A New Method for Determination of Left-to-Right Cardiac Shunts

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Left-to-right cardiac shunt quantitation can be determined from first pass radionuclide angiography. The traditional technique fits a gamma variate to the lung time-activity curve (TAC) and a second gamma variate to the recirculation portion of the curve. Problems may arise, however, with the fitting of the gamma variate to the subtracted recirculation curve. We have investigated a new technique in which the recirculation fitting is no longer required. The new method fits a gamma variate to the first-pass portion of the lung TAC. This gamma variate is used to generate a curve which simulates the expected shape of a normal lung TAC in response to systemic recirculation. The simulated data is then subtracted from the observed lung TAC. A correlation coefficient of r = 0.87 was obtained when these two methods were compared. We now prefer the new method since it overcomes the problem of fitting the subtracted recirculation position of the curve.

A left-to-right cardiac shunt is defined as the premature return of part of the systemic blood flow to the pulmonary circulation. Regardless of its cause, the quantitative assessment of a cardiac shunt by noninvasive technique plays a key role in the clinical management of a cardiac patient with a ventricular septal defect (VSD), atrial septal defect (ASD), or patent ductus arteriosus (PDA) (*1*).

Historically, first-pass radionuclide angiography has been used to evaluate the degree of shunting. The theory behind this technique is that if a tracer is delivered to the central circulation as a compact bolus with uniform mixing in the blood, and there is constant detector counting efficiency, the time-activity curve (TAC) of the tracer's first transit through the lung and early recirculation will be proportional to the respective blood volumes (*2*).

DEVELOPMENT OF TIME-ACTIVITY CURVES

As early as 1948, Prinzmeter described a TAC over the precordium after an intravenous injection of sodium-24 (^{24}Na) (*2*). By the 1960s, the pulmonary TAC was observed to better delineate between pulmonary and recirculation curves (*3*).

In 1974, Folse and Braunwald used the count ratio method (C_2/C_1) to describe the degree of shunting. The two main problems with this technique are that single counts are greatly influenced by statistical variation and that all laboratories need to develop their own set of normal values.

By 1975, Alderson used the exponential area ratio method (X/Y) to establish shunt values. Alderson stated that the downslope of the lung curve has a monoexponential shape. Its value from the peak activity to the beginning of the early recirculation is exponentially extrapolated to 1% of the maximum (*3*). This method gives a quadratic equation for X/Y versus a percent of shunt (*4*). The main problem with this method is that normal values need to be established for each laboratory (*3*).

In 1973, Maltz and Treves used a gamma variate method (*5,6*) to describe a curve with a rapid upslope, a peak, and an exponential downslope, using the following equation.

$$[C(t) = Kt^{\alpha}e^{-t/B}]$$

C(t) equals the concentration of the tracer at time t, α and B equal arbitrary parameters obtained from the curve fit, and K equals the constant scale factor.

The first-pass portion of the pulmonary curve is fitted by the least squares technique to a gamma variate function. The points chosen to fit the gamma curve are those that are approximately 10% of the maximum on the upslope to those just before the shunt recirculation peak, which usually occurs below 70% of the maximum on the downslope. The fitted lung area is represented as A_1; this is shown in Figure 1. The gamma function curve is then subtracted from the original TAC to give the recirculation curve. This recirculation curve is then fitted by least squares to another gamma variate function. The points chosen on the recirculation curve are 10% of the maximum on the upslope and the point after the maximum on the downslope. This fitted recirculation area is represented as A_2 (Fig. 1). It is proportional to the shunt, which is expressed in terms of quantitative pulmonary/quan-

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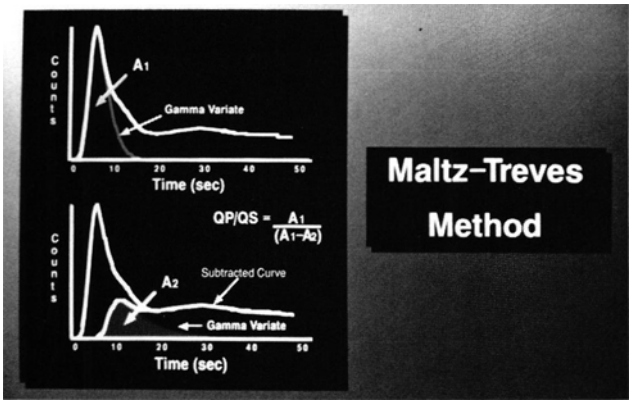

FIG. 1. Maltz-Treves method of cardiac shunt quantification. A gamma variate is fitted to the first transit portion of the observed lung time-activity curve and subtracted. A second gamma variate is fitted to the difference curve.

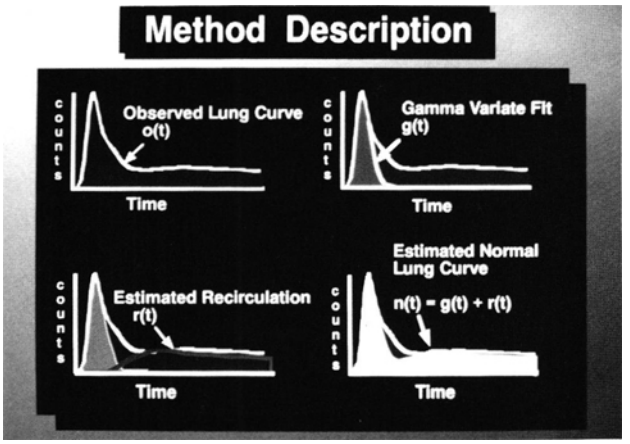

FIG. 2. Proposed method for cardiac shunt quantification.

titative systemic blood flow (QP/QS).

$$QP/QS = \frac{A_1}{A_1 - A_2}$$

This area ratio method (QP/QS) is only correct for shunts between 1 and 3:1 (*5*).

There is a poor fit at the tail of the observed curve when the curve declines faster than the exponential function. Another problem is the difficulty of fitting the gamma variate to the subtracted recirculation curve (*3,7,8*). This method may be inadequate because it is often difficult to distinguish between a small shunt and systemic recirculation (*9*). Since there are rarely any definitive landmarks, the results are generally arbitrary and operator dependent (*8*). To overcome this problem, we have investigated a new technique in which the recirculation fitting is no longer required.

MATERIALS AND METHODS

Method

Our technique fits the first-pass portion of the bolus through the lung to a gamma variate function as does the Maltz-Treves method (*5*). This gamma variate fit is used to generate a curve that simulates the expected shape of a normal lung TAC in response to systemic recirculation. The expected normal lung curve is constructed by adding the scaled time integral of the gamma variate to the initial gamma variate curve (*10*). The integral function is scaled to equal the recirculation portion of the observed lung curve, constrained by a maximum value of 25% of the curve's maximum (Fig. 2). The 25% maximum level and the time offset of the scaled integral were determined empirically from the inspection of normal lung TACs (Fig. 3 and Table 1).

The abnormal recirculation is then found by subtracting the simulated curve or estimated normal lung curve, point by point, from the observed lung curve. QP/QS is calculated as $A_1/(A_1 - A_2)$ where A_1 is the integral of the gamma variate and A_2 is the integral of the difference curve (Fig. 4).

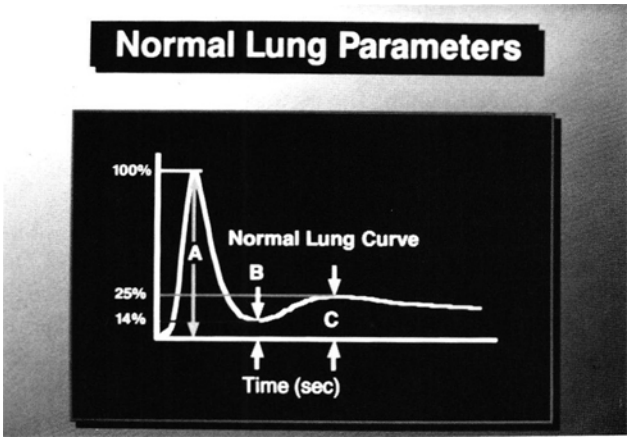

FIG. 3. Normal lung time-activity curve (TAC). The lung radioactivity falls as the bolus passes through the lungs and then rises as the bolus recirculates. Eleven lung TACs were examined from patients with no evidence of cardiac shunts. The values found at points B and C are shown in Table 1.

TABLE 1. Normal Lung Data

Patient	Recirculation Minimum (B)*	Recirculation Maximum (C)*
1	11%	24%
2	17%	30%
3	15%	24%
4	13%	26%
5	11%	25%
6	16%	25%
7	15%	29%
8	12%	20%
9	17%	29%
10	19%	30%
11	12%	25%
Mean	14.4% ± 2.7	26% ± 3.1

* Minimum (B) and maximum (C) recirculation points are shown on the normal lung curve in Figure 3.

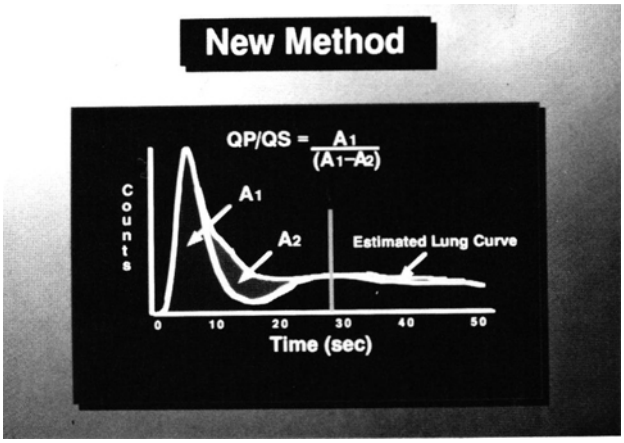

FIG. 4. Calculation of the QP/QS in the new method.

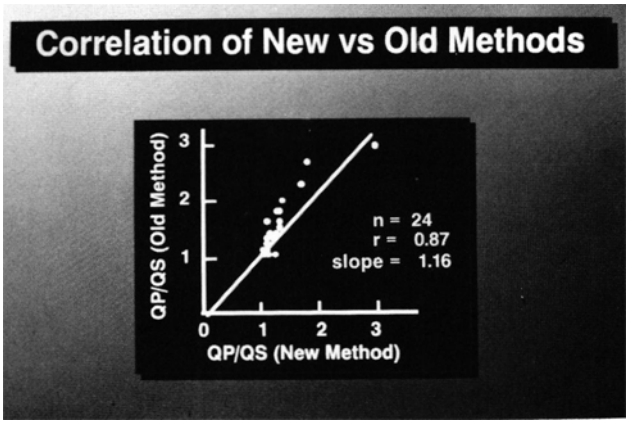

FIG. 5. Plot of QP/QS values from Maltz-Treves method versus new method.

Patient Studies

Scintigraphic studies were performed on 20 patients who were divided into two groups. The first group consisted of 15 patients, referred to the nuclear medicine department to rule out left-to-right shunt. The second group consisted of five patients, referred to the nuclear medicine department for other types of cardiac studies, and we considered it unlikely that these patients would have a shunt.

All of the patients were studied with a Siemens LEM (Siemens Gammasonics, Shaumburg, IL) small field of view scintillation camera. An intravenous line was established in the right medial basilic vein using an infusion set with a #18-20 gauge needle. Twenty-five mCi of technetium-99m DTPA (Squibb Diagnostics, Princeton, NJ) in a volume of 0.5 ml or less was then rapidly injected, followed by a bolus flush of 10 ml of normal saline. We have determined that this technique provides a satisfactory compact bolus in the majority of patients (FWHM = 1.5 sec/FW 1/10 M = 3 sec). In 10%–18% of patients, the technique produces an unsatisfactory bolus score; in these cases we perform a deconvolution on the lung curve (*8,11,12*).

Data Acquisition

Data were acquired at a rate of 2 frames/sec during the first transit of the tracer through the heart. The camera was positioned for an anterior view in order to best visualize the superior vena cava (SVC) and right lung (RL). The scintigraphic data were then analyzed using two regions of interest to produce TACs of the SVC and RL.

RESULTS

Calculations were done to determine the QP/QS values with the Maltz-Treves method (MDS A^2 Computer, Medical Data Systems, Ann Arbor, MI and MIPS version 2.0 software, Medasys Inc., Ann Arbor, MI) and the new method. Both of the analytic methods were also evaluated for intraoperator variation. A comparison of the results of the two methods is shown in Figure 5. Relatively good agreement was found between the two methods with a correlation coefficient of r = 0.87.

When different operators used the traditional method to calculate the QP/QS values on simulated lung TACs with simulated cardiac shunts, the interoperator correlation coefficient of QP/QS values varied from r = 0.85 to r = 0.90. When the same operators used the new method to calculate QP/QS values on the same simulated lung TACs, the interoperator correlation coefficient varied from r = 0.96 to r = 0.97 (Table 2). The wider range of QP/QS values obtained when using the traditional method is probably due to variation in the selection of boundary points for the fitting of the subtracted recirculation portion of the curve.

DISCUSSION

Each method is thought to be a valid analytical method for determining QP/QS values for the clinical management of a left-to-right cardiac shunt. A few problems have arisen with the Maltz-Treves method since it requires two fittings of the lung TAC. When fitting the second gamma variate function, operators have found that there are no defined landmarks to guide them in the selection of points. In addition, the calculated result seems to be sensitive to the operator's selection of these boundary points.

The new method involves operator intervention in only one part of the curve, and the accuracy of the QP/QS value depends only on how well the normal lung recirculation can be estimated. Since there is less operator influence, the new method tends to yield results that are more systematically reproducible, and the method is easier to use. This is an important feature since left-to-right cardiac shunt studies are infrequently performed in many clinics, and they are often analyzed by individuals with limited experience.

Under certain conditions, operators may have problems calculating accurate QP/QS values using either analytical method. If blood is continually shunted and contributes to early recirculation, then there may be an overestimation of a large shunt. This inability to discriminate systemic recirculation will produce false QP/QS values. The validity of the lung

TABLE 2. Three Operators' Determinations of Simulated Cardiac Shunts

Simulated Curves	QP/QS Values					
	Operator 1		Operator 2		Operator 3	
	New	Old	New	Old	New	Old
1.2	1.25	1.2	1.25	1.4	1.25	1.0
1.5	1.53	1.6	1.53	2.1	1.4	1.4
1.75	1.91	2.1	1.74	2.0	1.55	2.5
2.0	2.07	2.0	1.92	2.3	2.02	2.0
1.2	1.24	1.5	1.23	1.3	1.24	1.1
1.5	1.48	1.5	1.45	1.7	1.48	1.5
1.75	1.70	1.8	1.75	2.1	1.58	1.8
2.0	2.10	2.1	2.07	3.2	2.03	2.2
1.2	1.25	1.4	1.28	1.4	1.18	1.4
1.5	1.57	1.7	1.46	1.7	1.57	1.7
1.75	1.8	1.8	1.66	3.2	1.8	2.2
2.0	2.04	2.2	2.0	3.3	2.0	2.6
1.2	1.25	1.2	1.22	1.3	1.22	1.1
1.5	1.45	1.7	1.47	1.7	1.45	1.6
1.75	1.68	2.3	1.87	2.3	1.82	2.7
2.0	1.76	2.4	1.88	3.3	1.97	2.3
1.2	1.22	1.3	1.24	1.4	1.28	1.1
1.5	1.51	1.8	1.44	1.8	1.51	1.8
1.75	1.77	2.2	1.73	2.1	1.77	2.4
2.0	2.04	2.1	1.99	2.2	2.04	2.1

TAC may also be altered when the bolus injection is too slow or when there are circulatory abnormalities.

CONCLUSION

Based on the results of our study comparing the two methods, we have chosen to use the new method. It yields more reproducible results and provides a more time efficient method of determining QP/QS values.

ACKNOWLEDGMENTS

This manuscript would not have been possible without the efforts of the nuclear medicine staff in our hospital. Also, thanks to Pat Van Dyke for her secretarial skills in putting together this manuscript.

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