Direct-Reflection Oximetry in Routine Cardiac Catherization

By K. K. Bossina, M.D., G. A. Mook, M.D., and W. G. Zijlstra, M.D.

Earl H. Wood was the first to stress the desirability of immediate oxygen saturation readings during diagnostic cardiac catheterization.\(^1,2\) The direct availability of oxygen saturation values together with pressure tracings and fluoroscopy leads to a more dynamic catheterization, in which each step is partially determined by the data already obtained. During the last 3 years we have been using a reflection cuvette oximeter providing immediate saturation values in some 200 cardiac catheterizations. This type of direct oximetry proved to be a remarkable asset. It simplified diagnosis, saved much work, and reduced blood loss to a negligible minimum. After a brief outline of apparatus and methods and a short survey of our results, this paper presents a discussion of selected cases in which direct oximetry provided a quick and accurate diagnosis, whereas the conventional sample methods most probably would have failed to yield the necessary information.

Principles and Methods

All photometric methods for determination of the oxygen saturation of blood are based on the difference in light absorption between hemoglobin and oxyhemoglobin: in the spectral range of 600 to 700 m\(\mu\) hemoglobin absorbs much more light than oxyhemoglobin does. Most oximetric methods\(^3-6\) measure variations in light transmission; Brinkman and Zijlstra\(^7\) in 1949 started measuring light reflection and developed a number of oximetric methods based on this principle.\(^8\) The main advantage of this approach is that light reflection is under certain conditions largely independent of the total hemoglobin concentration of the blood and thus is, within certain limitations, solely dependent on one variable, the oxygen saturation. Therefore reflection methods can be 1-color methods.

The CC oximeter\(^9\) is a reflection oximeter that is especially designed for cuvette oximetry during cardiac catheterization.\(^8-10\) The catheter is connected to a small luette cuvette. Half of this is filled with india ink and the other, entirely separate half receives the blood from the catheter. Rouleaux formation of the erythrocytes, which influences light reflection is prevented by a small magnetically driven stirring rod in the blood compartment. A reflectometer piece fits over the cuvette and may be alternately shifted over the black india ink part or over the blood sample just withdrawn through the catheter. The reflectometer is connected to a galvanometer (fig. 1) on which the scale has been calibrated in per cent oxygen saturation. The immediate readings give an exact indication of the differences in oxygen saturation between the samples and a fair approximation of the absolute values. After analysis of one or more samples by another method (Van Slyke's manometric method, spectrophotometric methods, hemoreflector\(^5\)) the instantaneously obtained oxygen saturation values can later be converted into absolute values by simple addition or subtraction.

The oximeter cuvette is sterilized in a 1 per cent cetyltrimethylammonium bromide solution; just before connecting the cuvette to the catheter, it is flushed with sterile saline solution. We did not encounter any untoward effects (including febrile reactions) that could be traced to the use of the cuvette.

For each measurement (1) blood is drawn into the cuvette, (2) the stirring device is started, (3) the galvanometer is read, (4) the blood is reintroduced into the patient or stored in a syringe for analysis by other methods, (5) the cuvette is flushed with saline solution containing some heparin (10 mg./L), and (6) the stirring motor is switched off. The entire procedure takes less than a minute.

The accuracy of the instrument is sufficient for clinical purposes. For a total of 228 measurements with 3 different CC oximeters, the standard deviation of the differences between the CC oximeter and the control instrument (hemoreflector,\(^8\) spectrophotometer) was calculated at 1.68 per cent oxygen saturation.\(^9\) No systematic difference was found.

The presence of the oximeter cuvette between

*Kipp and Sons Company, Delft, Netherlands.
the catheter and the pressure transducer (fig. 1) has no influence on the shape or magnitude of the pressure curves.

Right heart catheterization was performed under light thiopental anesthesia; a conventional Courand catheter, no. 6 or 7, was introduced through the great saphenous vein. The adjacent femoral artery was prepared and punctured under direct vision with a needle catheter especially designed for this purpose.10, 11

Results

From September 1956 to October 1959 direct oximetry was used in 195 cardiac catheterizations of infants and children, ranging from 3 months to 13 years of age. The average number of oxygen saturation readings per catheterization was about 15; in some cases 20 or more readings were made.

In nearly 70 per cent of our cases some type of shunt between the pulmonary and the systemic circuits could be demonstrated during catheterization. In the remainder the existence of a hemodynamically significant shunt was excluded by the oximetric data.

The following 6 cases have been selected because of the highly important part played by direct oximetry in the elucidation of an accurate and complete diagnosis. The catheterization data of these patients are presented in table 1.

Abstracts of Cases

Case 1


Case 2


Case 3

A. H., a 2-year-old girl. Dyspnea on exertion, easy fatigue, and recurrent respiratory infections. Right ventricular impulse. Thrill at lower left sternal border. First heart sound normal, second heart sound slightly accentuated, third heart sound at apex; grade-IV systolic murmur in second and third left intercostal spaces, radiating to the back;
### Catheterization Data of Six Cases

<table>
<thead>
<tr>
<th>Case</th>
<th>FA</th>
<th>IVC</th>
<th>SVC</th>
<th>RA</th>
<th>RV</th>
<th>PA</th>
<th>PV</th>
<th>LA</th>
<th>LV</th>
<th>Aorta</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. G.R. F 10 Pulmonary veins draining into SVC</td>
<td>pressure (mm. Hg)</td>
<td>115/60</td>
<td>4/1</td>
<td>5/1</td>
<td>4/1</td>
<td>27/0</td>
<td>20/6</td>
<td>10/6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>% O₂ sat.</td>
<td>97 near RA 75</td>
<td>high 77, 77, 78 low 82</td>
<td>near RA 95, 94</td>
<td>81</td>
<td>81, 81</td>
<td>RPA 81</td>
<td>97 (draining into SVC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. C.V. F 8 Cerebral AV shunt, patent ductus arteriosus</td>
<td>pressure (mm. Hg)</td>
<td>100/65</td>
<td>3/-2</td>
<td>4/0</td>
<td>3/-2</td>
<td>35/0</td>
<td>35/7</td>
<td>100/55</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>% O₂ sat.</td>
<td>99</td>
<td>84</td>
<td>96</td>
<td>92, 92</td>
<td>91, 92</td>
<td>conus 93</td>
<td>RPA 92</td>
<td>99 (via patent ductus)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RJV 94, 97</td>
<td>LJV 96</td>
<td>RSV 76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. A.H. F 2 Sinus venous variety of atrial septal defect</td>
<td>pressure (mm. Hg)</td>
<td>85/40</td>
<td>4/-2</td>
<td>4/-2</td>
<td>5/-2</td>
<td>50/0</td>
<td>35/7</td>
<td>10/0</td>
<td>10/0</td>
<td>100/0</td>
</tr>
<tr>
<td></td>
<td>% O₂ sat.</td>
<td>98</td>
<td>79</td>
<td>high 67</td>
<td>high 97</td>
<td>TV 88</td>
<td>conus 89</td>
<td>RPA 89</td>
<td>99 (via ASD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>lower 71</td>
<td>TV 87</td>
<td>mid 87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. M.W. M 1½ Ventricular septal defect</td>
<td>pressure (mm. Hg)</td>
<td>80/65</td>
<td>5/-2</td>
<td>6/-4</td>
<td>4/-7</td>
<td>65/0</td>
<td>65/30</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>% O₂ sat.</td>
<td>99</td>
<td>80</td>
<td>high 66, 66</td>
<td>mid 70, 71, 69</td>
<td>TV 91, 94</td>
<td>conus 88</td>
<td>wedge 20/0</td>
<td>LPA 88</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>near RA 68, 69</td>
<td>low 72</td>
<td>TV 68, 70, 72</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. P.O. M 5 mo. Atrial septal defect, ventricular septal defect</td>
<td>pressure (mm. Hg)</td>
<td>95/55</td>
<td>0/-5</td>
<td>1/-3</td>
<td>0</td>
<td>60/0</td>
<td>55/15</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>% O₂ sat.</td>
<td>95</td>
<td>73</td>
<td>high 70</td>
<td>mid 75</td>
<td>TV 83</td>
<td>conus 91</td>
<td>RPA 91</td>
<td>LPA 92</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>near RA 68</td>
<td>TV 76</td>
<td></td>
<td>TV 83</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. K.d.W. F 4 Complete transposition of great vessels</td>
<td>pressure (mm. Hg)</td>
<td>90/75</td>
<td>5/2</td>
<td>6/2</td>
<td>5/-1</td>
<td>90/0</td>
<td>30/10</td>
<td>15/10</td>
<td>8/5</td>
<td>38/0</td>
</tr>
<tr>
<td></td>
<td>% O₂ sat.</td>
<td>75</td>
<td>70</td>
<td>66, 65</td>
<td>75</td>
<td>mid 76</td>
<td>conus 94, 94</td>
<td>100</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TV 74, 75</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Abbreviations:** FA, femoral artery; IVC, inferior vena cava; SVC, superior vena cava; RA, right atrium; RV, right ventricle; PA, pulmonary artery; PV, pulmonary vein; LA, left atrium; LV, left ventricle; RJV, right jugular vein; LJV, left jugular vein; RSV, right subclavian vein; TV, tricuspid valve; RPA, right pulmonary artery; LPA, left pulmonary artery; ASD, atrial septal defect.
grade-II diastolic murmur at apex. Electrocardiogram: slight right ventricular hypertrophy. Radiologic findings: right atrium enlarged, pulmonary vascular engorgement, hilar dance. Diagnosis: sinus venosus variety of atrial septal defect.

Case 4

Case 5
P. O., a 5-month-old boy. Tired and dyspneic at feedings. Recurrent respiratory infections. Dyspnea at rest. Thrill at lower left sternal border. Left ventricular impulse. First heart sound normal, second heart sound split and accentuated; grade-IV systolic murmur at lower left sternal border, radiating to the back. Electrocardiogram: first-degree atrioventricular block, left axis deviation, left ventricular hypertrophy. Radiologic findings: combined ventricular enlargement, pulmonary vascular engorgement, hilar dance. Diagnosis: atrial and ventricular septal defect.

Case 6

Discussion
The routine application of a reflection cuvette oximeter allowing instantaneous determination of the oxygen saturation during cardiac catheterization appeared to be a considerable advance on the conventional sampling technic. The oxygen saturation values may be used for locating and directing the catheter tip; a virtually unlimited number of readings can be obtained from any area; the catheterization data can easily be obtained; the blood used for the measurements can be reintroduced into the patient, the loss of blood thus being greatly reduced. After the introduction of direct oximetry it soon became customary to develop the diagnosis during the catheterization; in almost any case accurate insight into the existing malformations or disturbances could be gained in the course of the examination.

Cases 1 and 2 showed a remarkably high oxygen saturation in the superior vena cava. The source of highly saturated blood could in both cases easily be ascertained by successive saturation readings. In case 1 a sudden rise in oxygen saturation occurred when the catheter approached the right atrium, but in the right atrium itself lower saturation values were obtained. These findings exclude almost certainly the existence of an atrial septal defect and demonstrate an abnormally draining pulmonary vein. In case 2 exploration of the superior vena cava and the vessels draining into it revealed high saturation readings in both jugular veins. The postulated cerebral arteriovenous fistula was later demonstrated by cerebral angiography. The small but undeniable difference in oxygen saturation existing at the two sides of the pulmonary valve suggested a left-to-right shunt, which was thereupon proved by passing the catheter through a patent ductus.

In each case of atrial septal defect a series of oxygen saturation readings was taken from the superior vena cava and the right atrium in order to elucidate the exact location of the defect. In case 3 a rise in oxygen saturation was observed before the catheter reached the right atrium. On its way through the atrium the catheter passed through a region of high oxygen saturation values (97 per cent), but before reaching the tricuspid valve the saturation was at the level existing further throughout the right heart. These findings are typical for the sinus venosus variety of atrial septal defect. Attempts to pass through a septal defect were much more often successful after the introduction of direct oximetry, as is illustrated also by this case. In case 4 a primum defect was suspected. Repeated measurements, however, failed to
show any significant differences in oxygen saturation throughout the caval veins and right atrium, but revealed a considerable rise (22 per cent saturation) when the catheter tip passed the tricuspid valve, thus demonstrating a ventricular septal defect.

Extensive oximetric examination of infants is virtually impossible without the use of a direct method, allowing the reinjection of blood. With the aid of a cuvette oximeter, however, even the demonstration of combined atrial and ventricular septal defects (case 5), which usually requires many oxygen saturation readings, does not offer any special difficulty.

In case 6 the nature of the existing abnormalities was completely obscure before catheterization. The diagnosis (complete transposition of the great vessels) was built up step by step, mainly because of simultaneously obtained fluoroscopic and oximetric data.

**Summary**

A reflection cuvette oximeter providing instantaneous values has been used in a series of 195 cardiac catheterizations in infants and children. The introduction of this method had considerable influence on the entire catheterization procedure, since the direct availability of fluoroscopic, pressure, and oxygen saturation data allows development of an accurate and complete diagnosis during the catheterization. Six cases, selected because of the important part direct oximetry played in their elucidation, are discussed.

**Summario in Interlingua**

Un oxymetro reflexional a cuvette, providente valores instantanee, esseva usate in un serie de 195 catheterisationes cardiac in infantes e juveniles. Le introduction de iste metodo exerceva un considerabile influencia super le integre manovra catheterisational, proque le directe disponibilitate de datos fluoroscopic, de pression, e de saturation oxygenic permite le desenvoloppamento de un accurate e complete diagnosse durante le catheterisation. Es disusette sex casos, selegite a causa del importante rolo de oxymetria directe in lor elucidation.

**References**


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Medicine absorbs the physician's whole being because it is concerned with the entire human organism.—Goethe.
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