The Surgical Relief of Aortic Stenosis by Means of Apical–Aortic Valvular Anastomosis

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A means has been devised whereby the aortic valve can be effectively by-passed. Left ventricular blood leaves via the apex through a lucite tube in continuity with a modified Hufnagel valve and then enters the thoracic aorta. In dogs so treated the ascending arch of the aorta may be totally and permanently occluded without apparent impairment of the circulation. Postoperatively these dogs run, jump and swim and are not readily distinguishable from normal dogs. The entire ventricular manipulation is completed in 30 to 60 seconds. The applicability of this procedure to the alleviation of aortic stenosis in man is discussed.

The basic defect in aortic stenosis is a mechanical or hydraulic one involving a small cross-sectional area in the outflow tract of the left ventricle. This results in high intraventricular systolic and low aortic systolic and pulse pressures. The main physiologic derangement, a low and limited cardiac output, is attributable to the high outflow resistance which greatly increases the ventricular work load in the presence of a low coronary perfusion pressure. Coronary vasodilation can compensate for the imbalance between ventricular work and low coronary perfusion pressure up to a point, but when this compensatory mechanism has been fully utilized, circulatory compromise results.1 The reader is referred to the writings of Gorlin and his associates for a detailed analysis of the hydraulic factors in this disease.2

The objective of any procedure aimed at correcting the derangement produced by aortic stenosis should, accordingly, be aimed at decreasing the left ventricular work load, increasing coronary perfusion pressure or, preferably, both. Any measure which substantially decreases the resistance to the outflow of blood from the left ventricle will accomplish this as long as it does not at the same time produce regurgitation or increase that which may already be present.

Unlike the heartening progress made in correcting stenosis of the mitral valve, a direct attack on the stenosed aortic valve has carried with it a high operative mortality and less convincing improvement in those who survive.3, 4, 5

If a direct attack on the aortic valve is to be avoided it is apparent that some other avenue of egress from the ventricle to the aorta must be provided. A connection between the ventricular apex and thoracic aorta appeared to be the method of choice. The apex was chosen as the site for left ventricular intubation for the following reasons. (1) It appears to be the least irritable area. (2) It is the least vascular area, and it does not compromise tissue distal to it if its vessels are cut across. (3) The ventricular wall is thinnest at the apex. (4) A tube placed through the apex lines up neatly with the long axis of the left ventricle and thus provides the most hydraulically desirable outflow tract.6 It also precludes obstruction of the inlet end of the tube by the septum during systole.

The results of earlier acute experiments were described in a brief preliminary note.7 These appeared to justify the more serious attempts of improving the technique and

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initiating survival experiments. Since that
time, effort has been devoted to developing a
prosthesis which makes a comfortable fit be-
tween the ventricular apex and thoracic aorta.
A method has also been developed for intro-
ducing the prosthesis into the ventricle which
(A) involves little or no blood loss, (B) re-
quires only 30 to 60 seconds for its completion,
(C) eliminates the hazard of left ventricular
and coronary artery air embolus, (D) assures
that the insertion is made precisely into the
ventricular apex through the apical dimple,
and (E) may be done, if desirable, without the
use of any myocardial sutures.

PROCEDURE

Instruments. The valve prosthesis used in these
experiments is shown in figure 1.1 The ventricular
end has an inside diameter of 11 mm., (cross-
sectional area 0.95 cm.2) and an outside diameter of
12 mm. The ventricular end of the tube is 16 mm.1
long and it is this segment which extends from the
external surface of the apical myocardium well into
the lumen of the ventricular cavity. Just distal to
this segment there is a small ridge which rests on the
epicardium and there is also a freely rotating spokeed
wheel. The latter is used to affix sutures to the myo-
cardium, the pericardium or both. After the tube
curves and leads the blood through a valve of the
Hufnagel5 type, it leads to the wide-angled, Y-
shaped aortic end. One end of the Y tube conducts
blood cephalad, the other caudad. The internal
diameter of each arm of the Y tube is 10 mm.; the
outside diameter is 12 mm. Two grooves are present
on each arm of the Y tube; a number 2 silk tie fixes
the aorta in the proximal groove and a Hufnagel5
nylon, multiple point suspension ring fixes it in the
distal groove. (See fig. 2.)

The instruments required to perform the apical-
aortic anastomosis (AAA procedure) as outlined
below are shown in figure 2. The introducer (2C) is a
curved stainless steel tube bent to the shape shown
with a handle on it. The apical end of the introducer
has on it a lucite bulb the end of which in turn is
capped with a rubber piece fixed onto it with a silk
ligature. A stylet runs the length of the tube and
terminates in a long, sharp, trocar point which
emerges 35 mm. from the apical end of the introducer
when pressure is made on the stylet button.

The apical retraction ring (2C) is used to retract
the apex of the left ventricle back over the end of the

* The authors are indebted to Mr. Carl Hewson,
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thesis.

† This has been shortened to 13 mm. in a later
series.

introducer as the latter seeks the internal apex. This
simple ring serves three highly important functions.
First, it prevents the dislocation and overstretching
of the heart and ventricle; this abolishes or greatly
diminishes the arrhythmias which are observed if it
is not used. Secondly, it stretches an isolated segment
of the apex over the end of the introducer, steadies
it, and delineates the precise spot (apical dimple)
where the myocardial hole is to be cut. Lastly, it
enables the introducer to be gently and precisely
persuaded through the small hole cut in the apex by
coning the apex down over the tip of the introducer.

The apical circumcision knife is an 8-mm. derma-
tology biopsy punch renamed for this purpose. The
only way in which it has been altered is the provision
of a hole up its middle long enough to accept the full
length of the pointed stylet after the latter has
emerged from the end of the introducer and has
pierced the apex (2C).

The aortic clamp approximator is shown in figure
2B. Its function is simply to draw together and
maintain parallel the two Gross aorta clamps after
the latter have occluded the thoracic aorta, thus
providing a slack rather than a taut aorta during
the intubation of that vessel. In principle it is
similar to the Bradshaw clamp but is simpler, and
in the hands of the authors, appreciably more rapid
and convenient to use.

Steps in the Procedure. (1) Under Nembutal
anesthesia and intermittent positive pressure
breathing, the sixth rib is removed with the dog in
the right lateral position. The artificial respiration
device (Starling pump) is so adjusted by means of a
screw clamp resistance on the expiratory line that
there is an end-expiratory pressure of at least 4 cm.
H2O. Permitting the lungs to collapse further than
this during expiration produces arterial hypoxia.

(2) The right and left intercostal arteries, 1
through 5, are ligated, divided, and the aorta
mobilized.

(3) The nylon clip, shown in figure 2A, is then
put in place across the ascending arch of the aorta
2 to 3 cm. above the aortic valve and proximal to
the brachiocephalic artery. This clip is to be per-
manently closed immediately after the AAA
FIG. 2. (A) Aorta is mobilized, the pericardial aperture is formed, the pericardium is slit over the left atrium and the nylon clip is in place on the ascending aortic arch. Note the apical dimple, a whitish, dimpled spot which is clearly present in about three out of four dogs. When not clearly present visually, its location can be ascertained by exploratory dimpling with the tip of the fifth finger. It signals the precise location of the true left ventricular apex. The phrenic nerve has been omitted. (B) Gross aorta clamps on the thoracic aorta are drawn together with the aortic clamp approximator, producing slack in the segment to be intubated with the Y end of the valve prosthesis. Multiple-point suspension rings and ligatures are in place. (C) Valve prosthesis intubation into aorta has been completed and prosthesis filled with saline and stoppered. Introducer has been placed into left ventricle via the left atrium and the apex is drawn over the end of introducer with the apical retraction ring. The introducer stylet has been made to pierce the apical dimple by pressure on the stylet button. Assistant is preparing to slide the apical circumcision knife over the stylet and cut out plug of myocardium. (D) Myocardial plug has been cut and removed and stylet has been retracted. Stopper has been removed from the prosthesis and the coupling of it to the introducer begun. Not shown is the catheter which plays a stream of saline into the prosthesis as the coupling proceeds. (E) The prosthesis has been coupled onto the introducer and is being drawn into the left ventricle. (F) Ventricular intubation is completed. Myocardial sutures are being affixed to the spoked wheel.
procedure is completed, thus insuring that total cardiac output (minus coronary flow) will leave the ventricle via the apical route.

4 A pericardial aperture is formed by incising the pericardium near the apex and retracting it with sutures tied to the Balfour retractor as shown in figure 2A.

5 A second pericardial incision is made lateral to the left phrenic nerve over the site of the left atrium. The atrial appendage is then picked up, and the nose of a Rumel tourniquet slipped over it and slid well down over the atrium, care being taken not to impinge on the left circumflex coronary artery. The appendage is opened, picked up in four fine hemostats and the trabeculae cleared so as to permit the ready insertion of the introducer.

The foregoing steps are completed in an unhurried fashion. The subsequent sequence, however, should be performed expeditiously so as to, (a) keep the time of total thoracic aortic occlusion under 10 minutes, and (b) limit the time of the ventricular intervention.

6 Two Gross aorta clamps are placed 8 to 10 cm. apart on the thoracic aorta and closed. They are then brought closer together and fastened in place with the aortic clamp approximator so as to give the aorta some slack and thus facilitate the introduction of the Y end of the prosthesis into it. The aorta is then transected between the clamps and with the help of fine hemostats, the aortic intubation is completed. The use of the aortic clamp approximator (fig. 2B) has made this part of the procedure easy instead of troublesome. A number two silk ligature ties the aorta securely in each proximal groove and a multiple point suspension ring fixes the aorta in each distal groove (fig. 2C). The prosthesis is then filled with saline through a catheter inserted in the ventricular end. When the air has been exhausted therefrom, a soft rubber stopper is placed in the ventricular end of the prosthesis and the aortic clamps removed, thus permitting resumption of aortic flow. In the last seven operations performed, the time of thoracic aortic occlusion varied from five and four tenths to eight and four tenths minutes with a mean of six and nine tenths minutes. This is comfortably under the critical limit for avoiding postoperative spinal cord damage.

7 The introducer is then promptly inserted into the left ventricle via the atrium, seeks the apex and has the latter drawn down over it with the apical retraction ring (fig. 2C). Pressure is then made on the stylet button causing the stylet point to pierce the apex. While the apex is thus steadied by the introducer on the inside and the retraction ring on the outside, the apical circumcise knife is slid down onto the protruding stylet (fig. 2C) and cuts out a circular plug of apex. The plug thus cut out is removed, the stylet is retracted and the introducer eased out through the apical hole with the help of gentle counter-pressure from the apical retraction ring (fig. 2D).

8 The stopper previously placed in the ventricular tube end of the prosthesis is now removed and the tube coupled onto the soft rubber end of the introducer. The function of the soft rubber tip is to preclude the possibility of scratching the internal surface of the prosthesis (fig. 2D and E). Air is exhausted from the tube by a stream of saline from a catheter as the coupling is completed.

9 The tube is then drawn back through the apical hole with the introducer (fig. 2E) and after the tube is well in the ventricle the introducer is disengaged from the prosthesis and gently withdrawn from the ventricle.

In the last seven operations attempted, more confidence and facility with these maneuvers was acquired. In them, without any particular sense of urgency, it was possible to complete steps 7, 8 and 9 (fig. 2C, D and E) in 24 to 65 seconds with a mean time of 46 seconds.

10 The nylon clip previously placed around the ascending arch is tied closed with a number 2 silk ligature.

11 The atrial appendage is doubly ligated.

12 Three to five triple zero cotton sutures are then placed in the myocardium immediately adjacent to the tube and fixed to the spoked wheel (figs. 1 and 2F). The edges of the pericardial aperture are then affixed firmly to the spoked wheel by means of additional cotton sutures. In two of the surviving dogs the myocardial sutures were omitted and the tube held in place solely by pericardial sutures.

The end result of this procedure is a 12-mm. lucite tube in an apical hole produced by an 8 mm. circular knife. The fit is sufficiently snug to prevent leakage around the tube. The removed myocardial plug measured 5 to 6 mm. in diameter and weighed an average of 170 mg. or approximately 0.1 per cent of the estimated total heart weight.

Penicillin and streptomycin were administered for one to two weeks postoperatively. All dogs received distemper vaccine and vaccine.

With the exception of the 51-Kg. Great Dane described below, the dogs weighed from 18.1 to 30.8 Kg. with an average of 21.6 Kg.

**RESULTS**

A total of 17 operations were attempted under aseptic conditions of which 10 were fatalities. These include early attempts which were largely failures associated with now avoidable errors but will be described both in the interests of completeness and also because some of the errors were fruitful.

**Fatalities.** Three dogs died of postoperative hemorrhage resulting from our early attempts
to occlude the ascending aortic arch, a part of the procedure which would, of course, not be included in the therapeutic operation. These fatalities were not helpful except in that the proper use of the nylon clip was eventually found to be a successful means of totally and permanently occluding the ascending aortic arch. The use of such a device was suggested by Hufnagel in connection with other studies.\footnote{One dog died of postoperative hemorrhage from an unsecured intercostal vessel in the spinal angle where the sixth rib had been removed. This was demonstrated by careful postmortem perfusion of the aorta via the left subclavian artery. One dog died of massive empyema following an obvious break in asepsis during the procedure.}

The other five fatalities were more informative about the procedure itself. One occurred consequent to tearing the aorta while attempting the Y-end intubation and the subsequent hurried and poor ventricular intubation. This failure prompted the design and use of the aortic clamp approximator shown in figure 2B. After this no further difficulty was encountered on that score. One ambitious attempt was made to insert the same prosthesis used in 20-Kg. dogs into a 51-Kg. Great Dane. From this experience it became clear that it would be desirable to be provided with prostheses of different lengths if the method were to be applied clinically. One fatality occurred 25 days postoperatively. At postmortem examination it was found that hemorrhage had occurred from the cephalad aortic tube-vessel junction where one of the teeth of the multiple point suspension ring had been placed directly on and had eroded through the aortic ostium of one of the ligated intercostal arteries. Previously no particular effort had been made to avoid this. Another dog died with much the same picture at postmortem examination on the fifth postoperative day; in this dog, however, damage at the tube-vessel junction was severe enough so that it was difficult to be sure that placement of the nylon ring through an intercostal ostium was the only cause. The last fatality occurred in one of the three dogs in which no myocardial sutures were placed. The ventricular tube was held in place solely by four triple zero cotton sutures affixing the pericardium to the spoked wheel. The tube pulled out on the fifth postoperative day and it was seen that the pericardial stay sutures had been cut through by the sharp edges of the spoked wheel. The spoked wheel has since been made thicker and with smooth edges. The other two dogs with no myocardial sutures have survived.

Two of the 10 fatalities died at operation, namely, the 51-Kg. Great Dane and the dog in which the aorta was torn prior to the use of the aortic clamp approximator. The other eight died on the first, first, second, fifth, fifth, seventh, ninth and twenty-fifth postoperative days.

Survivals. Seven dogs have survived from two to four months after the operation and are in robust health at the present time. The longest survivor, Clicks, has become a household pet. During a three-month stay in Vermont he frequently swam across a one-mile lake and back. He has acquitted himself creditably in several vigorous dog fights. Having been a stray and apparently not well fed, he was anemic and undernourished preoperatively, weighing 29 Kg. On a proper diet and with worming postoperatively he has gained 6 Kg. He runs rapidly, jumps 3½ foot hurdles, is playful and is, in fact, indistinguishable from a normal dog except for the clicking sound. It is clear therefore that an apical ventricular tube with a cross-sectional area of 0.95 cm.\sup{2} can transport sufficient flow to support vigorous activity in a 35-Kg. dog without producing overt evidence of an excessive imposition on the myocardium. It should be noted that, whereas in man resting cardiac output is approximately 75 cc. per kilogram per minute, it is approximately 125 cc. per kilogram per minute in the dog.\footnote{Seven dogs survived from two to four months after operation and are in robust health at the present time.}

The other six dogs are in the same good health and exhibit their normal tendency to run, play and fight. It has been planned to mate the two females with two of the males to ascertain if they will be unduly handicapped by gestation.
Of the last seven operations attempted, five dogs survived, one of the failures being the dog described above in which no myocardial sutures were placed.

Complications. Cardiac arrhythmias, chiefly ventricular ectopic beats, of occasional to moderate frequency, occurred in all dogs in the immediate postoperative period and lasted from one-half to approximately four days although precise observations were not made in this regard. No dog died of cardiac arrhythmias postoperatively. Ventricular fibrillation occurred during the operation in 2 of the 17 dogs. One of these was an early attempt described above, in which the aorta tore and the ventricular intubation was hurried and poorly placed. The other instance of fibrillation occurred about five minutes after the ventricular intubation while the nylon clip was being closed on the ascending aortic arch. It was noted that the myocardium was cyanotic and that the blood traversing the prosthesis was dark. The expiratory resistance and tidal volume of the respiratory pump were found to be low; these were increased and vigorous manual massage was carried out. Defibrillation was successfully accomplished on the second shock. It was of interest that the prosthesis remained securely in place during this sequence. The dog survived until the twenty-fifth postoperative day, as described above. Thus, in the group of 17 dogs, only 1 succumbed to

Fig. 3. Angiocardiograms taken in one of the early acute experiments in which the ascending aortic arch was stenosed with umbilical tape. Sequence progresses from top left to bottom right and is completed in two and four tenths seconds. The prosthesis used was long, with the result that the ventricular end of the tube did not coincide perfectly with the long axis of the left ventricle. It nevertheless functioned well. The catheter through which contrast medium was injected was in the left atrium or orifice of pulmonary vein. Note position of valve ball in systole in the lower right figure.
ventricular fibrillation; and the cause for this was clear and avoidable.

No dog succumbed from the consequences of embolization. In one of the seven surviving dogs, however, a transient period of right hind-leg coldness, lameness and absence of femoral arterial pulsation was noted on the twenty-eighth postoperative day. This episode lasted 24 hours after which the femoral pulse reappeared and no further difficulty was noted. The only other clinical evidence suggestive of embolization has been hemoglobinuria in the postoperative period. Circumscribed renal infarcts were observed at postmortem examination in some of the dogs that succumbed from thoracic hemorrhage or empyema; on the other hand hemoglobinuria was observed when subsequent postmortem observation revealed the absence of obvious infarcts. The observed discoloration of the urine was accompanied by an obvious hemoglobinemia. The nature of this observed hemolysis is being investigated by Stohlman and coworkers; the results will be published in detail. These findings suggest that the red cell destruction in the dog is a result of the action of the ball valve and introduces the possibility that this action may also account for the postoperative anemias seen after the Hufnagel operation.21

Other Studies. Angiocardiograms were obtained in one early acute preparation in which the ascending aortic arch was tightly stenosed by umbilical tape instead of the subsequently used nylon clip. The results are shown in figure 3.

Right atrial, pulmonary artery, left atrial and femoral arterial pressures were recorded in an acute, open-chest preparation in which a segment of donor aorta was used to connect the ventricular tube-valve segment with the Y tube in the aorta. This was done so that the apical-aortic anastomotic by-pass could be closed and opened at will. Before the beginning of left hand tracing in figure 4 a severe constriction of the ascending aorta had been produced. When the apical-aortic anastomosis was closed (signal at bottom) the severity of the stenosis can be seen from the markedly lowered systolic, diastolic and pulse pressures

**Fig. 4.** Dog in which apical-aortic anastomosis had been performed and severe stenosis of ascending aorta produced. At the beginning of the left-hand tracing, the anastomosis was open. During the middle of this tracing, the anastomosis was closed (signal at bottom). Note severity of the induced "aortic stenosis." Anastomosis reopened again at end of signal. In the right-hand tracing, the anastomosis was closed, and the normal outflow tract unconstricted. Note similarity of values. R. A. = right atrium. P. A. = pulmonary artery. F. A. = femoral artery. L. A. = left atrium. R. A., P. A. and L. A. are mean pressures. F. A. shows full pulse and mean pressures at regular intervals. Time at bottom in seconds. The right hand tracing starts 20 seconds after the end of the left hand tracing. See text.

**Fig. 5.** Postoperative femoral arterial pressures in four dogs after apical-aortic anastomosis procedure and total occlusion of ascending aorta. Indicated time interval = 1 second on each tracing. A. Blackie, 21.4 Kg. Tracing taken immediately after operation. Survival. B. Pepper, 30.8 Kg. Tracing taken immediately after operation. Died of empyema on ninth postoperative day. C. Sybil, 21.1 Kg. Tracing taken one month postoperatively. Survival. D. Angie, 22.0 Kg. Acute preparation. Tracing taken immediately after operation.
in the femoral artery and the marked elevation of left atrial pressure. The subsequent opening of the apical-aortic anastomotic by-pass, a crude simulation of a therapeutic intervention, resulted in the re-establishment of satisfactory levels. Perhaps of more import is a comparison of the values in the latter part of the left hand tracing with those in the right hand tracing taken 20 seconds later. In the former there was almost complete stenosis of the ascending aorta and the apical-aortic anastomotic by-pass was open. In the latter the by-pass was closed and the normal aortic outflow path re-established. The difference does not appear to be great. Of particular significance is the fact that the mean left atrial pressure was less than 1 cm. H_{2}O higher when the cardiac output traversed the apical-aortic anastomosis as compared with the normal route.

Femoral artery pressure tracings were taken in four dogs after complete occlusion of the ascending aortic arch and the by-pass procedure was performed. These are shown in figure 5.

In addition to the above series, two dogs were studied in which another type of prosthesis was used. This was similar to the one shown in figure 1 except that, instead of having a Y tube at the aortic end, the prosthesis was connected to the thoracic aorta with a donor aortic graft by means of an end-to-side anastomosis. Just at the free end of the aortic graft, where the graft was attached to the distal end of the prosthesis, the graft perforated on the fourteenth and twenty ninth days post-operatively in the two dogs so studied.

Figure 6A shows the weight supported by the apical-tube junction 14 days postoperatively. Figure 6B shows the appearance of the apical hole in the same heart after the tube had been removed. The ventricular end of the prosthesis extends through this hole well up into the ventricle. In the dog described above which died on the twenty-fifth postoperative day, the apical-tube junction was extremely difficult to disjoin by manual traction. This was due to a firm fibrotic overgrowth of tissue which made the spoke densely adherent to the apex.

**DISCUSSION**

Biologically it is more attractive to alleviate a disease without the use of prosthetic devices if this can be achieved, that is, by direct attack upon and correction of the stenosed valve. There is no assurance, however, that even if the stenosed valve itself were amenable to repair, the deformity would not recur. In the relatively brief history of mitral-valve surgery, recurrence of mitral stenosis has
already been reported and it was held unlikely that the initial operation was inadequate.\textsuperscript{12}

With the exception of a spring loaded valve or similar device, no man-made valve is known to the authors which is as free of slip or regurgitation in normal use as the aortic or pulmonic valves. The backward flow of blood required to seat the ball when the direction of the pressure gradient is reversed is undoubtedly larger than that which occurs when the normal aortic valve closes. That this amount of regurgitation is of little practical significance, however, is indicated by the above data showing the small elevations of left atrial pressure when blood leaves via the apical-aortic anastomosis instead of the normal aortic outflow tract. The marked lowering of left atrial pressure if the anastomosis is opened when "aortic stenosis" is present, is a highly significant measure of the reduced work load of the ventricle.\textsuperscript{13}

Postmortem inspection and palpation of a severely stenotic aortic valve gives the impression that valve fracture, commissurotomy and removal of portions of the valve are a good deal more difficult to accomplish precisely and uniformly in this area than in the mitral area.\textsuperscript{14} Further, an alteration may be made which is so extensive as to produce or significantly increase regurgitation. With the apical-aortic anastomosis procedure as outlined above, little significant regurgitation is added to what is already present, and the resistance of the new outflow tract is precisely known.

Bailey, Glover, O'Neill and Redondo-Ramirez\textsuperscript{15} were also apparently influenced in their thinking by such considerations since, in their earlier efforts to alleviate aortic stenosis, they similarly attempted to by-pass the aortic valve. Only when "discouraged by these attempts at by-passing or replacing the aortic valve" did they redirect their effort to the direct operation. Hufnagel also reported that his attempts "have had little success."\textsuperscript{12}

In regard to the stability of the ventricular end of the prosthesis, the authors have recently examined the hearts of four dogs three to three and one half years after operation in which a lucite tube had been placed in the anterior wall of the right ventricle.\textsuperscript{16} This tube conducted right ventricular output to the bifurcation of the pulmonary artery via a vena-caval graft. The main pulmonary artery was tied off. The appearance of the tube and myocardium were such as to suggest that both would have continued to function well indefinitely had the dogs not been sacrificed.

In regard to the aortic end of the prosthesis, the experiences of Hufnagel\textsuperscript{3} have demonstrated that a double-ended lucite-tube valve can be placed in the thoracic aorta in man with relative safety if the multiple point suspension ring principle is used.

The main residual hazard is that of embolization. It is Hufnagel's opinion,\textsuperscript{17} as well as ours, that the greatest hazard is the fibrin ring that forms around the tube distal to the nylon multiple-point suspension ring at the tube-vessel junction where blood stagnates. This fibrin ring was present at the aortic tube-vessel junction in each of the nonsurviving dogs examined postmortem. Attempts are being made to devise a means of obliterating this dead space in the hope of eliminating the fibrin ring and embolic sequelae. These attempts, if successful, will be reported at a later date. In any case, even though the hazard of embolization is not large enough to contraindicate the use of the apical-aortic anastomosis procedure, the risk must be counted as a real one at the present time.

It was previously thought that the restriction of cardiac mobility by the insertion of a rigid prosthesis between apex and aorta might significantly hamper the mechanical activity of the ventricle. There are now reasons to believe that this is not a significant limitation. First, the heart affixed to the apical end of the prosthesis can easily rotate in a circle described by the rotation of the prosthesis around the long axis of the aorta. This has been demonstrated by rolling the open-chested dog with the prosthesis in place from the right lateral to the left lateral position. Second, the descent of the diaphragm and pericardium which lowers the heart in the chest is readily accomplished with only a slight change in the angle which the prosthesis makes with the thoracic aorta. Third, the apex of the heart can move to right or left somewhat since the aorta probably
yields a little under these circumstances. The experiments of Ferguson, Shadle and Gregg suggest that this facet of the problem is not one of great importance. These investigators, seeking a chronic preparation in which they could conveniently make dye injections and measure the pressures in the left ventricle, prepared their dogs by preliminary thoracotomy during which the apex of the left ventricle was firmly sutured to the anterior chest wall. Circulatory compromise was not noted as a result thereof. Finally, and most convincingly, the chronic dogs carry the apical-aortic anastomotic prosthesis without overt evidence of limitation of cardiac performance.

The myocardium which carries an excessively high work load in the presence of a low coronary perfusion pressure may be presumed to have little or no compensatory reserve. In such an individual, even the brief introduction of a valvulotome into the stenosed aortic valve must be looked upon as hazardous. For, however momentarily, it intensifies the hydraulic and physiological derangements the procedure is aimed at alleviating. The apical-aortic anastomosis procedure outlined above does not either obstruct ventricular outflow or lower coronary perfusion pressure in the course of achieving the result. The intracardiac intervention is as brief as any currently-practiced cardiac surgical maneuver (30 to 60 seconds). While this is probably not of great importance while operating on the normal dog’s heart, it is anticipated that this factor may be of importance in the more irritable, marginal, hypoxic myocardium of the patient with severe aortic stenosis. It is also an advantage not to have to subject the patient to the complicated and incompletely understood techniques of hypothermia.

It is to be emphasized that in the above procedure, the ascending aorta was occluded simply for the purpose of demonstrating that the cardiac output could be effectively directed through the apex. It would not, of course, be done as part of the therapeutic maneuver. However, occlusion of the outflow tract of the left ventricle proximal to the coronary ostia would, together with the apical-aortic anastomosis procedure, provide relief from aortic insufficiency as well as aortic stenosis. Attempts to accomplish this are under way. It is also within the realm of possibility that the anastomosis procedure may make possible the repair or resection of certain types of aortic aneurysms as well as lengthy aortic coarctations.

Lastly, the timely and detailed studies of Gorlin and his coworkers have provided a sound basis for predicting the lumen size of a prosthesis which would provide a satisfactorily low outflow resistance in man. These workers found that major hydraulic obstruction was encountered when the cross-sectional area of the aortic valve fell to approximately 0.5 cm², or below. The cross-sectional area of the prosthesis used in the above dog experiments was 0.95 cm². Discounting the pressure drop due to the length of the prosthesis, the same sized tube would provide substantial relief in man, and this opinion is confirmed by the observation that it supported vigorous activity in a 35-Kg. dog. If the internal lumen were increased to a diameter of 14 mm., the cross-sectional area would be 1.54 cm² and the outside diameter would be only 15 mm. Its resistance would be physiologically negligible when used for this purpose.

It may be that performance of this procedure in the heart of a patient with severe aortic stenosis will bring with it certain technical and physiological difficulties not readily imitated in the experimental laboratory. Unless these difficulties prove insuperable, the above procedure may prove to be a reasonable means of alleviating aortic stenosis.

**Addendum**

Since submitting this article for publication two of the seven surviving dogs succumbed 66 and 76 days after operation. One death was from a mesenteric embolus and the other from thoracic hemorrhage, apparently from the ascending aorta near the nylon clip. The other five dogs, six to eight months after operation, are vigorous and apparently not limited in their activities.

Doctors Sarnoff and Case, now at the National Heart Institute, Bethesda, Md., are continuing with this procedure and after several modifications of the prosthesis and method,
have done another series. The results indicate that some of the previous difficulties have been eliminated. No tube-vessel junction erosion or embolic phenomena have been encountered in this group although it is too early to be certain that they will not occur.

From the historical point of view it is of interest that Jeger occluded the ascending aorta and established a bypass from left ventricle to thoracic aorta by means of a vein containing a valve and succeeded in keeping one such dog alive for four days. 20

**SUMMARY**

An effective means of by-passing the aortic valve has been described. The applicability of this to the treatment of aortic valvular disease was discussed.

**SOMMARIO IN INTERLINGUA**

Esseva elaborate un efficace metodo pro poner le valvula aortica in derivatio. Le sanguine sinistroventricular exi via le apice per un tubo de lucite connectite con un modificate valvula Hufnagel e alora entra le aorta thoracica. In canes assi tractate le arco ascendent del aorta pote esser occludite complete e permanentemente sin causar ulle disrangiamiento apparente del circulation. Post le operation iste canes currea, saltava, e natava, e non esseva facilemente distinguibile ab canes normal. Le integre manipulation ventricular es completate intra 30 a 60 secundas. Es discutite le applicabilitate de iste procedimento al alleviation de stenosis aortic in humanos.

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The Surgical Relief of Aortic Stenosis by Means of Apical—Aortic Valvular Anastomosis

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