The Influence of the Ventriculotomy Site on the Contraction and Function of the Right Ventricle

By Harold W. March, M.D., J. Keith Ross, F.R.C.S., William L. Weirich, M.D., and Frank Gerbode, M.D.

Experiences in the surgical research laboratory and in the operating room have served to refine the technique of open cardiotomy for the repair and correction of anomalies involving the ventricular septum, the right ventricular outflow tract, and the pulmonary valve. These refinements have been reflected in a steadily declining mortality following the repair of ventricular septal defects and the correction of Fallot's tetralogy.1, 2

There remains, however, a group of patients with these lesions in whom surgery continues to be hazardous. In this group right ventricular pressures are high preoperatively and right ventricular work burden remains increased postoperatively. This includes patients with ventricular septal defects in whom the pulmonary artery pressure preoperatively was 70 per cent or more of the systemic pressure, particularly when this was associated with high pulmonary vascular resistance.3 It embraces some of those with Fallot's tetralogy in whom, because of incomplete relief of outflow tract obstruction, the right ventricular pressure remains elevated.4 And, finally, there should be included certain patients who had incomplete repairs of ventricular septal defects in association with infundibular stenosis.5

One factor that these patients have in common is the persistence postoperatively of increased right ventricular work loads. Clinical observations and physiologic considerations suggest that postoperative morbidity and death may be a consequence of impaired right ventricular functional capacity. Since right ventricular failure in untreated cases is a late event, and is rare preoperatively, it would seem likely that the factor causing failure is acutely imposed and that it appears somewhere in the course of surgical intervention. Previous studies have shown that cardiac bypass with the pump oxygenator of itself does not cause a significant decrement of ventricular function in animals if the perfusion rate is kept at adequate levels, above 0.3 liters per minute per square meter or between 30 to 50 milliliters per kilogram per minute.6 Although it has been established that both potassium and acetylcholine arrest of the heart result in pronounced depression of ventricular function,7 operating-room experience had already indicated that these drugs are undesirable expedients and their use has been abandoned in many centers. They have been superseded by general body hypothermia or local cardiac cooling. Recent studies indicate that when hypothermia is effectively induced, so that temperatures are lowered sufficiently to produce and maintain cardiac standstill, no depression in ventricular function eventuates upon warming and restarting the heart.8 On the whole, it seems unlikely that any of the foregoing aspects of open cardiotomy are currently responsible for impairment of right ventricular function. Nor are the details of postoperative care likely to be of great relevance in view of the fastidious care that distinguishes the management of these patients.

On the other hand, certain considerations involving the ventriculotomy procedure itself indicated that an investigation into the effects of right ventricular cardiotomy might be fruitful. This communication reports the ob-
ventriculotomies made in acute and chronic experiments in dogs by means of high-speed cinematography and ventricular function curves.

Methods
Fourteen healthy mongrel dogs weighing from 15 to 21 Kg., were anesthetized with sodium pentobarbital, and respiration was mechanically supported on a respirator after endotracheal intubation. In most of the animals the thoracotomy incision extended across the chest, and the sternum was transected in order to provide adequate exposure of the right ventricle for photography.

In eight of the animals, conventional vertical ventriculotomies were made from base to apex paralleling the interventricular groove. In six of the animals ventriculotomies were oriented horizontally from the atrioventricular groove across the ventricle to a terminus at the interventricular septum, and roughly parallel to the plane of the pulmonic valve ring. Four of the animals with vertical ventriculotomies were restudied 2½ to 3 months after recovery from the thoracotomy procedure.

The cinefilms were made by a technic to be described fully elsewhere. The camera was a 16-mm. Wollensak-Fastax run at frame rates of 800 to 1250 per second. The camera has a double-lens system permitting the superimposition on the film of any oscilloscopic signal. Superanseochrome daylight film was used, and illumination was provided by a high-intensity quartz lamp. The heat level from the lamp was low, and no damage to tissues was noted. Because of the high frame rates and the technical difficulties in reproducing long 16-mm. film strips with clarity, the cinefilm observations are presented by composite drawings of the pertinent portions of the cardiac cycle as derived from direct tracings of individual film frames.

Eight vertical and six transverse ventriculotomies were done in 14 additional animals in order to study the effects of these incisions by means of ventricular function curves constructed in the manner described by Sarnoff and Berglund and Stirling and associates. Ventriculotomy was performed under cardiopulmonary bypass with a pump oxygenator of recent design. For the purpose of constructing right ventricular function curves, pre- and postventriculotomy, blood from the venae cavae cannulae was pumped back into the right atrium via the azygos vein over a suitable range of flows, 0.9 to 3.8 liters per minute per square meter. Heart rate and mean right atrial and pulmonary artery pressures were continuously monitored. The curves were constructed by plotting right ventricular stroke work in gram-meters against mean right atrial pressure in centimeters of water.

Results
Cinefilm observations in the control animals indicate that right ventricular contraction is sequential, beginning at the apex. Early in systole the outflow tract bulges as blood is ejected into the pulmonary artery. It is maximally contracted late in systole and appears to relax later than the main right ventricular chamber. The pre- and postventriculotomy drawings in figures 1 and 2 illustrate the systolic events described.

In the eight animals undergoing conventional vertical ventriculotomy paralleling the interventricular groove, adverse effects on the mobility of the entire right ventricle and on

Figure 1
Vertical ventriculotomy. R.V., right ventricle; R.V.O., right ventricular outflow tract; P.A., pulmonary artery; L.V., left ventricle. In the control study the R.V.O. bulges in early systole, moving concordantly with the P.A. In late systole the outflow tract is maximally contracted. A transverse depression marks the boundary between R.V. and R.V.O. After vertical ventriculotomy the R.V.O. bulge persists throughout systole. Note the almost complete lack of late systolic border motion. In addition there is paradoxical movement in the immediate vicinity of the ventriculotomy and the R.V.O. is not well delineated from the R.V.
the behavior of the outflow region were observed. The sequential pattern of contraction was either absent or markedly altered, and the final phase of ejection in the outflow tract appeared to occur passively. The area of the incision tended to move paradoxically. The outflow tract in most instances continued to bulge throughout systole and late contraction did not occur. In fact little change in this segment could be observed throughout the cardiac cycle. These abnormalities are represented in figure 1.

Four of these animals were studied between 2½ and 3 months after the ventriculotomy. Slight improvement was noted, and right ventricular activity continued to be grossly abnormal.

The six animals undergoing horizontal ventriculotomy showed little change in the contraction pattern of the right ventricle. Functionally these incisions were oriented along the axis of fiber shortening during systole. Ventricular contraction remained vigorous and its sequential character continued undisturbed. There was almost no paradoxical movement even in the immediate vicinity of the incision. The specific activity of the outflow tract was preserved. These observations are illustrated in figure 2.

Figures 3, 4, and 5 illustrate the typical effects of ventriculotomies on right ventricular function curves. After a long vertical ventriculotomy (fig. 3) there is distinct depression. Maximum stroke work is reduced and each increment is performed at rising right atrial pressures. When the vertical ventriculotomy is kept quite short, lesser degrees of impairment are noted (fig. 4). After horizontal ventriculotomy, no significant depression of the curve is noted (fig. 5).

Discussion
Previous experiences have suggested that right ventricular cardiotomy as customarily performed can be a traumatizing procedure. Moulder and co-workers reported a higher
incidence of complications after ventriculotomy than after atriotomy or aortotomy. Cooley’s group observed that patients tolerate atriotomy better than ventricular incisions and recommended it as the method of choice in the repair of ventricular septal defects that can be palpated through the atrial appendage. Lillehei at one time suggested this approach in patients with pulmonary hypertension. This has also been advocated recently by Kay.

Rams and co-workers made observations in a series of dogs after recovery from right ventriculotomy. They reported ventricular irritability and the precipitation of fatal arrhythmias in one group of animals cathe terized postoperatively with the chest closed. A second group was reoperated upon. It was noted that needle puncture of the right ventricle precipitated hazardous arrhythmias. This group had a high mortality and only half survived more than 2 days after reoperation. At autopsy, congestive heart failure was present, the right ventricles were dilated, and hepatomegaly and effusions were present. Stirling and co-workers studied the effects of right ventriculotomy by means of ventricular function curves, noting significant depression when long vertical incisions were made. This was not so apparent when the incisions were kept short or made parallel to the anterior branches of the right coronary artery.

The present data add further support to the foregoing impressions. They contradict previous studies maintaining that extensive damage may be inflicted on the right ventricle without conspicuous functional impairment. Both cinefilm analysis and ventricular function curves indicate that important changes occur in right ventricular contraction and work characteristics after the conventional longitudinal incision. They indicate, too, that transverse incisions are preferable in that they interfere far less with right ventricular physiology. This is consistent with previous knowledge pertaining to the functional anatomy of the right ventricle. The thin external and internal spiral muscles invest the ventricles from base to apex and
combine to shorten the long axis of the chambers. Between these spiral groups, the chambers are enveloped by the deep constrictors, which fan out in horizontally oriented bundles. It is these muscles which in contracting reduce the diameter of the heart. Whereas a vertical ventriculotomy transects the right ventricular constrictor fibers, the horizontal cardiotomy more nearly splits them along their horizontal plane. The latter incision is less likely to damage them functionally just as a muscle-splitting incision anywhere is functionally less disturbing. Moreover, the vertical wound interrupts these bundles throughout its extent from base to apex, while the horizontal one interrupts them at a single level along their axis of shortening, leaving those bundles above and below this site unscarred. Other explanations for the results obtained are not readily forthcoming. Differences in the degree of coronary artery interruption are not obvious, and with both types of incisions, care was taken to spare vessels of appreciable size. Nor does interference with right ventricular conduction appear to play a role, since widening of the QRS complex was noted in only one instance when a vertical ventriculotomy was extended through the base of the anterior papillary muscle.

The clinical implications of this study bear upon the problem of repairing ventricular septal defects with pulmonary hypertension and Fallot's tetralogy. Previous observations have suggested that atriotomy is better tolerated in these conditions than ventriculotomy,11,13,14 and this has been forcefully advocated recently in the treatment of defects associated with pulmonary hypertension.8 However, atriotomy cannot provide adequate access to the right ventricle on all occasions and ventriculotomy is essential for the proper repair of complicated lesions. It cannot readily be employed, for example, when the ventricular septal defect is anterior nor can it provide inspection of the aortic valve which is in close approximation to these defects. Nor can lesions involving the infundibulum or the pulmonic valve be corrected by this approach.

Transverse ventriculotomy may be a practical alternative. The access it provides is comparable to that of the traditional cardiotomy. As in the latter approach, the precise orientation of the incision has to be tailored to spare the coronary circulation, but in general the distribution of the vessels on the surface of the right ventricle favors the transverse approach. Initial experiences with it in our clinics have been encouraging. There have been no particular difficulties in its application, it is well tolerated, and patients with pulmonary hypertension appear to have a smoother postoperative course.19

Summary

The effects of right ventricular cardiotomy were investigated in a total of 28 dogs. Half of the group were studied by high-speed cineradiography and half by means of ventricular function curves. In both groups long vertical ventriculotomies were done in eight animals and transverse ventriculotomies were performed in six.

Adverse effects on the contraction and function of the right ventricle were observed in the animals undergoing vertical cardiotomy. On the other hand, transverse ventriculotomy did not result in significant abnormalities of right ventricular performance.

It is concluded that transverse ventriculotomy is more physiologic and may be the incision of choice, especially in the higher-risk group of patients with pulmonary hypertension.

References

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Sometimes, amid campaigns against so many diseases we don’t want to die of, I think, somewhat flippantly, that we might sensibly focus our attention on deciding which among several mortal diseases we do like, which exits we prefer; and, in dignified acceptance of the inevitable, we might depart after perhaps less stampeding and general confusion.—Alan Gregg, M.D. Challenges to Contemporary Medicine. New York, Columbia University Press, 1956, p. 91.
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