Radionuclide Quantitation of Left-to Right Cardiac Shunts Using Deconvolution Analysis: Concise Communication

Hamphrey R. Ham, André Dobbeleir, Pierre Viart, Amnon Piepsz, and André Lenaers

St. Peter's Hospital, University of Brussels, Belgium

Quantitative radionuclide angiocardiography (QRAC) was performed with and without deconvolution analysis (DA) in 87 children with various heart disorders. QRAC shunt quantitation was possible without DA in 70% of the cases and with DA in 95%. Among 21 patients with prolonged bolus injection, quantitation of the shunt was possible in 52% of the cases without DA and in all cases with DA. Correlation between oximetry and QRAC with DA was better than between oximetry and QRAC without DA. It is concluded that QRAC with DA is a more reliable, noninvasive means for detection and quantitation of left-to-right cardiac shunts than QRAC without DA.

J Nucl Med 22: 688–692, 1981

Quantitative radionuclide angiocardiography (QRAC) has been used for the detection and quantitation of left-to-right cardiac shunts for several years (*1–6*). The most recent method consists in the recording of a first pass through the lung and the determination of the pulmonary-to-systemic flow ratio (QP/QS)using a gamma-function fit (*2*). It has proved to be accurate when the tracer is delivered as a quick, discrete bolus. Unfortunately, despite all precautions and the use of various methods of injection, prolonged or double-peak boluses are still encountered in about 20% of the patients (*2,4,6,7*). In these cases, a repeat study is necessary in order to obtain an acceptable result. De Graaf et al. (*8*) proposed deconvolution of the pulmonary curve in order to correct for the effect of an elongated bolus. As a matter of fact, such a deconvolution yields a function representing the shape of the pulmonary curve that would be obtained if an injection could be given directly into the right atrium. Alderson et al. (*9*) have shown that deconvolution analysis does improve left-to-right shunt quantitation in dogs.

The purpose of the present work was to learn whether deconvolution analysis of the pulmonary curve improves detection and quantitation of a L → R shunt in clinical practice.

Received Feb. 20, 1980; revision accepted Feb. 19, 1981.

For reprints contact: H. R. Ham, Dept. of Radioisotopes, Univ. Hosp. Saint-Pierre, Rue Haute, 322, 1000 Brussels, Belgium.

PATIENTS AND METHODS

The study was conducted jointly, in the department of nuclear medicine and in the pediatric cardiac unit, on 87 successive patients ages 4 wk to 18 yr, admitted to the hospital for cardiac catheterization. Infants with severe defects calling for immediate surgery were not included.

Radionuclide angiography was performed with the patient in the supine position under a gamma camera linked to a computer. The patient was not sedated for this test. The interval between the radionuclide procedure and the cardiac catheterization was less than 24 hr in all cases. An injection of pertechnetate (200 μCi Tc-99m per kg body wt., minimum 2 mCi) was delivered into an antecubital vein, followed by a saline flush according to the technique described by Lane et al. (*10*). An external jugular vein was used for the injection if no suitable peripheral vein could be found.

Data were recorded in list mode during 60 sec. Different frame rates (0.2–0.4 sec) were used depending on the patient's age. It is well known that the circulation time in infants is much shorter than in adults (*11*). To record the input curve, a small area of interest was outlined on the midregion of the superior vena cava. This curve was also used to determine the quality of the bolus. A curve presenting more than one peak was called a "fragmented bolus," while a single-peak bolus longer

TABLE 1. TYPE OF HEART DISEASE INVESTIGATED

	Diagnosis	No. of cases
Cases with systemic to pulmonary communication	Ventricular septal defects	24
	Atrial septal defects	9
	Patent ductus arteriosus	5
	Tetralogy of Fallot	5
	Miscellaneous	9
	Subtotal	52
Cases without systemic to pulmonary communication	Valvular lesions	18
	Post operative status	9
	Coarctation	7
	Cardiomyopathy	1
	Subtotal	35
All cases		87

than 3 sec at 10% of the peak was considered a "prolonged bolus."

A large area of interest was outlined over each lung. Another area of interest was outlined over the abdominal aorta to detect the presence of a R → L shunt. To avoid superimposition with the heart or the pulmonary artery, these regions of interest were drawn on a parametric image as described by Goris et al. (*12*).

The flow ratio was first calculated from the pulmonary transit curve using the gamma-function technique (*2*). The peak of the recirculation curve was determined by the operator, taking into account two criteria: The peak must be followed by at least one data point with a lower count rate, and the time interval between the peak of the pulmonary curve and that of the recirculation curve should be about twice the interval between the peak of the superior-cava curve and the peak of the pulmonary curve. The same pulmonary curve was then deconvoluted using the caval curve as input. The technique used for deconvolution analysis was that of discrete deconvolution using a matrix algorithm (*13*). The deconvoluted pulmonary curve was smoothed twice using a standard three-point, data-smoothing technique; a gamma function was fitted, and a second calculation of the flow ratio was made.

Cardiac catheterization was performed under general anesthesia. The absence of abnormal anatomical communication between the systemic and pulmonary circulations was ascertained at catheterization in 35 patients by selective cineangiography, intracardiac phonography, and/or by contrast echography. The final diagnosis in these patients and the types of cardiac shunt in the other 52 patients are listed in Table 1.

TABLE 2. EFFICIENCY OF RADIONUCLIDE SHUNT QUANTITATION AS RELATED TO BOLUS CHARACTERISTICS

Shunt quantitation was possible	Poor bolus: Fragmented	Poor bolus: Prolonged	Good bolus	Total
With and without deconvolution	0	11	49	60
Only with deconvolution	2	10	11	23
Only without deconvolution	0	0	0	0
Not possible with either method	4	0	0	4

No patient was discarded from this study, not even those with poor bolus injection (27 patients), bidirectional shunts (14 patients), or valvular incompetence (18 patients).

Oximetric determinations were made using a reflection oximeter. Pulmonary flow (Qp) and systemic flow (Qs) were calculated classically (*14*). The mixed-venous oxygen saturation taken into account was the mean of four right-atrium samples, except with a shunt at the atrial level; in such a case the ratio (2 IVC + 1 SVC)/3 was used, IVC and SVC being the oxygen saturations in the inferior and superior venae cavae.

RESULTS

Radionuclide quantitation of left-to-right cardiac shunt was possible with deconvolution in 83 of 87 patients (95%), and without deconvolution in only 60 instances (70%). The difference is highly significant ($p < 0.005$). Among the 21 cases with prolonged bolus, shunt quantitation was possible with deconvolution in all cases, but without deconvolution in only 11 cases (Table 2). The four cases in whom shunt quantitation

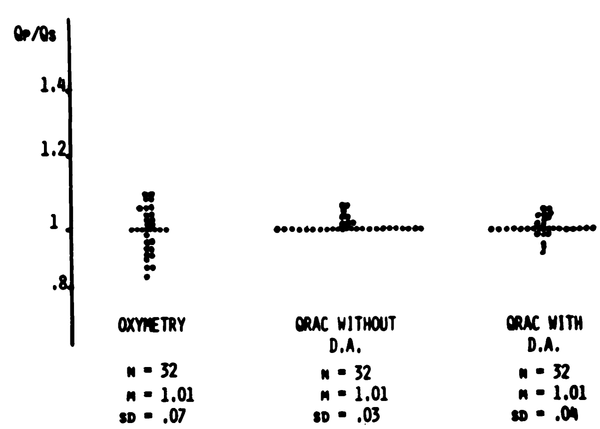

FIG. 1. L → R shunt values in 32 cases without demonstrable anatomical communication between systemic and pulmonary circulation. (For abbreviations see abstract).

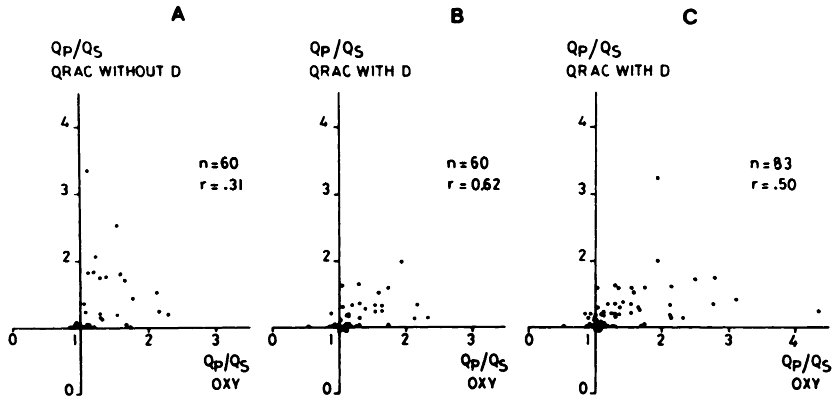

FIG. 2. Correlations between oximetry and QRAC, with or without deconvolution, were poor. (A) Between oximetry and QRAC without deconvolution. (B) Between oximetry and QRAC with deconvolution: patients presented were the same as those in (A). (C) Between oximetry and QRAC with deconvolution: all patients, including those in whom Qp/Qs could not be calculated without deconvolution.

failed even after deconvolution all suffered from fragmented bolus.

The radionuclide and oximetry shunt quantitations obtained in 32 of 35 patients without abnormal anatomical communication are compared in Fig. 1. No significant difference in precision was found between the three methods, although the variance in the oximetric determinations was slightly higher. The linear correlations between oximetry and QRAC values were poor (Fig. 2).

The greatest discrepancy between oximetric and radionuclide values occurred in children under 2 yr of age (22 cases), in cases with atrial septal defects and in those with bidirectional shunt (Fig. 3). When these were discarded, the correlation between oximetry and nondeconvoluted radionuclide angiography remained poor, whereas the correlation between oximetry and the deconvoluted radionuclide method improved (Fig. 4).

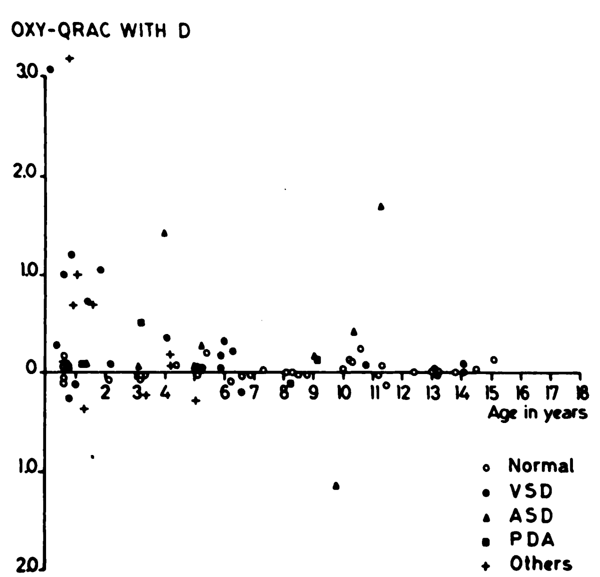

FIG. 3. Differences between shunt values by oximetry and by QRAC with deconvolution as a function of age. Important differences are observed, especially in children under 2 yr of age or with atrial septal defects.

DISCUSSION

Radionuclide detection and quantitation of left-to-right shunt are often inaccurate or even impossible to obtain when the injected bolus is inadequate. A double-peak bolus may lead to a false-positive result, while a prolonged bolus may give a false negative or a low or high estimate of the shunt flow. With a fragmented bolus, it is difficult to determine which part of the curve belongs to the pulmonary curve and which part to the shunt curve.

In this study, QRAC without deconvolution failed to quantitate the shunt in 18% of the cases with correct bolus injection and in 47% of the cases with prolonged bolus. This failure resulted from the difficulty of the gamma-function fitting to the shunt curve because not enough points could be found in the descending limb of the curve. This problem occurred in cases with correct injection when the shunt was either tiny or very large.

Given an ambiguous curve, deconvolution analysis resulted in a better separation of the pulmonary, shunt, and recirculation curves (Fig. 5). It provided more points on the descending limb of the shunt curve, facilitating the fitting of the second gamma function. Given a multiple-peak bolus, however, the deconvolution analysis did not perfectly restore the pulmonary curve. In four of six cases, the deconvoluted pulmonary curve showed important oscillations. Whether this problem can be solved by another method of deconvolution analysis, or by preprocessing of the data, requires further investigation.

The poor correlations obtained between oximetry and radionuclide shunt quantitation were to be expected in the present study owing to its design, which was aimed at the testing of QRAC efficiency as a noninvasive screening tool. Thus the technique was applied to an unselected series of cardiac patients, regardless of the patient's age or type of defect. Furthermore, oximetric and radionuclide measurements were made at different times using different sedative expedients. It is well known that shunts in infants and children are liable to fluctuate even in normal circumstances (*15*).

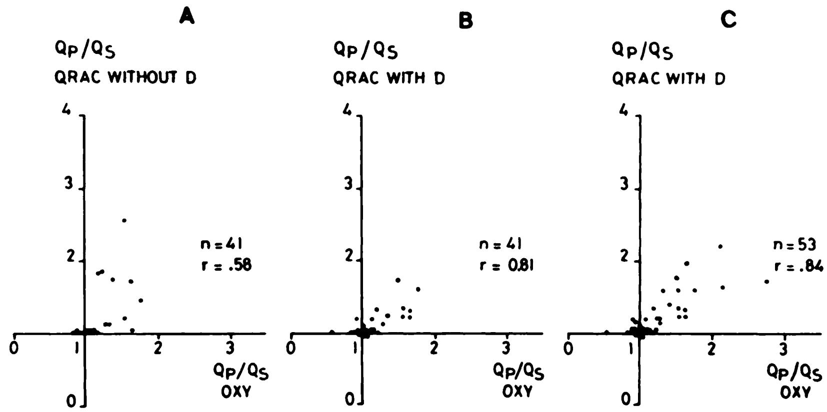

FIG. 4. Correlations between oximetry and QRAC in children above 2 yr of age and without ASD or R → L shunt. (A) Correlation between oximetry and QRAC without deconvolution remained poor. (B) Between oximetry and QRAC with deconvolution, in same patients as in (A), correlation was better. (C) Even including patients in whom Qp/Qs could not be calculated without deconvolution, correlation remained satisfactory.

The correlation obtained with deconvolution analysis in patients above 2 yr of age, after exclusion of atrial septal defects and bidirectional shunts, is in fact highly satisfactory (Fig. 4), considering the errors inherent in each method.

The absence of correlation in children under 2 yr of age is not necessarily related to an error in radionuclide shunt quantitation. The oximetry was performed under general anesthesia whereas radionuclide angiography was performed without sedation. In small children, the stress and the act of crying might well induce a transitory increase in pulmonary vascular resistance, resulting in a true decrease of a shunt that would be present under resting conditions. This possibility should be tested before claiming the unreliability of QRAC shunt measurement in small children.

The discrepancies obtained in cases of atrial septal defect probably resulted from the poor reliability of oximetry in the measurement of a shunt at the atrial level (*16*). In the presence of R → L shunts, it is well known that L → R shunt determinations are inaccurate.

In conclusion, deconvolution analysis improves radionuclide detection and quantitation of a L → R shunt: it eliminates the necessity of repeating the test in cases of prolonged bolus, and it gives more accurate shunt quantitation.

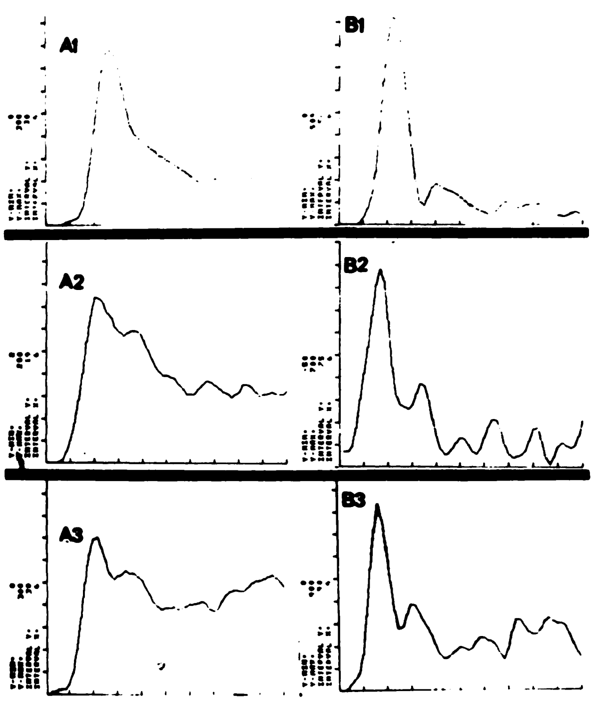

FIG. 5. Three examples of pulmonary time-activity curves. The pulmonary, shunt, and recirculation curves are better separated in the deconvoluted pulmonary curves (B) than in the undeconvoluted ones (A). More points are also available in descending limbs of pulmonary and shunt curves after deconvolution, making fitting of second gamma function more precise.

ACKNOWLEDGMENT

This work was carried out partly under Contract of the Ministère de la Politique Scientifique, within the framework of the Association Euratom, University of Brussels, and University of Pisa.

REFERENCES

1. ALAZRAKI NP, ASHBURN WL, HAGAN A, et al: Detection of left-to-right cardiac shunts with the scintillation camera pulmonary dilution curve. *J Nucl Med* 13:142-147, 1972
2. MALTZ DL, TREVES S: Quantitative radionuclide angiocardiography. Determination of Qp:Qs in children. *Circulation* 47:1049-1056, 1973
3. ANDERSON PAW, JONES RH, SABISTON DC: Quantitation to left-to-right cardiac shunts with radionuclide angiography. *Circulation* 49:512-516, 1974
4. ALDERSON PO, JOST RG, STRAUSS AW, et al: Radionuclide angiocardiography. Improved diagnosis and quantitation of left-to-right shunts using area ratio techniques in children. *Circulation* 51:1136-1143, 1975
5. ASKENAZI J, AHNBERG DS, KORNGOLD E, et al: Quantitative radionuclide angiocardiography: Detection and quantitation of left to right shunts. *Am J Cardiol* 37:382-387, 1976
6. KLEIN CP, BRILL G, OBERHAUSEN E, et al: Radioisotopic diagnosis and quantitation of left to right shunts in childhood and adolescence. *Acta Cardiol* 33:241-251, 1978
7. PARKER JA, TREVES S: Radionuclide detection, localization, and quantitation of intracardiac shunts and shunts between the great arteries. *Prog Cardiovasc Dis* 20:121-150, 1978

8. DE GRAAF CN, VAN RIJK PP, HARINCK E: Noninvasive technique for quantitative detection of cardiac left to right shunts by least square gamma function variate fitting of deconvolved radioisotope dilution curves. *Comp Cardiol* 275-280, 1976
9. ALDERSON PO, DOUGLASS KH, MENDENHALL KG, et al: Deconvolution analysis in radionuclide quantitation of left-to-right cardiac shunts. *J Nucl Med* 20:502-506, 1979
10. LANE SD, PATTON DD, STAAB EV, et al: Simple technique for rapid bolus injection. *J Nucl Med* 13:118-119, 1972
11. SILVER HK, KEMPE CH, BRUYN HB: *Handbook of Pediatrics.* Lange Medical Publication, 1973, p 212
12. GORIS ML, BAUM D, WALLINGTON J, et al: Nuclear angiocardiography: automated selection of regions of interest for the generation of time-activity curves and parametric image display and interpretation. *Clin Nucl Med* 1:99-107, 1976
13. VALENTINUZZI ME, MONTALDO VOLACHEC EM: Discrete deconvolution. *Med Biol Eng* 13:123-125, 1975
14. ZIMMERMAN HA: *Intravascular Catheterization.* Springfield, Charles C Thomas, 1968, p 358
15. RUDOLPH AM: Congenital diseases of the heart. In *Yearbook Medical*, 1974, p 163
16. DALEN JE: Shunt detection and measurement. In *Cardiac Catheterization and Angiography.* Grossman W, Ed. Philadelphia, Lea and Febiger, 1974, pp 96-107

ANNOUNCEMENT OF BERSON—YALOW AWARD

The Society of Nuclear Medicine invites manuscripts for consideration for the Fifth Annual Berson—Yalow Award. Work will be judged on originality and contribution to the fields of basic or clinical radioassay. The manuscript will be presented at the 29th Annual Meeting of the Society of Nuclear Medicine in Miami Beach, FL, June 15-18, 1982, and a suitably engraved plaque will be awarded to the authors by the Education and Research Foundation of the Society of Nuclear Medicine.

The manuscript should be approximately ten pages in length (typed, double-spaced). A letter requesting consideration for the award, including the author's full mailing address and telephone number, should accompany the manuscript. Original manuscript and eight copies must be received by January 18, 1982 at the Society of Nuclear Medicine office, 475 Park Ave. So., New York, NY 10016, Attn: Mr. Dennis L. Park.

DEADLINE FOR RECEIPT OF MANUSCRIPTS: January 18, 1982

ANNOUNCEMENT OF THE PAUL C. AEBERSOLD AWARD FOR OUTSTANDING ACHIEVEMENT IN BASIC SCIENCE APPLIED TO NUCLEAR MEDICINE—1982

Nominations are invited for this award, which commemorates the contributions of Dr. Paul Clarence Aebersold to the applications of nuclear physics to nuclear medicine and radiation biology, and his contributions to the Society of Nuclear Medicine. Dr. Aebersold contributed greatly to the emergence of nuclear medicine as a discipline by his energetic leadership in the provision of cyclotron-generated and reactor-produced radionuclides, and by his numerous publications and lectures.

In giving this award, the Society thus symbolically signifies its appreciation of the warm and vital person who became our first Honorary Member and whose enthusiastic encouragement and support contributed importantly to the formation and success of the Society of Nuclear Medicine.

Nominations should be supported by the curriculum vitae of the nominee and at least two letters supporting the nomination. These letters should describe briefly the contributions in basic science for which the nominee is proposed. The nominee need not be a member of the Society of Nuclear Medicine.

Please submit nominations and supporting documents to:

William H. Blahd, M.D.
c/o Society of Nuclear Medicine
475 Park Avenue South
New York, NY 10016
Deadline for nominations: December 31, 1981.