Bedside nuclear probe for detection and quantification of left to right intracardiac shunts

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SUMMARY A cadmium telluride nuclear probe with an Elscint gamma camera was used to detect and measure left to right intracardiac shunts at the bedside in 34 patients. Fifteen also had right heart catheterisation and oximetric measurement of the shunt. For the nuclear technique 740 MBq (20 mCi) of technetium-99m pertechnetate was injected into the right antecubital vein and the pulmonary to systemic flow ratio (QP:QS) was measured by the gamma variate technique. Data were not obtained in four patients because the nuclear probe failed in three patients and one storage disc was corrupted. Data from the gamma camera were lost in another patient. When the size of the shunt measured by the nuclear probe was compared with that measured by the oximetric technique the mean difference (SD of mean difference) was 0.36 (SD 0.78) and when it was compared with the gamma camera it was 0.08 (SD 0.67). Analysis of scatter plots showed that the larger the shunt, the larger the discrepancy. Twenty four of 29 data sets showed complete agreement between the nuclear probe and gamma camera on the size of the shunt. Any differences were small.

These data indicate that left to right intracardiac shunts may be measured accurately by a nuclear probe at the bedside in either the coronary care unit or outpatient department.

A method for detecting and measuring left to right intracardiac shunts at the bedside would be useful. It could rapidly confirm the clinical diagnosis of suspected rupture of the interventricular septum in outpatients and in the coronary care unit.

Earlier studies have shown good agreement between the results of a radionuclide technique and oximetry¹⁻³ and some believe that the radionuclide technique is more accurate.⁴ We have compared the estimates of intracardiac shunts measured by a gamma camera and by a miniaturised cadmium telluride nuclear probe with those of standard oximetry.

Patients and methods

To test the discriminatory function of the radionuclide technique we studied 28 patients (mean (range) age 38 (14-72)) with suspected left to right

shunts and a further six with either impaired left ventricular function or mitral regurgitation. Fifteen patients in whom clinically significant shunts were suspected also had right heart catheterisation and oximetric measurement of the shunt.

Two experienced consultant radiologists independently reported on the size of the shunts from standard chest x rays and graded the size of the shunt (A = no shunt; B = QP:QS < 2:1; and C = QP:QS > 2:1).

RADIONUCLIDE TECHNIQUE

A first pass radionuclide angiogram was acquired in the anterior projection simultaneously for both the gamma camera and nuclear probe. Data were collected in list mode by an Elscint gamma camera linked to a PDP 11 computer. Two miniaturised cadmium telluride detectors were positioned on the anterior chest wall and the patient was positioned under the gamma camera. One nuclear probe was located over the clavicular region to indicate the compactness of the bolus at the superior vena cava and the other was positioned over the right lung to detect a left to right shunt, which is shown by a prolongation of the normal time activity curve. During the study we

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Accepted for publication 29 October 1987

found it necessary to provide additional collimation for these probes to prevent pick up of activity in adjacent areas (for example the superior vena cava and aorta).

These probes were connected to a solid state memory recorder (Memolog - 500, Novo Diagnostics). The data were later transferred to the PDP 11 computer, which was used to calculate the size of the shunt. The patient's red cells were prepared for *in vivo* labelling by a preliminary intravenous injection of (inactive) pyrophosphate and stannous ion. Twenty minutes later, 740 MBq (20 mCi) of technetium-99m pertechnetate was injected into the right antecubital vein. The nuclear probe would require 150 MBq (4 mCi) of technetium-99m when used alone.

Early in the study the bolus was injected through a 18G Venflon. Because some of the injections gave a fractionated bolus the injection technique was modified. The Venflon was connected to a short length of clear tubing which was connected to a three-way tap. A 1 ml syringe containing 99m Tc was connected to the side arm and a 50 ml syringe of saline was connected to the other. The three-way tap and tubing were loaded with saline. The dose of technetium, marked on both sides by a small air bubble, was advanced into the clear tubing and on into the Venflon by means of the saline syringe. This bolus was then injected rapidly into the antecubital vein. This method gave a good non-fractionated bolus in most patients.

The time-activity curves from both systems were analysed by the same method. A time-activity curve from the superior venacaval region of interest was used to check that the bolus was not fractionated. The gamma camera was used to image the superior vena cava and a region of interest over the right lung was entered visually, whereas with the nuclear probes this information was taken directly from the detectors. If the time-activity curve from a region of interest over the right lung was acceptable it was analysed by gamma variate fits.^{2,3} Where the bolus was attenuated we used deconvolution analysis⁵⁻⁷ to correct the lung time-activity curve before the shunt was calculated.

We used the same software (Gamma 11) for gamma variate fitting for data from both the gamma camera and the nuclear probe, which were both written to a file on disc in the same format.

OXIMETRIC TECHNIQUE

During right heart catheterisation paired blood samples were taken from the inferior vena cava, low, mid, and high right atrium, superior vena cava, apex, mid, portion, and outflow of the right ventricle, and main pulmonary artery. An arterial sample was obtained

from a femoral needle puncture. The samples were taken in rapid sequence once the patient was considered to be physiologically stable. The oxygen saturation was measured with a reflectance oximeter.^{8,9} The pulmonary to systemic flow was calculated by the formula:

$$\frac{QP}{QS} = \frac{\text{systemic arterial } \text{SO}_2 - \text{mixed venous } \text{SO}_2}{\text{pulmonary venous } \text{SO}_2 - \text{pulmonary arterial } \text{SO}_2}$$

where SO_2 is the oxygen saturation. The mixed venous oxygen saturation was estimated from saturation in the superior vena cava (SVC) and inferior vena cava (IVC) by the formula¹⁰:

$$\text{Mixed venous } \text{SO}_2 = \frac{3 \times \text{SVC } \text{SO}_2 + \text{IVC } \text{SO}_2}{4}$$

DATA ANALYSIS

The calculated pulmonary to systemic flow ratios calculated by both techniques were compared by constructing scatter plots and calculating the standard deviation about the mean difference. Correlation coefficients were not calculated because according to Altman and Bland they are not appropriate in method comparison studies.¹¹ Only the lines of identity are shown in the figures. The important question is how well the two measures agree? We calculated the difference between the two measurements for each subject. The mean of these differences is a measure of the accuracy (bias) and the standard deviation is a measure of precision. The size of the shunt was graded arbitrarily: 1 = no shunt; 2 = QP:QS from 1.3:1 to 1.5:1; 3 = QP:QS from 1.6:1 to 2:1; and 4 = > 2:1.

To compare shunt size as graded by the radiologists and by the nuclear techniques the arbitrary grading was transformed to that used by the radiologists. This change was used solely to compare the shunt sizes as graded by the radiologists with the sizes given by nuclear techniques.

Results

Thirty four patients were recruited into the study. Four data sets were rejected—three because of failure of the nuclear probe and another patient's data were lost when the storage disc was corrupted and one patient's data lost from the gamma camera because of technical problems. This left 29 data sets for comparison of the nuclear probe and gamma camera and 30 data sets for the comparison of the nuclear probe and radiologists.

The size of the shunt as estimated by the nuclear probe and gamma camera showed complete accord in 24 patients and discord in five patients (table 1). When the nuclear probe was compared with

	<i>Complete agreement</i>	<i>Disagreement (by 1 grade)</i>	<i>Disagreement (by 2 grades)</i>
Gamma camera <i>vs</i> nuclear probe	24	5	—
Nuclear probe <i>vs</i> oximetry	11	4	—
Gamma camera <i>vs</i> oximetry	8	6	—
Nuclear probe <i>vs</i> first radiologist	11	16	—
Nuclear probe <i>vs</i> second radiologist	14	13	3
Radiologist 1 <i>vs</i> radiologist 2	17	9	4

oximetry there was complete concordance in 11 patients and minor variation in four patients (table 1). For the comparison of the gamma camera and oximetry the figures were eight and six respectively. There was some discordance between each radiologist but there was greater discordance between each radiologist and the nuclear probe (table 1).

Generally there was a good agreement between the nuclear probe and standard gamma camera and between each isotopic method and oximetry. The larger the size of the shunt the greater the scatter of the data. This does not, however, affect clinical interpretation of the size of the shunt.

The results reported in this study confirm the close agreement in the size of left to right shunts measured by the standard gamma camera and by the oximetric method. They also demonstrate that the cadmium telluride miniaturised nuclear probe provides estimates of shunt size that agree with the gamma camera and with the oximetric methods. During the

Fig 2 Scatter plot and frequency histogram of oximetry and the nuclear probe. (Details of layout as for fig 1.)

Fig 3 Scatter plot and frequency histogram of oximetry and the gamma camera. (Details of layout as for fig 1.)

study there were a few minor changes to the technique. The injection of the bolus was improved as was collimation of the cadmium telluride crystal. These changes assisted processing by producing better curves but did not affect the final results. The size of the differences between the nuclear data and oximetric data was similar at the beginning and end of the study as were the differences between the nuclear probe and gamma camera. The nuclear probe, when used alone, needs only a quarter of the dose of radiopharmaceutical required for the gamma camera.

It was instructive to note the variation in shunt size as estimated by two experienced radiologists. We conclude that radiology is therefore at best a very

Table 2 Mean (SD) shunt size for between-method comparisons

	Mean difference	SD of difference
Nuclear probe vs gamma camera (n = 29)	0.08	0.67
Nuclear probe vs oximetry (n = 15)	0.36	0.78
Gamma camera vs oximetry (n = 14)	0.53	0.95

rough guide to the clinical significance of the shunt size.

The cadmium telluride miniature probe can be used to detect left to right shunts and to estimate the size of the shunt. In most patients the results of the nuclear probe and gamma camera methods agreed on the size of the shunt (large, moderate, or small). The nuclear probe can therefore be regarded as a useful clinical tool. The nuclear technique becomes less accurate in three situations. It cannot be used to measure right to left shunts because it works on the principle of measuring the increased pulmonary transit time which does not occur in this situation. The time-activity curves, from which the shunt is calculated, may also be prolonged in severe left ventricular dysfunction and in pronounced mitral valve regurgitation, making estimation of the shunt size unreliable; however, we found no evidence of this effect in our data.

In many units the demand for the gamma camera is high. The cadmium telluride miniature detectors can provide useful data at a much lower cost than the gamma camera, and although no pictures are available the miniature detectors are easily portable and may be interfaced with a small microcomputer. This technique can be used in both the coronary care unit and the outpatient department. The nuclear technique complements cross sectional echocardiography, which will determine the site of the shunt. Ginzton *et al* showed that the combination of contrast cross sectional echocardiography and radionuclide shunt detection led to a proper diagnostic and therapeutic decision in 24 of 25 patients.¹²

We consider that the nuclear probe is a useful investigative tool in the determination of the pulmonary systemic flow ratio in patients with left to right intracardiac shunts.

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