Effective Doses from Scan Projection Radiographs of the Head: Impact of Different Scanning Practices and Comparison with Conventional Radiography

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Effective Doses from Scan Projection Radiographs of the Head: Impact of Different Scanning Practices and Comparison with Conventional Radiography

ORIGINAL RESEARCH

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BACKGROUND AND PURPOSE: For CT scan planning, scan projection radiographs (SPR) are used. Tube tension and current for head SPR can be reduced to a minimum because of the small head diameter and because only high-contrast structures need to be visualized for planning. The goal of this study was to investigate SPR of the head in respect to effective doses, the influence of dose-reduction measures, and comparison with conventional x-ray.

MATERIALS AND METHODS: Entrance doses for default and minimal settings were measured on a LightSpeed Ultra CT scanner and on conventional x-ray equipment. Effective doses for different scanning fields of the head were calculated for an adult, a 10-year-old child, and a neonate by using the commercially available software PCXMC.

RESULTS: Depending on projection and technique, SPR effective doses for adults were 1.9–27.7 μSv; for the 10-year-old child, 2.1–31.1 μSv; and for the neonate, 5.2–97.2 μSv. Doses with the tube under the table were 1.3–3.4 times lower. Doses for conventional radiography were higher than SPR doses for adults and partially lower for children.

CONCLUSIONS: Depending on the scanning technique, effective doses for head SPR can differ up to 17-fold. The dose is significantly reduced by lowering tube voltage and current, by positioning the tube under the table, and by keeping the thyroid out of the scan or by protecting it with a lead collar. Compared with the conventional x-ray technique, SPR doses tend to be lower due to x-ray beam characteristics.

To plan a CT scan, one must first acquire a scan projection radiograph (SPR). SPRs are technically projection radiographs rather than CT scans because they are performed with the tube fixed, usually in an anteroposterior and/or lateral projection. The radiograph is registered while the table is moving through the gantry along the z-axis. It is generally assumed that the radiation dose from SPRs is negligible. A textbook[1] on radiologic technique says that for SPRs "the radiation dose is one hundred times lower than for a conventional radiograph due to the high sensitivity of the detectors." In a more recent book[2] on radiation doses from multidetector CT, the issue is treated very briefly, stating that SPRs "usually contribute a very low percentage to the global exposure."

In contrast, O'Daniel et al[3] observed doses for chest SPR amounting to the dose of 4.5 chest radiographs when using default settings implemented by manufacturers in certain multisection scanners. They recommended the adjustment of scanning parameters for children and slim patients if image quality is not critical. Head SPR seems particularly suitable for dose reduction because head diameter is smaller than trunk diameter and only high-contrast bony structures need to be visible for planning. Positioning the tube below the table (posteroanterior projection) has also been recommended[3] because then part of the x-ray is absorbed by the table and the thyroid dose will be smaller. At our institution, scanning parameters and tube position for head SPR were adjusted more than a year ago. We did not experience any problems related to these measures. The goal of this study was to assess effective doses from head SPR, to evaluate the influence of different scanning practices on dose, and to compare effective doses from SPR with those from corresponding conventional radiography performed with modern x-ray equipment.

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Materials and Methods

Dose-Measurement Technique

Entrance doses (EDs) and effective doses resulting from head SPR performed with default settings (as implemented by the manufacturer, ie, 120 kV and 10 mA) and minimum possible settings (80 kV and 10 mA) were assessed in anteroposterior, posteroanterior, and lateral projections on an 8-section CT scanner (Lightspeed Ultra, GE Healthcare, Milwaukee, Wis). ED measurements were performed in anteroposterior projection with the probe positioned at the isocenter. EDs were also measured with the tube in the posteroanterior position, with and without the head holder, which is made of synthetic resin, in place to assess the head holder absorption fraction. All measurements were performed 3 times, and mean values and relative variation coefficients (RVC) were calculated. A Barracuda Electrometer (RTI Electronics, Mölndal, Sweden) with a solid-state probe MPD was used. The system had been calibrated in the manufacturer's laboratory less than 12 months before the measurements. The MPD probe is equipped with lead shields preventing entrance of scattered radiation; thus, only direct radiation from the source (ie, ED) is measured. According to the manufacturer's recommendation, the longer side of the measuring field was positioned at a right angle to the table direction, though our own initial experiments did not show any significant dif-

BRAIN ORIGINAL RESEARCH

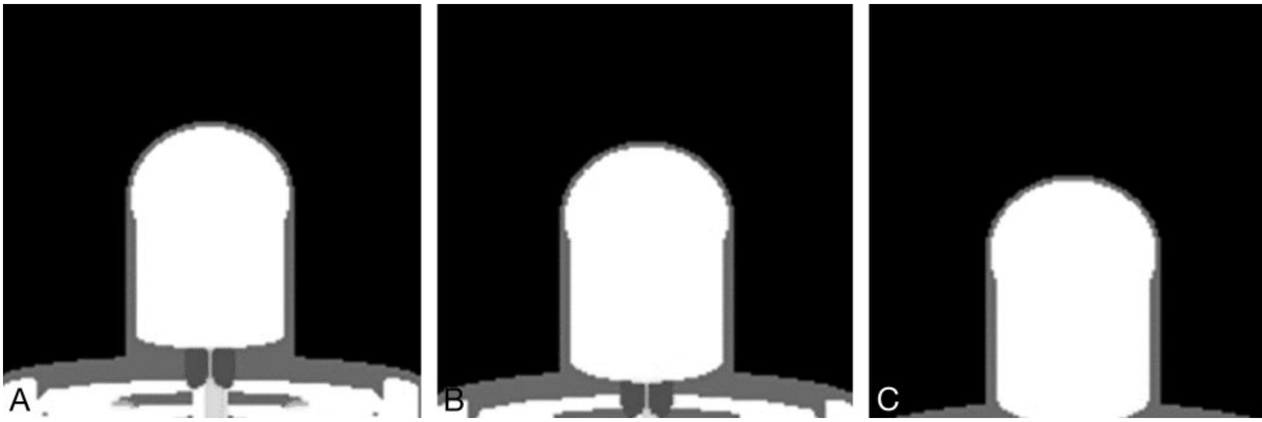

Fig 1. Screenshots from the PCXMC software showing the lower scanning borders used for effective dose calculations. Note the upper scanning border–assumed vertex for all SPR calculations.

ference between positioning the probe at a right angle or alongside the moving direction of the table.

We decided to measure ED because from ED, effective doses can easily be calculated by using the Monte Carlo simulation software PCXMC (Radiation and Nuclear Safety Authority, Helsinki, Finland; see next paragraph). Measured ED was corrected for the skin entrance point at the cheek for an adult, a 10-year-old child, and a neonate by applying the law of inverse square dose decrease with distance from the source. Typical head diameters were assessed analyzing 5 head CT scans from patients of each age group.

To compare SPR doses with modern conventional projection radiographic techniques, we performed dose measurements with the same methods as described previously with an Optimus 80 x-ray system (Philips, Leiden, the Netherlands), equipped with a digital imaging plate reader system FCR PROFECT CS (FUJIFILM, Tokyo, Japan) for the adult and with a Digital Diagnost x-ray system, Optimus 50 (Philips), equipped with a flat panel detector for the 10-year-old child and the neonate. This latter x-ray machine is installed at our pediatric radiology unit and is equipped with additional filtration (0.2-mm copper and 1-mm aluminum) for dose optimization. Typical exposure parameters for the adult were gathered by using a tissue-equivalent head phantom (XR-100; Alderson Research, Stamford, Conn) because the x-ray system is equipped with an automatic exposure control. For children, we used the same exposure parameters as in clinical routine.

Information on tube design and x-ray beam quality was gathered by contacting the manufacturer and from the literature.[4] Information on beam geometry was obtained by analyzing the CT scanner beam with the method described by O'Daniel et al,[3] by using Gafchromic XRCT dosimetry films (ISP, Wayne, NJ). CT table speed was measured by performing a 1590-mm-long SPR, measuring moving time with a chronometer 6 times. Mean speed and SD were calculated.

Effective Dose Calculation

Effective doses were calculated by using the commercially available Monte Carlo simulation software PCXMC[5] Version 1.5. The program simulates photon-tissue interaction by using a stochastic mathematic model and hermaphrodite humanoid phantoms of different ages. It calculates organ doses, effective doses, and the margin of inaccuracy of the simulation process. Its performance was compared with the general purpose Monte Carlo code MCNP by Schultz et al,[6] and a good agreement for effective dose calculation was found. The software was designed for projection radiography. SPR has geometric beam characteristics, which, in some ways, differ from those of projection radiography. To evaluate the suitability of the program for our purpose, we simulated SPRs, calculating effective doses, adding the doses from multiple narrow fields, and compared the results with effective doses from full-field geometry. Calculations with the beam characteristics of our CT scanner resulted in effective doses differing between 0.5% and 40% from those for projection radiography when all other factors were unchanged. We, therefore, calculated all effective doses from SPR by adding the effective dose of the multiple adjoining scanning fields with a field width of 7.5 mm each, so that the total surface sum equaled the whole scanning surface. For example, for the adult model, 34 fields with a width of 7.5 mm each were used. The small scan strip above the vertex, which contributes only a small amount of scattered radiation emitted from the scanner gantry and table, was neglected.

Effective doses for different projections (anteroposterior, posteroanterior, lateral) and a scanning extension typically used in daily routine from the vertex to the neck, including the thyroid and parts of the first rib (Fig 1), were calculated for an adult and a 10-year-old child. For effective dose calculations, the thyroid is important because of the organ-weighting factor giving major weight to a small organ. We, therefore, also calculated effective doses for lower scanning borders just below and above the thyroid (Fig 1). For the neonate, scans including the chest and parts of the upper abdomen were calculated (Fig 2), simulating a typical adult scanning extension (300 mm), as if, inadvertently, scanning length had not been adapted, as happens occasionally in daily practice. Effective doses for scanning fields including and excluding the thyroid were calculated for the neonate as well.

Results

Effective doses for SPR for different settings, projections, and scanning limits are given in Table 1, and effective doses for conventional radiographs, in Table 2. RVC was <0.015 for all measurements.

EDs measured with the tube under the table were 10.5% lower than EDs with the tube above the table. Effective doses for anteroposterior projections were 1.25–3.4 times higher than those for the posteroanterior projection. The adult effective dose for a scan in 2 projections (anteroposterior or posteroanterior and lateral) was in the range of 41.8 μSv for the scanning performed with default settings and a typical scanning extension including the thyroid and parts of the upper mediastinum; and it was in the range of 3.9 μSv when scan-

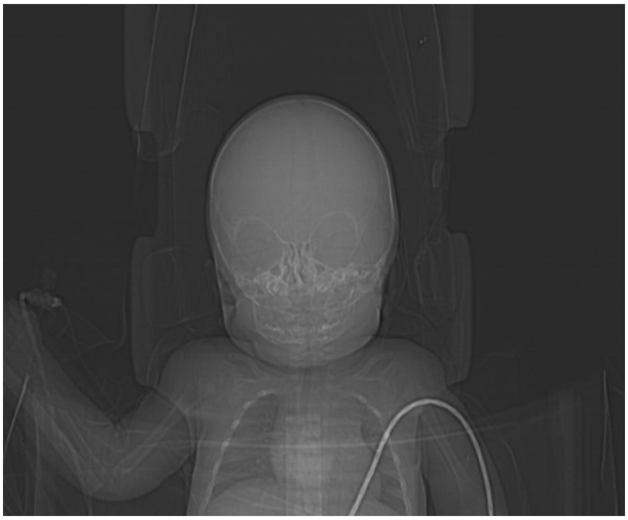

Fig 2. SPR of a neonate with a 300-mm craniocaudal extension.

ning was performed with the lowest setting—that is, the tube in the posteroanterior position and the shortest possible scanning extension excluding the thyroid. For the 10-year-old child, the highest dose was 40.3 μSv and the lowest possible dose was 3.4 μS, whereas for the neonate, the highest dose (for the scan including the chest and part of the abdomen) was 169.3 μSv and the lowest possible dose was 9.6 μSv.

For the adult, effective doses from SPR performed with default settings were 1.7–4.7 times lower than those for corresponding skull x-rays and, when performed with minimal settings, as much as 6.1–15.9 times lower. For the 10-year-old child, doses from SPR were 1.7–2.7 times higher with default settings and 1.5–2.7 times lower with minimal settings, whereas for the neonate, doses with default settings were 7.5–7.7 times higher; and with minimal settings, still 1.2–2.5 times higher than effective doses for conventional radiographs.

The uncertainty inherent in the simulation of the photon-tissue interaction process was below 0.5% for all calculations for the adult and the 10-year-old child and up to 3.8% for the neonate (posteroanterior) at 80 kV. Beam width measured in the z-axis was 7.5 mm at the isocenter. Beam width in the x-axis was 52 cm. Table speed indicated by the manufacturer was 100 mm/s. Table speed measured was 95.8 $\pm$ 0.36 mm/s.

Discussion

The literature offers little information on radiation doses delivered by SPRs, and the information available is contradictory.[1-3] The scant attention that the radiologic community has paid to this topic can probably be attributed to the widespread opinion that SPR doses are very small and, therefore, negligible. On the other hand, considerable doses for chest SPR were found.[3] To resolve this lack of clarity, we decided to assess effective doses delivered by head SPR, to evaluate the impact of different dose-reduction measures and to compare SPR doses with those delivered by conventional radiography.

We found significantly lower doses for adult head SPR than for conventional radiography, even when SPR was not performed with optimized settings. However, our results (Tables 1 and 2) show that, depending on the scanning technique, considerable effective dose differences in the same scanner can result. An SPR in 2 projections (anteroposterior or posteroanterior and lateral) is required to plan a head CT scan with our scanner. If the settings implemented by the manufacturer are applied, the effective dose can be up to 11 times higher than the achievable minimum attained by carefully positioning lower scanning limits above the thyroid and by using the posteroanterior projection with minimum tube settings. When scanning a neonate or baby without adjusting tube settings and scan length, the dose can even be 17 times higher than that with the most dose-saving approach. When only tube parameters are adapted, the dose is still nearly 5 times higher than the achievable minimum. Hence, care must be taken to adapt scanning length when scanning infants; otherwise a dose many times higher than necessary can be inadvertently delivered by including parts of the trunk into the scanning field (Fig 2).

The influence of changing the tube position from above to under the table is remarkable. Although the head holder absorption reduces the entrance dose by only 10.5%, the total effective dose for adults is reduced by a factor 3.4 under the best conditions. This striking dose reduction is mostly due to the fact that the thyroid is away from the radiation source in the posteroanterior tube position.

In conclusion, it seems beneficial to apply the following rules for head SPR rigorously: use of the lowest tube voltage and current (in so far as image quality is acceptable), positioning the tube below the table, and carefully excluding the thyroid from the scanning field. The latter rule might be difficult to comply with, especially when the patient has a short neck, and it is easier to protect the thyroid with a circular lead collar. This is recommended anyway, because its use also significantly reduces thyroid dose during the CT scanning.[7]

The relative dose reduction reached by all of the previously mentioned measures together is impressive, but the absolute dose reduction and, therefore, the reduction of the individual stochastic risk seem rather small. A typical plain head CT scan at our institution imparts an effective dose of about 2.5 mSv. The head SPR in 2 projections contributes, therefore, only about 0.2%–1.7% to the total effective dose of an adult head CT scan. This seems negligible. On the other hand, a positive effect on population dose can be expected from the described dose optimization measures if applied on a routine basis. In the first year since introduction of these measures, 2580 head CT scans have been performed with our scanner, corresponding to a cumulative dose-saving potential of approximately 97.5 mSv or 39 head CT scans if the dose-optimized technique is applied. For the future, factory delivery of new scanners with optimized settings would allow a significant population dose reduction worldwide, and we suggest that such measures be taken by manufacturers.

Of course the dose-reduction measures we propose concerning SPR should be implemented in radiology departments in the setting of a broad dose-reduction and optimization program. Recent publications show, for example, that in neuroradiologic CT, radiation-dose reduction of >50% can be achieved by using modern dose-modulation techniques[8] and by using low-dose protocols for subgroups of patients examined for follow-up where a limited image quality is acceptable.[9]

Some scanners need only 1 SPR projection (either posteroanterior/anteroposterior or lateral) to plan a scan. In-

Table 1: Effective doses (μSv) for SPRs at default and at reduced settings

		Adult			10-Year-Old Child			Neonate		
		Lower Scanning Border								
Projection	Settings (kV/mA)	Below Clavicle	Lower Thyroid Limit	Upper Thyroid Limit	Below Clavicle	Lower Thyroid Limit	Upper Thyroid Limit	Below Diaphragm	Lower Thyroid Limit	Upper Thyroid Limit
AP	120/10	27.7	23	9	23.1	19.9	7	97.2	30.7	16.3
	80/10	8.3	6.8	2	7.3	6.3	1.9	32.3	10.1	5.2
PA	120/10	8.9	7.9	3.7	8.6	6.7	4.8	65.9	17	11.9
	80/10	2.4	2.0	1.6	2.3	1.8	1.3	22.9	6.2	4.4
Lateral	120/10	14.1	12.6	6.9	17.2	15.8	10.2	72.1	25.4	15.9
	80/10	4.1	3.6	1.9	4.2	3.8	2.1	24.9	8.3	5.2

Note:—AP indicates anteroposterior; PA, posteroanterior.

Table 2: Adult and pediatric effective doses (μSv) for conventional head radiography

	Anteroposterior	Posteroanterior	Lateral
Adult	107.8	27.5	22.0
10-Year-old	11.6	5.0	5.8
Neonate	4.6	–	3.3

Note:— – indicates not performed in clinical practice.

stead of a second projection, a single CT section is obtained to check the accuracy of FOV centering. In these scanners, dose reduction that can be obtained from the measures we described are smaller. If only 1 projection is used, a posteroanterior SPR is preferable over an anteroposterior or lateral SPR because it causes the smallest dose. Furthermore, it should be ensured that the single CT section be performed with adjusted dose-relevant parameters to avoid unnecessary radiation exposure.

How does head SPR compare with conventional x-ray techniques in our investigation? Our results show significantly lower effective doses for head SPR compared with conventional radiography for adults, whereas for the 10-year-old child, doses are partially higher, and for the neonate, significantly higher. This difference between adults and children primarily reflects the very low doses for conventional pediatric x-ray imaging at our pediatric radiologic institution as a consequence of a dose-optimization program,[10] by which an overall dose reduction of 63% for conventional x-ray imaging has been achieved, whereas the CT scanner has not been adapted for pediatric scanning. Our data show, therefore, that SPR doses can, under certain circumstances, especially for children, be in the range of conventional x-ray doses; hence, the same need for radiation-dose justification should be demanded as for conventional imaging. These facts support the need for dose-reduction measures for SPR, even if SPR doses appear negligible in the light of the much higher doses from CT scanning.

Concerning the comparison between SPR and conventional radiographic techniques, our adult data mirror the typical situation better than our pediatric data, and they show that SPR generally imparts smaller doses than conventional radiography. This comes as no surprise. Irving et al[11] examined a modern linear slit scanner and found the effective dose for a head anteroposterior scan to be a third of the typical conventional radiography dose. For the same scanner, Maree et al[12] found significantly lower doses for all pediatric examinations compared with conventional radiography. The doses for a skull in an anteroposterior projection were, for example, >10 times smaller. Samei et al[13] found an overall dose reduction of 34% for chest examinations with a slit-scan radiography system.

There are several reasons for the advantageous dose performance of slit-scanning techniques. First, for slit-scanning techniques, an inverse-linear dose-distance relationship applies instead of the square-inverse relation,[14] because field size in the z-axis does not increase with distance. Second, a narrow fan-shaped beam results in a far better scatter-to-primary ratio,[13,15-17] which is why no dose-absorbing antiscatter grid is needed.[14,16] The latter effect alone is estimated to reduce dose requirements by 50%.[14] Because of its slit-scanning design and, moreover, because of the limited image quality required, one would expect SPR to work with markedly lower doses than any other device designed for diagnostic imaging, be it full-field or slit-scanning technology. In practice however, SPR is performed with equipment designed for CT, and many dose-relevant factors, including filtration, generator, and tube design, have not been optimized for low-dose SPR, but only for CT. Additionally, the relatively short focus-skin distance used in CT as a consequence of the strong centrifugal forces from the rotating tube further increases skin doses significantly. Finally, dose-relevant settings are often chosen for optimal image quality despite the fact that only a basic image quality is needed. Therefore, SPR in CT takes only partial advantage of the previously mentioned advantageous dose characteristics of slit-scanning systems.

A dose-modulating aspect of SPR, which is not encountered in conventional radiography, is the table movement. Lower doses are to be expected with a higher table speed and vice versa. Table speed cannot be modulated in our scanner though, and effects of a higher table speed on image quality are uncertain. Therefore, we do not regard table-speed modulation as a practical means of dose reduction.

Image quality was not investigated systematically in this study. Contrary to conventional x-rays, SPRs are usually used only for planning; therefore, image quality is not critical. This holds especially true for head SPR, in which bony landmarks used for planning yield a high contrast. Furthermore, the head has a smaller diameter than the trunk; therefore, less energy is required to penetrate, making dose reduction seem reasonable. An exception is emergency imaging in which image quality might be affected by vacuum mattresses, spine boards, or equipment used to treat and monitor the patient. In practice, however, we did not

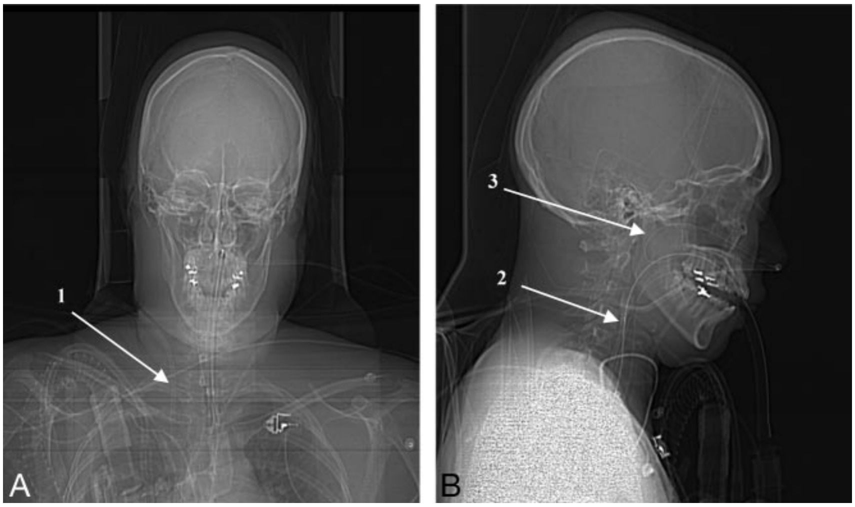

Fig 3. SPR for planning of head CT and neck CT angiography, performed with 80 kV and 10 mA. 1 indicates the jugular vein line on the right; 2, the endotracheal ventilation catheter; 3, the nasogastric line curled up in the mouth (confirmed by CT). All are very visible. The photon-starving effect over the shoulder and chest in the lateral projection is more pronounced than at 120 kV.

experience any problems related to impaired image quality. As an example, Fig 3 shows an SPR used to plan head CT and neck CT angiography, performed at minimal settings. Anatomic details from the head, neck, and chest as well as iatrogenic foreign bodies are very discernible. Because the experience with our scanner may not be universally applicable, a stepwise dose reduction is recommended for other scanners. Further studies systematically investigating image quality and dose requirements in different scanner models would be desirable.

Our study has a few limitations. First, our dose calculations refer to 1 scanner type of a certain manufacturer and are, therefore, not uncritically applicable to other scanners because differences in tube and gantry design, total filtration, and other dose-relevant factors may influence dose characteristics of other scanners.

Second, our measurement and calculation methods have some inherent inaccuracies. The accuracy of the dose measurement instrument has been specified by the manufacturer as ±3%. An estimated 2% error has to be taken into account from suboptimal positioning of the probe, which has an angle-dependent sensitivity. Another 0.5%–3.8% inaccuracy needs to be added for the uncertainty of the photon-tissue interaction simulation in PCXMC. Therefore, our effective dose calculations are accurate within 3.7%–5.2% only. Furthermore, it should be emphasized that our dose calculations are based on hermaphrodite models, which represent average physical properties of adults and children. Our calculations are, therefore, not applicable for patients whose physical properties differ significantly from the average.

Conclusions

Depending on the scanning technique, effective doses can differ 11-fold for adults and up to 17-fold for neonates. Doses can be significantly reduced by adjusting tube voltage and current to minimal possible settings, by positioning the tube below the table, and by carefully choosing lower scanning limits, keeping the thyroid out of the scan, or by protecting the thyroid with a circular lead collar. When scanning small children, one should take care to reduce scanning length adequately. In comparison with conventional x-ray technique, doses from SPR tend to be smaller due to advantageous physical characteristics of the x-ray beam geometry.

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