The Direct Vision Correction of Calcific Aortic Stenosis by Means of a Pump-Oxygenator and Retrograde Coronary Sinus Perfusion

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Direct vision for intracardiac surgical procedures improves the quality of surgery performed, and for this reason it is likely that the blind or closed techniques will gradually be abandoned for all intracardiac lesions.

This transition has been accelerated by the development of an expendable and efficient oxygenator1, 2, 3 which is used in conjunction with an equally simple pump4, 5 to permit total cardiopulmonary by-pass in patients of any size (Figure 1). The reader is referred to these publications for details concerning the pump-oxygenator.

The remaining twin obstacles to a feasible method for open surgery upon the aortic valve in an unhurried manner have been the necessity of maintaining some coronary blood flow to the myocardium and the prevention of coronary air embolism.

Two possible solutions to these problems have been investigated in our experimental laboratories. For one approach we have perfused the coronary arteries via the direct cannulation of their aortic orifices with appropriately sized polyethylene tubes during the interval that the aortic valve was exposed. This method, although feasible, was found to have several undesirable features: It was technically somewhat difficult, the intima of the coronary arteries could be damaged by the cannulations, the presence of the polyethylene tubes interfered with widest exposure to the aortic valve, and finally there was an interval after opening the root of the aorta and before insertion of the cannulae during which the myocardium was without blood flow and when coronary artery air embolism could occur.

It may be suggested that direct vision reparative procedures be carried out upon the aortic valve rapidly enough to allow completion of the operation during a brief interval without coronary blood flow. While this is certainly possible, we have rejected this approach a priori for two physio-

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Supported by Research Grants from: (1) Graduate School, University of Minnesota, (2) Life Insurance Medical Research Foundation, (3) American Heart Association, (4) Minnesota Heart Association and (5) National Heart Institute (H-830), USPHS.

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logic reasons. First, a time limitation is imposed which is undesirable for the patient. Secondly, however short the procedure can be made, the myocardium at the end of such an interval is left in an anoxic state. This is also true when selective cardiac arrest is induced without coronary circu-

![Figure 1: The Pump-Oxygenator Utilized for this Direct Vision Aortic Valvotomy.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21281/)

The pump consists of a single explosion-proof electric motor which activates two pump-heads (arterial, venous) each equipped with an individual speed changer all mounted on a single base. The artificial (large bubble) oxygenator has no moving parts, is sterilized by autoclaving, and is constructed entirely of polyvinyl plastic tubing which is discarded after each perfusion. From right to left may be noted: the vertical mixing tube, the transverse debubbling chamber, and the helix reservoir immersed in a constant temperature water bath. From the lower end of the helix the oxygenated blood is returned through disposable filters to the patient's arterial system. The oxygen gas enters the venous blood directly through a nylon diffusion plate at the base of the mixing tube. The venous blood carbon dioxide escapes with the excess oxygen during oxygenation.
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lated. In critically ill patients this metabolic debt in the myocardium could be intolerable and vitiate an otherwise successful surgical procedure. The same considerations in a large measure pertain to the use of hypothermia and temporary arrest of the circulation for exposure of the aortic valve.

Pratt in 1898 discovered that the excised cat heart could be temporarily nourished by way of its coronary venous system.

Roberts et al suggested that this method might be of value in revascularizing the ischemic myocardium. Blanco, Adam, Fernandez, and Raffucci have reported on experiments applying these observations to direct aortic valve surgery.

We have applied this principle to overcome the above mentioned obstacles to direct vision work on the exposed aortic valve.

The patient herein reported, the 116th to undergo total cardiopulmonary by-pass at the University Hospitals with maintenance of the circulation by an extracorporeal perfusion system, was the first individual we have operated upon with aortic stenosis. The pump utilized to replace temporarily the heart in this instance is depicted in Figure 1 and is the same instrument as previously described. Oxygenation was by the simple disposable oxygenator (Figure 1). The patient's body temperature was maintained at a normal level throughout the operative procedure.

Report of Case

Case Report: M. J., the mother of two children, was 37 years of age at the time of her admission to the University Heart Hospital on January 9, 1956. She was diagnosed as having calcific aortic stenosis, functional Class IV (New York Heart Classification). There had been no definite history of rheumatic fever in the past, but she had had frequent episodes of pharyngitis and tonsillitis requiring hospitalization as a child. A heart murmur had been noted for the first time at the age of 24 years during her first pregnancy which otherwise was uneventful. At the age of 26 years with a second pregnancy and during delivery she experienced an acute episode of pulmonary edema, and was advised to avoid further pregnancies.

By age 28 dyspnea and easy fatigability had become prominent and she was considered a functional Class II cardiac.

When 31 years old she experienced episodes of paroxysmal tachycardia lasting up to 30 minutes. She received quinidine therapy at that time. Two years later she began to have episodes of vertigo, syncope, and paroxysmal nocturnal dyspnea. Frank congestive failure likewise appeared and she was digitalized. In the months immediately prior to admission she underwent rapid progressive deterioration. Despite digitalization, low sodium diet, and weekly injections of mercurial diuretics peripheral edema and orthopnea persisted. Severe dyspnea and angina upon even very slight exertion now resulted in her complete incapacitation.

Physical examination upon admission disclosed a chronically ill appearing woman who was dyspneic and orthopneic at rest. There was a harsh grade IV systolic murmur and thrill maximal over the midsternum at the level of the second interspace with transmission upward into the neck vessels. Also, there was a grade II-III diastolic murmur along the left sternal border. The blood pressure was 90/70 mm. of mercury, the pulse rate was 100. Crepitant rales were present in the lungs and some peripheral edema was present.

Fluoroscopy disclosed cardiomegaly involving predominantly the left ventricle. Marked calcification was present in the aortic valve area. The electrocardiogram revealed left axis deviation, left ventricular hypertrophy and first degree heart block.

Operative Procedure

On January 31, 1956, the patient's chest was entered through an anterior bilateral thoracotomy in the third interspace with a transverse sternotomy. There were numerous adhesions to the lungs bilaterally. When the peri-
cardium was opened the heart appeared enlarged and there was an easily palpable thrill in the ascending aorta in association with a well defined poststenotic dilatation of the ascending aorta. Heavy deposits of calcium were palpable at the origin of the aorta.

The aortic valvotomy was done under direct vision utilizing total cardio-pulmonary by-pass with maintenance of the systemic circulation by the pump oxygenator. This technique was combined with the use of a retrograde perfusion of oxygenated blood through the coronary venous system to maintain the myocardial circulation and to prevent air embolism during the interval that the ascending aorta was open.

After heparinization of the patient, plastic catheters were inserted transauricularly into the superior and inferior cavae. Another plastic catheter was inserted into the aortic arch via the left subclavian artery for the return of arterialized blood. The pump-oxygenator was then calibrated to deliver 1800 cc. of oxygenated blood per minute to the patient via

FIGURE 2: Some Causes of Failure with Aortic Valvotomy Performed Blindly. Congenital aortic stenosis in a girl aged 6 years dying of aortic insufficiency 9 days after transventricular aortic commissurotomy. The arrow points to the false passage made by the dilator through a sinus of valsalva. A probe tip defines the true aortic valve orifice.
this subclavian artery catheter and to remove an equal quantity from the caval conduits. With the patient’s catheters linked to the pump oxygenator and the caval inflow occluded by pulling up upon the previously placed encircling tapes, a short right atriotomy incision was made to expose the orifice of the coronary sinus. This sinus was cannulated with a No. 14-F plastic catheter which was anchored in place in the sinus with a silk stitch. This coronary sinus catheter was then connected to the efferent limb of the oxygenator through a separate small pump set to deliver 125 cc. of oxygenated blood per minute. Following this the aorta was cross clamped just below the origin of the innominate artery. The arch of the aorta proximal to the clamp was now rendered bloodless. After incising this segment of the aorta down to the valve ring, an excellent exposure of the aortic valve resulted. The latter was severely stenotic and had a fishmouth orifice of no more than 4 mm. Verrucous deposits of calcium surrounded this dome-shaped stenotic area. The commissures were handily opened in a tricuspid manner out to the annulus with dissecting scissors. Some of the verrucous calcium was also trimmed off and the synchia binding the cusps against the inner aortic wall were cut with the scissors tip. These procedures resulted in a valve appearing to function very satisfactorily despite its diseased state. After closure of the aortotomhy the aortic cross clamp was removed. The myocardium had been nourished for 11 minutes by retrograde coronary perfusion and during this interval the heart color remained pink and had continued to beat at a slow, regular rate. The total duration of the cardiopulmonary by-pass was 15½ minutes. The patient’s temperature during the by-pass remained at 100° F. (rectally). The heart responded immediately at the conclusion of the by-pass and the blood pressure (measured by a catheter in radial artery) was 100/60 mm. of mercury within one minute after release of the cavae. The jet-like thrill palpable in the aorta before the by-pass had disappeared.

The patient’s convalescence was uneventful and she was discharged after three weeks. Follow-up examination four months postoperatively revealed a sustained and effective improvement in her exercise tolerance. She was not actively performing the duties of a housewife. To date she required no diuretics and as well has been relieved completely from her angina, vertigo, and dyspnea. She could now climb stairs without difficulty whereas preoperatively this was impossible. Her blood pressure is 110/74. A grade II systolic murmur without thrill remains over the aortic area. The diastolic murmur of aortic insufficiency present preoperatively has disappeared.

Comment

Blind techniques for the relief of aortic stenosis have demonstrated that the pathologic and physiologic abnormalities associated with this lesion may at times be improved. However, the results especially in the more seriously ill patients with calcified valves and in children with congenital stenosis have shown the pressing need for superior methods. An analysis of the partial successes as well as our failures (Figures 2 and 3) has suggested that many of the problems could be obviated by a direct vision
FIGURE 3B
Failure to Open More Than One Commissure in a Severely Calcified Aortic Stenosis. This 55 year old man died 6 weeks after closed transventricular aortic commissurotomy due to aortic insufficiency. A. Shows valve at autopsy, only one commissure had been opened adequately by the dilator. The other two commissures although clearly definable remained sealed. B. Same valve, at autopsy, with cusps pulled apart to show right and left cusps, the calcified cusps resulted as soon as the other two commissures were opened out to their annulus and the synechiae binding the cusps against the aortic wall were cut under direct vision.

FIGURE 3A
Failure to Open More Than One Commissure in a Severely Calcified Aortic Stenosis.
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approach which would allow the fused commissures to be opened precisely out to the annulus but without tearing the cusps, rupturing a sinus of valsalva, or permitting free calcific emboli to enter the systemic circulation.

Admittedly those markedly diseased valves cannot be restored to normal; however our study of fresh autopsy material suggests that it is possible despite the existence of calcific aortic stenosis to effect a gratifying improvement in mobility available to the aortic cusps if all three commissures are accurately opened and some of the verrucous calcific vegetations are trimmed from these diseased structures. Moreover, an important adjuvant to the success of this direct vision reparative procedure has been the recognition of the value of cutting of the old inflammatory synechia which bind the valve cusps back against the aortic wall thus restricting their function.

Another advantage inherent in the by-pass approach to the aortic valve lies in the fact that with the myocardium totally by-passed, its workload is sharply reduced so that nourishment derived from the retrograde perfusion of only a very small quantity of oxygenated blood via the coronary sinus is adequate at normal body temperature to avoid the risks of hypoxia or arrhythmias. It appears that the best direct vision approach to the aortic valve is through the ascending aorta and this avenue fortunately further spares the myocardium the trauma of a cardiotomy. Too, it eliminates the difficulty of severe hemorrhage from a ventriculotomy provoked in some patients by their very high pressure and friable heart muscle.

Clowes⁹ has reported the only previous attempt to perform aortic valvotomy under direct vision with support by a pump-oxygenator system. It is perhaps significant that he records no attempt to support the myocardium by maintenance of coronary flow. During the six-minute interval that the aortic valve was exposed, the coronary circulation was completely interrupted. This patient expired and there was a failure of the heart in this case to take over adequately following the valvotomy.

In the experimental laboratory we have found that the non-working (by-passed) normal canine heart invariably goes into arrest or ventricular fibrillation upon release of the inflow after only 6 to 8 minutes of total interruption of coronary circulation at normal body temperature. The use of hypothermia will lower this threshold further. Retrograde perfusion of the coronary sinus with but a trickle of oxygenated blood we have shown will consistently protect the unloaded myocardium against this complication. Moreover, the back perfusion techniques prevent the entrance of air into the coronary arteries for the duration of the opened aorta. Measurements upon the oxygen content of the blood trickling out of the coronary artery orifices during this procedure indicate that the myocardium is taking up available oxygen. This fact is further substantiated by the healthy pink color of the heart during the test period.

SUMMARY

Blind or closed techniques for the correction of calcific aorta stenosis either through the left ventricle or the aorta have been encouraging but
not all together satisfactory. The failures or deaths have been from uncontrollable hemorrhage, ventricular fibrillation, or the creation of aortic insufficiency. The successes have all too frequently been partial and incomplete.

It is predictable that a direct vision approach to the aortic valve utilizing the pump-oxygenator would lessen or obviate many of these complications. The twin obstacles to the direct vision approach to the aortic valve (interruption of the coronary artery circulation, coronary air embolism) can be prevented by a retrograde perfusion of oxygenated blood into the coronary sinus.

In a critically incapacitated 37-year-old woman this technique was applied to the correction, under direct vision, of her calcific aortic stenosis. Total cardiopulmonary by-pass was instituted utilizing a pump and a simple disposable oxygenator. The aortic valve was exposed for 14 minutes through the opened aorta. During this interval the myocardium was maintained by the retrograde coronary sinus perfusion of a small quantity of oxygenated blood from the oxygenator. The heart remained a healthy pink color and continued to beat at a slow regular rhythm throughout this interval. Recovery was uncomplicated and the patient's status post-operatively has improved dramatically.

**RESUMEN**

Las técnicas ciegas o cerradas empleadas para la corrección de la estenosis aórtica calcificada a través del ventrículo izquierdo o de la aorta han sido alentadoras pero no del todo satisfactorias. Las muertes o los fracasos han debido a hemorragia incontrolable, fibrilación ventricular, o a la producción de insuficiencia aórtica. Frecuentemente los éxitos han sido incompletos.

Es posible predecir que una vía de acceso que permita controlar directamente bajo la vista a la válvula aórtica, utilizando la bomba oxigenadora, disminuirá o evitará de estas complicaciones. El doble obstáculo para el acceso directo de dicha válvula (interrupción de la circulación arterial coronaria, embolia aérea coronaria) puede obviarse mediante perfusión retrógrada del seno coronario con sangre oxigenada.

Esta técnica fue utilizada en una enferma de 37 años de edad seriamente incapacitada, para corregirle, bajo visión directa, una estenosis aórtica calcificada. El corazón y los pulmones fueron excluidos totalmente de la circulación, empleando una bomba y un oxigenador sencillo y desechable. La válvula aórtica fue expuesta durante 14 minutos mediante aortotomía. Durante ese lapso el miocardio se mantuvo irrigado por la perfusión retrógrada del seno coronario con una pequeña cantidad de sangre oxigenada procedente del oxigenador. El corazón conservó su color rosado normal, siendo sus contracciones lentas y ritmicas durante dicho intervalo. La recuperación se llevó a cabo sin complicaciones, y el estado postoperatorio de la paciente ha mejorado dramaticamente.
RESUME

Les techniques aveugles fermées pour le traitement correctif des sténoses aortiques calcifiées, utilisant la voie d'abord par le ventricule gauche ou par l'aorte, ont donné des résultats encourageants mais non entièrement satisfaisants. Les échecs ou les décès résultant de cette technique ont été dus à des hémorragies impossibles à contrôler, à la fibrillation ventriculaire ou à la création d'une insuffisance aortique. Les succès ont été trop souvent partiels et incomplets.

Il est possible de prédire qu'une voie d'abord permettant une vision directe des valves aortiques, et utilisant le système de pompe oxygénateur diminuerait ou même éviterait les complications des méthodes indirectes. Les deux obstacles de la voie d'abord des valves aortiques sous vision directe (interruption de la circulation artérielle coronaire, embolisme gazeux des coronaires) peuvent être évités si l'on procède à une perfusion rétrograde de sang oxygéné par le sinus coronaire.

Une telle technique fut utilisée pour pratiquer une chirurgie correctrice sous vision directe d'une sténose aortique calcifiée chez une femme de 37 ans qui se trouvait dans un état d'invalidité critique. Une exclusion totale du cœur et des poumons de la malade fut obtenue en utilisant une pompe et un oxygenateur simple dont on peut disposer après l'intervention. Les valves aortiques demeurent visibles par une ouverture de l'aorte, pendant 14 minutes. Pendant ce temps, l'oxygénation du myocarde était maintenue grâce à une perfusion rétrograde par le sinus coronaire d'une petite quantité de sang oxygéné provenant de l'oxygenateur. Pendant tout ce temps, le cœur conserva son aspect rosé normal et continua de battre à un rythme lent et régulier. L'évolution vers la guérison se déroula sans complications, et l'état post opératoire de la malade s'est amélioré d'une façon dramatique.

ZUSAMMENFASSUNG

Blinde oder geschlossene Methoden für die chirurgische Beseitigung der verkalkten Aortenstenose durch den linken Ventrikel oder durch die Aorta sind, im ganzen betrachtet, nicht zufriedenstehend. Die Versager oder Todesfälle beruhen auf nicht kontrollierbarer Blutung, Kammerflimmern oder der Schaffung einer Aorteninsuffizienz.

Es lässt sich voraussagen, dass das chirurgische Angehen der Aortenklappe unter Sicht des Auges mit Hilfe der Herz-Lungen machine diese Komplikationen vermindert oder beseitigt. Die beiden Hindernisse, die dem chirurgischen Angehen der Aortenklappe unter Sicht des Auges im Wege stehen, nämlich die Unterbrechung des Koronarkreislaufes und Luftembolie der Koronararterien, können beseitigt werden durch die retrograde Perfusion durch den Koronarsinus mit sauerstoffgesättigtem Blut.

Diese Technik der chirurgischen Behandlung der Aortenstenose unter Sicht des Auges wurde angewandt bei einer 37 jährigen Frau, die infolge ihrer verkalkten Aortenstenose in einem schwerkranken Zustand war. Unter vollständiger Ausschaltung von Herz und Lungen mit Hilfe der Herz-Lungen machine wurde die Aortenklappe durch die eröffnete Aorta für 14 Minuten exponiert. Während dieser Zeit wurde das Herz retrograd

REFERENCES