Organ doses and cancer LAR evaluations in scoliosis examinations with the EOS Imaging System

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Aims and objectives

The radiological investigation of spinal and bone structure deformity, both in adult and in pediatric patients, is an essential tool in the identification of pathological changes and in guiding the surgeon in choosing the best and least invasive treatments. The standard modalities used to image skeletal deformities are X-ray conventional radiography (CR and DR). The EOS scanner is a bi-planar X-ray scanning system, created to investigate particular musculoskeletal pathologies, that allows acquiring images of the lower extremities and of the column in load, with the patient in vertical position or, if it is not possible, sitting down inside the machine. Thanks to these characteristics, the Eos System is particularly suited for scoliosis examinations [1-3]. The EOS system employs two narrow fan beams, an antero-posterior (AP) and a lateral (LAT), that translate along the length of the patient's spine. Both X-ray beams are completely intercepted by two digital image detectors that move with the tubes. The beam/detector pairs are located at 90°, allowing for computerized reconstruction of the images in three dimensions. Many studies has proved that the EOS system is able to decrease the entrance skin dose when comparing to conventional radiography [3-6], but few works has investigated organ dose [7,8].

The goal of this work was to evaluate the organ doses and effective dose due to a single scoliosis examination. Because scoliosis patients are usually children or adolescent, thus highly radiosensitive, and they are subjected to frequent expositions for disease management, we investigated also Lifetime Attributable Risk (LAR) of cancer incidence and cancer mortality in scoliosis examinations performed with the EOS Imaging System, in order to optimize patient dose and protocols, and to compare results with those of the same exam performed with Computed Radiography (CR).

Note: the abstract of this work has been presented also at the national AIFM conference, 2016 (M. Branchini, C.R. Gigliotti, A. del Vecchio, A. Loria, A. Zerbi, R. Calandrino., Organ doses and cancer lifetime attributable risk evaluations in scoliosis examinations with the EOS imaging system, Physica Medica (2016), doi: 10.1016/j.ejmp.2016.01.252).
Methods and materials

Experimental settings

A Rando Alderson Phantom, with 60 Thermo Luminescent Dosimeters (TLD) Type GR200A (LiF:Mg,Cu,P) positioned in correspondence to the main organs at risk (Table 1), was imaged both with EOS (Fig.1) and with CR, following clinical procedures for scoliosis management, to simulate a young male examination. In particular, the CR protocol for scoliosis exam consists in one AP and one LAT projection. In the LAT projection, the phantom was orientated in the same direction as in the EOS. The CR fields’ dimensions were set as in the clinical practice, excluding the eyes from the field of view. Moreover, because patients routinely wear a gonad shield, the testes were kept outside the fields. The expositions protocols were:

- **EOS**: scanning speed 7;
  
  AP field: 90 kV - 200 mAs - 619.4 mGy*cm²;
  
  LAT field: 105 kV - 250 mAs - 1007.7 mGy*cm².

- **CR**:
  
  AP field: SDD=187cm, 90 kV - 80 mAs - 110 ms;
  
  LAT field: SDD=172cm, 95 kV - 100mAs - 146ms.

Organ dose

After exposition, dose data were extracted from TLD through a reader calibrated in terms of personal dose equivalent Hp(0.07) and Hp(10), the latter used for some externally positioned TLD. The dose to the bladder was estimated as the dose at 1 cm depth from values of the TLD on the abdomen’s surface. According to the ICRP 103, the effective dose to the remainder tissue was evaluated from a weighted average of the dose to the stomach, intestine, oesophagus, liver and bladder. Moreover, the other tissue values were evaluated with the mean value of the skin entrance dose. Standard deviations of dose data from internally positioned TLD were calculated for each organ while for externally positioned TLD the calibration of the dosimeters assures an error within 20%.

Effective Dose and LAR

Starting from the values of organ doses, the effective dose was calculated using ICRP 103 recommendations [9]. LAR of cancer incidence and cancer mortality for a 20-year-old
male due to a standard scoliosis examination were calculated for both systems, according to the studies of the Committee on the Biological Effects of Ionizing Radiation (BEIR VII) [10]. LAR of cancer incidence and mortality for all tumors were calculated starting from the average of the measured organ doses.
**Table 1:** Investigated organs at risk.

<table>
<thead>
<tr>
<th>Position</th>
<th>n. TLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colon</td>
<td>3</td>
</tr>
<tr>
<td>Bone Marrow</td>
<td>6</td>
</tr>
<tr>
<td>Lungs</td>
<td>12</td>
</tr>
<tr>
<td>Stomach</td>
<td>3</td>
</tr>
<tr>
<td>Small intestine</td>
<td>6</td>
</tr>
<tr>
<td>Oesophagus</td>
<td>6</td>
</tr>
<tr>
<td>Liver</td>
<td>3</td>
</tr>
<tr>
<td>Thyroid</td>
<td>3</td>
</tr>
<tr>
<td>Testicles</td>
<td>6</td>
</tr>
<tr>
<td>Eyes</td>
<td>6</td>
</tr>
<tr>
<td>External Abdomen</td>
<td>3</td>
</tr>
<tr>
<td>External Pelvis</td>
<td>3</td>
</tr>
</tbody>
</table>
Fig. 1: Positions of the external dosimeters on the surface of the Alderson Rando Phantom and positioning of the phantom during exposure in the EOS system.

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Results

For all the organs we measured definitely lower delivered doses using EOS, except for testes and eyes that are usually shielded in the CR procedure (Fig. 2). Dose of the conventional exam ranges between 2 and 5.1 times bigger than that of the EOS system excluding eyes and testes.

Despite EOS exam was performed using best image quality protocol, the effective dose value was $(0.44 \pm 0.06)$ mSv, about 3 times less than CR dose exam $(1.46 \pm 0.21)$ mSv (Table 2). Consequently, also the LAR of cancer induction and mortality are substantially lower: for a 20-year-old patient the radiological examination produces 1 induced cancer in 15,625 studies with the EOS in respect to 1 in 5,400 with the CR and 1 cancer death in 29,900 studies with the EOS in respect to 1 in 10,325 studies with the CR. Even though for a 5-year-old patient the effective dose is lower than that of an adolescent (-31% as found in [7]), the risk coefficients of cancer incidence as reported in BEIR VII are around 2 times bigger thus resulting in considerably greater LAR for younger patients.
**Fig. 2:** Comparison of the organ doses measured during the EOS and the conventional radiology exposure.

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Table 2: Effective dose evaluated for the EOS and the conventional expositions.

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Conclusion

The main aim of this study was to assess the organ doses for a scoliosis examination with the EOS imaging system and to compare them to the doses received in the same exam performed with a CR system. This kind of investigation permits gaining useful information for patient dose and protocols optimization. The effective dose for a full spine examination in an adolescent male patient (20-year-old) with the EOS is 0.44 mSv and the LAR of cancer incidence is 1 in 15,625 studies. This values are both about 3 times smaller than those in the same examination imaged with a conventional radiology system. Although cancer induced probability is very low also using conventional radiology, nevertheless, considering the absorbed doses due to the large number of diagnostic exams during the lifetime, is high recommended to optimize the exposition dose especially for young patients. The EOS system was proven an efficient modality to decrease patient dose in scoliosis examinations. The shielding of the testes and the exclusion of the eyes from the scan could allow to further reduce the dose and the risk of stochastic effects.
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