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Quantification of Left-to-Right Shunts Using a Po_2-electrode Cardiac Catheter

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SUMMARY. **A rapid, simple and low-cost method is presented for intracardiac left-to-right shunt quantification in children with congenital heart disease. The percentage of shunt is calculated from data obtained by continuous Po_2 measurement during oxygen inhalation, using a nondisposable intravascular Po_2-electrode cardiac catheter.**

These values are compared with those obtained by the dye-dilution method (correlation coefficient $r = 0.89$) and the Fick method (correlation coefficient $r = 0.98$).

The Po_2 measurement proved reliable for small, medium, and large sized shunts.

KEY WORDS: **Left-to-right shunt — Po_2 measurement — Cardiac catheterization — Congenital heart disease**

In more than 40% of all cases of congenital heart disease (CHD), a left-to-right (L to R) shunt is present. The quantification of this shunt by cardiac catheterization is of considerable clinical and surgical interest. Several methods for shunt determination are available, of which the Fick method, using oxygen content or saturations, and dye dilution are the most common.

The most important disadvantage of the Fick method is that it is not a continuous measurement. The applicability of the dye-dilution method in children is still controversial. Both methods are subject to the problem of being reliable only in shunts of a certain magnitude.

The use of Po_2 measurements has been suggested previously [1, 3], but only to localize the shunt. With the oxygen sensor we have used it is possible to quantify the shunt. On breathing oxygen the arterial Po_2 increases considerably, from 100 mm Hg to 600 mm Hg, while the venous Po_2 shows hardly any increase. This means that in the presence of an L to R shunt, there is a proportional, substantial Po_2 rise in the pulmonary artery: a "magnifying-glass effect," as it were. The method is accurate and reproducible and it does not need sampling.

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Materials and Methods

Twenty-two patients were studied: three without an intracardiac shunt, 15 with an isolated defect and four with a more complicated defect. The ages ranged from 3 months to 16 years (mean = 6.2 years). The diagnosis was established by clinical evaluation and complete cardiac catheterization by conventional techniques.

The Po_2 was measured by a membrane-covered electrode (Clark type) built into the tip of a F5 NIH cardiac catheter (Fig. 1) (Subdivision of Medical Electronics, Sophia Children's Hospital, electronic equipment by Skalar Medical Instruments B.V., Delft, Holland). The correlation coefficient between the Po_2 measured by the catheter and independently in 50 blood samples, was 0.98 [2].

This catheter, giving a continuous reading of the intravascular oxygen tension, was introduced into the femoral vein and passed into the pulmonary artery, until a stable value was reached. Then 100% oxygen was supplied via a rubber face mask. In the case of an L to R shunt, the Po_2 increased in 2–3 min (Fig. 2) to a final value, corresponding with the increase of Po_2 in pulmonary veins (Fig. 3). Next, the Po_2 was measured in the superior and inferior caval veins and, if possible, in the left atrium. Before and afterwards a venous sample (superior and inferior caval veins) was taken to measure pH, Pco_2 and Hb.

In older children the mixed-venous Po_2 was calculated assuming that inferior vena caval flow contributed about two-thirds and superior vena caval flow about one-third of the venous supply. In infants it is assumed that each caval flow contributes about half of total venous return [4].

The measured arterial, pulmonary and mixed venous oxygen tensions were converted into oxygen content (Fig. 3), taking into account the pH, Pco_2 and temperature [5]. The percentage of shunt was calculated from the oxygen contents. Preceding the

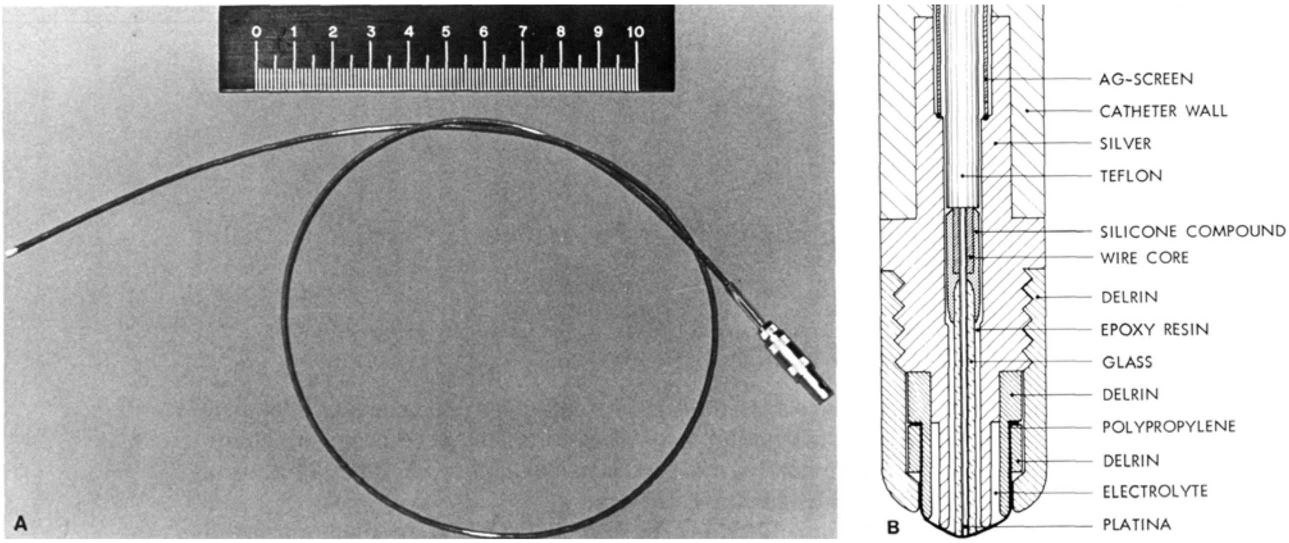


Fig. 1. P_{O_2}-tip cardiac catheter (**A**) with detail of the tip (**B**).

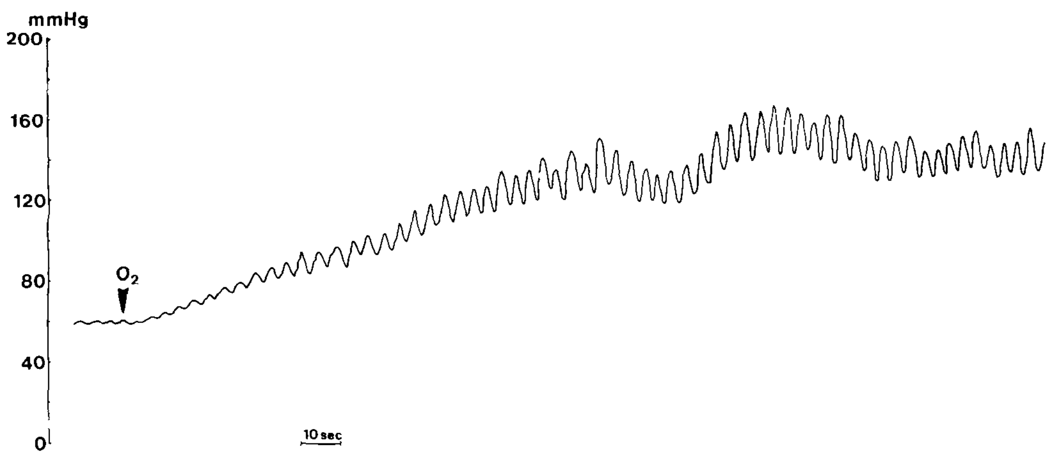


Fig. 2. Increase of oxygen tension in the pulmonary artery following administration of 100% O_2 (arrow). A 10-year-old girl with an atrial septal defect and L to R shunt of 64%.

P_{O_2} measurement the shunt was estimated by measuring saturations with a reflection oximeter, the patient breathing room air. The samples were taken in rapid succession from similar locations.

The dye-dilution method (indocyanine green) was carried out in 17 patients by injecting into the pulmonary artery and sampling in the femoral vein.

The patients had various sedative mixtures as premedication and were kept mildly anesthetized with ketamine and diazepam. In three patients we measured the pulmonary artery pressure simultaneously with the P_{O_2}. No significant change in pressure was recorded.

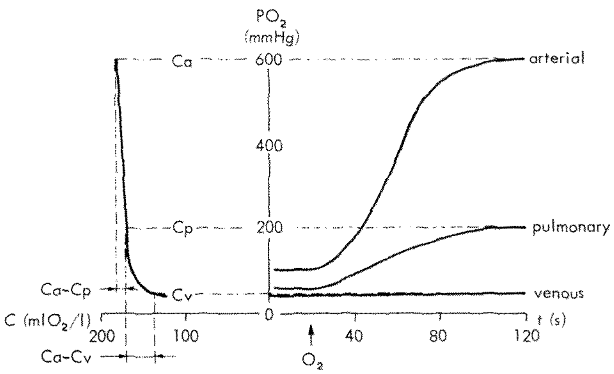
Results

The results acquired from the 22 patients are presented in Fig. 4. The percentage of L to R shunt was calculated in relation to the pulmonary blood flow and for the sake of brevity referred to as 'shunt.'

There was a good correlation ($r = 0.98$) between the shunt measured by the P_{O_2} method and that calculated from saturations by the Fick method. The correlation between the P_{O_2} and dye-dilution methods was good for shunts up to 40%, where $r = 0.95$. The correlation for the large shunts was poor. However, it is known that dye dilution is less reliable in children with shunts larger than 40%.

Discussion

We encountered the same difficulty with this as with other methods in finding a correct mixed



$$\frac{Qp}{Qs} = \frac{Ca - Cv}{Ca - Cp} \qquad \% \text{ shunt} = \frac{Qp - Qs}{Qp}$$

Fig. 3. Relation between oxygen tension and oxygen contents. *Ca*, arterial oxygen content; *Cp*, oxygen content, pulmonary artery; *Cv*, venous oxygen content; *Qp*, pulmonary flow; *Qs*, systemic flow.

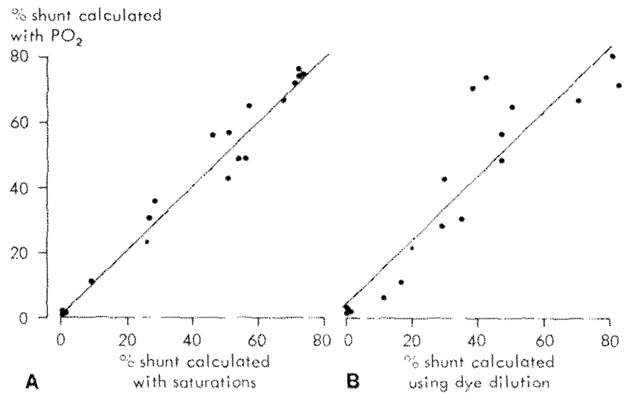


Fig. 4. Comparison of the Po_2 and Fick methods. **(A)** $r = 0.98$; $n = 18$; $y = x + 0.96$ **(B)** $r = 0.89$; $n = 17$; $y = 1.02x + 3.4$.

venous sample, especially in children with an atrial septal defect. However, the continuous recording has the advantage of showing physiological variations in oxygen content in the course of the measurement, making it possible to choose a more correct mixed venous value.

This method can compete with the Fick and the dye-dilution methods, not only in reliability, but also for its simplicity and short duration.

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