A Prosthesis for the Palliation of Mitral Insufficiency

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Mitral insufficiency results from a failure of the valve leaflets to meet during ventricular systole. During exploratory surgery on patients afflicted with this disease, the observation was made by the authors and others that the regurgitant jet could be effectively controlled by the surgeon's index finger with significant improvement in the action of the heart as long as the finger remained as an obturator in this area of valvular deficiency. This observation suggested a possible therapeutic approach to mitral insufficiency by controlled production of a relative mitral stenosis. Theoretically, this concept would appear feasible as mitral insufficiency is generally less well tolerated than is mitral stenosis in man.

Dexter has calculated that the functioning mitral valve area may be reduced to two square centimeters without significant elevation of the pulmonary pressure at rest although some rise with exertion may be anticipated. Thus, if one could place a finger-like obturator through the incompetent area of a defective mitral valve such that it would properly fill the insufficient area, the lesion would be palliated provided that at least two square centimeters, or preferably more, of functioning valve area remained. Such a stationary prosthesis would not be dependent upon motion to serve its purpose, and consequently might be better tolerated by the heart and thus able to function indefinitely, especially if the prosthetic material was relatively non-reactive so that compromising adhesions did not form between it and the adjacent valve leaflets. Furthermore, this prosthesis could be shaped at the operating table to the size found necessary for control of the insufficiency. The dilated annulus characteristic of hearts with significant mitral incompetency could be expected to contract appreciably as a consequence of controlling the insufficiency, therefore, to maintain maximum valve efficiency it would be desirable for the prosthesis within the mitral orifice to contract also with time at a predictable rate.

The interesting properties and the preparation of polyvinyl surgical sponge† have been described by Grindlay and Waugh. These characteristics include the facts that this material can be molded to any shape, it is relatively non-reactive when inserted into the blood stream, and it will

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contract inversely proportional to the extent of compression upon insertion through the mitral ring. Here would seem to be a substance having a number of the desirable qualities postulated necessary for the finger-like obturator proposed above.

In this investigation preparation of the prosthesis, the technique of its insertion, and the acceptance by the heart of the prosthesis over the period of study, which was up to ten months, received particular emphasis.

**Method of Study**

For these experiments the polyvinyl sponge was compressed in several variations from its original texture. This was accomplished by carving cylinders of polyvinyl sponge larger than a cylindrical mold depending upon the amount of compression desired. The mold containing the sponge was then boiled which served to sterilize, compress, and shape the prosthesis. After cooling in the mold the sponge would retain the shape and compression imposed.

Two designs of the prosthesis were used in this study. The first was fusiform shaped and constructed so that its maximum diameter would lie at the annulus. After several experiments it was empirically thought better to minimize the amount of the obturator in the atrium. As a result the second design was tried. This took the shape of an inverted cone with its apex attached to the posterior papillary muscle and the base constructed to lie at the level of the annulus. A narrow protrusion of sponge extended from the base of the cone and was placed across the posterior commissure to serve as the atrial attachment of the prosthesis. In each instance the prosthesis was measured accurately before insertion and again at autopsy.

Clean but not sterile surgical technique was employed on the normal healthy mongrel dogs used in this project. The left chest cavity of the dog in each experiment was opened in the fifth interspace with the aid of pentothal anesthesia and positive pressure mechanical respiration using an endotracheal tube. The pericardium was incised anterior to the phrenic nerve, and then sutured to the chest wall which served to retract the lungs and provide a wide unhampered operative site. Next a purse string suture was placed around the base of the left auricular appendage or in the smaller animals it was placed partially on the left atrium proper. The auricular appendage was then opened on its anterior surface from its tip toward the atrium as far as necessary to admit an index finger. By this approach auricles even in the smallest dogs were of ample size to permit completion of the procedure in the usual manner.

The operator's finger having been introduced into the left auricular appendage and through the mitral orifice, the left ventricular cavity was explored and the posterior papillary muscle located. At this juncture in those animals selected to have a traumatically induced mitral insufficiency, a small hooked knife was introduced through the appendage, and the mural leaflet of the mitral valve was lacerated. The exact location and extent of the laceration was difficult to determine even with the finger as a guide,
and in the first attempts the aortic leaflet or chordae tendineae were inadvertently injured. These injuries were poorly tolerated by the animals. In the remaining animals the prosthesis was inserted into normal mitral valves.

For insertion of the prosthesis, a four inch slightly curved round needle carrying a doubled 00 silk suture was passed into the left ventricle in such a manner that emerged within the chamber just below the insertion of the chordae tendineae on the posterior papillary muscle. The point of the needle was palpated with the tip of the index finger inside the left ventricle and the needle guided through the mitral orifice and out of the incision in the left atrial appendage. This resulted in a doubled suture in place through the left chambers of the heart.

For the atrial attachment of the obturator a second needle and suture similar to that above is passed through the left atrial wall just below the right pulmonary vein as it enters the atrium and just above a dimple* which is consistently present in the dog. The suture is carried through the atrium and out the incision in the appendage. This suture will place the atrial attachment of the prosthesis about one centimeter above the posterior commissure, next to the junction of the atrial septum with the posterior atrial wall and just below the right inferior pulmonary vein. The external distance between the entrance into the heart of the ventricular and atrial sutures was then measured, and the previously prepared polyvinyl sponge cut to this length. The prosthesis was then trimmed with scissors to one of the previously described shapes. The maximum diameter of the prosthesis would be made to lie between two and three centimeters from the end intended for attachment to the posterior papillary muscle. This placed the maximum diameter of the prosthesis in the mitral valve orifice at its posterior commissure.

The sutures extending out of the atrial appendage were then sutured to the ends of the prosthesis with the stitches buried in its substance. The prosthesis was then introduced into the heart and positioned as a stationary finger-like obturator at the posterior commissure. The ends of the prosthesis were pulled tight to the endocardium but not through it, after which the transfixing sutures were sewed to compressed polyvinyl sponge buttons on the epicardium. This firmly fixed the intracardiac prosthesis in the desired place. The auriculotomy was repaired and the chest incision closed. All animals were given antibiotics for five days following surgery.

Results

Twenty-nine animals were included in this study of which 28 have died or were sacrificed at intervals from the day of surgery up to 10 months

*This marks the location of the coronary sinus at the junction of the intra-atrial septum and the left atrial wall posteriorly. It very closely approximates the external projection of the posterior commissure. A persistent left superior vena cava, of which we have seen one example in the dog, enters the heart at this point. No description of this dimple was found in veterinary anatomy books or literature, but it serves as a good landmark for this study.
**Figure 1**: A polyvinyl fusiform prosthesis acting as an obturator in the mitral orifice as viewed from the left atrium during simulated ventricular systole 90 days after insertion. The prosthesis has healed smoothly to the left atrial wall, and is covered by a smooth layer of fibrous tissue.—**Figure 2**: This is the same specimen as pictured in Figure 1. The left ventricle is opened through the anterior commissure of the mitral valve. The darker areas on the prosthesis represent the area in contact with the mitral leaflets. The fibrin coat is not as thick in these areas. Note how the prosthesis was shaped by the pressure of the leaflets. No adhesions are present. The cross sectional area at the annulus has contracted to 25 per cent of its original area.
later. The one remaining animal is still alive for observation over a longer time interval.

A traumatically induced mitral insufficiency was produced in 12 of these animals. A fusiform mitral obturator was placed in nine of these and the conical prosthesis placed in three. Eight died at intervals from the day of surgery to 120 days later while the other four were sacrificed (see below). Of the eight that died, two died the first day as a result of technical errors, two died from bacterial endocarditis proven by positive blood cultures, and three died a month or more after their operation from infected pulmonary edema associated with evidence of systemic infection either pyelonephritis or verrucous valvular lesions. The cause of death in the eighth was central nervous system emboli which apparently had originated from the base of the conical prosthesis used in this animal. The conical prosthesis mentioned previously was used in three of the eight animals that died and in none that survived. This shape was not well tolerated by the hearts and clots tended to form on the base of the prosthesis. This conical obturator did not develop a good even coating of fibrin that was generally present on the fusiform prosthesis. All three with the cone shaped prosthesis also had some associated infection.

Four of the 12 animals with induced mitral insufficiency were apparently in good health when sacrificed over 200 days after their operation. Two had had a positive blood culture after their postoperative recovery period, and each had a small organizing clot on the atrial portion of their prosthesis found at autopsy. The other two animals tolerated the trans-mitral obturator well and were in good health when sacrificed.

The prosthesis seemed to reduce or obliterate the traumatically induced mitral insufficiency, however, eight of these 12 animals developed some complication involving sepsis before death. It is obvious then that the prosthesis did not protect the animals from this complication of acute mitral insufficiency.

The fusiform prosthesis was placed in the hearts of 13 animals whose mitral valve was not injured while the conical prosthesis was placed in the hearts of three other normal animals. In the group of 13 one died as a result of a technical error and another died one week after surgery due to heart failure which was caused by a large interatrial septal defect. The atrial attachment of his prosthesis was placed too far medially, the atrial suture penetrated the septum and was anchored through the right atrial wall. The action of the heart apparently caused the prosthesis to crode through the septum creating a large defect. All of the remaining 11 animals were in good health until sacrificed at intervals up to ten months. The prosthesis was well tolerated in each and all had apparently avoided any infectious process.

The three normal animals in which the conical obturator was placed died, two as a result of bacterial endocarditis and one of distemper. All three had positive blood cultures before their death.

Figures 1 and 2 represent the optimum response of the animals to the fusiform shaped prosthesis as represented by the group of 11 animals
mentioned above. It may be noted in Figure 2 how the leaflets conform to the shape of the prosthesis, and how the pressure of the leaflets in ventricular systole have ultimately shaped the polyvinyl sponge. The ventricular and atrial portions of the sponge contracted very little after placement within the heart. The sponge seems to retain the same degree of softness as was present upon introduction into the heart, except for the central area which becomes more firm with contraction. The mitral leaflets did develop some thickening in the portions which coapted with the prosthesis. A couple millimeters of the chordae tendineae at their insertion on the posterior papillary muscle were often involved in the healing process with the prosthesis, however, no adhesions were ever present between the leaflets and the obturator. Six weeks was about the time necessary for the prosthesis to become well covered by a fibrin coat, and for most of the contraction to take place.

The surfaces of the prostheses were smoothly covered by a thin white layer. The areas of the prosthesis which coapted with the leaflets were the last to become well coated, and as Figure 2 demonstrates by the darker areas, the fibrin layer was thinner in these regions. Microscopically the surface of the polyvinyl sponge was a fibrin jacket which was firmly growing into the interstices of the sponge. The fibrin seemed to develop into collagen and no true endothelium was found. The remainder of the sponge was similar microscopically to that described by Johns and Blalock.5 Small capillaries invaded the prosthesis from each end and the general appearance was that of organizing clot interspersed with strands of polyvinyl sponge.

Compression of the polyvinyl sponge was determined by measuring how much the diameter of the sponge cylinder was reduced after molding. Polyvinyl sponge cylinders whose diameters were compressed from two to one or more, retained their original form within the heart with healing and time, the impact of the leaflets having very little effect on the ultimate shape of the prosthesis. Sponge cylinders compressed from one and one-half diameters to one, contracted in cross sectional area in the portion shaped by the leaflets by about fifty per cent. Cylinders not compressed contracted in cross sectional area to about twenty-five per cent. The sponge in all compressions seemed to be tolerated by the dogs' hearts equally well.

Discussion

Even a mild degree of acute traumatic mitral insufficiency was not tolerated well in the animals used for this study. The very high incidence of infection in those animals with acute mitral insufficiency in spite of antibiotics after placement of their prosthesis is noteworthy as infection was not the same problem in the control group. This may be related to previous observations5 which demonstrated the fact that a chronically increased work load on the heart of a dog predisposes that animal to infections and especially bacterial endocarditis. This would seem to offer an explanation for the high incidence of infection in these animals.
The streamlined (fusiform) design of the prosthesis was better tolerated in the animals used for these experiments, even in some that developed septic conditions associated with acute mitral insufficiency.

One can not compare the pathology of acute traumatic mitral insufficiency in the dog with human rheumatic mitral insufficiency, consequently the human applications of this study must be surmised.

For possible clinical use a prosthesis that would be able to contract up to fifty per cent probably would be desirable. The portion through the annulus will contract as a result of pressure by the valves, while the remainder will retain much of its original size. The action of the valves are the determining factor in the ultimate size of the prosthesis. As the regurgitation is controlled, a dilated annulus will regress. This will cause the leaflets to more closely approximate, which will make the prosthesis contract to the area of the remaining insufficiency. If the original insufficiency area is reduced less than fifty per cent when the regression of the dilated annulus is complete the contraction of the prosthesis would be arrested as the pressures of the leaflets would no longer be exerting a force on the obturator. The insufficient area of the valve would then be filled and the leaflets free to move unobstructed.

SUMMARY

A polyvinyl sponge is used experimentally to straddle the posterior commissure of the mitral valve in the dog. This material will contract and be shaped as the pressures of the mitral leaflets dictate and thus tend to fill any area of valve deficiency that is present. The clinical implication is that this technique may be used to reduce the quantity of regurgitation present in humans with significant degrees of mitral insufficiency.

RESUMEN

Se usa una esponja de polivinil experimentalmente para mantener abierta la comisura posterior de la válvula mitral en el perro.

Este material se contrae y se amolda a las presiones de las hojillas de la mitral y así tiende a llenar cualquiera área de deficiencia que existan.

La consecuencia clínica es que esta técnica puede usarse para reducir el volumen de la regurgitación en los humanos con grados significantes de insuficiencia mitral.

RESUME

Les auteurs ont utilisé expérimentalement une éponge de polyvinyle pour élargir la commissure postérieure de la valvule mitrale chez le chien. Cette matière se contracte et se modèlpe en fonction de la pression des valves mitrales et de là tendra à suppléer toute déficience de la valvule. On peut en déduire que ce procédé est utilisable pour réduire le reflux sanguin chez l'homme atteint d'insuffisance mitrale même assez importante.
ZUSAMMENFASSUNG

Im Experiment wird ein Polyvenylschwamm benutzt, um beim Hund die hintere Kommissur der Mitralklappe zu dehnen. Dieses Material wird zusammengezogen und geformt, wie es der Druck der Mitralsägel bestimmt, und neigt dazu, etwa vorliegende Klappendefekte auszufüllen. Die klinische Folgerung daraus besteht darin, dass diese Technik geeignet sein könnte, um die Stärke des Rückflusses zu mindern, die bei Personen mit schwereren Graden von Mitralsuffizienz vorkommen.

REFERENCES