Radiation Exposure of Pediatric Patients and Physicians During Cardiac Catheterization and Balloon Pulmonary Valvuloplasty

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Thermoluminescent dosimeters were applied to various areas of 61 pediatric patients and physicians to measure radiation doses during routine cardiac catheterization and during 4 cases of balloon pulmonary valvuloplasty. Radiation doses were measured during chest roentgenography, fluoroscopy and cineangiography. Average skin dose to the chest was 121 μGy during chest x-ray, 5,182 μGy during catheterization and 641 mGy during valvuloplasty. For the eyes, thyroid and gonads of the patients, the exposure during routine catheterization was equal to 0.4, 6 and 0.2 chest x-rays, respectively. Radiation dose of the operator was 3 μGy for the eyes and 6 μGy in the thyroid. About 56% of the operator's dose could be reduced by thyroid shields, and 80% by lead aprons. The assistant received only 1 μGy outside the thyroid shield. Therefore, we have concluded that the patients' dose during routine catheterization is largely based on our experimental results, but the dose is acceptable based on the risk factor analysis. The skin dose to the right lateral chest of the patient during valvuloplasty is extremely high, perhaps as high as the equivalent of 1,000 chest x-rays. Besides the clinical benefits of valvuloplasty, the long-term radiation-related hazards to the patient should be carefully monitored.

(Am J Cardiol 1991;68:221–225)

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Several investigations have examined the radiation dosage received by patients and physicians during cardiac catheterization.[1-9] Recently, interventional cardiac catheterization has developed rapidly, and has been applied worldwide in the treatment of moderately severe valvular pulmonary stenosis and a variety of congenital heart diseases.[10,11] Although many studies have been published on its clinical applications and complications, the problems regarding radiation hazards have never been addressed.[12] In this study, we measured various radiation doses to pediatric patients and the physicians performing cardiac catheterization, and evaluated the risks to radiosensitive organs. Preliminary results of radiation dose during balloon pulmonary valvuloplasty are also presented.

METHODS

Between January 1989 and June 1990, 61 infants and children chosen at random were evaluated during clinically indicated cardiac catheterization studies. Their ages ranged from 28 days to 15 years (mean 4.7 years). Thirty-six had left to right shunts, 9 had cyanotic congenital heart disease, 10 had obstructive heart disease and 6 had Kawasaki disease. All underwent complete 2-dimensional echocardiographic study before catheterization; all patients had right- and left-sided cardiac catheterizations, which were performed percutaneously from the right groin area. Cardiac catheterization was performed in the standard fashion.[1] A single-plane U-arm televised fluorocinescopy (Toshiba KX-1250) was used. It consisted of an undercouch tube and an overcouch dual-mode image intensifier. There was no protective ceiling shield between the table and the operator. The distance from focus to table top was 75 ± 4 cm, and the total filtration in the beam was 1.1 mm aluminum. The fluoroscopic field size ranged from 132 to 256 cm^2. During fluoroscopy the nominal voltage was in the range of 60 to 89 kV, with a tube current from 0.4 to 1.0 mA. During cineangiography, the corresponding values were 60 to 66 kV, and 250 to 400 mA, respectively. Cineangiograms at a filming speed of 60 frames/s were performed as clinically indicated. To reduce exposure to scattered radiation, during cineangi-

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TABLE I Entrance Skin Dose Over the Organs of the Pediatric Patients During Each Cardiac Catheterization and Cineangiography (μGy for examination)

Age (yr)	No. of Pts.	Time: Fluoro +Cine (min)	Time: Cine (sec)	Eye	Thyroid	Midsternum: Fluoro +Cine	Midsternum: Cine	Right Lateral Chest: Fluoro +Cine	Right Lateral Chest: Cine	Umbilicus	Gonad
<2	23	6 ± 4	6 ± 5	63 ± 47	877 ± 694	5,517 ± 3,183	3,107 ± 1,676	11,864 ± 5,402	7,637 ± 4,326	144 ± 62	31 ± 24
2–6	21	5 ± 2	11 ± 4	57 ± 52	586 ± 458	6,569 ± 4,762	3,337 ± 2,559	11,338 ± 6,489	7,710 ± 4,828	113 ± 62	17 ± 16
>6	17	6 ± 4	10 ± 4	35 ± 40	472 ± 318	3,014 ± 1,810	1,821 ± 1,128	6,984 ± 4,912	4,453 ± 3,759	105 ± 60	12 ± 7
Total	61	6 ± 5	11 ± 5	51 ± 46	764 ± 558	5,182 ± 3,815	2,828 ± 2,017	10,098 ± 6,048	6,448 ± 4,019	123 ± 64	24 ± 20

The radiation dose ratio during cineangiography compared with that during fluoroscopy and cineangiography is 61% at sternum and 70% at right lateral chest.
Cine = cineangiography; Fluoro = fluoroscopy.

ography all personnel stood ≥2 meters away from the table.

Thermoluminescent dosimeters were applied to the body to measure radiation exposure during cardiac catheterization. Each dosimeter contained 80 mg of dehydrated powder of highly sensitive dysprosium-activated calcium sulfate that was sealed in a 0.3 × 0.1 × 2.0 cm black polyethylene cylindrical tube.[13] Precatheterization chest roentgenography was performed in all children, and dosimetry was measured in 22. During hemodynamic assessment, the dosimeters were located on the skin over the glabella, thyroid, midsternum, right lateral chest, umbilicus and pubic area of the patient. During cineangiography, unexposed dosimeters were added to midsternum and the right lateral chest. For the operator, the dosimeters were put on the glabella, left third finger, left knee area outside the apron, the thyroid area inside and outside the shield, the umbilical area inside and outside a full wraparound apron of 0.5-mm thickness. For the assistant, standing to the right of the operator, the dosimeter was located outside the thyroid shield. The dosimeters were prepared, processed and read as previously reported.[14] Using the peak of the glow curve, they were read out on a Harshaw 2000 B & C Reader. The reader stability was ± 0.8%. The total error of the reader system in μGy was ±3.0%.

Another 4 children with pulmonary stenosis, whose mean pressure gradient was 67 mm Hg, were also enrolled in this study to measure the radiation exposure of the sternum and right lateral chest during routine catheterization, angiography and balloon pulmonary valvuloplasty. After a lateral projection of right ventriculography, valvuloplasty was then performed 2 to 3 times using the technique described by Lababidi and Wu.[11] After dilation, the balloon catheter was removed and pressure measurements were repeated. Finally, a postdilation right ventricular angiography was performed again.

RESULTS

The mean fluoroscopic time was 6 ± 5 minutes. The number of cineangiograms performed varied with the complexity of the lesion. Most children had 2 single-plane cineangiograms. The mean cineangiographic time was 11 ± 5 seconds. Average skin dose over the organs of the patients during the complete catheterization study (fluoroscopy plus cineangiography) are listed in Table I. In the midsternum and right lateral chest area, cineangiography contributed 61 and 70% of total radiation dose during complete catheterization, respectively.

The correlation analysis of radiation dose at midsternum area was calculated by the Pearson correlation method. Figure 1 implies a weak negative linear relation ($r = -0.39$, $p < 0.01$) between fluorocineangiographic radiation dose and patient age. However, radiation dose has no significant relation to cinefluorographic time ($r = 0.14$, $p > 0.05$) (Figure 2). In Figure 3, the radiation dose shows a clear correlation with cine time ($r = 0.64$, $p < 0.01$).

Precatheterization chest roentgenography was performed in all children; dosimetry was measured in 22 children. Average skin dose to the chest was 121 ± 27 μGy. As a means of comparison, the radiation dose on the skin over the organs was expressed as chest x-ray equivalents, defined as the ratio of the skin dose over the organ of interest to that over the chest. When so expressed (Table II), the fluoroscopic phase of the chest area was equal to an average of 43 chest x-rays, whereas cineangiography was equivalent to an average of 23 chest x-rays. In cases of complete cardiac catheterization, the average thyroid dose was equivalent to 6 chest x-rays. That value of the right lateral chest, umbilicus and gonads was equivalent to 83, 1.2 and 0.2 chest x-rays, respectively.

The doses of the operator and the assistant are given in Table III. The left knee of the physician received highest exposure during catheterization. The doses on different sites of the operator's body and that of the assistant were relatively small in terms of chest x-ray equivalents. The radiation exposure outside/inside of the thyroid shield was 6/3 μGy. In other words, about 56% of the radiation exposure could be reduced by the thyroid shield. The value outside/inside of the lead apron in the umbilical area was 7/2 μGy. For the body, about 80% of the exposure could be reduced by using wraparound aprons.

In valvuloplasty, the mean time of fluoroscopy was 28 minutes and the mean time of cineangiography was 63 seconds. The radiation dose to the sternum and right

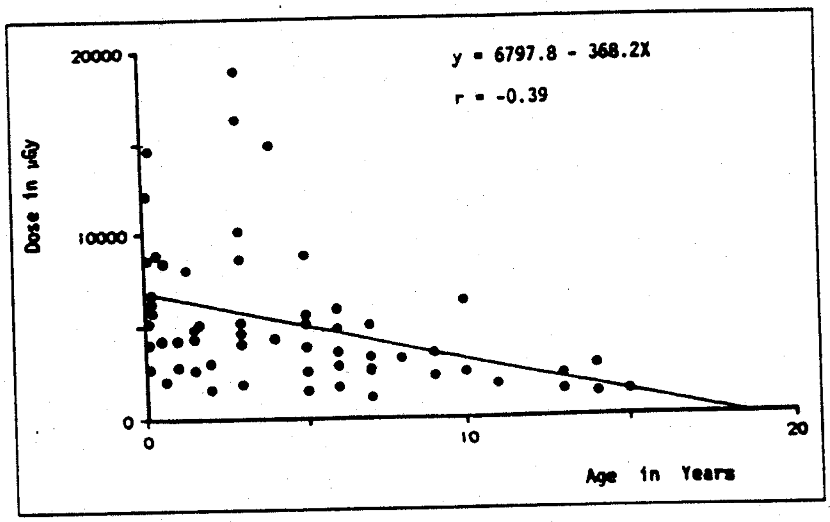

FIGURE 1. Relation between patient's age and fluorocineangiographic radiation dose at midsternum.

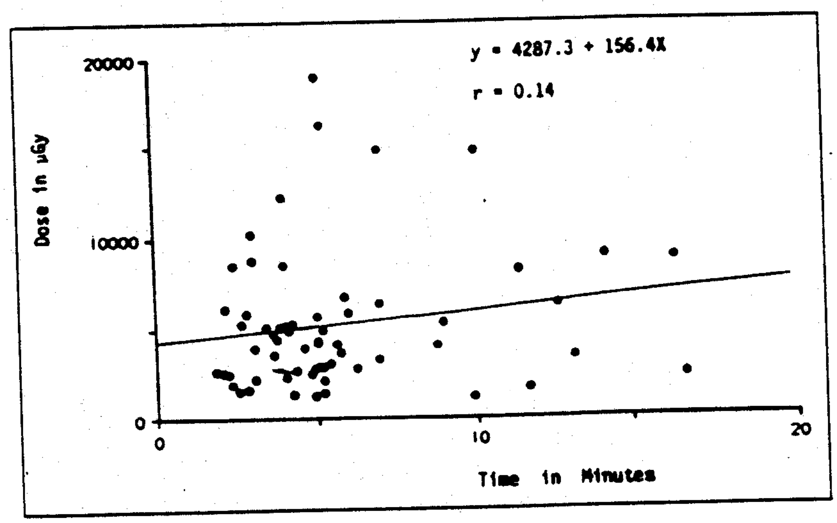

FIGURE 2. Fluorocineangiographic time versus dose at midsternum.

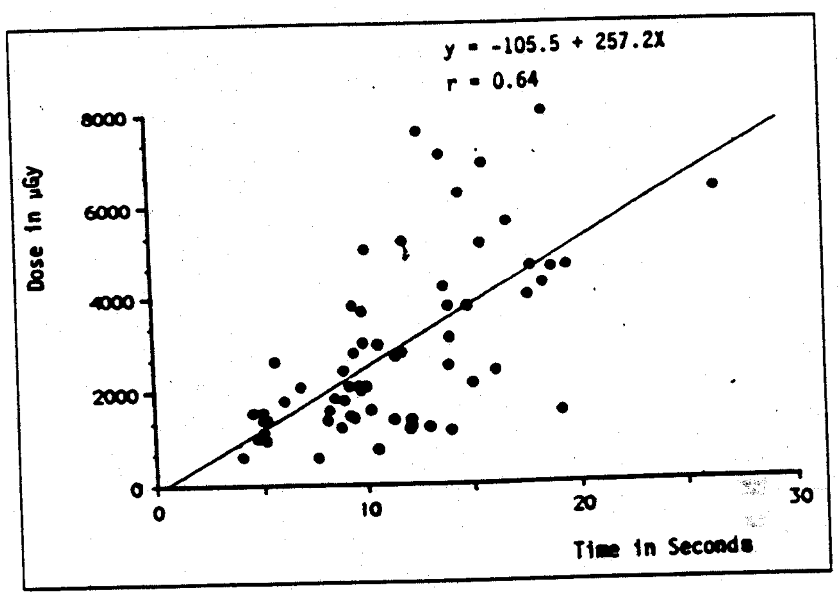

FIGURE 3. Cineangiographic time versus dose at midsternum.

...y of radiation-induced cataracts. The radiation ...the operators' eyes range from 1 to 180 μGy/...m.[3-5,19] Balter et al[5] suggested that radiation-in...ed cataracts were not very likely if a doctor's accu...lative exposure is at a rate of 0.15 Gy/year for an ...ire 40-year work life. Radiation-induced neoplasia of ...e thyroid gland of personnel is another area that ...uld be considered.[20] The exposure of the thyroid ...ring catheterization by a doctor ranged from 35 to ...0 μGy/exam in other studies[3-5,21] and 6 μGy/exam ...ours. The maximal permissible dose was 3 mSv/...ek[21]; thus, the risks of radiation-induced thyroid neo...sia appear to be negligible in our studies.

For years, balloon pulmonary valvuloplasty has been ...cepted as an effective means of reducing pulmonary ...tflow gradients in pediatric patients with valvular ...lmonary stenosis.[10-12] The procedure has been prov... safe, with a lower mortality than surgery and proba...y an overall lower morbidity as well.[22] Nevertheless, ...is sometimes very difficult to manipulate the guide...ire and the big balloon across the stenotic pulmonary ...lve. This means that more time is needed in fluoros...opy for this procedure than in routine catheterization. ...r survey discloses a relatively large dose of radiation ...Table II). The skin dose of the chest might be as much ...10 times higher than that during routine catheteriza...n, or the equivalent of 1,000 chest posteroanterior ...entgenograms. The value is tremendously higher for ...owing children. However, during the follow-up peri...l, the 4 patients had normal leukocyte counts and ex...nal appearances, and their chromosome studies 3 to ...months after valvuloplasty revealed no aberrations.

The procedure can be successfully performed in ...es of critical neonatal pulmonary stenosis with good ...ort-term results.[23] This report indicates that it lasted ...to 4 hours with a total fluoroscopy time of 30 to 68 ...utes. In this preliminary study, the number of cases ...died may be too small to form a conclusion about ...e radiation hazards of valvuloplasty. However, based ...our results of 60 to 70% of radiation dose during ...heterization arising from cineangiography, we would ...ggest minimizing the number of cineangiographic ...ns or reducing the filming rate whenever possible. ...fore more information is obtained, one should pay ...eater attention to the probable effects of radiation-...ated complications of balloon-directed valvuloplasty ...pediatric patients.

Acknowledgment: We express our cordial thanks ...the financial support of the Atomic Energy Council of the Executive Yuan, Republic of China. We are also grateful to Chi-Hsiun Chiang, MD, Pao-Shu Chang, PhD, and Hung-Chi Lue, MD, for their helpful suggestions in this manuscript.

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