Evaluation of the cardiopulmonary size on slot-scanning full-spine radiographs

PERSHALIA NAIDOO and BÁLINT BOTZ

Department of Medical Imaging, Medical School, University of Pécs, Pécs, Hungary

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ABSTRACT

Background: Slot-scanning EOS radiography is increasingly utilised in skeletal imaging. It has been shown that EOS often reveals significant incidental findings including cardiopulmonary abnormalities. Furthermore, the slot-scanning image acquisition of EOS can substantially influence depiction of cardiac morphology, which can be confusing for those unfamiliar with the technique.

Patients and methods: We aimed to explore the relationship between the depicted cardiac anatomy EOS and chest x-ray, by analysis of the differences in the measurements of the cardiothoracic ratio in 52 patients who had an erect, postero-anterior chest radiograph in deep inspiration, with less than a year difference to the EOS spine radiograph. Internal chest and cardiac diameter were measured, and the cardiothoracic ratio (CTR) was calculated as a surrogate marker for gross cardiac size.

Results: We have found that EOS consistently yields a lower internal chest diameter, and as a result higher CTR (P < 0.0001). However CTR measured on EOS and plain radiograph show strong correlation (P < 0.0001). Bland-Altman plots also revealed a consistently higher CTR on EOS, and a high intra-individual variability of cardiac and chest diameters on EOS vs. x-ray. CTR measured on EOS showed correlation with age (P < 0.05).

Discussion: We show that the CTR on EOS radiographs is consistently higher compared to the chest radiography, and while cardiac diameter shows only minimal difference, chest diameter measured on EOS is markedly lower. This should be considered by those reporting spine EOS imaging to avoid overcalling incidental cardiomegaly.

KEYWORDS

EOS, slot-scanning radiography, cardiac size, chest x-ray

Introduction

The EOS imaging technique (EOS Imaging Ltd., Paris, France) is a relatively new way of collecting whole-body radiograph data simultaneously in two planes while the patient is in an anatomical erect position. The equipment, although costlier than comparable conventional radiography systems, is widely beneficial as it utilises a low radiation dose and the images taken can be computerised to form 3D models. During projection radiography, the imaged body part is irradiated all at once. In contrast, during slot-scanning acquisition a slit beam fans through the imaged region, resulting in improved rejection of scattered beams, better signal to noise ratio, and a reduction of radiation burden [1–3]. The EOS technique is mostly used for scoliosis diagnostics and other bone and vertebral pathologies. The imaging technology in previous studies showed higher quality images where both sharpness and clarity is improved; image pixel resolution is substantially increased in comparison to the conventional x-ray. There is also less radiation exposure and the EOS imaging is much less affected by scattered radiation [4]. A new addition to the EOS technology is the microdose technique that allows the radiation dosage to be further reduced. The microdose delivers 5.5 times less radiation than the usual low-dose protocol, and 45 times less radiation than conventional radiography [5]. Despite its manifold added benefits, the considerably higher cost of the EOS system has led to concerns being raised about its cost-effectiveness [6].
Since its invention, the equipment has been used to follow spinal deformity progression in both adult and children populations, particularly for scoliosis and pelvic structure abnormalities [7]. The technique operates with a multi-wire gas chamber which is placed between the detector and the patient being examined. Thus, the rays emitted from the patient release a second wave of photons in the gas chamber, which are received and analysed by the detector [8, 9]. EOS utilises slot-scanning approach. This means that instead of diverging x-ray photons emanating from a pinpoint source the x-ray is moving in a cranio-caudal direction as a linear beam (very much like a household photocopier). This eliminates divergence, characteristic of conventional radiography (Fig. 1A and B), but introduces other potential sources of spurious information. Whereas conventional x-ray images are typically acquired virtually instantaneously, EOS builds images sequentially in a downward direction. EOS whole spine radiographs thus take considerably more time to acquire (5–20 s depending on patient size and whether full spine or full body imaging is done). This leaves more potential of e.g. movement artifacts caused by patient non-compliance, and cardiac pulsations. It has been shown that EOS artifacts often have distinct appearances, which can be puzzling for readers who had no prior exposure to slot-scanning systems [10]. There are also differences in that one area may be completely normal and artifact-free, whereas another area may have a small artifact in the imaging which makes it more difficult to detect or differentiate [11]. Whilst during conventional x-ray movement artifacts typically degrade entire image quality, EOS movement artifacts often affect only segments of the image where they often produce mild to severe distortions and undulating effects that can mimic pathology (Fig. 1C and D).

The increased likelihood of movement artifacts coupled with their peculiar appearance may unfortunately mimic pathology (e.g. scoliosis), and can lead to misdiagnosis if the user is unfamiliar with their EOS appearance. Awareness of the dissimilarity of EOS artifacts remains low, and this could lead to biases during image interpretation (Supplementary Fig. 1). Another significant disadvantage of the long duration of the EOS acquisition are respiratory movement-related artefacts, as the patients are breathing freely throughout the image acquisition.

Since whole body low dose radiography images large body regions the likelihood of incidental extraspinal findings is high. This has been confirmed by a recent study which showed that the overall rate of incidental findings is 60.4%, although most findings are considered of minor relevance. Fortunately, the rate of clinically significant extraspinal findings was modest at 0.8%. It has also been shown that cardiopulmonary incidental findings such as apparent enlargement of the cardiothoracic silhouette are also occasionally observed [12]. We have empirically observed that EOS cardiothoracic silhouette size is often relatively larger in comparison to the chest x-ray in patients who had both types of imaging at short intervals. This empirical, but unproven observation led us to validate it by performing a comparative evaluation of cardiothoracic silhouette between these modalities, using the ubiquitously accepted and easily reproducible cardiothoracic ratio (CTR) as the surrogate marker for apparent cardiac size (which is typically judged subjectively in clinical practice). The CTR is a widely

Fig. 1. Key differences between slot-scanning and projection radiography. A) Conventional projection radiography results in object magnification due to the divergence of the primary beam emanating from a pinpoint source. B) Slot-scanning uses a slit-like narrow beam and as a result the size of objects is correctly depicted. C) In conventional radiography the entire image is acquired simultaneously, object movement results in image blur. D) In slot-scanning the image is gradually acquired and as a result object movement results in undulating artifacts, often only affecting parts of the image.
accepted estimation of gross cardiac size. Previous studies state that the physiological ratio in postero-anterior (PA) radiographs is 0.42–0.50 whereas the pathological values for CTR are <0.42 and >0.50 [13].

In the current work, we aimed to perform a comparative assessment of cardiothoracic silhouette size evaluated on EOS vs. the gold standard erect, PA chest radiographs obtained in deep inspiration. This question is hitherto unaddressed to the best of our knowledge, and has relevance for those assessing whole spine/body EOS radiographs as part of their clinical reporting duties.

**Patients and methods**

**Patient selection**

This was a retrospective study of the period between 2019 and 2022. The study was conducted in accordance with the Declaration of Helsinki, and approved by the Clinical Centre of the University of Pécs (KK/795-1/2023) as well as the Regional Committee on Research Ethics of the University of Pécs (9627-PTE 2023). Requirement for individual informed consent was waived due to the retrospective nature of the study. All patients have signed the general institutional informed consent form for the EOS and chest x-ray exams. A total of 52 patients were retrospectively identified, who had a chest x-ray and EOS examination with close interval. Patients who had an erect PA chest radiographs in sufficient inspiration and did not opt out were included in the study. As a further inclusion criteria, the interval between the EOS and chest x-ray exams had to be less than 12 months. Both the EOS images and chest x-rays were first assessed by a board certified consultant radiologist with more than 5 years experience in reporting EOS radiographs. Studies with an oblique, nonstandard imaging plane, or significant artifacts due to patient movement on either the EOS, or plain radiographs were excluded from the study. Significant gross qualitative changes between the exams, or presence of pathology (e.g. consolidation, effusion) obscuring the cardiothoracic silhouette were also criteria for exclusion. Patients having significant scoliosis limiting chest assessment and in particular those having rotational components were also excluded.

**Measurement of CTR**

Internal chest and cardiac silhouette diameter was measured in millimetres using a digital calliper in the MedView (Aspyra LLC, Jacksonville, FL USA) picture archiving and communication system (PACS) as described earlier (Fig. 2) [13]. The numerical values were entered into a spreadsheet where CTR was automatically calculated using the standard formula.

**Statistical analysis**

The results were evaluated using the GraphPad Prism software (GraphPad Software, Boston, MA, USA). CTR, chest diameter and cardiac diameter were compared using paired samples, two-tailed *t*-test. Correlations between EOS and plain radiograph measurements, as well as with patient age were done using linear regression and Pearson Correlation. The intra-individual and group-wise consistency of the two modalities were also compared using Bland-Altman plots. In all cases *P* < 0.05 was considered as significant. Symmetrical distribution of the measurements was confirmed by calculating skewness. Error bars represent mean ± standard error of mean (SEM).

**Results**

**Patient demographics**

Among demographic parameters, patient age (at the time of the EOS) and gender were registered (Supplementary Table 1).
EOS underestimates chest diameter, and thus overestimates cardiothoracic ratio compared to conventional chest radiography

First, we have compared the CTR measured on EOS and plain radiographs (means: 0.50 vs. 0.42). The mean and median differences of CTR were 0.08 and 0.086, respectively. We have found a striking overall increase of CTR ($P < 0.0001$) on EOS (Fig. 3A). By comparing the cardiac and chest diameters we have found no significant difference in the former (means 112.3 vs. 109.8 mm, Fig. 3B), whilst chest diameter was markedly lower on EOS compared to conventional radiography ($P < 0.0001$, means 224 vs. 260.5 mm, Fig. 3C).

CTR, cardiac, and chest diameters measured on chest radiographs and EOS strongly correlate with each other

Based on the observed difference in the above values, next we have asked whether the CTR on EOS correlates with the one measured on chest x-ray. Plotting the values against each other showed that EOS CTR, and CTR measured on plain film show a strong correlation ($P < 0.0001$), which was also true for cardiac and chest diameters respectively ($P < 0.0001$) (Fig. 3D–F).

We have further compared the two methods using Bland-Altman plots. CTR was found to be consistently higher using EOS (bias: 0.08, 95% confidence interval (CI): $-0.02$ to $0.19$, Fig. 4A). Cardiac diameter was overall only minimally different (bias: 2.62), however the wide 95%CI ($-22.61$ to $27.84$) indicates substantial intra-individual variation between the two methods (Fig. 4B). Chest diameter showed substantially lower values on EOS (bias: $-36.52$), and again high variability (95%CI: $-68.17$ to $4.87$, Fig. 4C).

CTR measured on EOS and chest x-ray does not correlate with patient age

Finally, we aimed to verify whether CTR measured on either modality correlates with age. For EOS we have found a weak but significant ($P = 0.047$) correlation with age, while no significant effect could be detected for plain radiographs (Fig. 4D and E). We also assessed whether the relative CTR difference (EOS CTR minus chest x-ray CTR) shows no correlation with age, which could indicate an age-related confounding effect. Data showed a clear absence of such correlation (Fig. 4F).

Discussion

In this study, we aimed to assess the performance of EOS in determining cardiopulmonary silhouette size, using CTR as a surrogate marker for this purpose. We have found that EOS generally yields a higher CTR, and the measured internal chest diameter is lower. The measurements are...
altogether consistent, as all measured parameters correlated strongly between the two modalities. However, Bland-Altman plots revealed a high intra-individual variability of the measurements as well.

EOS images are taken in standing position and in two imaging planes simultaneously. The timing and dynamic body movements like heartbeats and breathing can influence the accuracy of the EOS images, as it is noted that there is a long imaging delay with EOS (10–25 s) [14]. Hence, the chest diameter results are affected by the patient’s normal breathing movements more than during plain radiography, as multiple cardiac and respiratory cycles are completed during a single image acquisition. A further source of difference is caused by the slot-scanning technique itself, as unlike during projection radiography no magnification occurs. It has been shown that moving structures introduce a focal “undulating” effect on the EOS images, unlike the typical blurring which occurs during plain film acquisitions. This influences the appearance of the left cardiac margin in particular (Fig. 5) [10, 15] (Central illustration).

It has also been proven that in the absence of movement EOS measurements are very accurate, deviating only about 1.5% from the ground truth [16]. A recent study of the EOS imaging system demonstrated that chest phantom radiographs obtained with the system have sufficient visual quality for diagnostic use [17]. However, our results also indicate that the longer acquisition time and characteristics of the system have a distinct influence on the apparent size of cardiopulmonary structures. It has been shown that image quality of a properly acquired conventional digital radiograph exceeds that of EOS [5]. Nonetheless, the substantial radiation dose reduction which can be achieved by EOS compared to conventional whole body radiography must be also emphasized, as it has been shown that the latter results in a 5.4-fold increase in lifetime cancer risk in the paediatric population [18].

This study has several limitations. As EOS is primarily utilised for functional orthopaedic imaging in a pediatric population, the majority of the patients fell into this age category. As a result with few exceptions the patients had normal CTR measured on the gold standard chest x-ray. Also, due to the length of the image acquisition patients were asked to breathe freely throughout the image acquisition instead of the deep inspiration typical for conventional radiography. Further prospective studies using limited chest imaging protocol could reduce the scan time, and thereby at least partially alleviate breathing-related artefacts.

In summary, the cardiopulmonary silhouette and chest diameter appearing on EOS is more subjective to variable motion-related artefacts. Interestingly, we have found that both CTR and the parameters on which it is based showed strong correlation between EOS and plain radiography. As a result, gross cardiopulmonary silhouette size can be still assessed, while keeping in mind the characteristics of the technique. Since due to the longer acquisition EOS is more prone to respiratory and cardiac motion artifacts, future slot-scanning systems for chest applications will need to approach this limitation by reducing scan time.

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Fig. 4. Bland-Altman plot comparisons of chest x-ray and EOS measurements. A) Cardiothoracic ratio, B) Cardiac diameter, C) Chest diameter. D) correlations of the EOS, and E) chest x-ray results of cardiothoracic ratio, F) relative cardiothoracic ratio difference compared to patients’ age (linear regression and Pearson correlation, *p* < 0.05)
Central illustration. A) Conventional postero-anterior chest radiographs and EOS slot-scanning x-ray images have distinct appearance. Note the wavy movement artifacts of the left heart border on the EOS image, which are caused by gradual image acquisition occurring through multiple cardiac cycles. B) EOS consistently overestimates cardiothoracic ratio (CTR, *P* < 0.0001), but C) CTR on EOS and plain radiographs shows strong correlation (*P* < 0.0001). D) The overestimation of CTR stems from the underestimation of internal chest diameter (*P* < 0.0001), also demonstrated by E) the Bland-Altman plot of the difference (note: the central illustration represents summary of the main findings of the study, also shown on Figs 2–5 earlier).

Fig. 5. Effect of cardiac movement on the cardiothoracic silhouette. A) In the plain radiograph the cardiac contours of this patient with mild scoliosis are unremarkable. B) In the EOS of the same patient, a peculiar, undulating appearance of the left cardiac margin caused by multiple cardiac contractions during acquisition is striking.
Conclusion

In the surveyed population, CTR measured on EOS is higher, primarily due to the lower internal thoracic diameter. CTR on EOS is however strongly correlated with the one measured on the gold standard chest x-ray. Based on our data and the observed mean and median difference, a slightly increased threshold of 0.60 can be proposed as a provisional upper limit for normal CTR on whole spine/body EOS. Professionals interpreting EOS examinations should be aware of this effect, and the specific artefacts inherent to the modality in order to avoid incorrect assessment.

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1556/1647.2024.00180.

REFERENCES


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