The Use of an Oxicmetrically Determined Circulation Time from the Right Ventricle to the Ear in Congenital Heart Disease

By Richard P. Lasser, M.D., Alvin J. Gordon, M.D., Raymond Borun, M.D., and Frederick H. King, M.D.

Evans Blue (T-1824) was injected into the right ventricle through a cardiac catheter and the time of the arrival of dye at the ear was measured with an oximeter. This circulation time appeared to indicate reliably the presence of venoarterial shunting through an over-riding aorta. The difficulties ordinarily encountered in positive identification of this defect are discussed. The importance of the identification, particularly with regard to the differential diagnosis between tetralogy of Fallot and pulmonary stenosis with an interatrial communication, is stressed.

The TIME interval between the injection of dye into the right ventricle and its detection in the capillaries of the ear by an oximeter was measured in 18 individuals during the course of cardiac catheterization. This test of circulation time was designed as a supplement to the cardiac catheterization of patients with congenital heart disease in order to assist in the identification of over-riding aorta. It was anticipated that the short circuit of the lung and left heart circulation which resulted from the venoarterial shunting would be detectable as a shortened "circulation time."

In all previous investigations of the circulation time in congenital heart disease, the test substance was injected into a peripheral vein. Using such a technic, abnormally rapid arrival of the test substance at the point of detection was frequently demonstrated. However, there was equally frequent failure to demonstrate shunts in patients who had marked arterial unsaturation. Moller, for example, in a study using fluorescein, reported that a shortened dye arrival time was observed in only 7 of 18 patients with tetralogy of Fallot. Moreover, the problem of the localization of the site of the shunt, which is the chief diagnostic concern, is not solved even by the finding of a rapid arrival time. This same difficulty applies to all technics in which substances are injected into a peripheral vein, angiocardiography included. Rapid visualization of the aorta, even if simultaneous with that of the pulmonary artery, cannot be considered positive proof of over-riding of the aorta, as will be subsequently demonstrated.

The importance of a clear distinction between cases of venoarterial shunt due to defective interatrial septum accompanied by pulmonic stenosis and those due to tetralogy of Fallot lies in the fact that the operative procedure of choice at present is valvulotomy in the former and the Blalock-Taussig procedure in the latter. This consideration was the reason for the selection of the right ventricle as the site of release of the dye.

Technic

The 18 subjects in whom the test was performed were, with one exception, patients suspected or known to have congenital heart disease. The sole exception was an adult with normal cardiovascular dynamics who was catheterized as part of a study of cardiac output and renal function.

The earpiece of a Millikan-type oximeter was fastened to the patient's ear at the time when the cardiac catheter (No. 6F or 7F) lay in the right ventricle at the tricuspid orifice. The location of the catheter was always confirmed by fluoroscopy and pressure tracings. When the ear was sufficiently warmed to insure adequate vasodilation, rapid injection of a 0.5 per cent aqueous solution of Evans Blue (T-1824) was made through the catheter. Three cc. of dye were used in children and 5 in adults. A stopwatch was started at the beginning

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of injection and was stopped at the first perceptible
deflection of the oximeter galvanometer. The total
time consumed was taken as the circulation time.
This included the time for passage of the dye through
the catheter which was estimated by tests outside
the body to be about 0.75 to 1.0 second. The pro-
cedure was simple to perform, did not interfere
with the progress of the catheterization, and gave
sharp endpoints.
The relation between the initial galvanometric
deflection and the appearance of dye as determined
by an arterial concentration curve is not known.

The results are therefore arranged in order of increasing
circulation time (table 1). The table also shows the
age, heart rate during the catheterization,
arterial oxygen concentration and the clinical
diagnosis.
The first five cases all show circulation times
under 5 seconds, the average of the five being
4.0 seconds. All of these children were cyanotic.
Four of the five were thought to have tetralogy

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Name</th>
<th>Age</th>
<th>Heart Rate</th>
<th>Arterial Oxygen Saturation</th>
<th>Circulation Time</th>
<th>Diagnosis:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>J. G.</td>
<td>5</td>
<td>96</td>
<td>70</td>
<td>3.5</td>
<td>Eisenmenger's complex with interatrial septal defect</td>
</tr>
<tr>
<td>2</td>
<td>G. L.</td>
<td>6</td>
<td>120</td>
<td>82.5</td>
<td>3.5</td>
<td>Tetralogy of Fallot</td>
</tr>
<tr>
<td>3</td>
<td>A. M.</td>
<td>2½</td>
<td>120</td>
<td>77.6</td>
<td>4.0</td>
<td>Tetralogy of Fallot with interatrial septal defect and right aortic arch</td>
</tr>
<tr>
<td>4</td>
<td>S. B.</td>
<td>8½</td>
<td>90</td>
<td>89</td>
<td>4.4</td>
<td>Tetralogy of Fallot</td>
</tr>
<tr>
<td>5</td>
<td>M. D.</td>
<td>3½</td>
<td>110</td>
<td>visibly cyanotic</td>
<td>4.7</td>
<td>Tetralogy of Fallot</td>
</tr>
<tr>
<td>6</td>
<td>C. R.</td>
<td>3</td>
<td>110</td>
<td>87.3</td>
<td>5.3</td>
<td>Lutembacher's syndrome</td>
</tr>
<tr>
<td>7</td>
<td>S. L.</td>
<td>19</td>
<td>90</td>
<td>90.3</td>
<td>5.5</td>
<td>Isolated pulmonary stenosis</td>
</tr>
<tr>
<td>8</td>
<td>C. B.</td>
<td>11</td>
<td>90</td>
<td>96.3</td>
<td>6.0</td>
<td>Patent ductus arteriosus</td>
</tr>
<tr>
<td>9</td>
<td>M. D.</td>
<td>32</td>
<td>100</td>
<td>59.8</td>
<td>6.0</td>
<td>Pulmonary stenosis with interatrial septal defect</td>
</tr>
<tr>
<td>10</td>
<td>G. K.</td>
<td>13</td>
<td>105</td>
<td>97.0</td>
<td>6.2</td>
<td>Normal with prominent pulmonary artery</td>
</tr>
<tr>
<td>11</td>
<td>R. P.</td>
<td>12</td>
<td>90</td>
<td>100</td>
<td>7</td>
<td>Normal with prominent pulmonary artery</td>
</tr>
<tr>
<td>12</td>
<td>M. A.</td>
<td>11</td>
<td>115</td>
<td>95.7</td>
<td>7</td>
<td>Pulmonary stenosis with interatrial septal defect</td>
</tr>
<tr>
<td>13</td>
<td>M. H.</td>
<td>8</td>
<td>80</td>
<td>93.4</td>
<td>7</td>
<td>Subaortic stenosis</td>
</tr>
<tr>
<td>14</td>
<td>S. D.</td>
<td>6</td>
<td>85</td>
<td>98.1</td>
<td>9</td>
<td>Isolated pulmonary stenosis</td>
</tr>
<tr>
<td>15</td>
<td>E. G.</td>
<td>6½</td>
<td>100</td>
<td>93</td>
<td>9</td>
<td>Patent ductus arteriosus</td>
</tr>
<tr>
<td>16</td>
<td>L. G.</td>
<td>19</td>
<td>70</td>
<td>92.6</td>
<td>9.5</td>
<td>Isolated pulmonary stenosis</td>
</tr>
<tr>
<td>17</td>
<td>V. D.</td>
<td>30</td>
<td>80</td>
<td>99</td>
<td>9.5</td>
<td>Pulmonary stenosis with interatrial septal defect</td>
</tr>
<tr>
<td>18</td>
<td>E. W.</td>
<td>40</td>
<td>70</td>
<td>no cyanosis</td>
<td>10</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Therefore, the values recorded probably do not
represent the true minimum circulation time. They
merely represent the apparent minimum dye ap-
pearance time which is dependent upon the sensi-
tivity and speed of response of the detecting in-
strument used. Since the instrument was always the
same, values within this series are comparable but
comparisons with values obtained with other in-
struments or technics would be hazardous.

**Results**

The purpose of the study was to determine
whether a reliable abbreviation of the circula-
tion time could be detected in patients believed
to have an over-riding aorta. This diagnosis was based upon the
clinical findings, cardiac fluoroscopy, angio-
cardiographic appearance and the data ob-
tained by cardiac catheterization. As indicated
previously, direct and positive proof of over-
riding aorta is lacking because in no case did
the catheter enter the aorta from the right
ventricle, and no child has died and come to
postmortem examination. One child (A. M.,
case 3) was operated upon by Drs. Gabriel
Seley and Arthur S. W. Touroff who performed
a Blalock-Taussig anastomosis, with marked
clinical improvement. The fifth child of this
group furnished indirect proof of over-riding aorta. The catheter, in this patient, passed through an atrial septal defect into the left atrium and left ventricle. The oxygen saturation of blood in the left ventricle was 90.8 per cent while that of the femoral artery was 70.4 per cent, demonstrating that a large veno-arterial shunt existed which was distal to the left ventricle, that is, an over-riding aorta. (J. G., case 1). \(^6\)

None of the remaining 13 patients was believed to have over-riding of the aorta. This belief was based on the clinical findings, the angiocardiographic visualization of the heart and on the absence of arterial unsaturation or visible cyanosis in 11 of the 13. Of the two patients in whom arterial unsaturation was found, one came to postmortem examination (M. D., case 9) and will be discussed later. The other (C. R., case 6) was a child with Lutembacher's syndrome whose heart was large with a large pulsatile pulmonary artery and increased vascular markings. Catheterization disclosed the presence of an atrial septal defect and normal pressures within the right ventricle and pulmonary artery. Over-riding of the aorta was excluded, therefore, because of the absence of hypertension within the right ventricle. \(^6\)

The patient who came to postmortem examination was one who presented the very problem in differential diagnosis which is at the basis of this study. Cardiac catheterization showed the presence of an atrial septal defect, pulmonary stenosis and marked elevation of pressure within the right ventricle. Arterial unsaturation was present. Angiocardiographic study, performed by Dr. Sigmund A. Brahms, demonstrated the presence of Diodrast within all chambers of the heart, the pulmonary artery and aorta within 1.2 seconds after injection. The consensus was that the amount of Diodrast present in the aorta was greater than could be accounted for by the opacity of the left atrium and ventricle. Therefore it was believed that an over-riding aorta did exist. The patient died some time later and postmortem examination revealed the presence of an atrial septal defect and marked valvular pulmonary stenosis. The interventricular septum was closed and no over-riding of the aorta could be demonstrated.

It was deemed probable that no over-riding aorta existed in any member of this group in which the circulation time was greater than 5 seconds. The values ranged from 5.3 to 10 seconds with an average of 7.4 seconds. The average circulation time of this random group of patients who probably did not have over-riding aorta was then 1.8 times as long as the average of the group with over-riding aorta. Moreover, there was no overlap between the shortest time of this patient group (5.3 seconds) and the longest time of the initial group (4.7 seconds).

### Table 2.—Comparison of Three Patients with Over-riding Aorta (Group I) with Three Children of Similar Ages without This Anomaly (Group II)

<table>
<thead>
<tr>
<th>Age</th>
<th>Circulation Time</th>
<th>Heart Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>I II</td>
<td>I II</td>
</tr>
<tr>
<td>J.G. 5</td>
<td>S.D. 6</td>
<td>3.5 9</td>
</tr>
<tr>
<td>G.L. 6</td>
<td>E.G. 6½</td>
<td>3.5 9</td>
</tr>
<tr>
<td>S.B. 8½</td>
<td>M.H. 8</td>
<td>4.4 7</td>
</tr>
<tr>
<td>Average.</td>
<td>6.5</td>
<td>6.8</td>
</tr>
</tbody>
</table>

The patients in this latter group however, were, on the average, much older than those in the initial group. This fact raised some question about whether the two groups were really comparable and therefore whether the observed difference of circulation time was attributable to venoarterial shunting or merely to the difference in age. To eliminate the age factor, table 2 was drawn up comparing three children of similar ages in both groups. The disparity between the average of the circulation times was even more marked than that observed when both entire groups were compared.

There is one further factor to be considered and that is the influence of heart rate. The average rate in the initial group of five patients is 106, while that in the later group is 91 beats per minute. It is felt that this difference is not large enough to be significant. Furthermore, in a more basic sense the circulation
time has been shown to depend upon only two factors, which are the minute output of the heart (cardiac output) and the active volume of blood between the points of injection and detection.\textsuperscript{7,8} Since the heart rate may reflect a true difference in cardiac output, this factor cannot be completely discounted in evaluating these results.

**Summary and Conclusions**

The problem of the identification of venoarterial shunting in congenital heart disease through an over-riding aorta was approached by determination of the circulation time from the right ventricle to the ear. The test was performed during cardiac catheterization and consisted in measuring the time interval between the injection of dye (T-1824) into the right ventricle and its detection in the capillaries of the ear by an oximeter. Eighteen patients were studied. Diagnostic study strongly indicated the probability that an over-riding aorta existed in five of the 18 patients. There was reasonable assurance that no over-riding of the aorta was present in the remaining 13 patients. The average of the circulation times of the first group was 4.0 seconds, with a range of 3.5 to 4.7 seconds. The average of the second group was 7.4 seconds, with a range of 5.3 to 10 seconds. There was thus a considerable difference between the average values in the two groups, and no overlapping of individual values. The factors of age and heart rate probably did not impair the validity of the comparison between the two groups. The importance of localizing the site of venoarterial shunting to an over-riding aorta was discussed as well as the difficulties involved. It is therefore suggested that the finding of a circulation time from the right ventricle to the ear of less than 5 seconds (using the described technic) is strong evidence of a venoarterial shunt through an over-riding aorta. However, final validation of these findings will depend upon future experience with the technic and confirmation from postmortem examinations.

**Addendum**

A short while after this paper had been submitted for publication, another similar study was reported which was directed toward the same purpose but used a somewhat different technic. The findings were generally consistent with ours.\textsuperscript{10}

**References**

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