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Experimental Protocols

Control Group (13 Dogs)

Group A. In five dogs, anesthesia was induced as described and 201Tl myocardial imaging was performed with the chest closed. The chest was then opened through a median sternotomy. The pericardium was opened with a 5-cm incision over the RV outflow tract and pulmonary artery which was extended over the left atrial appendage. The left atrial appendage and the femoral artery were then cannulated. The right ventricle was cannulated by introducing a catheter from the external jugular vein. Heart rate and systemic arterial and RV pressure were recorded. Myocardial imaging then was repeated in 60° and 70° LAO views to assess eventual positional changes of the heart within the thorax induced by the surgical procedure. For assessment of MBF, microspheres 15 ± 5 μ in diameter labeled with 51Cr, 85Sr or 141Ce were used. For each measurement, approximately 2.5 × 10^6 microspheres (3M Company) were injected through the left atrial cannula, while simultaneous reference blood samples were drawn from the femoral artery at 15 ml/min for 2 minutes according to standard techniques. The dogs were then sacrificed.

Group B. In four other dogs, anesthesia was induced, but 201Tl was injected after median sternotomy and exposure of the heart. In this manner, the potential effect of the surgical procedure on 201Tl uptake in the right and left ventricles was assessed. Myocardial scintigraphy was then performed as described above.

Group C. As a control for studies in the sedated state, 201Tl was injected in four additional dogs after sedation with chlorpromazine. The minimal dose of chlorpromazine (8–10 mg/kg) needed to render the dogs sedated but arousable was given. Experience in our laboratory has demonstrated that this low dosage is not associated with major hemodynamic changes. Sedated animals usually have significantly lower heart rate than anesthetized animals. Closed-chest myocardial imaging was performed in 60° and 70° LAO positions.

Acute Banding of the Pulmonary Artery (Six Dogs)

All dogs in this protocol underwent control myocardial imaging with 201Tl after sedation with chlorpromazine and 5–7 days before acute banding of the pulmonary artery. For the actual banding experiment, the dogs were anesthetized and a median sternotomy was performed. The femoral artery, left atrium and right ventercle were cannulated and baseline hemodynamic data were recorded. Aortic flow was measured with an electromagnetic flow transducer (Gould Statham) placed around the aorta. An initial left atrial injection with radioactive microspheres (51Cr) was made for baseline assessment of MBF. The pulmonary artery then was narrowed gradually with a loop of umbilical tape just above the level of the pulmonary valve. RV pressure was increased stepwise with increments of 15–20 mm Hg by tightening the loop. After each increment in pressure, the dog was allowed to stabilize for 5–10 minutes. The end point for pulmonary banding was the highest RV pressure reached without a significant decrease (less than 10%) in mean arterial pressure. When this end point was reached (usually RV pressure two to three times baseline value), the dog was allowed to stabilize for 5–10 minutes. Thereafter, 201Tl (500 μCi) was injected intravenously and myocardial imaging was performed 5 minutes later in the 60° and 70° LAO projections. These images generally provide the best separation of right and left ventricles. For the assessment of MBF after acute banding of the pulmonary artery, radioactive microspheres (85Sr or 141Ce) were injected into the left atrium. The dogs were then sacrificed.

Acute Left-to-right Atrial Shunt (Six Dogs)

Control 201Tl imaging was performed in all dogs as described above 5–7 days before the experiment. To create a left-to-right shunt, the dogs were anesthetized, a median sternotomy was performed and baseline hemodynamic variables (heart rate, arterial pressure, RV pressure and aortic flow) were measured. An initial intraatrial injection of radioactive microspheres (51Cr) was performed for assessment of baseline MBF. The right and left atria were cannulated and connected with ½-inch Tygon tubing passing through a roller pump. For each experiment, blood from a donor dog was necessary to expand circulating volume to maintain forward cardiac output. The magnitude of shunt was assessed by pulmonic:systemic blood flow ratio, determined from readings of electromagnetic flow transducers placed around the aorta and the pulmonary artery. A left-to-right atrial shunt was increased gradually by adjusting the roller pump. A rise of RV end-diastolic pressure to 8–10 mm Hg or RV systolic pressure to 35 mm Hg was considered an appropriate end point for the degree of left-to-right shunting. After hemodynamic stabilization, 201Tl was injected intravenously and myocardial imaging was performed in 60° and 70° LAO positions. Thereafter, radioactive microspheres (85Sr or 141Ce) were injected into the left atrium for assessment of MBF, after which the dogs were sacrificed.

Induction of Right Ventricular Hypertrophy (12 Dogs)

Baseline 201Tl myocardial imaging was performed after sedation with chlorpromazine. Seven days later, the dogs were anesthetized and the chest was opened under sterile surgical conditions via a left thoracotomy through the third intercostal space. The pericardium was opened to expose the aorta and pulmonary artery and the pulmonary artery was isolated by the exclusion method. After surrounding both vessels with a length of banding tape, the tape was retrieved from behind the aorta with a clamp introduced between the two major vessels, effectively encircling the pulmonary artery with the band. The left atrial appendage and the right ventercle were cannulated. Cardiac output was measured by an electromagnetic flow probe around the aorta. The band around the pulmonary
artery was then tightened gradually until RV pressure was two to three times baseline value. Aortic flow and aortic mean pressure remained within 10% of baseline.

After closure of the pericardium, the chest was closed and the dogs were allowed to recover. Imaging was repeated within 12 hours of surgical banding. Follow-up myocardial imaging was performed at 3-4 weeks in five dogs, 5-7 weeks in three dogs and at 8-12 weeks in 11 dogs after surgical banding of the pulmonary artery.

One dog was sacrificed at 2 weeks and one at 3 weeks after banding of the pulmonary artery. The other 10 dogs were sacrificed 10-12 weeks after banding. Immediately before sacrifice, after repeat thoracotomy, the heart rate, aortic pressure, aortic flow and RV pressure were recorded and radioactive microspheres (51Cr, 85Sr or 144Ce) were injected for assessment of MBF.

**Tissue Analysis**

After sacrifice, both atria were separated from the ventricles. The RV and LV free walls and the interventricular septum were weighed separately. The total ventricular myocardium was cut into pieces of approximately 1 g each. These tissue samples (usually 12 for the RV free wall, 18 for the LV free wall and five for the interventricular septum) were weighed and their specific radioactivity was measured in a well counter (Beckman). Each radionuclide was assessed independently by differential spectrometry. In the present study, all data refer to tissue measurements of the RV free wall or LV free wall. Because the septum includes myocardium common to both chambers, measurements from the septum were not included.

In this study, RV mass was compared among various groups as the RV/LV weight ratio. The MBF (ml/min) is expressed as the RV/LV ratio of total MBF or as the RV/LV ratio of MBF per gram tissue. Thallium-201 myocardial tissue activity (counts/min) is expressed as the RV/LV ratio of total 201Tl tissue activity or as the RV/LV ratio of 201Tl activity per gram tissue. Comparison of absolute 201Tl tissue activity is not meaningful because it may vary greatly among individual dogs.

**Analysis of 201Tl Images**

The 201Tl images were reviewed, graded and quantitated without knowledge of the experimental data. For logistic reasons only, 201Tl images of control group C and all images obtained in the dogs with RV hypertrophy could be acquired by computer and were stored on magnetic tape for quantitative analysis. The remaining 201Tl images (control groups A and B and the dogs with either acute banding of the pulmonary artery or left-to-right shunts) were analyzed by subjective interpretation of analog images. In these studies, RV visualization was graded as no RV, faint RV visualization or marked RV visualization.

The digitized 201Tl studies (128 × 128 matrix, word mode) were analyzed by comparing average counts per pixel in various regions of interest. Six regions of interest were chosen (fig. 1): (1) RV free wall (in control studies not showing RV visualization, this region was chosen arbitrarily as an anatomicographically appropriate area anteromedial to the septum); (2) LV free wall (the septum and apex were not included); (3) RV background (anteromedial to RV free wall); (4) LV background (along the base of the left ventricle); (5) area of right ventricle (RV free wall and RV cavity), and (6) area of left ventricle (LV free wall, septum and LV cavity). For quantitation of RV visualization and correlation with 201Tl tissue activity and degree of RV hypertrophy, the following ratios of average counts per pixel were assessed: (1) RV free wall/background; (2) RV free wall/LV free wall with and without background correction; and (3) area RV/area LV with and without background correction. The reproducibility of the assessment of count density per pixel was good: For 38 regions, the mean variability between two determinations determined on two occasions was ± 2 counts/pixel.

**Statistical Analysis**

Data are mean ± SD. Sequential data within the same group were analyzed with the paired t test. The significance of differences among different groups were analyzed using the t test. A p value < 0.05 was considered significant.

**Results**

**Control Group**

In group A, the heart rate was 150 ± 20 beats/min. Thallium-201 myocardial scintigraphy showed normal LV visualization but no, or only faint, RV visualization. Myocardial imaging with the open-chest compared with the closed-chest state revealed a slightly more vertical cardiac position and slight counterclockwise rotation of the heart. We do not believe that these differences affected interpretation of the images. The RV pressure was 25 ± 3 mm Hg and the RV end-diastolic pressure was 2 ± 1 mm Hg. Arterial systolic pressure was 135 ± 20 mm Hg. The results of tissue analysis are summarized in table 1. The RV/LV weight ratio was 0.42 ± 0.07 (range 0.36-0.52). The MBF in the right ventricle was 0.66 ± 0.17 ml/min/g and in the left ventricle, 1.13 ± 0.34 ml/min/g (p < 0.02). The ratio of RV/LV total MBF was 0.25 ± 0.07 and the ratio of RV/LV MBF per gram tissue was 0.59 ± 0.10. The RV/LV ratio of total 201Tl tissue activity was 0.30 ± 0.06. The RV/LV ratio of 201Tl activity per gram tissue was 0.71 ± 0.08.

In group B, the mean heart rate was 135 ± 22 beats/min, which is not significantly different from that in group A. The RV systolic pressure was 26 ± 3 mm Hg and RV end-diastolic pressure was 4 ± 1 mm Hg (NS compared with group A). Arterial pressure was not measured in these dogs. Myocardial imaging with 201Tl showed no or faint RV visualization, and images were comparable in all aspects to those obtained in group A. The RV/LV weight ratio was 0.44 ± 0.01. The ratio of RV/LV total 201Tl tissue activity
Acute Banding of the Pulmonary Artery

Baseline myocardial scintigraphy 1 week before the experiment in all six dogs showed no or faint visualization of the right ventricle and normal visualization of the left ventricle. Baseline heart rate at the beginning of the experiment at the time of the injection of radioactive, labeled microspheres was 157 ± 25 beats/min. Baseline RV systolic pressure was 30 ± 4 mm Hg and RV end-diastolic pressure was 2 ± 1 mm Hg. Baseline aortic systolic pressure was 138 ± 20 mm Hg (mean aortic pressure 116 ± 20 mm Hg), and aortic flow was 1.4 ± 0.2 l/min. Baseline RV MBF was 0.70 ± 0.13 ml/min/g and LV MBF was 0.92 ± 0.10 ml/min/g (p < 0.01). Baseline RV/LV ratio of MBF per gram tissue was 0.72 ± 0.09.

After banding of the pulmonary artery, a mean increase in RV systolic pressure of 2.4 ± 0.8 times baseline value was achieved. Mean RV systolic pressure was 82 ± 10 mm Hg (p < 0.001) and RV end-diastolic pressure 8 ± 4 mm Hg (p < 0.025). The heart rate (155 ± 22 beats/min), aortic systolic pressure (134 ± 20 mm Hg), aortic mean pressure (113 ± 19 mm Hg) and aortic flow (1.3 ± 0.4 l/min) were not significantly different from baseline.

Thallium-201 myocardial imaging, performed 5–15 minutes after stabilization, showed marked 201TI uptake in the right ventricle in all cases (fig. 2). These images are indistinguishable from those in dogs with established RV hypertrophy (fig. 3).

At sacrifice, RV/LV weight ratio was 0.42 ± 0.05 (NS, compared with controls). The RV MBF per gram tissue was 1.65 ± 0.59 ml/min (p < 0.01 compared with baseline), the LV MBF per gram tissue was 1.11 ± 0.41 ml/min (NS compared with baseline and compared with RV MBF after banding) (table 1).

The ratio of RV/LV total 201TI tissue activity was 0.45 ± 0.07 (p < 0.001 compared with controls). The

### Table 1. Myocardial Weight, Myocardial Blood Flow and Thallium-201 Tissue Accumulation of Right Ventricular Free Wall and Left Ventricular Free Wall (Septum excluded)

<table>
<thead>
<tr>
<th></th>
<th>Control (group A) (n = 5)</th>
<th>Left--right shunt (n = 6)</th>
<th>Acute banding (n = 6)</th>
<th>RV hypertrophy (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV/LV weight</td>
<td>0.42 ± 0.07</td>
<td>0.43 ± 0.05</td>
<td>0.42 ± 0.05</td>
<td>0.80 ± 0.14*†</td>
</tr>
<tr>
<td>RV MBF (ml/min/g)</td>
<td>0.66 ± 0.17</td>
<td>1.05 ± 0.25*</td>
<td>1.65 ± 0.59*</td>
<td>0.89 ± 0.37†</td>
</tr>
<tr>
<td>LV MBF (ml/min/g)</td>
<td>1.13 ± 0.34</td>
<td>1.20 ± 0.10</td>
<td>1.11 ± 0.41</td>
<td>1.07 ± 0.41</td>
</tr>
<tr>
<td>Total RV MBF (ml/min)</td>
<td>15 ± 4</td>
<td>28 ± 8*</td>
<td>42 ± 18*</td>
<td>53 ± 22*</td>
</tr>
<tr>
<td>Total LV MBF (ml/min)</td>
<td>67 ± 27</td>
<td>76 ± 24</td>
<td>68 ± 25</td>
<td>77 ± 31</td>
</tr>
<tr>
<td>RV/LV total MBF</td>
<td>0.25 ± 0.07</td>
<td>0.38 ± 0.13</td>
<td>0.60 ± 0.11*</td>
<td>0.67 ± 0.17*</td>
</tr>
<tr>
<td>RV/LV MBF per g</td>
<td>0.59 ± 0.10</td>
<td>0.85 ± 0.22*</td>
<td>1.42 ± 0.22*</td>
<td>0.84 ± 0.18*†</td>
</tr>
<tr>
<td>RV/LV total 201TI</td>
<td>0.30 ± 0.06</td>
<td>0.37 ± 0.04</td>
<td>0.45 ± 0.07*</td>
<td>0.59 ± 0.16*</td>
</tr>
<tr>
<td>RV/LV 201TI per g</td>
<td>0.71 ± 0.08</td>
<td>0.86 ± 0.04*</td>
<td>1.07 ± 0.20*</td>
<td>0.73 ± 0.13†</td>
</tr>
</tbody>
</table>

*Actual p values are given in text.

*Significant difference when compared with controls.

†Significant difference when compared with acute banding.

Abbreviations: RV = right ventricular; LV = left ventricular; MBF = myocardial blood flow.
ratio of RV/LV $^{201}$TI activity per gram tissue was 1.07 ± 0.20 ($p < 0.001$ compared with controls).

**Left-to-right Shunt**

Baseline myocardial scintigraphy 1 week before the experiment showed normal images in all six dogs. Baseline heart rate at the beginning of the surgical procedure 1 week later was 162 ± 11.6 beats/min. Baseline RV systolic pressure was 25 ± 5 mm Hg and end-diastolic pressure was 4 ± 1 mm Hg. Systolic aortic pressure was 142 ± 28 mm Hg (mean aortic pressure 128 ± 28 mm Hg) and aortic flow was 1.2 ± 0.21/min. Baseline RV MBF per gram tissue was 0.61 ± 0.09 ml/min, and LV MBF per gram tissue was 0.83 ± 0.11 ml/min. The ratio of RV/LV total MBF was 0.30 ± 0.04 and the ratio of RV/LV MBF per gram tissue was 0.72 ± 0.03.

The average magnitude of pulmonic/systemic flow ratio achieved with the left-to-right shunt was 2.8 ± 0.7:1. After hemodynamic stabilization, the heart rate (153 ± 13 beats/min), aortic systolic pressure (130 ± 30 mm Hg), mean aortic pressure (113 ± 33 mm Hg) and aortic flow (1.0 ± 0.1 l/min) were not significantly changed from baseline. The RV systolic pressure was 33 ± 3 mm Hg (p < 0.01 compared with baseline) and RV end-diastolic pressure was 7 ± 3 mm Hg (p < 0.01 compared with baseline).

The right ventricle was visualized by thallium-201 myocardial imaging 5–15 minutes after the stabilization period, but not to the same degree as in the dogs that underwent acute banding of the pulmonary artery. At sacrifice, the RV/LV weight ratio was 0.43 ± 0.05 (NS compared with controls). The RV MBF per gram tissue (table I) had increased to 1.05 ± 0.25 ml/min ($p < 0.005$ compared with baseline; $p < 0.025$ compared with controls; NS compared with acute banding of the pulmonary artery). The LV MBF per gram tissue was 1.20 ± 0.10 ml/min (p < 0.001 compared with baseline; NS compared with RV MBF during left-to-right shunt; NS compared with RV MBF after acute banding of the pulmonary artery).

The ratio of RV/LV total MBF was 0.38 ± 0.13 (NS compared with controls and baseline). The ratio of RV/LV MBF per gram tissue was 0.85 ± 0.22 ($p < 0.001$ compared with baseline; $p < 0.05$ compared with controls). The ratio of RV/LV total $^{201}$TI tissue activity was 0.37 ± 0.04. This is not significantly different (NS) from control, but less ($p < 0.005$) than after acute pulmonary artery banding. The ratio of RV/LV $^{201}$TI myocardial uptake per gram tissue was 0.86 ± 0.04. This is greater ($p < 0.005$) than that in controls, but less ($p < 0.005$) than that after acute pulmonary artery banding.

**Right Ventricular Hypertrophy**

Baseline myocardial imaging with $^{201}$TI showed normal images in all 12 dogs. At the beginning of the surgical procedure 1 week later, all dogs had normal hemodynamics: heart rate 136 ± 26 beats/min, RV systolic pressure 27 ± 8 mm Hg, aortic systolic pressure 135 ± 14 mm Hg and aortic mean pressure 121 ± 12 mm Hg. After the banding of the pulmonary artery, a mean increase of 2.1 ± 0.9 times baseline RV systolic pressure was achieved (NS compared with acute pulmonary artery banding). Mean RV systolic pressure increased to 53 ± 24 mm Hg ($p < 0.005$ compared with baseline; NS compared with acute banding group). After banding, heart rate (139 ± 28 beats/min), aortic systolic pressure (132 ± 34 mm Hg) and mean aortic pressure (117 ± 25 mm Hg) were not significantly different from baseline values.

Myocardial imaging with $^{201}$TI within 12 hours of pulmonary artery banding showed marked RV visualization in all dogs (fig. 3). Quantitative analysis (fig. 4) of the images revealed a background-corrected RV/LV count ratio of 0.66 ± 0.11 (compared with 0.19 ± 0.06 at baseline, $p < 0.001$). The RV free wall-to-background ratio was 1.9 ± 0.2 (compared with 1.2 ± 0.1 at baseline, $p < 0.001$).

Repeat imaging during the follow-up period showed marked RV visualization in all dogs. In fact, at any time after banding (fig. 3) and at sacrifice, the degree of RV visualization was strikingly similar. Quantitative analysis of the images obtained at intermediate studies showed that the background-corrected RV/LV count ratio was 0.73 ± 0.13 at 3–4 weeks, and 0.61 ± 0.05 at 5–7 weeks after banding (NS). The RV free wall-to-background ratio at two intermediate studies was 2.0 ± 0.2 (fig. 4).

At the time of sacrifice, background corrected RV/
LV count ratio was 0.66 ± 0.12 (NS compared with intermediate studies) and RV free wall-to-background ratio was 1.9 ± 0.2 (NS compared with intermediate studies).

RV systolic pressure before sacrifice was 37.6 ± 10 mm Hg (NS compared with pressure measured shortly after banding). This slight decrease in pressure over time may have resulted from resorption of fat tissue.

**Figure 3.** Serial thallium-201 (201TI) myocardial imaging in a dog with experimental right ventricular (RV) hypertrophy. At baseline (top left), the left ventricle is normally visualized, but the right ventricle is only faintly visible. Four hours after banding of the pulmonary artery (top middle), the right ventricle is clearly visualized. On subsequent 201TI images, obtained at 3, 5, 9 and 10 weeks after banding, the degree of 201TI RV visualization remains essentially the same. The ratios of RV free wall to RV background counts (RV/bkg) and of background-corrected RV free wall to LV free wall counts (RV/LV) are given for each of the images (see text). On sacrifice, 10 weeks after banding of the pulmonary artery, marked RV hypertrophy was present, and the RV/LV weight ratio was 0.77.

**Figure 4.** Serial quantitative analysis of thallium-201 (201TI) myocardial images in 12 dogs with experimental right ventricular (RV) hypertrophy. The ratios (mean ± sd) of RV free wall to RV background counts (RV/bkg) and background-corrected RV free wall to left ventricular free wall counts (RV/LV) are given. Shortly after banding and during the follow-up, RV/bkg and RV/LV count ratios both are significantly increased compared with baseline (p < 0.001). The values after banding are not significantly different from each other.
surrounding the pulmonary artery, which gradually reduced the induced pressure gradient despite the fixed length of the band itself.

Aortic systolic pressure was 135 ± 25 mm Hg and mean aortic pressure was 115 ± 21 mm Hg, which are not different from values before banding (NS).

At sacrifice, all dogs (including those sacrificed at 2 and 3 weeks after surgical banding) had marked RV hypertrophy. The RV/LV weight ratio (table 1) was 0.80 ± 0.14 (p < 0.001 vs control).

The RV MBF per gram tissue was 0.89 ± 0.37 ml/min in the hypertrophied ventricles, compared with 0.66 ± 0.17 ml/min/g in controls (NS) and 1.65 ± 0.59 ml/min/g shortly after acute banding of the pulmonary artery (p < 0.001). The LV MBF per gram tissue was 1.07 ± 0.41 ml/min in the dogs with RV hypertrophy, compared with 1.13 ± 0.34 ml/min/g in controls (NS) and 1.10 ± 0.41 ml/min/g after acute banding (NS).

Total RV free wall MBF in hypertrophied ventricles was 53 ± 2.2 ml/min, compared with 15 ± 4 ml/min in controls (p < 0.005). Total LV free wall MBF in dogs with hypertrophy was 77 ± 31 ml/min, compared with 67 ± 27 ml/min in controls (NS).

The ratio of RV/LV total MBF in dogs with RV hypertrophy was 0.67 ± 0.17, compared with 0.25 ± 0.07 in controls (p < 0.001) and 0.60 ± 0.11 in acute banding of the pulmonary artery (NS). The ratio of RV/LV total MBF correlated well (r = 0.83) with the RV/LV weight ratio.

The ratio of RV/LV MBF per gram tissue was 0.84 ± 0.18 in RV hypertrophy, compared with 0.59 ± 0.10 in controls (p < 0.025) and 1.42 ± 0.22 in acute banding of the pulmonary artery (p < 0.001).

The ratio of RV/LV total 201TI tissue activity was 0.59 ± 0.16 in RV hypertrophy, compared with 0.30 ± 0.05 in controls (p < 0.001) and 0.45 ± 0.07 after acute banding of the pulmonary artery (NS) and correlated fairly (r = 0.77) with RV/LV total MBF ratio.

The ratio of RV/LV total 201TI activity per gram tissue was 0.73 ± 0.13 in the hypertrophied ventricle, compared with 0.70 ± 0.11 in controls (NS) and 1.07 ± 0.20 in acute banding of the pulmonary artery (p < 0.001).

A similar degree of RV visualization was noted in 201TI images obtained under conditions of acutely increased RV MBF and of increased RV mass; thus, we compared the product of RV MBF and RV mass with total RV 201TI tissue activity.

The product of RV/LV weight ratio and RV/LV ratio of MBF per gram tissue (which reflects total RV/LV MBF) and RV/LV ratio of total tissue 201TI activity are not significantly different in RV hypertrophy and after acute banding of the pulmonary artery (fig. 5). This emphasizes that total RV/LV MBF is the most important pathophysiologic correlate of RV 201TI visualization.

The RV/LV weight ratio correlated well (r = 0.91) with the ratio of RV/LV total 201TI tissue activity in 25 dogs (13 control dogs and 12 dogs with RV hypertrophy) (fig. 6). Thus, the degree of RV hypertrophy could be predicted from measuring 201TI tissue activity. Of the approaches to quantitate RV visualization in 201TI myocardial images, only background-corrected RV/LV count ratio showed a fair correlation with both total RV/LV 201TI tissue activity ratio (r = 0.77) and RV/LV weight ratio (r = 0.77). For other quantitative analyses, the correlation was poor: RV free wall-to-background ratio, r = 0.66; uncorrected RV/LV free wall ratio, r = 0.42; area RV/area LV count ratio, r = 0.33; background-corrected area RV/area LV count ratio, r = 0.52.

Discussion

The present study demonstrates that RV visualization by 201TI myocardial imaging is determined by RV MBF and RV myocardial mass and therefore by total RV MBF. An acute increase of RV work load by either pressure or volume loading resulted in a substantial increase in RV MBF (table 1). This response has been documented by others in experimental models.7-12 The acute increase of RV MBF thus resulted in a sufficient increase of 201TI uptake in the RV to allow RV visualization in myocardial images. The increase in RV MBF and 201TI tissue accumulation was more pronounced in pressure than in volume overload, a finding consistent with previous observations.4, 6, 12 Serial myocardial imaging after banding of the pulmonary artery during the development of RV hypertrophy revealed very similar visualization of the right ventricle at any time after surgery. Consistent with these similar 201TI images is that the product of RV/LV MBF per gram tissue and RV/LV weight (i.e., the ratio of RV/LV total MBF) and RV/LV ratio of total 201TI tissue accumulation were similar after acute banding of the pulmonary artery and after establishment of RV hypertrophy (fig. 5).

Murray et al.13, 14 reported RV MBF per gram tissue to be increased in RV hypertrophy. In our study, the dogs with RV hypertrophy had higher RV MBF per gram tissue, although this did not reach statistical significance. However, total RV MBF in these dogs was increased markedly compared with controls. Thus, at the two ends of the continuum, from acute banding to RV hypertrophy, either increased MBF or increased mass appears to be the predominant mechanism for increased 201TI uptake. At intermediate points there probably is a combined effect induced by both mechanisms.

An excellent correlation existed between the degree of RV hypertrophy and the total amount of 201TI accumulated in the myocardium (r = 0.91). Rabinovitch et al.15 reported a similar excellent correlation in rats with hypobaric hypoxia-induced RV hypertrophy. However, as our study demonstrates, tissue data do not necessarily apply fully to scintigraphic images. The correlation between the degree of RV hypertrophy at postmortem examination and quantification of the visualization of the right ventricle in 201TI images in vivo was, at best, only fair (r = 0.77). Therefore, in individual dogs with RV hypertrophy, no reliable prediction of the amount of RV hyper-
trophy is possible. Apparently, although the total tissue $^{201}$TI accumulation closely correlates with total myocardial mass, complex factors involved in the generation of scintigraphic images do not allow extra-

**Figure 5.** Comparison of total right ventricular (RV) myocardial blood flow (MBF) and total RV thallium-201 ($^{201}$TI) tissue accumulation in control dogs (group A) and dogs with a left-to-right shunt, acute banding of the pulmonary artery and with RV hypertrophy (RVH).

For comparison, RV/left ventricular (LV) ratios are used. The product of RV/LV MBF/g and RV/LV weight (mass) represents RV/LV total MBF. No significant difference exists for RV/LV total MBF and RV/LV total tissue $^{201}$TI in acute banding of the pulmonary artery and in dogs with experimental RVH.

**Figure 6.** Correlation between the degree of right ventricular hypertrophy (RVH) (right ventricular/left ventricular [RV/LV] weight ratio) and amount of RV thallium-201 ($^{201}$TI) tissue accumulation (RV/LV total tissue $^{201}$TI).

Analyzing the quantitative data, the best correlation between actual RV hypertrophy and count-density ratios in $^{201}$TI images existed for background-corrected RV/LV free wall count rate ratio and the RV free wall-to-background count rate ratio. A count rate ratio higher than 0.5 and 1.5, respectively, indicated the presence of an increased RV work load or RV hypertrophy (fig. 4).

Clinically, visualization of the RV on resting $^{201}$TI
myocardial images has been recognized as abnormal and has been reported in a variety of congenital and acquired heart diseases resulting in increased RV work load. It has been proposed that $^{201}$TI imaging might provide an early and sensitive noninvasive method to detect RV overload and RV hypertrophy. This would be of particular clinical importance because the ECG and chest x-ray are relatively insensitive in detecting RV hypertrophy. Promising results have been reported using echocardiographic techniques for determination of RV wall thickness.16, 17 However, particularly in patients with chronic obstructive pulmonary disease, the clinical reliability of these techniques may be limited by attenuation of echo signals by interposition of lung tissue. Cohen et al.8 reported 18 patients with marked RV visualization in patients with pulmonary hypertension. However, no good correlation existed between the level of pulmonary artery hypertension and the intensity of RV $^{201}$TI uptake. Khaja et al.9 and Kondo et al.4 further extended these observations in patients with pressure and volume overload of the RV. Although both studies indicated that RV visualization on a resting $^{201}$TI study generally occurs in the presence of elevated RV systolic pressure, no direct relationship appeared between the degree of RV hypertrophy and the intensity of RV visualization. Although some patients with minimal RV hypertrophy showed marked RV visualization, other patients with severe hypertension showed considerably less intense RV visualization. Our results explain these clinical results. RV MBF, RV myocardial mass and physical factors involved in myocardial imaging are equally important in the resulting myocardial image. For appropriate clinical interpretation of resting RV $^{201}$TI visualization, the clinical and physiologic status of the patient must be considered. If there is clinical evidence of a recent increase of RV work load, as may occur in pulmonary embolism or acute cor pulmonale, $^{201}$TI RV visualization may be due predominantly to an increase of RV MBF. In contrast, in stable patients, resting RV visualization probably represents RV hypertrophy.

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