Motion of the Tricuspid Valve Annulus in Anesthetized Intact Dogs

By Anastasios G. Tsakiris, Douglas D. Mair, Shuji Seki, Jack L. Titus, and Earl H. Wood

ABSTRACT
Phasic variations in the size, position, and geometry of the tricuspid valve annulus during the cardiac cycle were studied in five normal anesthetized dogs 2-6 weeks after 8-11 lead beads had been sutured on the endocardial surface of the valve ring during cardiopulmonary bypass. Field-by-field measurements from biplane videoangiograms were used to assess changes in valve ring size and shape during normal control hemodynamic conditions and during increased heart rates. In addition, the percutaneous production of a complete atrioventricular block in two dogs enabled us to observe the effect of isolated atrial contractions on the valve annulus. During normal sinus rhythm, progressive narrowing of the annulus during atrial and ventricular contractions reduced its area by 20-39% of the maximal valve circumference during diastole; approximately two-thirds of the total ring narrowing was associated with atrial systole. These findings suggest that one of the functions of atrial contraction is the reduction in size of the atrioventricular valve orifices prior to the onset of ventricular systole.

KEY WORDS biplane videoangiography cardiopulmonary bypass dynamic geometry atrial contribution to valvular closure tricuspid regurgitation

In a recent paper, we reported our observations on the size, motion, and dynamic geometry of the mitral valve annulus in intact dogs (1). The main findings of the study were that the mitral valve annulus narrows considerably during the cardiac cycle (19-34% during control hemodynamic conditions) and that the annular size is influenced by both left atrial and left ventricular contractions. During normal sinus rhythm, approximately two-thirds of the total decrease in annular size is associated with atrial systole. This finding suggests that one of the functions of atrial contractions is narrowing of the atrioventricular valvular orifices before the onset of ventricular contraction.

The present experiments were carried out to study the motion of the tricuspid valve annulus during the cardiac cycle. Observations were made in dogs that had radiopaque markers sutured on the endocardial surface of the apparent tricuspid annulus 2-6 weeks prior to the study.

Methods
The surgical procedure and the techniques for recording and analyzing the motion of the tricuspid ring employed in the present study have been described in detail previously (1-3) and will be discussed only briefly. Under normothermic cardiopulmonary bypass, the tricuspid valve was exposed through a right atriotomy, and 8-11 lead beads were sutured on the endocardial surface of the apparent valve annulus in five dogs (12-15.5 kg). The dogs were anesthetized 2-6 weeks later, and catheters were placed in the right atrium (6F bipolar electrode catheter), the right ventricle (6F), the pulmonary artery (6F), the ascending aorta (5F), and the abdominal aorta. Pressures were measured with strain gauges and photographically recording galvanometers; cardiac output was determined by the dye-dilution technique.

The dogs were placed in the right decubitus position in a half-body Lucite cast and positioned in a biplane videosystem so that the plane of the tricuspid valve ring was parallel to the central axis of the roentgen beam in the vertically oriented image-intensifier system and the full circumference of the tricuspid annulus could be visualized in the horizontal image-intensifier system. The area of the tricuspid annulus was measured...
by planimetry and corrected for geometric distortion. An additional correction for the markers placed on the free wall portions of the annulus was necessary because of the change in orientation of the annular plane during ventricular systole.

Pressures, cardiac output, and size of the tricuspid valve annulus were measured repeatedly during the control state (heart rates 41-90 beats/min) and during increased heart rates (113-160 beats/min) when there was spontaneous sinus rhythm (two dogs) or pacing of the atria and ventricles (three dogs). The values reported in the present paper are the average for three cardiac cycles. During stable hemodynamic conditions, variations in annular size from beat to beat were minimal (1-2 mm²). The motion of the tricuspid ring was also studied in detail during spontaneous first-degree atrioventricular block (two dogs) and during complete atrioventricular block produced by a percutaneous technique (4) (two dogs).

Immediately after the experiments, the dogs were killed, the right atrial and right ventricular cavities were opened, and the heart was fixed in formaldehyde. Tissue blocks for histologic sectioning were cut from the right atrioventricular junction in a plane perpendicular to the atrioventricular ring; the blocks included the attachment of the base of the tricuspid valve and the adjacent atrial and ventricular tissues.

Results

ANATOMIC FINDINGS

All of the inserted beads were generally properly positioned along the atrial side of the bases of the tricuspid valvular leaflets. Only two beads were placed on the atrial septum 1-2 mm from the exact base of the septal leaflet. The beads were firmly united to the endocardium by a fibrotic healing process that was moderate and confined to the endocardium near the bead. In no instance was deformity or fibrosis of the leaflet tissue apparent. These findings suggest that the markers satisfactorily indicated the site of attachment of the tricuspid valve and that their presence did not compromise annular or valvular motion or function.

MOTION OF TRICUSPID VALVE ANNULUS

The maximal diastolic size of the tricuspid annulus, the percent of annular narrowing during the cardiac cycle, and the values for heart rate and cardiac output obtained in the five dogs during control hemodynamic conditions and during increased heart rates are presented in Table 1.

During control conditions, which were associated with slow heart rates because of the morphine medication used, the maximal diastolic area of the tricuspid ring varied in the five dogs between 3.2 cm² and 4.4 cm². In every dog, the maximal ring size decreased (range 2.7 cm² to 3.2 cm²) at higher heart rates.

A considerable decrease in the size of the tricuspid annulus was observed during atrial and ventricular systoles. Under control conditions, this decrease ranged between 20% and 39% of the maximal diastolic size. Generally less narrowing was seen when heart rates were higher. The degree and the temporal sequence of the decrease in the area of the tricuspid valve ring observed while the atria and ventricles were beating in normal sequence were as follows. In diastole, the size of the annulus increased (the rate of change depended on the duration of diastole) until a plateau was reached approximately before the onset of the P wave of the electrocardiogram. A small additional increment in

<table>
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<tr>
<th>Weight (kg)</th>
<th>Maximal diastolic area (cm²)</th>
<th>Narrowing (%)</th>
<th>Heart rate (beats/min)</th>
<th>Cardiac output (liters/min)</th>
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<td>4.4</td>
<td>39</td>
<td>41</td>
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<tr>
<td>14.0</td>
<td>3.8</td>
<td>31</td>
<td>74</td>
<td>1.5</td>
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</tbody>
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TABLE 1

Area of Tricuspid Annulus, Percent of Narrowing, and Hemodynamic Parameters in Five Dogs during Control Conditions and during Increased Heart Rates

Control

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>Maximal diastolic area (cm²)</th>
<th>Narrowing (%)</th>
<th>Heart rate (beats/min)</th>
<th>Cardiac output (liters/min)</th>
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<td>74</td>
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Increased heart rates

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>Maximal diastolic area (cm²)</th>
<th>Narrowing (%)</th>
<th>Heart rate (beats/min)</th>
<th>Cardiac output (liters/min)</th>
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*Spontaneous sinus rhythm.
annular size occurred during the early phase of atrial contraction; this increment was seen particularly well during slow heart rates. Progressive narrowing of the ring then occurred during the end of the atrial contraction and throughout the ventricular contractions. Approximately two-thirds of the total decrease in annular size occurred before the onset of ventricular systole. Annular size throughout the cardiac cycle was different for the two conditions studied.

During normal sinus rhythm in several of the cardiac cycles analyzed in detail, a brief small increase in annular size was observed during the initial portion of isovolumic ventricular contraction, suggesting minimal annular dilation between the end of the atrial contraction and the beginning of the ventricular contraction. Annular dilation after an atrial systole that was not followed immediately by a ventricular contraction was clearly demonstrated in cardiac beats with prolonged P-R intervals.

The sphincterlike action of isolated atrial contractions on the tricuspid ring was particularly clear in the two dogs in which a complete atrioventricular block was produced by percutaneous injections of formaldehyde into the area of the atrioventricular node. Annular narrowing ranging between 15% and 36% was observed after atrial contractions during spontaneous atrial rhythm and during atrial pacing at high rates (Fig. 2).

The geometry of annular motion associated with atrial systole was distinctly different from that during ventricular contraction. Atrial narrowing produced by atrial systole was eccentric and was caused by the almost equal shortening of all free wall portions of the ring with the anteroposterior commissure moving toward the septum. This motion suggests apposition of the anterior and posterior leaflets to the septal leaflet. The position of the annulus in the chest during atrial contraction remained practically unchanged, and the plane of the valve ring remained unchanged at approximately right angles to the long axis of the ventricle. In contrast, during ventricular contraction, ring narrowing was caused by some additional inward movement of the free wall and by the bulging of the ventricular septum into the cavity of the right ventricle. The annular plane changed its orientation; the free wall por-
FIGURE 2

Effect of isolated atrial contractions on the size of the tricuspid ring (solid line connecting solid circles) (12-kg dog, morphine-pentobarbital anesthesia, complete atrioventricular block, atria paced at 210 beats/min). Atrial contractions were followed by significant annular narrowing (15–36%). The small size of the annulus following ventricular contraction was presumably caused by a decrease in the size of the right ventricle.

FIGURE 3

Representative histologic sections of the tricuspid valve and the adjacent cardiac walls demonstrating the nature of the attachment of the valve leaflets at the tricuspid ring. A: Histologic section through the lateral part of the anterior leaflet of the tricuspid valve (TV) and the lateral free walls of the right atrium (RA) and the right ventricle (RV). The principal attachment of this tricuspid leaflet is the endocardium of the adjacent chamber with some prominence of collagen on the ventricular aspect where the ventricular endocardium turns onto the ventricular surface of leaflet. The bead was accurately positioned at the site of the valvular annulus; it elicited only a mild, nondeforming fibrotic response. Elastic-van Gieson stain. B: Histologic section of the anterior part of the septal leaflet of the tricuspid valve and related structures, with the bead marking the site of attachment of this tricuspid leaflet. The major attachment of the leaflet is the atrial and the ventricular endocardium. Ao = root of the aorta and VS = ventricular septum. The His bundle is the branching at the top of the ventricular septum. The slightly disrupted appearance of tissues at the arrow resulted from the removal of the marker. Elastic-van Gieson stain. C: Histologic section through the posterior leaflet of the tricuspid valve, the right atrium, and the right ventricle demonstrating that the attachment of the valve depends on reflections of atrial and ventricular endocardium onto the leaflet, atrial muscle fibers extending into the base of the leaflet, and condensation of collagen fibers at the ventricular subvalvular angle. Elastic-van Gieson stain.
tions moved toward the ventricular apex, since the external wall of the right ventricle shortened considerably more than did the ventricular septum. A moderate shift of the center of the ring toward the right was observed.

Discussion

This investigation was carried out since no pertinent information was available concerning the motion of the tricuspid ring in intact animals. Only observations in the isolated heart have been reported previously (5).

In the present study, we observed that the orifice of the right-sided atrioventricular valve is not a rigid structure. Its size and geometry undergo continuous changes during the cardiac cycle, and both are influenced by the contractions of the right atrium and the right ventricle. Also, during normal sinus rhythm, the major part of annular narrowing is caused by the atrial contraction.

These findings correlate well with the anatomic characteristics of the basilar attachment of the tricuspid valve, in particular with the absence of a well-defined continuous fibrous annulus, the direct attachments of the leaflets of the free wall (most of the anterior and all of the posterior leaflet) to the right atrium and right ventricle, and the insertion of atrial myocardial fibers into the base of the leaflets (Fig. 3).

A comparison of the motion of the tricuspid valve ring observed in the present study with that of the mitral annulus reported in a previous study (1) shows striking similarities between the two atrioventricular valves in both the temporal sequence and the degree of annular narrowing during the cardiac cycle. During normal sinus rhythm, the annulus of both valves is narrowed progressively by atrial and ventricular contractions, and the major part of the decrease in size usually occurs before the onset of ventricular contraction (Fig. 4). Therefore, one probable function of atrial contraction is the reduction in size of the atrioventricular valve orifice prior to the onset of ventricular contraction. The effect of atrial contraction in the mitral valve is the shortening of the lateral and posterior portions of the ring; such shortening tends to appose the posterior leaflet to the anterior one. In the tricuspid valve, atrial contraction leads to shortening of all free wall portions of the tricuspid annulus, which in turn causes the anterior and posterior leaflets to appose the septal leaflet that is firmly anchored in the ventricular septum.

The data reported in the present paper do

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**FIGURE 4**

Comparison of changes in the area of the mitral annulus (left) with that of the tricuspid annulus (right) and hemodynamic parameters during control hemodynamic conditions. (Two different dogs; mitral annulus of a 17-kg dog; tricuspid annulus of a 15.5-kg dog; morphine-pentobarbital anesthesia). Motion of both valve rings was similar; their area was reduced progressively during atrial and ventricular contractions. The major part of the total narrowing (approximately two-thirds) occurred before the onset of ventricular systole in both valves.
not allow evaluation of the importance of the presystolic annular narrowing in the prevention of tricuspid valvular regurgitation. During normal hemodynamic conditions with normal ventricular volumes and during increased heart rates, atrial annular narrowing probably is not important, because the valve orifice is relatively small at the onset of ventricular systole and is further reduced in size by ventricular contraction. In contrast, during conditions associated with increased ventricular volumes and large annular orifices, presystolic narrowing may be important and necessary for the apposition of the valve leaflet edges before ventricular contraction.

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