Cumulative radiation exposure during current scoliosis management

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ABSTRACT

INTRODUCTION: Patients undergoing scoliosis management are exposed to repeated radiological imaging. Previous studies have shown an increase in incidence of cancer among these patients. The primary aim of this study was to evaluate the radiographic examinations and cumulative radiation dose to which scoliotic patients are exposed. A secondary aim was to compare in-house algorithms of scoliosis management and radiographic follow-up to international spine centres and current consensus literature.

MATERIALS AND METHODS: A single-centre retrospective review evaluating type and frequency of radiographic imaging and total cumulative radiation exposure to patients treated for scoliosis. Inclusions: patients followed for idiopathic scoliosis in the years 2013-2016. A survey asking for information on management and radiological follow-up algorithms was sent to a number of international spine centres for comparison with the in-house algorithm.

RESULTS: Patients who underwent surgery received an approximately ten-fold higher median cumulative radiation dose than those treated conservatively. A variety of radiological follow-up algorithms among eight spine centres was observed.

CONCLUSIONS: Cumulative radiation dose during scoliosis treatment varies substantially depending on radiographic follow-up protocol, intraoperative and ancillary imaging. By using low-dose X-ray systems in combination with a low-dose protocol for intraoperative navigation, it is possible to keep exposure to patients at a minimum while still providing optimal care.

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Scoliosis patients are exposed to repeated radiological imaging during assessment, treatment and follow-up. Previous studies have shown a correlation between increased risk of cancer and exposure to ionizing radiation during scoliosis follow-up [1-3]; an increase in breast cancer mortality, in particular, has been of concern. In recent years, considerable efforts have gone into optimisation of X-ray equipment and imaging protocols in order to reduce exposure of our patients to ionizing radiation [4, 5]. As of today, no known lower threshold of amount of ionizing radiation has been established that might lead to radiation-induced cancer. We therefore need to limit the use of ionizing radiation, while maintaining adequate image quality for correct treatment of our patients. The primary aim of this study was to evaluate the frequency and type of radiographic examinations to which scoliotic patients are exposed at our institution and to estimate the total cumulative radiation dose to which a typical scoliotic patient is subjected. A secondary aim was via a survey sent out to nine international spine-centres inviting them to provide information on scoliosis assessment and follow-up to compare our in-house algorithms and the current consensus literature.

METHODS

A single-centre retrospective review of medical charts on patients treated for idiopathic scoliosis was performed. Ethical approval for the study was not needed according to the Regional Committee on Health Ethics. Approval for establishing a database was obtained as required under Danish law.

Inclusions: all patients aged 0-18 years of age, who were treated either surgically or conservatively, at our institution in the years 2013-2016 were included. Braced patients and patients followed only by radiological observation of curve progression were gathered in the same group and termed conservative. Patients with neuromuscular disease or any type of severe syndromic disease were excluded.

Medical records and the Picture Archiving and Communication System were scrutinised to retrieve information on the number and types of radiographic imaging to which patients were subjected. Included were all imaging in relation to the assessment, follow-up and treatment of idiopathic scoliosis used at our institution. This included conventional digital full-spine scoliosis radiographs (CR), low-dose full-spine stereo-radiography and CT, including both intraoperative navigation (O-arm), ancillary CT and PET-CT.

The number and projections of full-spine CR were registered as separate exposures, e.g., coronal and lateral imaging of the spine was counted as two exposures. In the case of splicing/stitching of full-spine images, each separate exposure was counted. The same method was used to quantify the number and projections of EOS images.

Estimation of cumulative radiation dose

The total cumulative radiation dose to the scoliotic pa-

FIGURE 1 / Illustration of the EOS low-dose scanner and the outcome.

tients was estimated by calculating the theoretical amount of full-body absorbed radiation dose in terms of effective dose in mSv. In order to calculate the cumulative radiation dose from CR and EOS, the number of images divided by two (coronal and lateral planes) was multiplied by effective dose references for CR and EOS stereo-radiography for full-spine examinations. The reference doses for full-spine examinations were estimated based on phantom dosimetry [6]. Reference doses: CR anterior-posterior-lateral (APL) projections (0.545 mSv) and EOS standard-dose APL projections (0.220 mSv). All doses were calculated according to the International Commission of Radiologic Protection (ICRP), ICRP-103 approach [7].

Effective doses for the O-arm 3D cone-beam CT and ancillary CT and PET-CT were calculated based on dose length product (and CT conversion factors according to the Danish Health Authority, Institute of Radiation Protection (SIS) [8]. Effective doses for intra-operative 2D fluoroscopy using the O-arm were calculated by using dose area product values and X-ray conversion factors according to the Danish Health Authority, SIS. At our institution, we routinely use the low-dose intraoperative scan protocol (70 kVp/20 mA) introduced by Petersen et al in 2012 [9], whereby the CT dose from the O-arm was reduced by nearly 90% compared with the default protocol.

Algorithms for scoliosis follow-up at our institution

Follow-up for scoliosis at our institution comprises clinical examination and biplane full-spine imaging. Since the autumn of 2014, EOS low-dose stereo-radiography has been the first choice for full-spine radiography. CR biplane imaging has been used solely in cases where EOS was not available. **Figure 1** illustrates the EOS low-dose scanner, a system that has been described to markedly reduce radiation dose exposure to patients. The system has previously been described in detail [10]. **Figure 2** illustrates the follow-up and treatment algorithms at our institution.

Post-operative radiographs are performed for all scoliosis cases: before discharge from hospital and at six months, one year and two years post-operatively.

Consensus survey for scoliosis follow-up at international spine centres

A survey was forwarded to nine international orthopaedic spine centres, in Denmark, Norway, Sweden, Spain, UK, France and the US, dealing with the assessment and treatment of scoliosis, using a web-based survey tool. All centres served a population larger than one million. Four of these centres were high-volume centres performing more than 100 surgeries for scoliosis annually.

The survey included questions about the practice of radiological follow-up of scoliotic patients to illustrate the similarities or differences among centres and to compare the answers with current international consensus guidelines [11-13]. The questionnaire used can be found at the following link as referred [14].

RESULTS

Final inclusions

Demographics for the 61 patients included in this study are shown in **Table 1**. Six patients underwent more than one surgery; three were managed initially with growing rod systems and afterwards with final correction surgery with posterior spinal fusion. Another three patients underwent additional revision surgeries; two cases owing to progression of curves adjacent to fusion, and one patient owing to implant failure (screw loosening and rod breakage).

Radiological exposure

Radiologic imaging and exposure have been expressed in terms of the number of images and radiation doses (effective dose) to patients from all modalities during assessment, treatment and follow-up, Table 1. In 66%

(73/111) of the intraoperative scans used for safe instrumentation, the O-arm low-dose protocol was used. The dose from a single low-dose scan (70 kVp/20 mA) was found to be 0.45 mSv; for comparison, a default scan of 120 kVp/40mA was 4.02 mSv.

Patients who underwent surgery received an approximately ten-fold higher median cumulative radiation dose (excluding ancillary CT and PET-CT) than those treated conservatively.

Ancillary radiological imaging from CT and PET-CT on average resulted in an approximate 100% increase of the total dose from all routine imaging (CR, EOS and intra-operative O-arm-based navigation and fluoroscopy), **Table 2**.

Approximately 25% (39.04 mSv/161.82 mSv) of the total intraoperative radiation dose from the O-arm was due to 2D fluoroscopy.

The mean/median weight and height at the time of surgery were 54.9/54 kg (range: 42-80 kg) and 166.2/165 cm (range: 147-184 cm), respectively. These values are directly comparable to the female dosimetry phantom from which the reference doses were estimated; weight 55 kg and height 160 cm [15].

Survey

Eight out of nine international spine centres, each serving a population of one million to more than ten million, completed our survey regarding treatment and radiological follow-up algorithms among patients with adolescent idiopathic scoliosis. The usual interval between preoperative imaging varied among the centres. Half (3/6) of those who answered this question saw patients for radiographic controls every three months; the other half every six months. Surgically treated patients were seen anywhere from one to four times for radiographic follow-up over a period ranging from six months to two years post-operatively. Five centres saw patients every six months after instituted brace treatment; three centres once annually. A variety of radiographic systems and techniques were used at the different centres.

DISCUSSION

To the best of our knowledge, this retrospective study represents the first assessment of the cumulative radiation dose from CR, EOS stereo-radiography and the O-arm for a typical patient undergoing current management for idiopathic scoliosis. Patient demographics and magnitude of perioperative X-ray/EOS acquisitions were comparable to those reported in other studies [1, 2, 16-18], as was the mean number of levels fused.

Exposures and radiation dose

As expected and previously shown by Presciutti et al [17], the patients who underwent surgery were exposed to substantially more radiographic imaging than the conservative group, and thus received a higher level of absorbed radiation dose. The large difference in observed absorbed radiation dose between the two groups was mainly due to intraoperative as well as ancillary imaging. Apart from this, the combined observation time for the conservative group was shorter. This was – in part – caused by the fact that a part of the conservative group was assessed only once or just a few

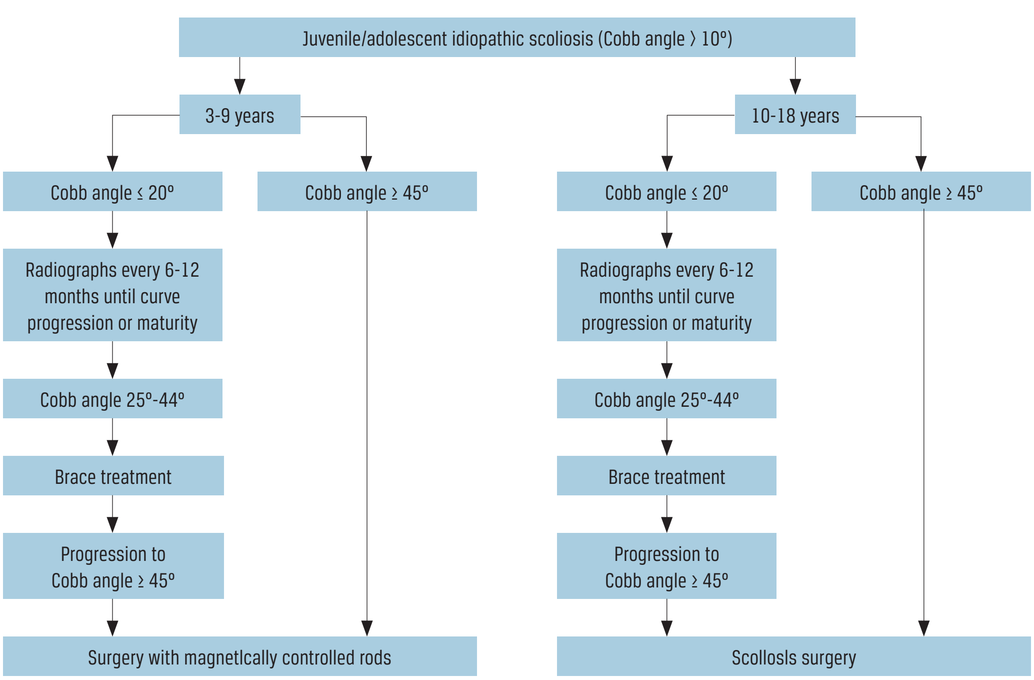

FIGURE 2 / Algorithms for scoliosis follow-up at our institution.

TABLE 1 / Demographics and radiation exposure..

	Treatment		
	conservative	surgery	both groups
Demographics			
Patients, n:			
Males	6	11	17
Females	13	31	44
Total	19	42	61
Age, yrs, median (range):			
At initial assessment	15 (5-18)	14 (3-17)	14 (3-18)
At final assessment	15 (9-19)	17 (14-20)	17 (9-20)
Time of follow-up, mo.s, median (range)	9 (0-52)	38 (13-163)	
Cobb angle, °, median (range):			
Initial assessment	19 (10-50)	45 (10-80)	
Just prior to surgery		52 (36-82)	
Final assessment	23 (12-65)	16 (4-30)	
Fused vertebrae, n, mean	-	11	
Radiation exposure, median (range)			
CR: spine X-rays, n/radiation dose, mSv	4 (0-20)/1.1 (0-5.5)[a]	14.5 (2-57)/4.1 (0.6-15.5)	
Biplanar EOS imaging, n[b] /radiation dose, mSv	2 (0-17)/ 0.58 (0-2.4)[a]	10.5 (0-26)/ 1.3 (0-3.1)	
O-arm 3D scans, n[b] /radiation dose, mSv	-	2 (1-4)/3.8 (0.9-10.0)	
O-arm 2D fluoroscopy time, sec/radiation dose, mSv	-	33.7 (20.3-136.0)/ 0.9 (0.4-3.5)	
Radiation dose combined: CR, EOS[c], O-arm, mSv	1.1 (0.2-7.2)[a]	10.3 (3.8-20.4)	
Additional CT and PET-CT, n[d]	0[a]	1 (1-2)	
Radiation dose, mSv	0[a]	11.9 (0.6-20.1)	
Total radiation dose, all modalities, mSv	1.1 (0.2-7.2)[a]	10.8 (3.8-35.9)	

CR = conventional radiographs.
a) Braced and observational.
b) Total number of coronal and lateral images.
c) Low-dose stereo-radiography.
d) A total of 6 patients had additional imaging owing to various reasons explained in the results section.

TABLE 2 / The magnitude of radiation dose from ancillary CT and PET-CT.

Patient ID	Modality	Radiation dose, mSV	Factor of increase in total radiation dose[b]	Part of total radiation dose, %[c]
13	CT cervical spine	5.38	2.0	50
27	CT thoraco-lumbar spine[a]	17.03	1.9	48
34	PET-CT full spine and CT lumbar spine[a]	20.13	3.1	67
38	CT lumbar spine	6.70	1.7	42
45	CT cervical spine	0.57	1.1	6
46	CT thoraco-lumbar spine[a]	18.03	2.1	53

CR = conventional radiographs.
a) Metal artefact reducing software technique.
b) (CR, EOS, O-arm and ancillary CT and PET-CT)/(ancillary CT and PET-CT).
c) (Ancillary radiation dose)/(total radiation dose from all modalities).

times, resulting in a low number of total follow-up images.

Intraoperative imaging from O-arm CT and fluoroscopy comprised roughly 50% of the total amount of absorbed radiation dose in the surgical group. In the study by Presciutti et al [17], intraoperative imaging accounted for 78% of the total accumulated dose. The reason why our percentage was lower may very well be the low-dose intraoperative scan protocols used at our institution. However, our intraoperative dose exposure would have been even lower if a higher degree of adherence to the low-dose protocol had been observed.

The fact that just one ancillary CT or PET-CT resulted in a two-fold increase of total cumulative radiation dose is a very disturbing finding seen in relation to the overall dose assessment of these patients. This once again emphasises the importance of keeping the number of CTs at a bare minimum.

Survey and consensus

Our survey showed that most of the spine centres agreed on surgical technique and on avoiding post-operative CT. However, the survey also illustrated some of the discrepancies among centres as to how often to assess and for how long to follow patients with idiopathic scoliosis, as well as a discrepancy in choice of radiographic systems. Roughly half of the centres used a follow-up algorithm similar to our algorithm, which is in line with the consensus guidelines of Kleuver et al [11] and Knott et al [12]. Implementation of international consensus guidelines on follow-up algorithms for scoliosis vary depending on the department, local tradition and on which consensus guideline was used.

In fact, there is still a lack of clear international consensus as to how often and how many X-rays are needed in the course of scoliosis treatment. A review of recent literature gives no clear picture of this [11-13, 18]. There is agreement as to the needs for at least one coronal and lateral radiograph during or after surgery, but not as to the timing of subsequent follow-up intervals or the duration of patient follow-up.

Only one in eight centres used post-operative CT routinely; likewise, one in eight used intraoperative navigation. At our institution, we use intraoperative navigation for all scoliosis surgery based on studies showing significantly less screw misplacements than for freehand technique and or fluoroscopy-based instrumentation [19, 20].

Limitations

Our study has some limitations. The size of the study population was limited and thus not well suited for statistical analysis, e.g., on various possible correlations. Because of the small number of patients, we combined braced patients and observation patients in the same group for comparison with the surgical group. This comparison provides an overview of the variation of doses between the groups, but it does not reflect very well what the typical dose is for braced patients specifically.

Dose reduction

There are several ways to reduce radiation exposure. The simplest is to reduce the number of X-rays and avoid CTs, while optimising radiological equipment is a continuously ongoing process. In fact, little might be gained from routine imaging unless the patient has unexpected symptoms. Garg et al [18] found that only 2.9/1,000 spine X-rays led to revision surgery. Thus, it may very likely be possible to lower the number of spine radiographs without affecting the quality of treatment.

CONCLUSIONS

The magnitude of cumulative radiation during scoliosis treatment varies substantially depending on the radiographic follow-up protocol and on intraoperative and ancillary imaging used. Future studies are needed to elucidate the clinical consequences of a lowered or an elevated frequency of X-ray monitoring. Such studies may also lay the foundation for future consensus guidelines on radiographic follow-up.

By using low-dose X-ray systems such as EOS stereo-radiography in combination with low-dose protocol for intraoperative navigation, it is possible to keep patient exposure at a minimum, balancing potential risks of adverse effects such as screw misplacement and radiation-induced cancer while still providing optimal care. One ancillary CT may double the total cumulative full-body absorbed radiation dose.

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