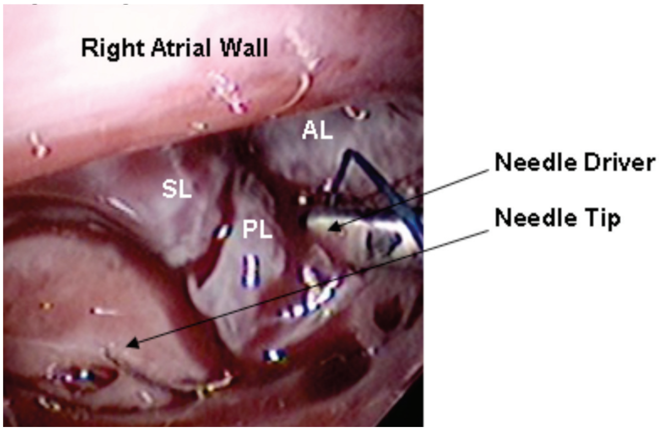

Figure 1. Placement of concentric stitch in posterior leaflet annulus. Under cardioscopic visualization, an endoscopic needle driver was used to place a concentric stitch in the posterior leaflet annulus. AL indicates anterior leaflet; SL, septal leaflet; PL, posterior leaflet remnant.

MATERIALS AND METHODS

Anesthesia and Initial Surgical Instrumentation

Six sheep, weighing 33 to 36 kg, were used for this study. All animals were cared for according to the *Guide for the Care and Use of Laboratory Animals* [Institute of Laboratory Animal Resources 1996].

Animals were sedated with Telazol (6 mg/kg). A preoperative Doppler echocardiogram was performed to confirm that there was no preoperative evidence of tricuspid regurgitation. General anesthesia was induced via a cuffed endotracheal tube with isoflurane (1.5%-2.0%). Volume ventilation was initiated with oxygen at 8 L/min (North American Draeger, Telford, PA, USA). Pulse oximetry, electrocardiograph leads, and a temperature probe were appropriately secured. Oxygen saturation, cardiac rhythm, and body temperature were monitored continuously.

An 18-gauge venous line was placed in the left external jugular vein for administration of intravenous fluids and pharmacologic agents. A maintenance infusion of normal saline was started.

A right femoral dissection was performed. The right femoral artery was cannulated with a 16-gauge Angiocath (BD Medical Systems, Franklin Lakes, NJ, USA). The Angiocath was secured and connected to a pressure transducer, and the arterial blood pressure was continuously monitored.

A midline sternotomy was performed, and the heart was suspended in a pericardial cradle. A bolus of lidocaine (3 mg/kg) was given for prevention of arrhythmia. The superior vena cava, inferior vena cava, and pulmonary artery were exposed, and tourniquets were placed around these vessels at their right atrial and right ventricular junctions.

Right Heart Shunt

A right heart shunt was established to empty blood from the right heart. The pulmonary artery was cannulated with a 16F wire-wound cannula. The cannula was then connected to the distal end of a roller pump (Sarns model 1800 pump; Terumo CVS, Ann Arbor, MI, USA). Two 24F wire-wound cannulae were used to cannulate the superior vena cava and inferior vena cava. The cannulae were connected to the proximal end of the roller pump with a 3-way connector. The animal then underwent systemic heparinization (400 units/kg). The roller pump was used to actively shunt blood from the superior vena cava and inferior vena cava into the pulmonary artery. The tourniquets encircling the superior vena cava, inferior vena cava, and pulmonary artery were tightened to prevent residual flow of blood into the right atrium and right ventricle. The pump cycled blood at approximately 60 mL/kg per minute. Suction tubing was connected to a reservoir system incorporated into the roller-pump circuit so that blood lost during cannulation could be suctioned, collected, and recycled via the reservoir. To complete the right heart shunt, we cannulated the coronary sinus with a 14F coronary sinus cannula, recycled the efflux from the coronary sinus via the reservoir, and shunted it into the pulmonary artery.

Induction of Tricuspid Regurgitation

The tricuspid valve was exposed via a right atriotomy, and the posterior leaflet of the tricuspid valve was partially excised to induce tricuspid regurgitation. The atriotomy was closed with 4-0 Prolene suture. The right heart shunt was temporarily stopped, and newly created tricuspid regurgitation was confirmed by epicardial Doppler echocardiography.

Cardioscopic Bicuspidization of the Tricuspid Valve

A 7.0-mm fiberoptic videoscope (Evis Pleuravideoscope; Olympus Medical Systems, Tokyo, Japan) was inserted into the right atrium. Images were transmitted to a video monitor, and the scope was positioned to visualize the tricuspid valve within the beating heart.

An endoscopic needle driver loaded with 4-0 Prolene suture was inserted into the right atrium. Under cardioscopic visualization, the endoscopic needle driver was used to place a concentric stitch along the posterior annulus of the tricuspid valve to cause plication of that annulus.

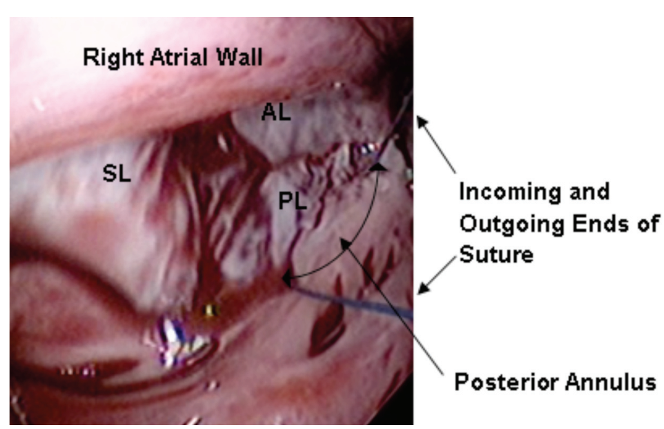

Figure 2. Continuation of posterior annulus stitch. The stitch was incorporated along the length of the posterior annulus. AL indicates anterior leaflet; SL, septal leaflet; PL, posterior leaflet remnant.

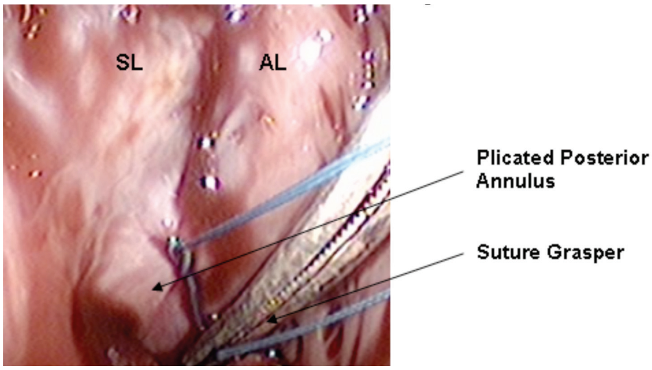

Figure 3. Completion of tricuspid valve bicuspidization. The stitch was tied down and secured under cardioscopy. This action resulted in plication of the annulus and functional tricuspid valve bicuspidization. AL indicates anterior leaflet; SL, septal leaflet.

Confirmation of Reduction of Tricuspid Regurgitation

The right heart shunt was stopped, and a repeat epicardial Doppler echocardiogram was performed to confirm that endoscopic bicuspidization had caused reduction of tricuspid regurgitation.

RESULTS

The right heart shunt successfully eliminated blood from the right atrium and right ventricle in the beating heart. Cardioscopy provided satisfactory visualization of the interior of the right heart and the tricuspid valve. An endoscopic concentric stitch was placed in the posterior leaflet annulus (Figure 1) and was successfully incorporated along the length of the posterior annulus (Figure 2). The stitch was tied down and secured, resulting in annular plication and functional tricuspid valve bicuspidization (Figure 3). All 6 ovines tolerated the cardioscopic bicuspidization procedure without complications.

A preoperative Doppler echocardiogram revealed no evidence of preoperative tricuspid regurgitation in any of the subjects. Intraoperative Doppler echocardiograms performed after partial excision of the posterior leaflet of the tricuspid valve demonstrated newly created 3+ tricuspid regurgitation in all of the animals (Figure 4). A repeat intraoperative Doppler echocardiogram performed after the cardioscopic bicuspidization procedure showed resolution of tricuspid regurgitation for all animals (Figure 5).

DISCUSSION

The goal of cardioscopy, as with any other form of endoscopic surgery, is to provide less invasive approaches to existing surgical techniques. One potential benefit of cardioscopic surgery is that it may allow procedures to be performed without cardiopulmonary bypass and cardiac arrest. Cardiopulmonary bypass provides a bloodless, motionless surgical field but is associated with a number of risks and complications, some of which can be life threatening [Hammon 2008]. By obviating the need for cardiopulmonary bypass, cardioscopy can eliminate these complications and further minimize the

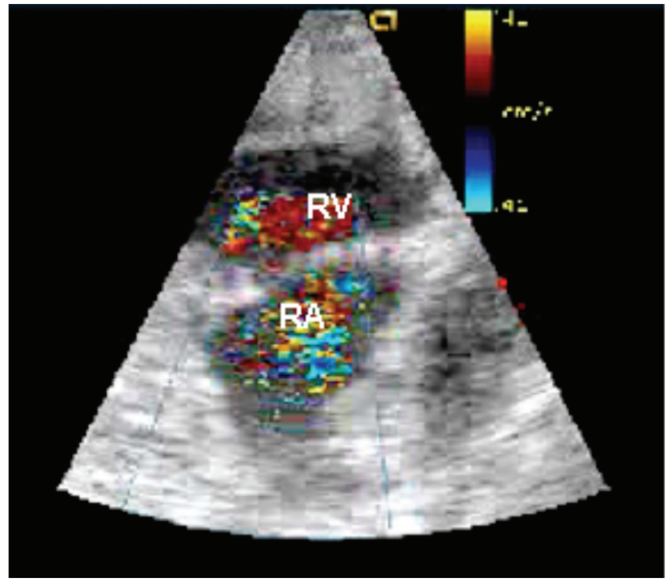

Figure 4. Echocardiography of tricuspid regurgitation: echocardiogram performed after induction of tricuspid regurgitation via partial excision of the posterior leaflet of the tricuspid valve. Regular flow of blood from the right atrium into the right ventricle is designated in red. Backflow of blood from the right ventricle into the right atrium due to 3+ tricuspid regurgitation is designated in light blue. RA indicates right atrium; RV, right ventricle.

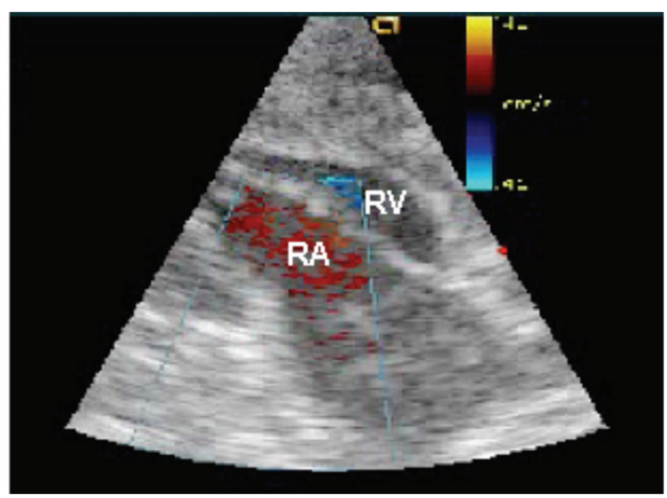

Figure 5. Resolution of tricuspid regurgitation: echocardiogram performed after the cardioscopic bicuspidization procedure. The previously noted backflow of blood into the right atrium from tricuspid regurgitation (as seen in Figure 4) is no longer evident. Regular flow of blood is still seen (in red). RA indicates right atrium; RV, right ventricle.

risks of cardiac surgery. A major current limitation of cardioscopy is the difficulty associated with attempting visualization through blood within the beating heart [Reuthebuch 1999]. Early cardioscopy devices consisted of a tube fitted with a glass window and illuminated by transmitted light. The device was pressed against cardiac structures to eliminate opaque blood from the field of view [Bolton 1954]. Beating heart endoscopy has also been attempted by means of a balloon-covered flexible endoscope [Reuthebuch 1999]. The balloon is filled with saline and pressed against the myocardial wall to enhance visualization. However, induction of arrhythmias and hemodynamic instability have been frequent complications involved with these methods, and subsequent applications were limited [Bolton 1954; Reuthebuch 1999].

In this study, we successfully used cardioscopy in an ovine model to visualize the interior of the right heart without cardiopulmonary bypass or aortic cross-clamping. In addition, we used cardioscopy to successfully perform tricuspid bicuspidization to repair tricuspid regurgitation.

Tricuspid valve bicuspidization has been shown to be a simple and feasible option for treating functional tricuspid regurgitation [Ghanta 2007]; however, standard techniques of tricuspid valve bicuspidization may use cardiopulmonary bypass and a full atriotomy to obtain access to the tricuspid valve [Cohen 1987; McGrath 1990]. The method of cardioscopic tricuspid valve bicuspidization we have described allows this procedure to be performed in a less invasive manner without the use of cardiopulmonary bypass. Our results demonstrate that this approach is feasible, is satisfactorily tolerated, and achieves successful resolution of tricuspid regurgitation.

Lee et al [2007] previously described the use of a right heart shunt similar to the one we have used for beating heart tricuspid valve surgery. The only difference was that we used cardioscopy to perform endoscopic surgery on the tricuspid valve, whereas Lee et al performed the procedure under direct vision by opening the right atrium.

Some may question the rationale for our choice to use cardioscopy to perform the procedure, instead of under direct vision by just opening the right atrium. What we want to emphasize is that the goal of our study was to promote a technique that is, "in principle," less invasive and to show that the concept is feasible. Because our study has now shown the feasibility of such an approach, it has demonstrated that the technique has potential for benefit once it is further developed and refined. For instance, if the right heart shunt could be performed percutaneously, then the procedure itself could potentially be performed thoracoscopically or endoscopically through a mini-thoracotomy incision. Percutaneous right heart bypass for posterior and posterolateral coronary artery bypass grafting without cardiopulmonary bypass has already been demonstrated in a prior study [Wirtz 2006]. Thoracoscopic tricuspid valve surgery using a mini-thoracotomy and advancing the endoscope into the right atrial cavity to produce excellent video imaging of the intracardiac structures under cardiopulmonary bypass have also been described [Robin 1999]. Because we have shown that endoscopic beating heart tricuspid valve bicuspidization is a safe and feasible technique, we postulate that combining our technique with a percutaneous right heart bypass could potentially enable the procedure to be performed thoracoscopically. This approach would then enable a less invasive surgical technique. It would obviate the need for a median sternotomy, decrease the risk of wound complications, and circumvent the risks of cardiopulmonary bypass.

Such techniques could prove especially beneficial for patients with tricuspid regurgitation who may have underlying comorbidities that would otherwise preclude them from undergoing cardiopulmonary bypass. They could also prove useful in patients with tricuspid regurgitation who are undergoing off-pump coronary artery bypass surgery by allowing off-pump tricuspid valve surgery to be performed during the same operation.

We chose to perform cardioscopy on the right heart because the anatomy involved is relatively simple compared with the left heart. Cardioscopy of the left heart is technically more challenging and may require a different approach altogether because of the concern of maintaining perfusion to the heart and the rest of the body.

Our technique of eliminating blood from the right heart was via a right heart shunt. Although a roller-pump circuit was used in this technique, it is important to note that the sole purpose of the pump circuit was to help shunt blood against the effect of gravity. An oxygenator system, which is part of a standard cardiopulmonary bypass circuit, was not used.

A limitation to the technique we have described is the presence of moderate to severe pulmonic insufficiency. Such insufficiency could produce residual backflow of blood into the right heart and make it difficult for the right heart shunt to generate a bloodless field.

Ultimately, the ideal cardioscopic procedure would be one that required no shunting to eliminate blood from the surgical field. In fact, a bloodless field may not be a requirement if cardioscopy permitted visualization through blood. This possibility is an area of active research, and current attempts involve experimenting with different wavelengths of light (ie, infrared) to "see" through blood by transmitting images in real time. Even though this approach has yet to be realized, if successful it would lead to an enormous advance in cardiovascular surgery.

Although this study represents a practical beginning, future technical advances with cardioscopy may allow beating heart surgery on both the right and left heart. This would then pave the path for minimally invasive cardiac surgery in the true sense of the term.

ACKNOWLEDGMENTS

This work was supported Brigham and Women's Hospital, Department of Surgery (F.Y. Chen); Brigham and Women's Cardiac Surgery Research Fund (L.H. Cohn); American Association for Thoracic Surgery, Andrew G. Morrow Scholarship (F.Y. Chen); and National Institutes of Health grants (F32HL080904 to R.K. Ghanta and RO1HL090862 to F.Y. Chen). F.Y. Chen is a consultant for St. Jude Medical. The authors also disclose that there are no potential conflicts of interest in connection with this research.

REFERENCES

Allen DS, Graham EA. 1922. Intracardiac surgery—a new method: preliminary report. JAMA 79:1028-30.

Bolton HE, Bailey CP, Costas-Durieux J, Gemeinhardt W. 1954. Cardioscopy: simple and practical. J Thorac Surg 27:323-9.

Burke RP, Michielon G, Wernovsky G. 1994. Video-assisted cardioscopy in congenital heart operations. Ann Thorac Surg 58:864-8.

Burke RP, Rosenfeld HM, Wernovsky G, Jonas RA. 1995. Video-assisted thoracoscopic vascular ring devision in infants and children. J Am Coll Cardiol 25:943-7.

Butterworth RF. 1951. A new operating cardioscope. J Thorac Surg 22:319-22.

Cohen ST, Sell JE, McIntosh CL, Clark RE. 1987. Tricuspid regurgitation in patients with acquired, chronic, pure mitral regurgitation. II. Nonoperative management, tricuspid valve annuloplasty, and tricuspid valve replacement. J Thorac Cardiovasc Surg 94:488-97.

Ghanta RK, Chen R, Narayanasamy N, et al. 2007. Suture bicuspidization of the tricuspid valve versus ring annuloplasty for repair of functional tricuspid regurgitation: midterm results of 237 consecutive patients. J Thorac Cardiovasc Surg 133:117-26.

Hammon JW. 2008. Extracorporeal circulation. In: Cohn L, ed. Cardiac surgery in the adult. 3rd ed. New York, NY: McGraw-Hill. p 349-414.

Inoue Y, Yozu R, Onoguchi K, Kabei N, Takeuchi S, Kawada S. 2003. Cardioscopic guidance of linear lesion creation for radiofrequency ablation. Ann Thorac Surg 75:1189-93.

Institute of Laboratory Animal Research. 1996. Guide for the care and use of laboratory animals. Commission on Life Sciences, National Research Council. Washington, DC: National Academies Press. NIH publication 86-23.

Kawai S, Okada R. 1987. A histopathological study of dilated cardiomyopathy—with special reference to clinical and pathological comparisons of the degeneration-predominant type and fibrosis-predominant type. Jpn Circ J 51:654-60.

Laborde F, Noirhomme P, Karam J, Batisse A, Bourel P, Saint Maurice O. 1993. A new video assisted thoracoscopic surgical technique for interruption of patent ductus arteriosus in infants and children. J Thorac Cardiovasc Surg 105:278-80.

Lee KK, Yu HY, Chen YS, Chi NH, Chang CI, Wang SS. 2007. Off-pump tricuspid valve replacement for severe infective endocarditis. Ann Thorac Surg 84:309-11.

Mazza IL, Jacobs JP, Aldousany A, Chang AC, Burke RP. 1998. Video-assisted cardioscopy for left ventricular thrombectomy in a child. Ann Thorac Surg 66:248-50.

McGrath LB, Gonzalez-Lavin L, Bailey BM, Grunkemeier GL, Fernandez J, Laub GW. 1990. Tricuspid valve operations in 530 patients. Twenty-five-year assessment of early and late phase events. J Thorac Cardiovasc Surg 99:124-33.

Murray G. 1950. A cardioscope. Angiology 1:334-6.

Okada R, Kawai S. 1989. Classification of viral or idiopathic myocarditis by endomyocardial biopsy. Annual report of the Japanese Committee for Idiopathic Cardiomyopathy. p 18.

Oshima T, Hirose J, Saski M, Morizuki O, Takahashi U. 1994. Detection of mural thrombus of the left ventricle by percutaneous cardioscopy. Presented at the Annual Meeting of the American Heart Association, 1994.

Reuthebuch O, Roth M, Skwara W, Klovekorn W, Bauer EP. 1999. Cardioscopy: potential applications and benefit in cardiac surgery. Eur J Cardiothorac Surg 15:824-9.

Rhea L, Walker IC, Cutler EC. 1924. The surgical treatment of mitral stenosis: experimental and clinical studies. Arch Surg 9:689-90.

Robin J, Tronc F, Vedrinne C, Champsaur G. 1999. Video-assisted tricuspid valve surgery: a new surgical option in endocarditis on pacemaker. Eur J Cardiothorac Surg 16:243-5.

Uchida Y, Fujimori Y, Hirose J. 1990. Percutaneous left ventricular endomyocardial biopsy with angioscopic guidance. Am Heart J 119:949-52.

Wirtz SP, Schmidt C, Van Aken H, Brodner G, Hammel D, Scheld HH, Berendes E. 2006. Temporary right heart support with percutaneous jugular access. Ann Thorac Surg 81:701-5.