Scintigraphic Assessment of Pulmonary and Whole-Body Blood Flow Patterns After Surgical Intervention in Congenital Heart Disease

Martha Pruckmayer, Sophie Zacherl, Ulrike Salzer-Muhar, Michael Schlemmer and Thomas Leitha

University Clinic of Nuclear Medicine and Pediatrics, University of Vienna, Vienna, Austria

Glenn shunt and Fontan procedure, the most widely used surgical procedures in congenital heart anomalies, may be associated with abnormal pulmonary blood flow patterns and the development of pulmonary arteriovenous fistulae. **Methods:** This study quantified pulmonary and whole-body blood flow using the microsphere technique by sequential injection of ^{99m}Tc microspheres into upper and lower limb veins and performing planar lung imaging in four projections and anterior and posterior whole-body scans in 46 patients with either Glenn shunt or Fontan procedure. The right-to-left shunt volume was estimated by a brain and kidneys-to-lungs ratio and compared with calculations from the whole-body scans. **Results:** In 31 of 46 patients, the blood from the superior vena cava was drained preferentially into the right lung (75% ± 19%). The inferior venous system was drained equally into both lungs. The right-to-left shunt volume was 24% ± 12% after injection into the superior caval system, 50% ± 18% after injection into the inferior caval system. A subgroup of patients who had undergone a palliative Blalock-Taussig shunt (BTS) before the final surgery showed a perfusion pattern that was not known after pulmonary angiography or contrast echocardiography: 15 of 24 patients with BTS had hypoperfusion of the upper lobe on the side of the BTS after injection into the arm vein and corresponding normal perfusion or hyperperfusion when injected into the foot vein. **Conclusion:** Lung perfusion scintigraphy after tracer application into the superior and inferior caval systems detects more abnormal pulmonary blood flow patterns than contrast echocardiography and is the only procedure able to quantify right-to-left shunt volume individually for the superior and inferior caval systems. Thus, this diagnostic technique should be part of the routine follow-up in children after Glenn shunt or Fontan procedure.

Key Words: congenital cardiac anomalies; lung perfusion scintigraphy; Glenn shunt; Fontan procedure

J Nucl Med 1999; 40:1477–1483

Lung perfusion scintigraphy with ^{99m}Tc-labeled macroaggregates or microspheres of human serum albumin is well established in imaging pulmonary blood flow for the diagnosis of pulmonary embolism. Less frequently used but equally well studied, the method can also be used to investigate flow patterns of other organs (*1*).

We applied the procedure to image pulmonary and main blood flow in patients with congenital heart disease after Glenn shunt or Fontan procedure. The Fontan procedure (for inferior vena cava to pulmonary artery communication) (*2*) (Fig. 1A), as well as the Glenn shunt procedure (for superior vena cava to pulmonary artery anastomosis) (*3*) (Fig. 1A), results in low pulsatile pulmonary blood flow and is often associated with pulmonary arteriovenous fistulae (PAVF). Whether this low pulsatile pulmonary blood flow is responsible for PAVF (*4*) or if it is caused by other factors, such as pulmonary hypertension in the unshunted lung (*5*), is still under debate. The resulting perfusion pattern may be further influenced by a pre-existent Blalock-Taussig shunt (BTS), often performed as an initial surgical procedure. The BTS is an anastomosis between the subclavian artery or the carotid artery and the pulmonary artery (Fig. 1C).

This study was initiated to investigate the clinical use of the microsphere perfusion technique for quantifying pulmonary and whole-body perfusion patterns in the postsurgical follow-up of children with congenital cardiac anomalies.

MATERIALS AND METHODS

Patients

Forty-six patients with complex cardiac anomalies who had undergone Glenn shunt or Fontan procedure were studied. The study population comprised 26 male and 20 female patients with a mean age of 8.2 y (range 2–31 y) at the time of the perfusion scintigraphy (Table 1). None of the patients had signs or previous evidence of obstructive airway disease. Eight patients had undergone the Fontan procedure. A Glenn shunt was present in 38 patients. Twenty-four patients underwent palliative BTS before the Glenn shunt or Fontan procedure. Three of these patients had right BTS, 15 had left BTS and 6 patients had BTS on both sides.

The mean duration between the final surgical procedure and the first perfusion scan was 46 mo (range 1–330 mo). The routine follow-up of these patients comprised contrast echosonography and pulmonary angiography in 10 patients as described later.

Lung Perfusion Scintigraphy

A separate day acquisition protocol was used with 48–96 h between the two studies. On the first day, the tracer was injected into an upper limb vein (the right cubital vein in most cases)

Received Aug. 24, 1998; revision accepted Mar. 8, 1999.

For correspondence or reprints contact: Martha Pruckmayer, MD, University Clinic of Nuclear Medicine, General Hospital Vienna, Leitstelle 3L, Waehringer Guertel 18–20, A-1090 Vienna, Austria.

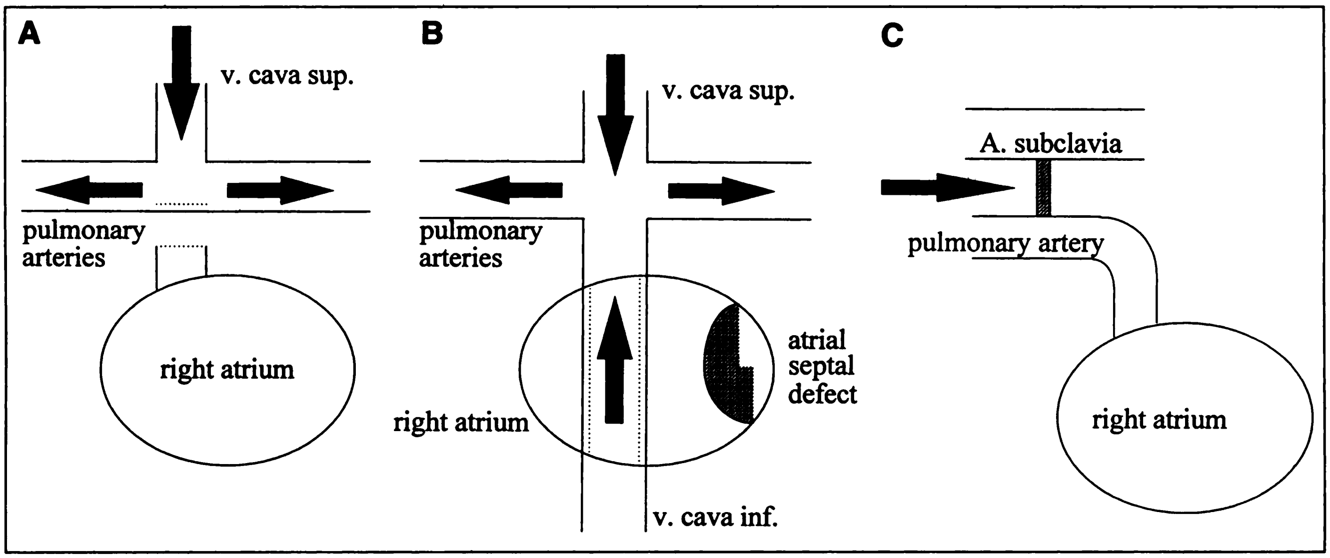

FIGURE 1. (A) Schematic illustration of bidirectional Glenn shunt, superior vena cava-to-pulmonary artery shunt; right atrium is separated from connected right and left pulmonary artery. (B) Schematic illustration of Fontan procedure, connection from inferior vena cava (through right atrium) to pulmonary arteries (after Glenn procedure). (C) Schematic illustration of Blalock-Taussig shunt (BTS), connection from subclavian artery to pulmonary artery (right, left or bilateral); modified BTS uses Goretex vascular graft.

through an indwelling catheter; on the second day, the application site was a lower limb vein. The catheter was flushed with at least 10 mL saline. In 9 patients (all with Glenn shunts), the second day protocol could not be performed because of organizational reasons. With the patient resting in a supine position, 1 MBq ^{99m}Tc microspheres (Sferetec, Sorin, Italy) per kilogram body weight with a maximum of 50,000 particles per injection were administered intravenously. The microspheres have a diameter ranging from 10 to 45 μm. The radiochemical purity, according to the manufacturer, should be ≤5%. In our studies, free ^{99m}Tc was not more than 1.4%. Visible activity in the bladder as an additional sign of free ^{99m}Tc was noted in 19 investigations, whereas in 64 whole-body scintigraphs, the urinary bladder area showed no significant tracer accumulation. As described later, the quantification of the blood flow was corrected for the amount of free ^{99m}Tc in the urinary bladder.

Imaging started immediately after injection, beginning with the whole-body scintigraph, followed by static images. Whole-body scintigraphs (mean counts 200,000) were performed using a dual-head large-field-of-view (LFOV) gamma camera (GCA 901A; Toshiba Corp., Tokyo, Japan) fitted with low-energy high- resolution parallel-hole collimators with a scanning velocity of 10 cm/min. Planar images were acquired with a LFOV gamma camera (GCA 901A) fitted with a low-energy parallel-hole collimator and analyzed by the new GMS software (V5.0; Toshiba). Four planar views (posterior, anterior, right posterior oblique and left posterior oblique) were acquired with 300 Kcts each and stored in a 256 × 256 matrix.

Quantification

Data analysis comprised visual assessment by two experienced observers and quantification using the region-of-interest (ROI) method. ROIs were drawn manually over the body, both lungs (each ROI divided into three segments), both kidneys, the brain, the urinary bladder and the injection site, if visible. Background ROIs were drawn outside the patient's body. (Fig. 2)

Whole-body retention (in counts per minute) was calculated from the mean of the anterior and posterior whole-body ROIs corrected for retained activity at the injection site and the activity in the urinary bladder. The latter was assumed to represent free technetium. The relative perfusion of the lungs was calculated from the mean of the anterior and posterior ROIs set over both lungs.

The right-to-left shunt volume was estimated by a ratio of the sum of activity in the brain and kidneys divided by the activity retention in both lungs (*6*). According to the literature the ratio ranges from 0.003 to 0.005 in healthy volunteers. We could validate these values in a short series (n = 8) of adult patients who were investigated for different conditions but had no evidence of right-to-left shunt.

The right-to-left shunt volume was additionally calculated as the percentage of whole-body retention outside the lungs. The mean ± SD in healthy volunteers (n = 8) was calculated as 5.6% ± 1.2%, thus any shunt volume > 8% is considered to be abnormal in our laboratory.

The nuclear medicine procedures were reviewed and quantified by agreement of two blinded observers. These scintigraphic results were then compared with the clinical data, the results of the angiography and the contrast echocardiography, along with the observations of the attending physicians, with particular attention being paid to the discrepancies between the different techniques and the additional information content provided by scintigraphy.

Echocardiographic Contrast Study

On the first day of perfusion scintigraphy, a two-dimensional contrast study was performed. An injection of 10 mg "activated" sodium chloride was administered into the same peripheral intravenous site used for the perfusion scanning. Normally, the echo quality of the bolus is lost after passage through the pulmonary capillaries, and therefore no "bubbles" occur in the left area of the heart (*7*). In patients with a Glenn shunt, bubbles observed in the pulmonary vein and left atrium suggest the presence of pulmonary arteriovenous fistulae, and bubbles in the right atrium indicate the presence of a systemic venous collateral (*6*).

TABLE 1
Study Population

Patient no.	Sex	Diagnosis	Surgery	Time from surgery to scan* (mo)	BTS
1	F	TS; PS; HRV; VSD	Glenn	60.20	Y
2	M	DC; UVH; MGA; PS	Glenn	13.20	N
3	F	ASDI; VSD; HRV; PS	Glenn	19.80	N
4	M	TA; PS; HRV; PS	Glenn	35.00	N
5	M	UVH; TAPVD; PS; CA	Glenn	11.70	N
6	M	TA; PS; HRV; VSD	Fontan	47.00	N
7	M	TA; PS; HRV; VSD	Fontan	60.00	Y
8	M	UVH; MA; MGA; COA	Glenn	12.70	N
9	F	DC; UVH; CA; PS	Glenn	66.30	N
10	M	DORV; PS; MGA	Glenn	23.40	N
11	M	UVH; MGA; PS	Glenn	15.30	Y
12	M	UVH; MGA; PS	Glenn	55.80	N
13	M	DC; DORV; MGA; PS	Glenn	32.20	N
14	F	DILV; TS; TGA; SAOC	Glenn	20.70	N
15	F	UVH; MGA; COA; SAOC; PS	Glenn	56.20	N
16	M	HRH	Glenn	28.60	Y
17	F	DC; UVH; MGA; PS	Glenn	10.20	Y
18	F	TA; VSD; HRV	Glenn	8.60	N
19	F	DILV; TGA; PS; SAOC	Glenn	11.70	N
20	M	UVH; PA; MGA; SAOC	Glenn	10.10	Y
21	M	TA; PS; HRV; VSD	Glenn	18.80	Y
22	M	DORV; MGA; PS; VSD	Glenn	25.00	N
23	F	HRH; CF	Glenn	40.60	N
24	F	UVH; PS; SPOC	Glenn	24.20	N
25	M	TA; PA; HRV; VSD	Glenn	35.70	Y
26	M	UVH; PS; SAOC	Glenn	47.30	N
27	M	TS; PA; HRV; CA	Glenn	2.00	Y
28	M	DC; UVH; PS; CA	Glenn	22.80	Y
29	M	DC; UVH; PA; MGA	Glenn	34.40	Y
30	F	DORV; MGA; PS	Glenn	63.30	N
31	F	TA; VSD; HRV	Glenn	135.70	N
32	M	UVH; PS	Glenn	49.80	N
33	M	UVH; MGA; PS	Glenn	40.00	Y
34	M	DC; UVH; PA; TAPVD	Glenn	60.60	Y
35	F	TS; PA; HRV	Glenn	35.60	Y
36	M	UVH; MGA; SAOC	Glenn	21.40	N
37	F	TS; PA; HRV	Glenn	1.00	Y
38	F	TS; HRV; PDA	Glenn	117.77	N
39	M	TA; VSD; HRV; PS	Glenn	330.19	Y
40	M	DORV; PS; HLV	Fontan	85.70	Y
41	F	DORV; PS; RI	Fontan	39.03	Y
42	F	DORV; PS; MGA	Fontan	30.16	Y
43	M	PA; HRV; CA	Fontan	101.77	Y
44	F	TA; PA; HRV	Fontan	20.80	Y
45	F	DILV; VI; PA	Fontan	74.06	Y
46	F	TA; VSD	Glenn	11.12	Y

---

*Time between final surgery and first perfusion scan.

BTS = Blalock-Taussig shunt before final surgery; TS = tricuspid stenosis; PS = pulmonary stenosis; HRV = hypoplastic right ventricle; VSD = ventricular septal defect; DC = dextrocardia; UVH = univentricular heart; MGA = malposition of the great arteries; ASDI = atrial septal defect primum; TA = tricuspid atresia; TAPVD = total anomalous pulmonary veinous drainage; CA = common atrium; MA = mitral atresia; COA = coarctation of the aorta; DORV = double outlet right ventricle; DILV = double inlet left ventricle; TGA = transposition of the great arteries; SAOC = subaortic outlet chamber; HRH = hypoplastic right heart; PA = pulmonary atresia; CF = coronary fistula; SPOC = subpulmonary outlet chamber; PDA = persistent ductus arteriosus; HLV = hypoplastic left ventricle; RI = right isomerism; VI = ventricular inversion; Y = yes; N = no.

Cardiac Catheterization Study

Cardiac catheterization was performed in 10 patients in a clinically indecisive situation after surgery. The time between operation and catheterization was between 4 and 55 mo (mean 29.2 ± 18.9 mo).

Pressures in the superior vena cava and right and left pulmonary arteries were measured directly by a catheter introduced through the right internal jugular vein. Routinely, an additional injection was made in the superior vena cava to look for venous collaterals or an anomalous left superior vena cava and to evaluate the anastomo-

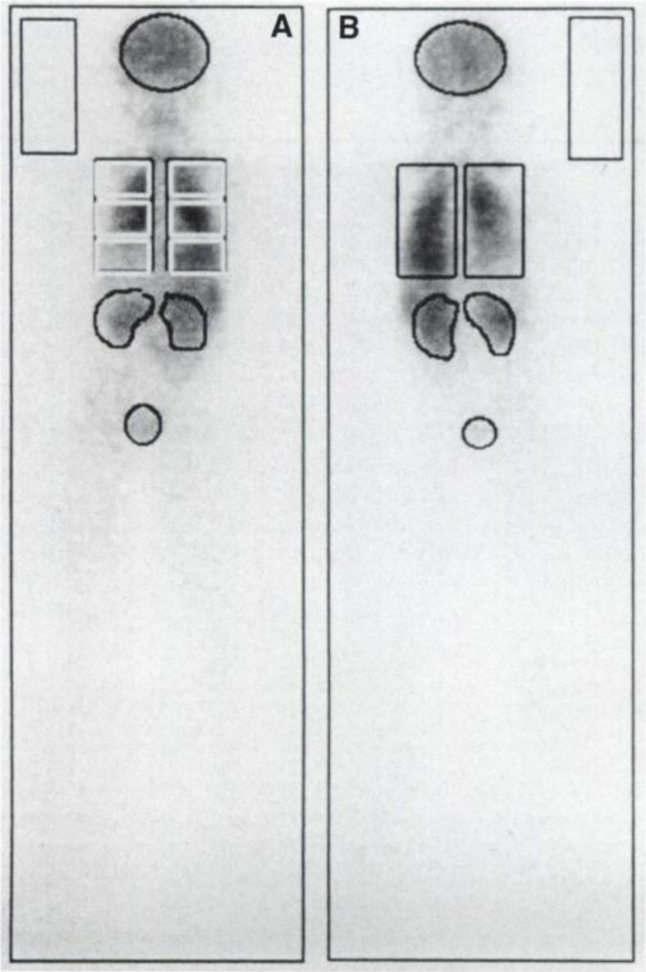

FIGURE 2. Whole-body scintigraphs in anterior and posterior views show ROIs used to quantitate lung perfusion and right-to-left-shunt volume.

sis and pulmonary blood flow. The heart was then catheterized through a femoral vein for obtaining angiograms and measuring the right and left intracardiac pressures (*8*).

RESULTS

The microsphere technique was safe in the applied manner, because no side effects were experienced by any of the patients. The mean duration of the investigation was 40 min and, thus, was clinically practical, because all studies could be performed without sedation.

Visual assessment of the studies revealed that 9 of 15 patients with a left BTS had hypoperfusion of the left upper lobe after injection into the arm vein. Four of these 9 patients had corresponding hyperperfusion when injected into the foot vein (Fig. 3); 5 had homogeneous perfusion into the left lung after injection into the foot vein. Of the 6 patients with a BTS on both sides, 4 had hypoperfusion in both upper lobes over the superior vena cava and had a normal perfusion pattern if injected into the inferior vena cava. Of these 6 patients, 2 had an identical perfusion pattern after both injections. Of the 3 patients with a right BTS, 2 had a hypoperfused right upper lobe after injection into the arm vein and corresponding hyperperfusion after injection into the foot vein, and 1 had no significant difference. This remarkable perfusion pattern with a preferential perfusion of the upper lobes through the systemic circulation and not through the pulmonary artery was not known in these patients, despite routine pulmonary angiography and contrast echocardiography.

Quantitative assessment of the relative perfusion is summarized in Table 2. Almost all Glenn shunt patients (unilateral and bilateral Glenn shunts with or without previous BTS) show a preferential drainage of the superior vena cava

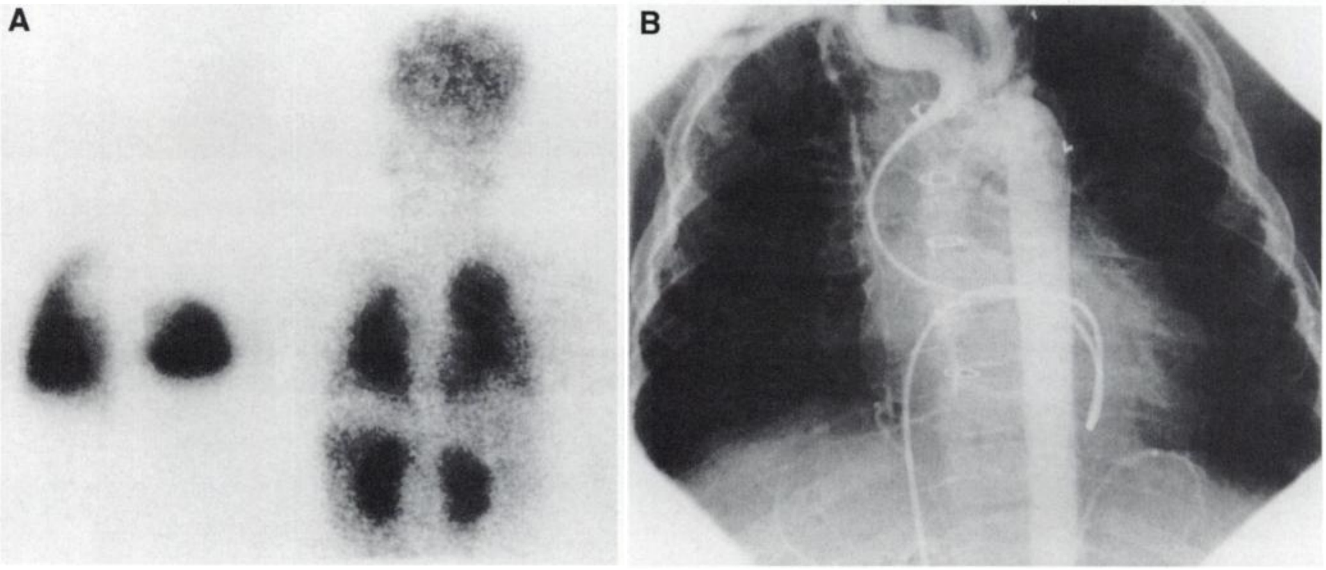

FIGURE 3. (A) Posterior view (after injection into arm vein on left, after injection into foot vein on right) of 8-y-old girl with dextrocardia after Glenn shunt and right BTS. We find missing perfusion of right upper lobe after tracer application into right cubital vein and hyperperfused right upper lobe after application into foot vein. Right-to-left shunt volume from inferior caval system in this patient was 61%. (B) Angiograph of same patient shows arterial anastomoses originating from descending aorta leading to right upper lobe.

TABLE 2
Summary of Tracer Uptake into Right Lung (Percentage of Total Lung Counts) After Glenn Shunt and Fontan Procedure

No. of patients	Type of surgery	Injection site Superior vena cava	 Inferior vena cava
38 (29*)	Glenn	78.7% ± 2.9%	45.2% ± 2.4%
8	Fontan	63.4% ± 8.7%	48.4% ± 8.4%

*In 9 patients with Glenn shunt, imaging through inferior vena cava was not performed because of organizational reasons.

into the right lung and a symmetrical perfusion of both lungs through the inferior vena cava in most patients (Fig. 4).

The two methods for the estimation of the right-to-left-shunt volume revealed comparable results. The calculation of a ratio of brain and kidneys-to-right and left lungs (*6*) as a parameter for the right-to-left-shunt volume gave 0.078 ± 0.01 in patients with Glenn shunt and 0.046 ± 0.01 with Fontan procedure after the upper limb injection (Table 3). After lower limb injection, the ratio was 0.59 ± 0.08 in Glenn shunt and 0.12 ± 0.05 in Fontan patients (Table 3). These ratios were significantly ($P < 0.01$) higher than the reference values in healthy volunteers (0.003–0.005), but the differences among patients after the different surgical interventions did not reach a level of statistical significance.

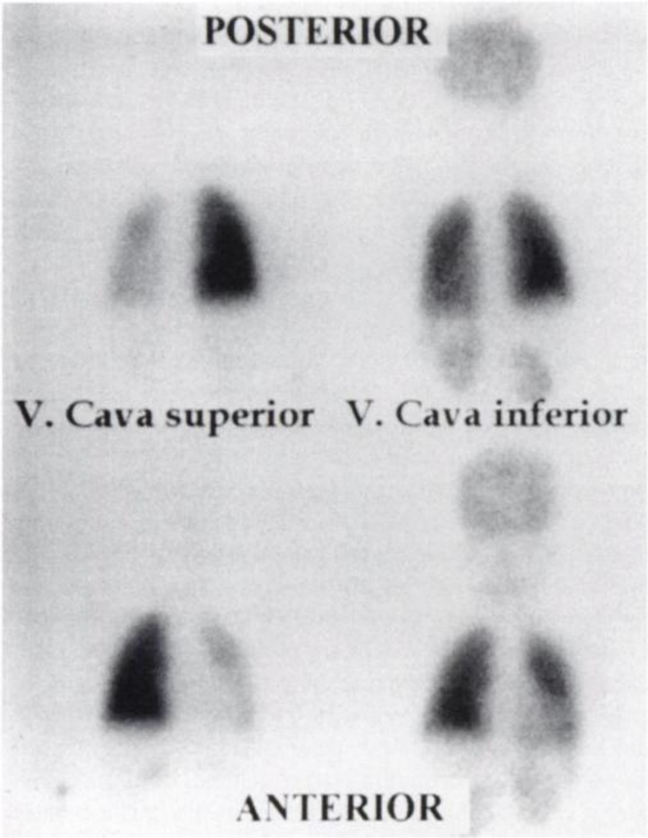

FIGURE 4. Of 46 patients, 31 showed significantly higher tracer uptake into right lung from upper vein system (left), while showing quite homogeneous distribution in both lungs from inferior caval system (right).

In addition, we estimated the percentage of right-to-left shunt directly from whole-body scans as a percentage of the administered dose. The right-to-left shunt volume was 24.7% ± 2.1% in patients with Glenn shunts and 19.2% ± 2.9% in patients with Fontan procedure after injection into the arm vein. After injection into the foot vein, the right-to-left shunt was 56.0% ± 2.7% in patients with Glenn shunts and 26.4% ± 5.2% in patients with Fontan procedure (Table 3). The total shunt volume, meaning the sum of the right-to-left shunt volume through upper- and lower-body circulation, was significantly lower in patients after Fontan procedure in comparison to Glenn shunt patients ($P < 0.05$).

The brain and kidneys-to-lung ratio was in good correlation with the estimated shunt from whole-body scans (correlation coefficient 0.8493, $P < 0.005$).

The O_2 saturation at the time of the perfusion scan was significantly higher (92.5% ± 1.5%) in patients with Fontan procedure than (82.4% ± 2.3%) after Glenn shunt ($P = 0.021$). The O_2 saturation was correlated to both the brain and kidney-to-lung ratio ($r = 0.4133$, $P = 0.014$) and the estimated total shunt volume (mean of shunt volumes from upper and lower circulation) ($r = -0.4887$, $P = 0.003$).

The quantitative results of the microsphere injection into the superior vena cava were compared with contrast echocardiography. The contrast echocardiography performed in our study was diagnostically inconclusive in 8 patients. Seventeen (2 Fontan/15 Glenn) of the 42 patients with a relevant right-to-left shunt volume on perfusion scintigraphy (more than 8% of the administered dose shunted into the main circulation) showed no evidence of right-to-left shunting in contrast echocardiography (Table 4).

DISCUSSION

The clinical follow-up of children with congenital heart disease relies on clinical parameters and contrast echocardiography. Invasive procedures, e.g., pulmonary angiography, are reserved for clinically deteriorating and diagnostically indecisive cases. Cases with decreasing oxygen saturation are especially challenging, because the differential diagnoses comprise deterioration of cardiac function, respiratory function or circulatory pathologies. The latter might be caused by the development of intrapulmonary or extrapulmonary anastomoses or the increasing contribution of a right-to-left shunt of the blood from the inferior caval system during growth.

Despite its ease and noninvasive nature, the microsphere technique has not found its way into routine management of children with congenital heart anomalies. This article focuses on the use of the microsphere technique not only for the above mentioned quantification but also for the visualization of the maldistributions in the pulmonary blood flow after surgery for congenital heart disease.

In our hands, the microsphere technique is a convenient, accurate and specific way of quantifying the shunt volume in

TABLE 3

Scintigraphic Studies After Injection into Superior Caval System and After Injection into Inferior Caval System

No. of patients	Type of surgery	Superior caval system		Inferior caval system	
		Shunt volume	Brain and kidneys-to-lungs	Shunt volume	Brain and kidneys-to-lungs
38 (29*)	Glenn	24.7% ± 2.1%	0.078 ± 0.01	56.0% ± 2.7%	0.59 ± 0.08
8	Fontan	19.2% ± 2.9%	0.046 ± 0.01	26.4% ± 5.2%	0.12 ± 0.05

*In 9 patients with Glenn shunt, injection into foot vein was not performed.

children with congenital heart disease. None of our patients experienced side effects or needed special sedation. An important factor seemed to be that we used a venous access that was inserted by personnel of the department of pediatrics for blood drawings and contrast echocardiography; thus, the patients were not further stressed by venous puncture. This is of special importance because invasive pulmonary and cardiovascular function tests are difficult to obtain in children younger than 5 y, because of poor patient cooperation (*9*). The necessity of limiting the number of injected particles in patients with suspected right-to-left shunt has already been stressed by others and must be carefully observed. Adhering to our protocol, we have observed no side effects in the 83 studies performed.

Visual assessment identified a remarkable perfusion pattern that was not known after pulmonary angiography or contrast echocardiography in a subgroup of patients who had undergone palliative BTS before the final surgery. Of the 24 patients with BTS, 15 had hypoperfusion of the upper lobe at the side of the BTS after injection into the arm vein and corresponding normal perfusion or even hyperperfusion when injected into the foot vein. All the patients who underwent palliative BTS had a notable right-to-left shunt through the inferior vena cava. Thus, the preferential perfusion of the upper lobes through the blood flow from the inferior vena cava suggests persisting anastomoses within the central arteries. These anastomoses seem to develop as a result of pulmonary arterial strictures at the site of the BTS surgery. Some authors previously suspected the negative impact of residual pulmonary artery distortion related to palliative procedures but could not visualize the effect on the pulmonary blood flow (*10,11*). The microsphere technique may be used as a decision tool in favor of an earlier Fontan procedure (*12*).

TABLE 4

Shunt Volume in Scintigaphic Studies Compared with Contrast Echocardiography After Injection into Superior Caval System

No. of patients	Type of surgery	Shunt volume/contrast echocardiography		
		Positive	Inconclusive	Negative
38	Glenn	14	7	17
		29.5% ± 4.4%	21.6% ± 1.9%	22.6% ± 2.5%
8	Fontan	2	1	3
		22.6% ± 5.2%	22, 3	15.0% ± 3.5%
46	All	28.6% ± 3.9%	21.7% ± 1.7%	21.5% ± 2.3%

Results of echocardiography were divided into positive (showing bubbles), negative and inconclusive cases. In 2 patients with Fontan, contrast echocardiography was not carried out.

The relative pulmonary perfusion after Glenn shunt is influenced by several individual factors, and the net effect of these is easily demonstrated by the microsphere technique. In bidirectional Glenn shunt, the blood volume of the upper caval vein is preferentially drained into the right lung, but the actual percentage of blood that reaches the left lung depends on the countercurrent flow in the right pulmonary artery. The magnitude of this flow is in part determined by the unshunted blood volume of the inferior vena cava and the degree of a possible pulmonary valve stenosis. Thus, in those patients with an evenly distributed blood volume from the inferior caval system, the right lung receives more blood volume than the left lung after original Glenn procedure.

Measurement and quantification of right-to-left shunt volume by perfusion scintigraphy are well-known methods first described in 1969 and 1974, respectively (*13,14*). Perfusion scan with microspheres was an accurate method of quantifying right-to-left shunts (*14–16*). In the literature the mean shunt volume in healthy volunteers is calculated to be 2.7% ± 1.2% at rest, eventually rising by 1%–5% during exercise (*16*). The scintigraphically obtained values with the microsphere technique do not necessarily refer to a physiologic shunt volume in this order but are the net effect of free label, a fraction of particles smaller than the pulmonary capillaries and a true shunt volume through physiologic anastomoses. On the basis of the data in the literature and our own experience, we considered 8% left-to-right shunt as a reliable threshold to discriminate a hemodynamic relevant shunt volume. The calculated shunt volume from the whole-body study correlated well with the proposed ratio of brain and kidneys-to-lungs. Both parameters were equally well correlated to O_2 saturation at rest. Although the proposed ratio is easy to calculate in two planar images and estimates the total shunt volume as well as the exact calculation from whole-body scans, the latter procedure, although a little more demanding, allows for a better quantification of the total shunt volume.

The intraindividual comparison of the scintigraphic quantification of the shunt volume with contrast echocardiography showed an underestimation of the shunt volume by contrast echosonography. Furthermore, the separate day protocol used in this study was able to assess the shunt volume from the inferior caval system, in addition to the usually assessed shunt volume from the superior caval system. The inferior caval shunt volume was significantly higher in most of the children with Glenn shunt procedure. Because the relation of blood distribution between upper and lower body in children is about 40%/60% and increases in favor of the inferior caval system, it can be assumed that the contribution of the shunt volume from the inferior caval system is of increasing importance in the follow-up of these children. This is the major difference and advantage of our study protocol in comparison with the literature, because all of the cited authors peformed lung perfusion scanning only after injection into an arm vein (*6,10,17–20*). Thus, the results underestimated the shunt volume by neglecting the increasing contribution of shunt volume from the inferior caval system.

CONCLUSION

We suggest that the separate day microsphere technique with intravenous application into an arm and a foot vein should be part of the follow-up of children with congenital heart anomalies. It was capable of identifying previously unknown perfusion patterns and may explain noninvasively the cause of clinical deterioration. The microsphere technique has a higher sensitivity than contrast echocardiography for the detection of a right-to-left shunt through the superior vena cava and is the only noninvasive procedure to estimate the right-to-left shunt volume through the inferior vena cava. It remains to be determined whether the additional diagnostic information of routinely performed scintigraphic investigations will affect the postsurgical management of pediatric patients with congenital cardiac anomalies.

REFERENCES

1. Taplin GV, Johnson DE, Dore EK, Kaplan HS. Suspensions of radioalbumin aggregates for photoscanning the liver, spleen, lung and other organs. *J Nucl Med.* 1964;5:259–275.
2. Fontan F, Baudet E. Surgical repair of tricuspid atresia. *Thorax.* 1971;26:240–248.
3. Glenn WW. Circulatory bypass of the right side of the heart: IV. Shunt between superior vena cava and distal right pulmonary artery—report of clinical application. *N Engl J Med.* 1958;259:117–120.
4. McFaul RC, Tajik AJ, Mair DD, Danielson GK, Seward JB. Development of pulmonary arteriovenous shunt after superior vena cava-right pulmonary artery (Glenn) anastomosis. *Circulation.* 1977;55:212–216.
5. Glenn WW, Hellenbrand WE, Henisz A, et al. Superior vena cava-right pulmonary artery anastomosis: present status. In: Tucker BL, Luiseswiter GG, Tarahashi M, eds. *Obstructive Lesion of the Right Heart.* Baltimore, MD: University Park Press; 1984:121–134.
6. Cloutier A, Ash JM, Smallhorn JF, et al. Abnormal distribution of pulmonary blood flow after the Glenn shunt or Fontan procedure: risk of development of arteriovenous fistulae. *Circulation.* 1985;72:471–479.
7. Seward JB, Tajiik AJ, Spangler JG, Ritter DG. Echocardiographic contrast studies, initial experience. *Mayo Clin Proc.* 1975;50:163–192.
8. Laks H, Mudd G, Staudeven JW, Fagan L, Willman V, Louis ST. Long-term effect of the superior vena cava-pulmonary artery anastomosis on pulmonary blood flow. *J Thorac Cardiovasc Surg.* 1977;74:253–260.
9. Gordon I, Helms P, Fazio F. Clinical applications of radionuclide lung scanning in infants and children. *Br J Radiol.* 1981;54:576–585.
10. Del Torso S, Milanesi O, Bui F, et al. Radionuclide evaluation of lung perfusion after Fontan procedure. *Int J Cardiol.* 1988;20:107–116.
11. Mayer JE, Helgason H, Jonas RA, et al. Extending the limits for modified Fontan procedures. *J Thorac Cardiovasc Surg.* 1986;92:1049–1064.
12. Juaneda E, Haworth SG. Pulmonary vascular structure in patients dying after a Fontan procedure. *Br Heart J.* 1984;52:575–580.
13. Haroutunian LM, Neill CA, Wagner HN. Radioisotope scanning of the lung in cyanotic congenital heart disease. *Am J Cardiol.* 1969;23:387–395.
14. Gates GF, Orme HW, Dore EK. Cardiac shunt assessment in children with macroaggregated albumin technetium 99m. *Radiology.* 1974;112:649–653.
15. Chilvers ER, Peters AM, George P, et al. Quantification of right to left shunt through pulmonary arteriovenous malformations using ^{99m}Tc albumin microsheres. *Clin Radiol.* 1988;39:611–614.
16. Whyte MKB, Peters AM, Hughes JMB, et al. Quantification of right to left shunt at rest and during exercise in patients with pulmonary arteriovenous malformations. *Thorax.* 1992;47:790–796.
17. Boothroyd AE, McDonald EA, Carty H. Lung perfusion scintigraphy in patients with congenital heart disease: sensitivity and important pitfalls. *Nucl Med Commun.* 1996;17:33–39.
18. Hashimoto K, Nakamura Y, Matsui M, Suzuki K, Kurosawa H, Arai T. Alteration of pulmonary blood flow distribution in patients with congenital left to right cardiac shunt. Pre- and postoperative study with macroaggregates of ^{99m}Tc-labeled human serum albumin. *Jpn Circ J.* 1993;57:291–298.
19. Matsushita T, Matsuda H, Ogawa M, et al. Assessment of the intrapulmonary ventilation-perfusion distribution after the Fontan procedure for complex cardiac anomalies: relation to pulmonary hemodynamics. *J Am Coll Cardiol.* 1990;15:842–848.
20. Dowdle SC, Human DG, Mann MD. Pulmonary ventilation and perfusion abnormalities and ventilation perfusion imbalance in children with pulmonary atresia or extreme tetralogy of Fallot. *J Nucl Med.* 1990;31:1276–1279.