EOS – A New Frontier in Spine Imaging

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Abstract

EOS is a new tool in the armamemtarium of orthopedicians. Its ability to give a standing 3 dimesnionla image of the spine, has made it an indespenisble tool, specially for spine surgeons. Scoliosis is a 3 dimesnional deformity with multiple compensatory mechanisms being applied at the level of the pelvis and lower limbs as well as in spine. Operating on such patients needs thorough understanding of the 3D anatomy. EOS, provides this along with its low radiation dose, quick scan time and ability to repeat test multiple times if needed. The uses of this modality is on the rise, and as awareness and accessibility to EOS increases, so will the diversity of uses of this tool. Spine surgeons need to understand and use EOS for planning of their surgeries more compared to orther specializations of orthopaedics. EOS is truly a game-changer for spine imaging.

Keywords: EOS; 3dimesnional scans; scoliosis surgery; spine radiographs; novel methods

Introduction

The intricate relationships of the human vertebral column, to its own bones as well as to the pelvis and lower limbs have been an area of interest for orthopedicians since times immemorial. The spine does not function independently, but a stable global spinal alignment is maintained by the compensatory mechanism employed in the pelvis and lower limbs. The advent of computed tomography (CT) scanning and magnetic resonance imaging (MRI) have solved most of the diagnostic problems in spine pathology. However, assessing spinal alignment as a whole, in a weight-bearing position continues to haunt the orthopedicians. This is either due to lack of true to size films, or inability to get weight-bearing films with spine and pelvis in the same film. EOS is a modern day imaging device, which tries to address these problems in spine imaging.

EOS is a biplane X-ray imaging, which uses slot scanning technology based on the multiwire proportional chamber, which is a Nobel prize winning technology developed by Dubousset et al. [1]. At present, this is manufactured by EOS imaging (formerly Biospace Med, Paris). EOS imaging is rapidly being adapted by the medical community due to its astounding benefits over conventional X-rays, namely – low dosage of radiation, a standing 3-dimensional radiograph from head to toe in a single film and the short time of scan. This is made possible by the novel technology used in this method of imaging. When X-rays are directed towards the object, the emergent rays from the object emanate a second wave of photons inside the gas chamber. This second wave is sensed by the detector in the multiwire proportional chamber. This second wave production is the rationale behind the usage of low dose of X-ray radiation [2]. Furthermore, this multiwire proportional chamber can give positional information about the trajectory of these particles, by tracking the trails of gaseous ionizations.

The imaging system is constituted by two pairs of X-ray tubes and detectors, placed at right angles to one another. This allows simultaneous orthogonal images to be captured and calibrated in a short duration of 30–45 s over a field of 180 × 45 cm. Next, a stereo-radiography based software, SterEOS, is used to develop a 3D reconstruction image of the spine as well as the lower limb bony structures [3]. 3D models are created with help of this software, based on bone shape recognition and statistical modeling. This allows measurement of 3D angles, dimensions as well as torsion angles which have been traditionally measured on CT scans. The large image field of the tubes, allows true to size images to be obtained, in contrast to the magnified images obtained with conventional radiography due to the single source divergent X-ray beam used in those machines. Thus a quick scan of the full body in a standing weight-bearing position is obtained in EOS and also with comparable image quality and lower radiation exposure (Fig. 1) [4]. A complete win-win situation for the

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Figure 1: EOS image acquisition in a weight bearing position and the final orthogonal films.


Figure 2: Multitude of variables measured on EOS films.

patients as well as the doctors. Such an imaging technology would be of potential use in a pathology that changes under load, has relevant rotational deformity or in which high exposure to radiation is a concern due to the need for repeated X-ray scanning.

EOS Versus CT Scanning

Al-Aubaidi et al. [5] showed no statistically significant difference in intra or inter observer reliability for measurement of apical vertebral orientation between EOS and CT scan. Although, EOS faired poorly in modeling the anatomical structure of pedicels as compared to CT scan ($P < 0.05$). A major feather in the cap for EOS is the significantly low dosage as compared to CT scanning. Delin et al. [6] showed that the skin dose was up to three times lower for nape of the neck and 6–9 times lower for the thoracolumbar spine when using EOS. For femoral or tibial torsion measurements, EOS showed 4.1 times lower radiation to ovaries, 24 times lower to testicles, and 13–30 times lower radiation to knee and ankle as compared to a CT scan. Luo et al. [7] compared EOS and digital radiography over the entire treatment duration of adolescent idiopathic scoliosis (AIS). An average of 20.9 radiographic examination were needed from start to skeletal maturity. They established that using EOS leads to 50% less radiation exposure. Micro dose protocol, is a newly developed EOS protocol, which claims to provide 5.5 times lower radiation exposure than standard low-dose protocol and up to 45 times lower radiation than conventional radiography.

AIS and Sagittal Balance

Scoliosis appears to be the disorder where EOS can spearhead better diagnosis, decision making, treatment strategies as well as monitoring. Scoliosis involves a 3D deformity of the spine with sizeable implications on coronal and sagittal alignment of the trunk and hence, needs weight-bearing radiographs of the whole spine and pelvis (Fig. 2). Also, such patients need radiography at regular intervals for monitoring of progression [8]. Intra and inter-observer reliability of using 3D EOS for measurements of global sagittal parameters are well established (Fig. 3). 2D sagittal measurements lead to overestimation of kyphosis due to axial rotation, whereas 3D reconstructed images, provided by EOS allow measurement of true kyphosis [9, 10, 11]. Scoliosis surgery planning is and simulation is allowed by the SpineEOS software. Preliminary studies with this software have performed well and were able to simulate postoperative alterations in global alignment accurately [12]. A unique takeaway from the whole body scanning abilities of EOS is the

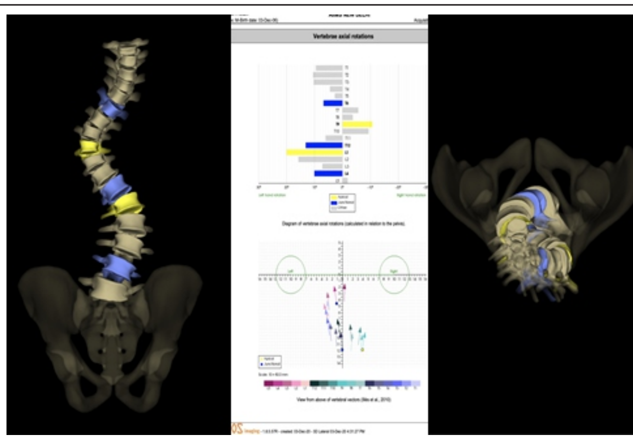
Figure 3: 3D reconstruction and measurements calculated by the EOS machine in a patient of adolescent idiopathic scoliosis.

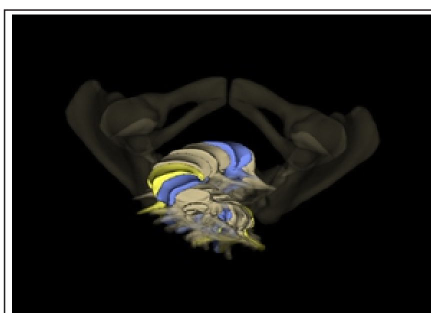
Figure 4: DaVinci Presentation of spinal deformity in a patient of adolescent idiopathic scoliosis.

ability to evaluate skeletal maturity along with spinal deformity. Skeletal maturity can alter decision-making in patients with spine deformity. Lau et al. [13] have shown excellent intra and interobserver reliability for computing the Thumb Ossification Composite Index using EOS, which gave an estimation of the skeletal maturity from the same standing film.

Great intra, as well as interobserver reliability, has been shown in the measurement of cobbs angle, thoracic kyphosis as well as lumbar lordosis by Vidal et al. [8] as well as Somoskeoy et al. [14] They have also shown better intraobserver reproducibility than 2D methods. Ilharreborde et al. [15] in their study evaluated the precision of 3D reconstruction of radiographs using EOS micro dose protocol in 32 patients of AIS and found excellent reproducibility for all spinal as well as pelvic parameters. In another studies, the authors [16] compared pre-operative and post-operative radiological parameters in AIS. They reported excellent inter and intraobserver reproducibility for spinal and pelvic parameters in pre-operative period but only good reproducibility in post-operative period.

Pulmonary Function/Thoracic Cage Geometry

Scoliosis being a rotational deformity also affects the volume and shape of the thoracic cage and in turn the pulmonary function. This is indicated by the Spinal Penetration Index (SPI), which quantifies the portion of the rib cage occupied by the vertebrae. Previously, CT scan was used to calculate the supine SPI. EOS was used by Ilharreborde et al. [16] to calculate the thoracic volume, the mean SPI, which is the percentage of the thoracic cage volume occupied by vertebrae, and the apical SPI, which is the percentage of the thoracic cage surface occupied by the apical vertebra, to be measured in an axial plane in a standing position. Although this was not compared to the CT scans neither could a 3D reconstruction of the rib cage possible due to software limitations. In another study, these authors [16] measured these thoracic cage parameters in 49 AIS patients, pre and post-operatively. They were able to show that there was an increase in thoracic volume in relation to the amount of correction of Apical Vertebrae Rotation. Such correlations could not be established in the era before EOS and this move toward the standing measurement of thoracic cage parameters can emerge as an important use of EOS in future [17].

3D Assessment of Spinal Flexibility

Lateral bending radiographic views are widely used for classifying scoliosis depending on pre-operative flexibility of the curve. Hirsch et al. [18] demonstrated an EOS "suspension test" for evaluation of spinal flexibility. Here the patient is put through constant traction using a rigid collar attached to cables until the patient is on their tip toes, at which point an EOS is taken. This test was similar in mechanism to the supine traction test on Cotrel's frame. Although patient tolerance was low for such a suspension test, this allowed coronal, sagittal as well as axial reduction in a single setting, which was not possible previously.

3D evaluation of brace treatment

Bracing is an essential tool in the armamentarium of the orthopedician to treat scoliosis. When bracing is chosen as the treatment of choice, disease status is monitored using radiographs. Conventional radiography allows estimation of sagittal and coronal correction to be evaluated, whereas EOS allows evaluation of axial correction too. Thus EOS has become an important tool for patients being treated by bracing [17].

3D classification by scoliosis research society (SRS)

Given the importance of viewing the scoliotic spine in 3D, 3D Scoliosis Committee has been appointed by SRS. This committee would gauge the effect of 3D analysis of the scoliotic spine and then establish a 3D classification of scoliosis based on it [19]. This will be accomplished using a database of 600 AIS spine reconstructions and mathematical clustering techniques to determine curve patterns. The final 3D classification will become available in the coming years and will be applicable to both CT-scan and EOS 3D reconstructions. This emphasizes the recognition EOS as a leading mode of radiography in the world of scoliosis surgery.

Cranial Alignment

Since a complete head-to-feet image is created in a single film in EOS, it opens up multiple new avenues which were not possible previously due to magnification or stitching of images. One such unique parameter is the Cranial Sagittal Vertical Axis (CrSVA). This is primarily a measure of global sagittal balance, similar to the previously accepted C7SVA. Furthermore, distance between a plumb line from cranial center to posterior corner of S1 (CrSVA-S) to the center of hip (CrSVA-H), knee (CrSVA-K), and ankle (CrSVA-A) have been found to correlate well with the SRS-22 scores. Similarly, Le Huec et al. [20] have described parameters for cervical sagittal balance, taking analogies from pelvic and thoracolumbar sagittal spine balance.

Osteoporosis

At present, dual-energy X-ray absorptiometry (DEXA) scanning is the sole method for Bone Mineral Density (BMD) estimation. A low BMD although suggestive, is not predictive of prospective fracture prospects [21]. Subject specific Finite Element Analysis values which are reached at using EOS imaging correlate well with quantitative CT-based models. This accentuates the likelihood of using EOS for testing vertebral strength [22]. Trabecular bone score (TBS) obtained via EOS have demonstrated substantially lower values in patients with osteoporotic fractures. Scoliosis, artefacts, bad image quality, as well as gas projection, make EOS-based TBS non-comprehendible in up to one-third of the patients, making it an unattractive option. In another study, EOS has shown comparable if not better results than DEXA in measuring BMD and diagnosing osteoporosis [23].

Ankylosing Spondylitis

Ankylosing spondylitis is a disease of the axial skeleton which presents as a global kyphotic deformity in young males. The orthopedician aims to surgically restore horizontal gaze and improve global spinal alignment. The development of the kyphotic deformity of the spine, in turn, leads to multiple compensatory mechanisms by the body like pelvic retroversion and flexion at the hip and knee. Only if all the above compensations are taken into note, can the true measure of the deformity be made. This looking at the body as a whole highlights the role of EOS in this disease. Le Huec et al. [20] described a Full Balanced Integrated technique to estimate the needed surgical correction in patients suffering from ankylosing spondylitis. This included three separate angles – the C7 Translation Angle (C7TA), Pelvic Tilt Correction Angle and Femoral Obliquity Angle. EOS is a tool that allows the surgeon to measure all the three measurements in a single image and in a true to size form. Earlier, there measurements required multiple X-rays and taking into consideration the magnification factor as well as stitching of images [24]. On the other hand, EOS has fared poorly in diagnosing sacroiliitis and thus cannot be used a tool for diagnosis in axial spondyloarthritis.

Adult Deformity and Degeneration

Although most of the talk regarding EOS revolves around its ability to provide an overview of global sagittal balance, EOS is also a useful tool to diagnose rotary subluxations and correlate them to other pelvic parameters, which is primarily useful in adult spinal deformity. Ferrero et al. [12] demonstrated that 27% of patients who has >10° of rotational deformity were skipped when only 2D images were studied, substantiating the role of 3D reconstructed films in the diagnosis of rotatory subluxations. The role of EOS has also been explored in degenerative spine disorders. Rillardon et al. compared discography by EOS to MRI for study of Intravertebral Discs spaces. Although EOS could diagnose disc space narrowing with decent accuracy, disc herniation could not be diagnosed on EOS, which was a major drawback [3].

Vertebral Vectors

Illes et al. [25] introduced the concept of vertebral vectors for the understanding of spinal deformities. These vectors were lines, starting from the mid-point of the interpedicular line and running parallel to the upper ends plate of the vertebrae in sagittal view. In axial view, these vectors run in the middle of the vertebral body. End of this line is at its junction with the anterior surface of the vertebral body. These vectors allow a visual representation and understanding of position, size, and rotation of each vertebrae. It allows measurements of all characteristics that define scoliosis as well as axial rotation of the vertebrae. It has been established that values obtained from vertebral vectors are more accurate than those obtained by 2D radiographs [26].

DaVinci Presentation

DaVinci presentation is a view from the cephalad side, which allows the physician to see the spinal deformity in two planes – the frontal plane (antero-posterior) and the sagittal plane (lateral). This allows understanding the deformity in a three-dimensional space (Fig. 4) In horizontal plane – the deviation of each vertebrae in relation to the sagittal plane, Central Sacral Line or C7 plumbline as well as location of Plane of Maximum Curvature in relation to the sagittal and coronal plane. This was previously possible only through a MRI or a CT scan. In a rotational deformity like scoliosis where 3D understanding is of utmost importance to correct all the components, EOS has made the DaVinci presentation easily accessible to the physician in a short time to plan the surgery better.

Why EOS?

EOS has emerged as a tool of great help for the spine surgeons and is considered the gold standard of radiography in the future. This is primarily due to the reduced radiation dose, the short duration of scan, weight-bearing position as well as ability to provide 3D reconstructions. But in reality, EOS imaging helps in reaching a diagnosis in only a fraction of the patients, furthermore, the treatment plan is altered only in a small proportion of these and even fewer have outcomes altered.

Limitation

With all the great things being highlighted about EOS imaging, this review won't be complete without shedding light on the short-comings of this technology. The patient has to sit or stand steadily for EOS imaging, which is difficult in patients suffering from neurological or neuromuscular disorders, leading to blurry images. Although a special chair has been developed to scan patients suffering from neuromuscular scoliosis [27], this chair is yet to be available widely. 2D images that are obtained have reduced brightness compared to the conventional X-rays. 3D reconstruction is developed using a software by an expert operator. The need for an operator introduced the chances of an error in measurements. EOS was ingeniously conceptualized for adult bones and hence, 3D reconstruction is still impossible for children below the age of 5–6 years. Similarly, 3D reconstruction of the patella, rib cage as well as congenital anomalies of the spine is not possible, and the software is still under development. Any new modality of investigation is used in mainstream medicine when it has proven benefits on patient outcomes. EOS at present, although promises reduced radiation, shorter time, and higher patient comfort, still patient-oriented outcomes with this technology are yet to show impressive supremacy when compared to other radiographic modalities. Also, cost-effectiveness is a major roadblock with this expensive technology [28]. With modern X-ray machines, already exposing to a very low radiation dose, the advantage of low dose radiation would only be useful in patients being scanned very frequently.

Conclusion

EOS is a remarkable new tool, especially for doctors associated with scoliotic spine surgery. 3D reconstruction has been made possible without a CT scan, which is a great stride forward. The striking advantages at present seem to overshadow the shortcoming, but EOS has a long way to go in the future of spine surgery and will hold a pivotal role in understanding, planing, and executing complex scoliosis correction surgeries.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his consent for his images and other clinical information to be reported in the Journal. The patient understands that his name and initials will not be published, and due efforts will be made to conceal his identity, but anonymity cannot be guaranteed.

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