Spine Deformity
www.spine-deformity.org

Spine Deformity 3 (2015) 144−150

Case Series

Cumulative Radiation Exposure With EOS Imaging Compared With Standard Spine Radiographs

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Received 18 July 2014; accepted 11 September 2014

Abstract

Study Design: Retrospective comparative study.
Objectives: This study sought to estimate the total radiation exposure to scoliosis patients during the entire treatment course using standard imaging techniques versus EOS posteroanterior (PA) and anteroposterior (AP) views.
Summary of Background Data: EOS is a slot-scanning X-ray system designed to reduce radiation exposure in orthopedic imaging. There are few independent studies comparing organ and total effective radiation dose from standard EOS PA, AP, and lateral imaging versus conventional projection radiographs for children with spinal deformity.
Methods: A total of 42 skeletally immature idiopathic scoliosis patients were treated with bracing (21) or spinal fusion (21) and were followed to skeletal maturity. The number of scoliosis radiographs (PA and lateral) for each patient was recorded. A computerized dosing model was used to calculate estimated patient and organ doses for PA and lateral scoliosis X-rays taken with EOS or computed radiography with a filter (CR) or without a filter (CRF). Assuming that each X-ray taken delivered the same radiation as the phantom calculation, the authors estimated the total effective and organ dose that each adolescent would have received using EOS, CR, or CRF. Annual background radiation is 3 mSv.
Results: Mean number of radiographs per patient was 20.9 (range, 8−43). Patients who underwent surgical treatment had a significantly greater number of X-rays than those who were braced (27.3 vs. 14.5; $p < .001$). Assuming all films were CR, the mean cumulative dose was estimated at 5.38 mSv. With standard EOS films, the mean cumulative estimated dose was 2.66 mSv, a decrease of 50.6%. An AP versus PA EOS radiograph resulted in an 8 times higher radiation dose to the breasts and 4 times higher dose to the thyroid.
Conclusions: The standard EOS imaging system moderately reduced the total radiation exposure to skeletally immature scoliosis patients. Over the entire treatment course, this represented 2.72 mSv mean reduction or 0.91 years of background radiation. Posteroanterior films significantly reduced breast and thyroid dose.

Keywords: EOS; Scoliosis; Radiation exposure

Introduction

Minimizing radiation exposure to children is the responsibility of all health care professionals, particularly pediatric spine surgeons. The treatment of spinal deformities frequently requires multiple radiographs taken over many years. Further interventions during the course of spinal deformity treatment can expose children to additional radiation, such as preoperative and postoperative computed tomography (CT) scans, intraoperative fluoroscopy, intraoperative CT guided navigation, and treatment of associated gastrointestinal or cardiac conditions. Patients with early-onset scoliosis in particular may have multiple organ system disease and require frequent procedures imparting high doses of radiation [1]. Multiple approaches can be taken to reduce the amount of radiation exposure to patients, including adopting pediatric dosing techniques [2,3], using other imaging modalities such as magnetic resonance imaging or ultrasound [4,5], and limiting the number of images taken [6,7]. EOS imaging (EOS Imaging, Paris, France) is a

Author disclosures: TDL (none); AAS (none); BAS (none); ANL (none).

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2212-134X/$ - see front matter © 2015 Scoliosis Research Society.
http://dx.doi.org/10.1016/j.jspd.2014.09.049

new low-dose imaging system that provides high-quality radiographs with a lower radiation dose to patients and has been adopted at many centers [8,9].

Like other centers, the authors' institution has always taken additional steps to decrease the radiation dose to children observed for spinal deformity. Traditionally for scoliosis radiographs, the authors have placed a lead acrylic filter at the X-ray tube to compensate for lower patient attenuation in the head, neck, and upper thorax region. The increased X-ray beam filtration also acts to decrease patient radiation dose. X-rays in medical imaging have a wide spectrum of energy. The higher-energy photons are more likely to pass through tissues and not be absorbed. Lower-energy photons may be absorbed and may then cause deoxyribonucleic acid (DNA) damage. The filter used preferentially removes the lower-energy photons from the beam and thus reduces the amount of radiation absorbed to the tissues. In addition, the authors use a dual-sided computed radiography (CR) reader with dual-side read image plates (PCR CosimaX, Philips Medical Systems, Hamburg, Germany). By detecting the emitted light signal from both sides of the image plate, this CR system allows for an approximate 40% reduction in radiation dose compared with conventional single-side CR [10]. Also, as most centers in the United States do, the authors use posteroanterior (PA) rather than anteroposterior (AP) radiographs whenever possible to reduce radiation exposure to sensitive organs such as the breast and thyroid [11].

The researchers' center obtained an EOS imaging system in February 2013, which was installed and used according to manufacturer specifications. This EOS machine does not have a copper filter, which is a subsequent refinement to the EOS that is reported to further decrease patient radiation exposure. The EOS imaging system consists of 2 orthogonal X-ray fan beams that simultaneously acquire frontal and lateral projection images of a standing patient. The researchers sought to compare the estimated cumulative radiation exposure for scoliosis patients using standard radiography such as is available at most centers, radiography with a filter (CRF), and the EOS technique. They focused on the absorbed dose to specific organs and effective dose. Initially the radiology technologists preferred to obtain AP radiographs in the EOS because it was easier to position the patient. For this reason, the researchers also sought to determine the difference in organ and total dosing for a standard EOS AP versus PA view to determine whether there was a significant difference between the 2 techniques. They also sought to identify whether braced versus surgical patients undergo more scoliosis radiographs.

Materials and Methods

A total of 42 skeletally immature patients started treatment at the authors' center for adolescent idiopathic scoliosis and were observed to skeletal maturity. The number of radiographs (PA and lateral) for each patient obtained during this time was recorded, as well as the phase of treatment when the radiographs were taken (observation, bracing, or surgery). The authors then modeled the expected cumulative radiation dose per patient considering whether these studies had been obtained using a standard EOS machine compared with traditional imaging (CR or CRF).

To allow for standardized dose calculations, a 15-year-old patient model (weight, 56 kg; height, 168 cm; trunk thickness, 20 cm; width, 30 cm) was assumed [12]. In clinical practice, the researchers adjust EOS and radiograph settings based on patient characteristics, but the computerized model allowed either for a 10- or 15-year-old patient, so the authors used a 15-year-old patient, which seemed more representative of the patient population. Image acquisition techniques for EOS were the manufacturer-recommended pediatric exposure parameters (medium setting): 90 kV/200 mA for the PA-AP plane and 105 kV/250 mA for the lateral plane and speed setting of 4 (7.6 cm/s scan speed). Anatomic coverage extended from the top of the ear to mid femur. Arms were held out from the body and not included in the dose calculation. For the PA-AP and lateral planes, the patient entrance air kerma was 0.18 and 0.33 mGy, respectively. The authors' EOS unit did not include a copper filter, which is reported to further reduce the patient dose.

For CRF, exposure parameters were 90 kV for the PA projection and 125 kV for the lateral projection, both with a 244-cm source to image receptor distance. These are the standard exposure parameters specified for a patient the size of the model described above at the researchers' facility using a long 35 × 86-cm interlocked CR cassette (Fujifilm, Fuji, Japan) and a dual-sided CR system. Anatomic coverage extended from the top of the ear to just above the testes. No left–right collimation of the X-ray beam was used for the PA projection and the lateral projection was collimated to the sternum with the patient's arms extended at a right angle from the body. For the PA projection, a lead acrylic filter was positioned at the X-ray collimator. The upper section of the filter is of uniform thickness and placed at the top of image while the lower section is tapered and positioned to end at the bottom of the lung field. For the lateral projection, 2 separate filters are used. The upper filter covers the patient's head and ends at the top of the shoulder. The lower filter is placed to cover the patient's lungs, from the bottom of the outstretched humerus to the bottom of the lung. For the PA projection, the patient entrance air kerma ranged from 0.05 mGy (under the thickest portion of the filter) to 0.16 mGy (unfiltered region). For the lateral projection, the entrance air kerma ranged from 0.05 mGy (under the thickest portion of the filter) to 0.83 mGy (unfiltered region). Additional information about the beam filters is outlined in a prior publication [13].

For standard (CR) radiography, technique parameters from a pediatric patient dose survey were used [14]. For the 13- to 18-year-old patient group, Gogos et al. [14]

measured a mean entrance surface dose and kVp of 1.1 mGy and 78 kVp for the PA projection and 2.0 mGy and 84 kVp for the lateral projection. The same anatomic coverage and collimation as described above was used. For intraoperative radiographs, exposure parameters were 70 kV/20 mAs for the PA projection and 80 kV/50 mAs for the lateral projection, both with a 100-cm source to image receptor distance. These are the standard exposure parameters specified for a patient the size of the model described above at the authors' facility using a 35 × 43-cm CR cassette (Fujifilm) and a single-side CR system. For the PA and lateral projections, the patient entrance air kerma was 0.96 and 4.7 mGy, respectively.

Patient organ doses for each projection of the 3 configurations were calculated using a Monte Carlo software program [15]. Effective dose was calculated from these organ doses combined with tissue weighting factors [16].

Results

Of the 42 patients, 21 were treated with surgery and 21 had bracing only. Of the 21 patients who underwent surgery, 11 were also braced before the surgery. Radiographs were considered over the entire course of treatment. Mean time to follow-up was 4.5 years. Mean time that patients were braced was 3.1 years. For patients that were bracing before surgery, mean time in a brace was 1.8 years.

Organ and effective dose per radiograph were calculated (Table 1). For EOS imaging, the researchers found that the organ dose to the thyroid, breast, and testes was higher for an AP view compared with a PA view. Organ dose to the bone marrow, however, was lower with an AP view. Interestingly, the standard EOS AP organ dose to thyroid, breast, and testes was higher than the estimated CR PA dose, assuming a medium-sized pediatric patient (56 kg) and dosing parameters as outlined above. The total effective dose for EOS PA was approximately a third of the dose of CR PA imaging (0.069 vs. 0.215 mSv) and comparable to CRF imaging (0.057 mSv) with much improved image quality with the EOS. An EOS AP total effective dose was approximately half that of a CR PA radiograph (0.121 vs. 0.215 mSv).

Mean number of radiographs per patient was 20.9 (range, 8–43). Patients who had surgery received more radiographs (Table 2), with a significantly greater number of X-rays than patients who were braced (27.3 vs. 14.5; $p < .001$). Assuming CR technique for all imaging, mean effective dose over the course of scoliosis treatment for all patients was estimated to be 5.38 mSv. Assuming EOS PA and lateral images were used during the course of treatment, the mean cumulative estimated dose was 2.66 mSv, a decrease of 51% (Table 3). Assuming EOS AP and lateral views were used, the mean cumulative estimated dose was 3.40 mSv, or a decrease of 37%. Assuming a CRF technique was used, the estimated dose over the course of treatment was 2.64 mSv, a decrease of 51%.

Table 1
Estimated dosing for each type of radiograph.

	EOS anteroposterior	Estimated dose posteroanterior				Estimated dose lateral			
		EOS posteroanterior	X-ray with filter	X-ray with no filter	Intraop T-spine	EOS lateral	X-ray with filter	X-ray with no filter	Intraop T-Spine
Thyroid, mGy	0.19	0.05	0.02	0.09	0.03	0.24	0.07	0.51	0.13
Breast, mGy	0.19	0.02	0.02	0.08	0.05	0.16	0.06	0.21	1.70
Ovary, mGy	0.08	0.08	0.07	0.27	0.00	0.09	0.20	0.25	0.00
Testicles, mGy	0.25	0.04	0.01	0.02	0.00	0.05	0.03	0.02	0.00
Active bone marrow, mGy	0.05	0.10	0.08	0.32	0.15	0.09	0.19	0.29	0.39
Effective dose ICRP 103,[16] mSv	0.121	0.069	0.057	0.215	0.119	0.121	0.162	0.295	0.712

Table 2
Cumulative number of radiographs per patient.

	Braced (n = 21)	Surgery (n = 21)	Overall (n = 42)
Posteroanterior scoliosis films obtained, mean n (range)			
Observation	2.4 (1–7)	3.1 (1–6)	2.7 (1–7)
Bracing	8.9 (2–23)	5 (2–10)	7.5 (2–23)
During surgery	Not applicable	3.1 (2–5)	1.6 (1–5)
After bracing/surgery	2.2 (1–5)	4.9 (1–11)	3.6 (1–11)
Total	13.5 (7–25)	18 (13–33)	15.6 (7–33)
Lateral scoliosis films obtained, mean n (range)			
Observation	0.9 (0–3)	1.8 (1–3)	1.3 (0–3)
Bracing	0	1.5 (0–6)	0.5 (0–6)
During surgery	Not applicable	3.0 (2–5)	1.5 (0–5)
After bracing/surgery	0.2 (0–2)	3.8 (0–8)	2.0 (0–8)
Total	1 (0–3)	9.3 (6–18)	5.0 (0–18)

Table 3
Cumulative estimated dosing for each imaging modality.

Imaging modality	Estimated effective dose, mSv*		
	Bracing (n=21)	Surgery (n=21)	Total Cohort (n=42)
EOS posteroanterior and laterals	1.06	3.03	2.66
EOS anteroposterior and laterals	1.76	3.81	3.40
Computed radiography posteroanterior and laterals	3.21	6.31	5.38
Computed radiography with filter posteroanterior and laterals	0.94	3.11	2.64

* Annual background radiation = 3 mSv.

All surgeons and radiology technologists at the authors' center were pleased with the image quality of EOS and workflow, and found improved image quality and similar efficiency compared with the previous CRF technique (Fig. 1). The radiology technologists preferred EOS over CRF technique for ease of use and reproducibility.

Discussion

In this article the authors sought to evaluate the cumulative differences in radiation exposure for scoliosis patients undergoing imaging with the standard EOS technique versus traditional CR radiographs at their center. Measurement of radiation exposure is complex, and many surgeons may not be familiar with common methods to quantify radiation exposure. Thus, to provide context to these results, it is helpful to outline some information on the known effects of radiation exposure.

Medical imaging such as CTs and X-rays use ionizing radiation, which contains enough energy to break chemical bonds, such as those found in DNA. X-rays and gamma rays are high-energy photons. Although most particles pass through tissues without disturbing chemical bonds, a certain number of the photons are absorbed by the tissues, potentially causing damage to DNA. The risks of low-dose medical radiation causing DNA damage are stochastic, or random. Once DNA damage occurs, a cell might repair the damage, die, or become abnormal, potentially causing cancer. Deoxyribonucleic acid damage to germline cells can result in heritable defects in offspring. Thus, the impact of radiation exposure on an individual and on society is difficult to measure. Theoretically, there is no safe dose of radiation. On the other hand, the risk of a single radiograph causing cancer is exceedingly low and much lower than the background rates of cancer owing to other causes.

Other factors, such as age and gender, also affect the risks of radiation exposure. The body has a certain capacity to repair damage to DNA from radiation exposure, and spacing out the exposure may allow time for DNA repair mechanisms. Children, who have rapidly dividing cells that are sensitive to radiation, are thought to be at particular risk from radiation exposure. Based on data from survivors of nuclear catastrophe, such as the atomic bomb and Chernobyl, ionizing radiation has been associated with increased incidence of solid organ tumors, with a stronger effect in young children [17-19]. Also, children have a long life expectancy, which gives more time for a potentially fatal cancer to develop from a radiation-induced mutation.

Estimating the dose and the effect of radiation exposure on tissues is challenging. Types of radiation differ significantly, including exposure time period, whole- or partial-body exposure, and rate of exposure [20]. Not all types of radiation are interchangeable and absorbed dose highly depends on patient size, weight, tissue type, and the technique used to take the radiograph. Thus, a scoliosis radiograph taken at 1 center for 1 patient may impart a different radiation dose from a radiograph taken at another center. Phantoms or models of human torsos with multiple radiation detectors implanted inside can be used to estimate absorbed radiation dose to organs. A computerized model based on phantom data was used for this study.

Table 4
Other literature with reported dosing from EOS compared with current study.

	EOS AP and lateral thyroid dose, mGy	EOS AP and lateral breast dose, mGy	Ovary dose AP and lateral EOS, mGy	Effective dose AP and lateral dose, mSv
Damet et al., 2014[28] (adult phantom)	0.45	0.3	0.13	0.29
Current study	0.33	0.35	0.17	0.24

AP, anteroposterior.

Different measurements are used to quantify radiation exposure. The gray is the absorbed dose from the radiation, typically measured in milligray, and describes the radiation absorbed by a particular organ or structure. Measurements using milligray have been used in previous scoliosis radiation studies [21]. The effect of radiation on biological tissue is variable, so this is multiplied by a corrective factor [22]. The effective dose is then called the sievert, typically measured as millisieverts. Sieverts have been used primarily to quantify occupational radiation exposure. According to the International Commission on Radiological Protection, up to 20 mSv/year of occupational radiation exposure is allowable and up to 1 mSv/year of exposure to the public from industry is allowable [22]. Annual natural background radiation in the United States (US) is 3.1 mSv/year and is increased to 4.0 to 9.0 mSv/year for those who live at higher altitudes or near radon, or by natural radioactivity in the soils: for example, Colorado [23]. On average, a US resident receives an additional 3.0 mSv/person/year of exposure in medical radiation exposure [23]. Older patients and patients receiving radiotherapy for cancer take in a large percentage of this dosing (typically on the order of greater than 100 mSv/cancer patient treated). For example, the effective dose of an abdominal or spine CT scan is 5 to 10 mSv. Skin entrance dosing can also be used to quantify radiation exposure, but it is difficult to correlate skin entrance dosing with future cancer risk [8,24,25].

Most reports predicting rates of cancer from radiation exposure are based on organ dosing or total effective dose data from nuclear disasters, typically with short-term human exposure to gamma rays, which are higher energy than X-rays. Some data indicate the cancer risk from medical imaging (primarily X-rays) may be somewhat lower than that from nuclear disasters (primarily gamma rays) [22]. Also, the radiation absorbed by a person in a single incident or daily

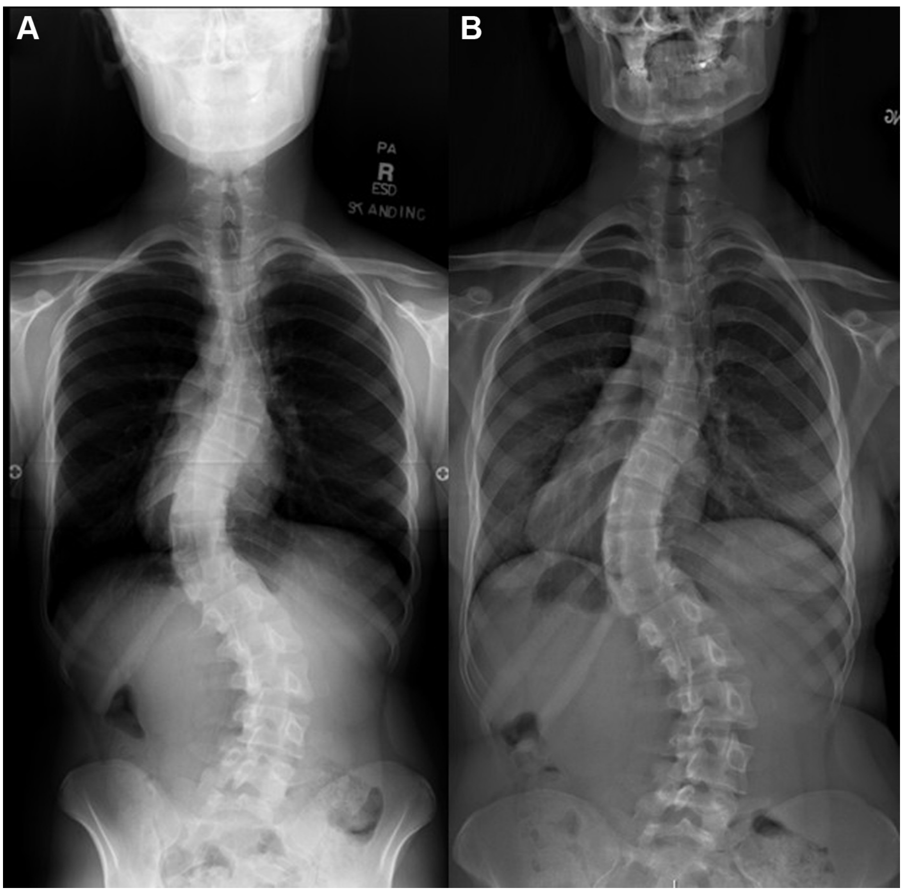

Fig. 1. (A) Filtered computed posteroanterior radiograph of a patient with scoliosis. (B) EOS anteroposterior image of the same patient.

occupational radiation exposure may have a different effect from intermittent medical radiation. The BEIR VII Phase II report developed a predictive cancer risk model based on survivors of Hiroshima and Nagasaki [20]. Exposure to 100 mGy at age 10 years resulted in 1.3 more cancers per 100 people in males and 2.5 more cancers per 100 people in females over a lifetime [20].

The US Scoliosis Study Cohort provides helpful data regarding long-term rates of cancer after scoliosis radiographs [26]. Using estimated radiation doses, Doody et al. [26] showed increased rates of thyroid and breast cancer in 5,466 female patients who underwent childhood treatment of scoliosis between 1912 and 1965. Estimated average cumulative radiation doses to the breast, lung, thyroid, and bone marrow were 109, 41, 74, and 10 mGy, respectively, and this resulted in an 8% increase in cancer mortality [21]. For reference, patients in the current study, including all PA and lateral films, had a cumulative breast exposure of 1.1 mGy with EOS and 2.3 mGy with traditional radiographs. Specifically, in the US Scoliosis Cohort, there were 77 breast cancer deaths compared with the expected 45.6 breast cancer deaths based on US mortality rates [26]. The breast dosing to these patients was the equivalent of 5,400 of today's EOS PA radiographs or 1,350 of today's CR PA radiographs. Interestingly, the mean number of radiographs for patients in the study by Doody et al. was 25 radiographs/patient; clearly, modern technology in the last 100 years has significantly reduced the radiation exposure associated with routine scoliosis radiographs.

The Secretary of State for Health in the United Kingdom commissioned a detailed cost analysis of EOS to weigh the effect of EOS on reducing cancer. Studies found that the average EOS machine must perform 4,077 to 26,000 imaging exams/year to become cost-effective in terms of decreased cancer risk and improved workflow [8,27]. One other published study also evaluated the organ and total effective radiation dose associated with EOS and found similar results to the current study (Table 4) [28]. Previous studies describing the radiation dosing with standard EOS only assessed the skin entrance radiation dose or dose area product, which is not as helpful in predicting solid organ cancer risk [8,24,25].

There are tradeoffs between image quality and dose [29]. Some centers may choose to use a higher-quality image for the films at the first visit. Then, ongoing monitoring films to assess curve progression or effectiveness of brace therapy could be at a lower dose [30]. The previous CRF technology at the authors' center resulted in a low dose producing images of sufficient quality in their opinion for treatment decisions. They find the image quality of EOS to be much superior to previous filtered radiographs. It may be possible to reduce EOS dose to a lower level and still achieve sufficient image quality for clinical use. Further study in this area is needed. Also, upcoming upgrades to the EOS system include a copper filter, which is currently used in Europe. Published reports regarding EOS dosing with the copper filter are pending. Copper filters have been shown to reduce dosing using a DR system [31].

For centers currently using EOS, a finding from this study which can be put into immediate action is to switch from AP to PA radiographs in the EOS machine. It has been a longstanding practice that PA scoliosis films are obtained rather than AP views to reduce breast and thyroid dose [11]. Based on the current study results, dose to the thyroid using the standard EOS system is not negligible. Although the technicians in the current study preferred to obtain AP views because this allows them to better communicate with the patient (Fig. 2), this results in an 8 times higher radiation dose to the breasts and a 4 times higher radiation dose to the thyroid. After analyzing the results of this study, the authors asked their technologists to switch to PA rather than AP EOS films whenever possible and this has not compromised image quality or results. The authors are also considering lowering the settings on their EOS system to achieve lower radiation dosing to patients, but this would likely affect image quality. One weakness of this study is that the researchers provided no assessment of image

Fig. 2. An EOS anteroposterior view allows the technologist to make eye contact with the patient (standing at left from the technologist's booth). A posteroanterior view requires the patient to face the wall, which can produce patient anxiety and a tendency to fidget. However, a posteroanterior image is superior in that there is much lower radiation exposure to the thyroid and breast.

quality with EOS compared with CR and CRF. The improved resolution of EOS imaging, however, has been well-reported in the literature [24,25].

This article recounts the changes in radiation dosing at the authors' center by switching to an EOS system. If PA and lateral EOS technique rather than standard computed radiography were used during the entire scoliosis treatment course, estimated cumulative effective radiation dose would be reduced from 5.38 to 2.66 mSv. Assuming that medical radiation is similar to environmental radiation, the total saved cumulative radiation to 1 patient treated by EOS versus CR is 2.72 mSv—less than 1 year's annual background radiation or similar to moving to Colorado for a year. The authors hope that this study will provide useful guidance and emphasize the utility of PA views for those using an EOS machine. Furthermore, the results may assist surgeons in counseling patients regarding the expected cumulative radiation exposure for patients undergoing radiographs for scoliosis treatment.

Key points:

- Surgical patients had more radiation exposure compared with braced patients.
- Dosing to the thyroid is 4 times higher and dosing to the breast is 8 times higher with AP compared to PA EOS films.
- Standard EOS imaging technology without a filter resulted in a 50% decrease in total effective radiation exposure compared with standard CR imaging.

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