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ORIGINAL ARTICLE

EOS microdose protocol for the radiological follow-up of adolescent idiopathic scoliosis

Brice Ilharreborde[1] · Emmanuelle Ferrero[1] · Marianne Alison[2] · Keyvan Mazda[1]

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Abstract
Purpose Imaging plays a key role in adolescent idiopathic scoliosis (AIS) to determine the prognosis and accordingly define the best therapeutic strategy to follow. Conventional radiographs with ionizing radiation have been associated with 1–2 % increased lifetime risk of developing cancer in children, and physicians, therefore, need a sensitive but harmless way to explore patients at risk, according to the "as low as reasonably achievable" concept. The EOS system (EOS imaging, Paris, France) is available in routine clinical use since 2007, and allows 3D reconstructions of the trunk in standing position with significant radiation reduction. With recent technical advances, further dose reduction can be obtained, but at the cost of image quality that might alter the reliability of 3D reconstructions. The aim of the present study was to analyze the reproducibility of a "microdose" protocol, and evaluate its use in clinical practice.
Methods 32 consecutive patients followed for AIS were prospectively included. Biplanar radiographs were obtained with the EOS system according to the new microdose protocol. From the microdose images obtained, three experienced operators performed 3D reconstructions, two times for each subject in a random order (total, 192 reconstructions). The intraoperator repeatability and interoperator reproducibility were evaluated, as recommended by the International Organization for Standardization, for the most clinically relevant 3D radiological parameters.
Results The identification of the required anatomical landmarks for the "fast spine" reconstruction process was possible in all cases. None of the patients required a second acquisition for 3D analysis. Mean time for reconstruction was 5 ± 2 min. The intraoperator repeatability was better than interoperator reproducibility for all parameters, with values ranging between 3° and 8° for frontal and sagittal spinal parameters, and between 1° and 8° for pelvic measurements. The agreement was very good for all clinical measurements. No correlation was found between the BMI and the reliability of the measurements.
Conclusions Because children are notably more sensitive to the carcinogenic effects of ionizing radiation, judicious use of imaging methods and a search for newer technologies remain necessary. Results of the current study show that the new microdose acquisition protocol can be used in clinical practice without altering the quality of the images. Relevant clinical measurements can be made manually, but the landmarks are also visible enough to allow accurate 3D reconstructions (ICC >0.91 for all parameters). The resulting radiation exposure was 5.5 times lower than that received with the prior protocol, corresponding now to a 45-fold reduction compared to conventional radiographs, and can, therefore, almost be considered negligible.

Keywords Adolescent idiopathic scoliosis · Imaging · Low-dose · Ionizing radiation

✉ Brice Ilharreborde
i_brice@hotmail.com; brice.ilharreborde@rdb.aphp.fr

1 Department of Pediatric Orthopaedic Surgery, Robert Debré Hospital, AP-HP, Paris Diderot University, 48 Bd Sérurier, 75019 Paris, France

2 Department of Pediatric Radiology, Robert Debré Hospital, AP-HP, Paris Diderot University, Paris, France

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional deformity of the trunk, in which imaging plays a key role to determine the prognosis and accordingly define the best therapeutic strategy to follow. The recommendation for population screening remains the clinical examination, but small curves with potential for severe progression can be missed at their initial stage. Physicians would ideally need a sensitive and harmless way to explore patients at risk. However, conventional plain radiographs with ionizing radiation have been associated with 1–2 % increased lifetime risk of developing breast and thyroid cancer in AIS patients [1]. Although current X-ray techniques have been able to partially reduce radiation exposure, posteroanterior and lateral acquisitions are often needed twice a year, especially in immature patients, who have a higher risk of long-term complications than older patients. Indeed, the longer life expectancy in children allows more time for expression of harmful effects of radiation, and their developing organs and tissues are also more sensitive. Therefore, reduction of the radiation, according to the “as low as reasonably achievable” (ALARA) concept, is essential in the pediatric population [2].

In addition, the clinical relevance and impact of 3D analysis in AIS has recently been pointed out by the Scoliosis Research Society (SRS) [3–5]. Computed tomographic scanning can be used, but at the expense of high radiation exposure, and with the limitation of being performed in the lying position. Since 2000, it has been possible to avoid the latter drawback while substantially reducing radiation exposure by use of the EOS system (EOS imaging, Paris, France). The validity of EOS imaging has recently been reported in routine preoperative and postoperative use, with an average irradiation dose 6 times less than that of conventional X-rays [6, 7]. With recent technical advances, further dose reduction can be obtained, but at the cost of a slight reduction in image quality that might alter the reliability of 3D reconstructions.

The aim of the present study was to analyze the reproducibility of a new radiation “microdose” protocol, and evaluate its use in routine clinical practice.

Materials and methods

Population and imaging protocol

Following institutional review board approval, 35 consecutive patients followed for AIS were prospectively included. Exclusion criteria included previous spine surgery, and patients with lumbosacral transitional vertebrae (lumbarized S1 or sacralized L5).

Biplanar radiographs were obtained with the EOS system in the standing position, as previously described [6], but according to the new microdose protocol delivering almost 6 times less ionizing radiations compared to conventional EOS (Table 1).

Data collection and 3D reconstructions

Demographic data included age, gender and body mass index (BMI). From the microdose image obtained, three experienced operators performed the 3D reconstruction process, two times for each of the 32 subjects in a random order (total, 192 reconstructions). Reconstructions were performed using the “fast spine” protocol, with the dedicated SterEOS software (EOS imaging, Paris, France).

The following clinical measurements were calculated from the 3D reconstructions and provided in each patient report: T1T12 and T4T12 kyphoses, L1L5 and L1S1 lordoses, Cobb angle of the main curve, pelvic incidence, pelvic tilt and sacral slope. Only one of the operators (operator 1, experienced pediatric orthopaedic surgeon) determined which were the apical and the end vertebrae in all of the subjects.

Statistical analysis

The intraoperator repeatability and interoperator reproducibility were evaluated as recommended by the International Organization for Standardization (ISO), with an effect size of 1° [8]. To assess intraoperator repeatability, the variances of the two measurements for all operators were averaged. Interoperator reproducibility was calculated using a cumulative factor that quantifies the variance of the

Table 1 Acquisition parameters of the EOS microdose and conventional low-dose protocols

	Low-dose protocol		Microdose protocol	
	Anteroposterior	Lateral	Anteroposterior	Lateral
DAP (mGy cm^2)	320 ± 73	483 ± 110	43 ± 13	92 ± 24
Air Kerma (μGy)	132 ± 26	214 ± 41	19 ± 4	44 ± 9
kV	90	105	65	90
mA	200	250	80	80

Air Kerma: kinetic energy released per unit mass in air, corresponding to the entrance skin radiation dose received by the patient in the center of the cabin

kV kilovolts, *mA* milliamperes, *DAP* dose area product, *Gy* gray mean value obtained by each operator. Furthermore, an intraclass coefficient with 95 % confidence interval was calculated. This coefficient expresses the proportion of the global variability that is due to the variability among subjects. An intraclass coefficient greater than 0.91, between 0.71 and 0.91, between 0.51 and 0.70, or less than 0.51 was considered to represent, respectively, very good agreement, good agreement, moderate agreement, or poor agreement. In addition, the coefficient of variation (in %) was reported. This coefficient is defined as the ratio of the standard deviation to the mean, and expresses the extent of variability in relation to the mean of the results.

Results

Study population and reconstructions

Among the 35 patients examined, 3 were excluded for lumbosacral transitional vertebrae. Those patients were excluded because the last lumbar vertebra was often named differently between the 3 operators, inducing a measurement bias especially for L1L5 lordosis (Fig. 1). Twenty-eight females and four males were kept for analysis. Demographic data of the study group are summarized in Table 2.

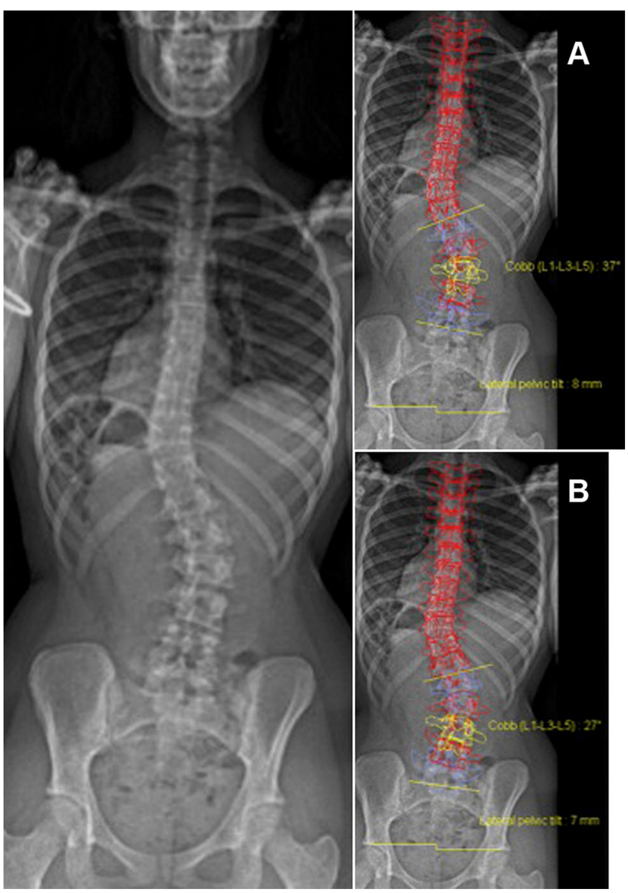

Fig. 1 Frontal microdose film of a 15-year-old AIS patient with lumbarized S1. Operator 1 (**a**) named L1 the most proximal lumbar vertebra without rib connection and measured a 37° Lenke 5 curve between L1 and L5. Operator 2 (**b**) named L5 the most distal lumbar vertebra, and his L1L5 Cobb angle measurement was, therefore, 27°

The identification of the required anatomical landmarks for the "fast spine" reconstruction process was possible in all cases. None of the patients required a second acquisition for 3D analysis. Mean time for reconstruction was 5 ± 2 min. Radiographic measurements obtained from the 3D reconstructions of the microdose biplanar stereoradiographs are reported in Table 3.

Reliability of the microdose protocol

The 3D measurement repeatability (intraoperator) and reproducibility (interoperator) are reported in Table 4. Values ranged between 3° and 8° for all frontal and sagittal spinal parameters, and between 1° and 8° for pelvic measurements. The intraoperator repeatability was better than interoperator reproducibility for all parameters. The agreement was very good for all clinical measurements. No correlation was found between the BMI and the reliability of the measurements (Fig. 2).

Discussion

Radiation exposure

The term scoliosis corresponds to a precise condition, defined as a lateral curvature of the spine that is 10° or greater on a posteroanterior radiograph, while the patient is in a standing position (even though the image is only a representation of a 3D deformity) [9]. Although the screening of the population at risk remains clinical, imaging plays a major role to confirm the initial diagnosis, and becomes essential to evaluate curve progression over time and compare different treatment options. Clinical and radiological follow-up of idiopathic scoliosis is usually required between 1 and 3 times a year, depending on the age

Table 2 Demographic data of the study group ($N = 32$, 28 females and 4 males)

	Age (years)	Height (m)	Weight (kg)	BMI (kg/m^2)
Mean	12.2	1.51	43.1	18.5
SD	2	0.16	12.5	2.9
Min	11	1.20	23.0	14.3
Max	18	1.80	69.0	26.1

BMI body mass index

Table 3 3D radiographic measurements (in degree) obtained from the microdose biplanar stereoradiographs ($N = 32$)

	Cobb angle	T1–T12 kyphosis	T4–T12 kyphosis	L1–L5 lordosis	L1–S1 lordosis	Pelvic incidence	Sacral slope	Pelvic tilt
Mean	24.8	30.4	22.5	47.7	55.6	50.9	42.5	8.0
SD	14.7	11.0	11.7	9.3	9.4	12.3	8.7	7.0
Min	4.6	9.4	−1.6	24.9	33.5	28.4	21.0	−1.3
Max	64.7	47.6	42.8	73.0	77.8	82.9	58.9	27.7

SD standard deviation

Table 4 Repeatability and reproducibility of the 3D measurements from the 192 reconstructions

$N = 32$ patients	Intraoperator repeatability	CV (%)	Interoperator reproducibility	CV (%)	ICC
Main cobb angle	3.6	7.4	5.4	11.1	0.98
T1–T12 kyphosis	4.8	8.1	7.1	11.9	0.94
T4–T12 kyphosis	4.5	10.3	5.7	12.9	0.98
L1–L5 lordosis	5.3	5.7	7.8	8.4	0.95
L1–S1 lordosis	5.8	5.3	7.9	7.6	0.92
Pelvic incidence	5.2	5.2	7.8	7.9	0.95
Sacral slope	5.2	6.3	7.0	8.4	0.92
Pelvic tilt	1.3	8.6	1.9	12.1	0.99

CV coefficient of variation, *ICC* intraclass correlation coefficient

of onset and, therefore, leads to non-negligible radiation exposure.

A full spine X-ray exposes the patient to a radiation of 3 mSv, which accounts for almost a year of natural exposure (estimated around 2.4 mSv) [10]. Moreover, Presciutti et al. recently showed in a series of AIS patients that the mean number of radiographs performed per year was 12.2 in the operated group, 5.7 in case of bracing, and 3.5 in the observation group [11]. They also pointed out that 78 % of the radiation exposure for operative patients, which reached 1400 mrad/year, occurred intraoperatively due to verification by fluoroscopy. Levels of radiation exposure from artificial sources, primarily from medical devices, have increased by 600 % over the past 2 decades, and Smith-Bindman et al. reported that 6.8 % of US patients who underwent imaging received a high annual exposure (>20–50 mSv) [12]. According to the International Commission on Radiological Protection system of dose limitation (ICRP), the annual dose of radiation below which no relevant consequences on the human body is noted is 10 mSv, which roughly corresponds to 3–4 full spine X-rays [13].

Because children are notably more sensitive to the carcinogenic effects of ionizing radiation, judicious use of imaging methods and a search for newer technologies remain necessary. In addition to radioprotection, the ALARA concept for radiation exposure must be always considered in AIS follow-up, but not at the expense of the accuracy of the radiological measurements that could impair management decisions. A subtle compromise is, therefore, necessary between radiation exposure and image quality.

3D analysis and EOS system

Another element to consider is the recent emphasis on the importance of evaluating spinal deformities in the transverse plane, providing the clinician with 3D parameters that might be used in the early stage to evaluate the risk of progression and, therefore, influence therapeutic decisions [3, 14, 15]. Computed tomographic (CT) scanning can be used, but at the expense of high radiation exposure, and with the limitation of being performed in the reclining position. CT scanning of the whole spine corresponds to a mean effective radiation dose of approximately 15 mSv, which can be reduced to 5 mSv with low-dose protocols [16–18]. In addition, the static global balance of a patient cannot be evaluated properly on CT scans. By use of EOS since 2007, these drawbacks have been avoided in our routine clinical practice, in which all patients consulting for a spinal deformity undergo low-dose stereoradiography [4, 7]. The latter has replaced conventional standing X-rays, and the images can be reconstructed in 3D for research purpose, or when surgery is considered.

Fig. 2 Microdose biplanar stereoradiographs of a Lenke 1 AIS, in an 11-year-old boy with a body mass index of 26

Microdose protocol

Results of the current study show that the new microdose acquisition protocol can be used in clinical practice without altering the quality of the images (Figs. 3, 4). Relevant clinical measurements can be made manually, but the landmarks are also visible enough to allow accurate 3D reconstructions (ICC >0.91 for all parameters). The intra-operator repeatability is similar to that previously reported on non-operated AIS with conventional low-dose protocol, allowing efficient follow-up of a patient during growth by the same surgeon [6]. However, the interoperator reproducibility was slightly worse for pelvic parameters (between 1° and 8°), but that might be a limitation of the fast spine reconstruction method, which is very rapid (5 min) but less precise. The resulting radiation exposure was 5.5 times lower than that received with the prior low-dose protocol, corresponding now to a 45-fold reduction compared to conventional radiographs and can, therefore, almost be considered negligible (Tables 1, 5).

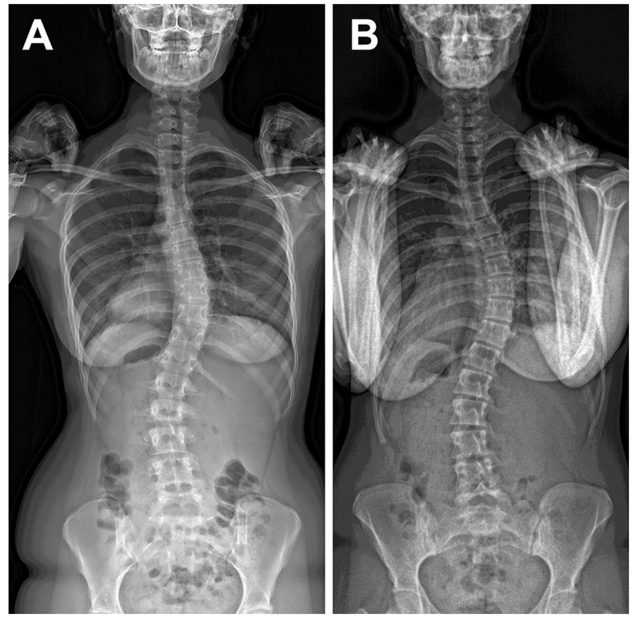

Fig. 3 Comparison of the frontal view of a Lenke 1 AIS patient obtained with conventional low-dose EOS (**a**) and with the microdose protocol (**b**)

Fig. 4 Comparison of the sagittal view of a Lenke 1 AIS patient obtained with conventional low-dose EOS (**a**) and with the microdose protocol (**b**)

Table 5 Radiation exposure (in mGy) of the most frequently used imaging techniques for spinal examination [16]

	Full spine frontal	Full spine lateral
EOS microdose	0.019	0.044
EOS low-dose	0.132	0.214
Conventional radiograph	1.662	1.862
Full spine CT scan	15.6	
Lumbar CT scan	5.6	
Low-dose full spine CT scan	5	
Low-dose lumbar CT scan	0.1	

CT computed tomography

Limitations

The main limitation of this study is that the reliability of the measurements was only evaluated on 3D reconstructions. However, we hypothesized that it would represent the worst-case scenario, and it seems relevant because the main advantage of EOS is to provide 3D parameters in the standing position. Only 8 clinically relevant parameters were evaluated in the current study, and the reproducibility of other measurements, such as secondary curve Cobb angles, iliolumbar angle and apical vertebral rotation need to be further studied in a larger cohort. Finally, the reliability of the new protocol also remains to be investigated in obese patients, who were not represented here, and when spinal instrumentation is present.

Conflict of interest The departments of Pediatric Radiology and Pediatric Orthopaedics of Robert Debré Hospital have received research funds from the company EOS Imaging in the past 2 years, but it was not related to this specific study which was independent.

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