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Review

Musculoskeletal imaging in progress: The EOS imaging system

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ABSTRACT

The EOS 2D/3D radio-imaging device (Biospace med, France) can disclose a digital radiographic image of bones with a very low radiation dose. This in turn allows in obtaining a single image of a large field of view, as wide as the full skeleton. The simultaneous capturing of spatially paired AP and lateral X-ray images is also a specificity of EOS imaging, which further provides secondary 3D (volumic) reformation of skeletal images. The main indications of this new imaging technology are assessment and follow-up of balance disorders of the spine and of the lower limbs.

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The EOS 2D/3D radio-imaging device (Biospace med, France) can disclose a full skeleton radiographic digital image with a very low radiation dose. In addition, data allow secondary 3D (volumic) reformation of skeletal images.

1. The three technological principles of the EOS imaging device

The first principle is based on the French physicist Georges Charpak's Xenon multiwire proportional chamber [1] (1992 physics Nobel Price winner). The chamber is placed between the X-rays emerging from the radiographed object and the distal detectors. Each of the emerging X-rays generates a secondary flow of photons within the chamber. These in turn stimulate the distal detectors that give raise to the digital image (Fig. 1). This secondarily increased photon flow explains how a low dose of primary X-ray beam is sufficient to display a high-quality digital radiograph, making it possible to cover a field of view of 180 × 45 cm in a single acquisition of about 30–45 s duration.

The second principle is the association within the EOS imaging device of orthogonally co-linked X-ray tube/detector pairs (Fig. 2) that allow the simultaneous capturing of spatially calibrated AP and lateral X-ray images (Fig. 3).

The last principle is a specific software disclosed by the Laboratory of Biomechanics of the French École Nationale des Arts et Métiers (ENSAM, Paris) together with the Canadian Laboratory of Research in Imaging and Orthopedics (LIO, Montreal). This software provides a sharp 3D reconstruction of the bones from the data simultaneously captured in both frontal and lateral 2D planes.

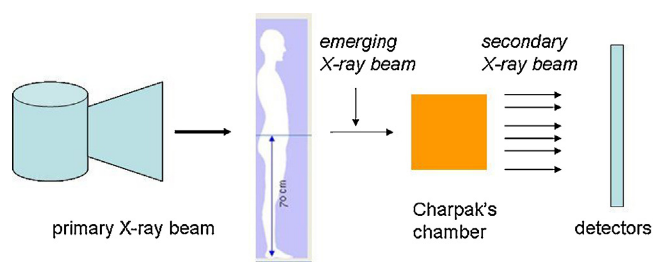

Fig. 1. Diagrammatic representation of the amplification of the low dose primary X-ray beam through the Charpak's chamber.

2. Historical background

EOS imaging was first clinically evaluated in France in 2002, through a radio-orthopedic study of child scoliosis at the Academic Hospital Saint-Vincent de Paul in Paris [3–5]. EOS imaging technology could bring a solution to both of the following problems:

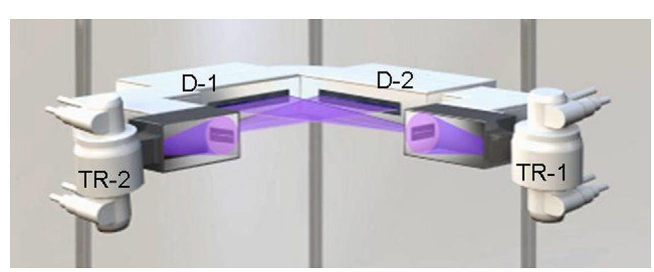

Fig. 2. Orthogonally co-linked X-ray tube (TR1 and 2)/detector (D1 and 2) pairs.

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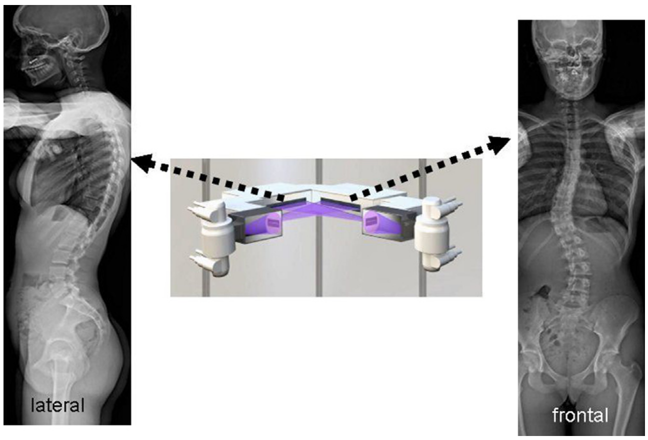

Fig. 3. Simultaneous capturing of spatially calibrated AP and lateral X-ray images.

- to determine the individual position of each vertebra in the axial plane, thanks to the 3D-reformatted images;
- to reduce the radiation dose, thanks to the Charpak's chamber, the ratio of reduction being as low as 1:10 when compared to a regular digital radiograph, and as low as 1:100 to 1:1000 when compared to a CT 3D reformation. The radiation dose to skin was also found to be six to nine times lower with EOS imaging when compared to regular digital radiography [2].

The EOS imaging device started to be commercially available in 2007. The same year, the French Authority for Academic Evaluation of New Medical Technologies (CEDIT-APHP) recommended that clinical departments dealing specifically with scoliosis be provided with EOS imaging devices. Currently, EOS system is available in the following Paris area academic APHP hospitals: Cochin-Saint-Vincent de Paul, Raymond Poincaré and Robert Debré hospitals. In addition, the ENSAM institution is still conducting new technological developments on its own EOS device.

3. Everyday clinical applications of EOS imaging

The EOS imaging device comprises an open cage having a 2-meter sized square basis and a 2.70-meter height (Fig. 4). The

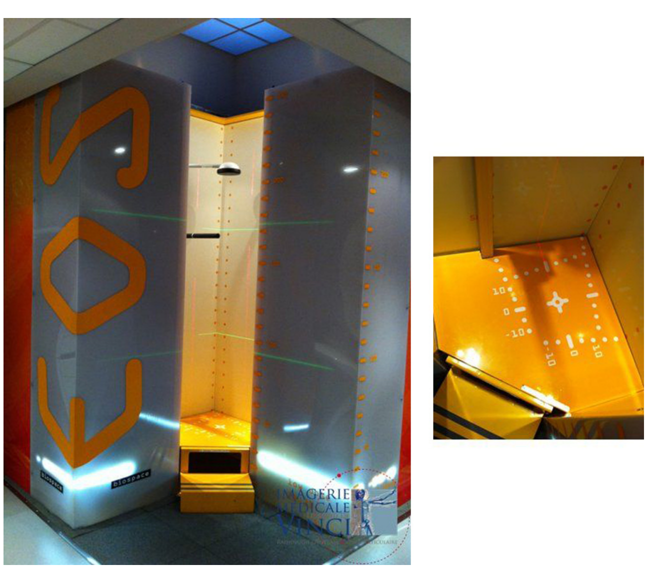

Fig. 4. EOS cage (left hand) and its landmarked floor (right hand).

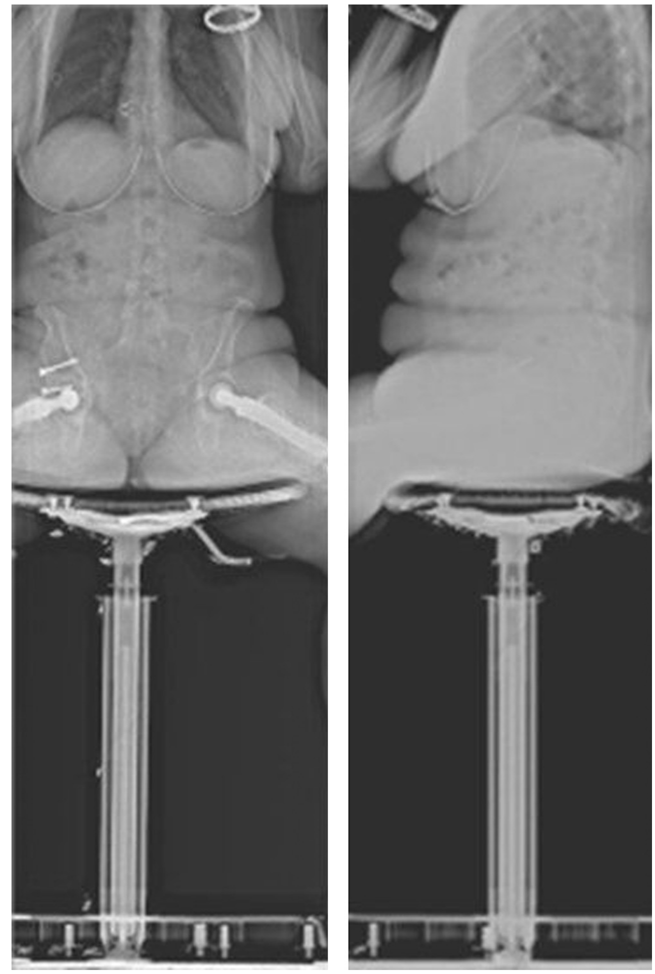

Fig. 5. EOS imaging of a sitting patient.

patient is placed in the weight-bearing standing position, the sitting position being also possible (Fig. 5).

The acquisition station is in a separate area, located near the cage and protected by a X-ray protection screen.

The co-linked X-ray tube/detector pairs are located within the walls of the cage. They can run vertically from the plantar aspect of the feet to the top of the head in the major part of the patient population, in about 30–45 s.

According to clinical requirements, one or both of the X-ray tube/detector pairs may be activated, resulting respectively in a single (frontal or lateral) or coupled (frontal and lateral) radiographic incidence. In the latter case, the radiation dose is double.

One main problem of EOS imaging is to avoid movement artifacts during the 30–45 s time of acquisition, while patients are asked to stand in the upright position, in the center – which means far from the walls – of the cage. The problem is more frequent in children and in the elderly. Specific devices help maintain the superior limbs and the head of the most instable patients. In addition, when only one plane is clinically requested (for instance, the AP view to follow-up a mild scoliosis), it is more convenient to let the patient stand against the appropriate wall of the cage (Fig. 6).

Detectors signals are then converted into a DICOM image on a separate workstation, which may be located elsewhere. The image high quality results from the following features:

- a strong collimation of the X-ray beam, avoiding any diffuse radiation beam which is occurring in regular radiography resulting in a poorer signal-to-noise ratio;

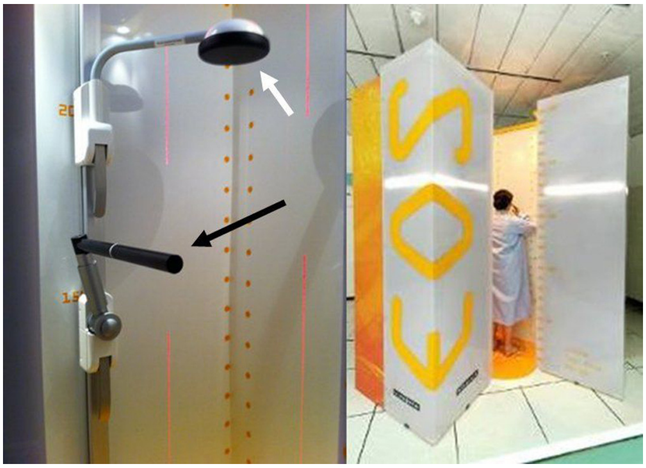

Fig. 6. Enhancing the patient stability within the EOS cage. On the left, devices aiming to help maintain the head (white arrow) and the upper limbs (black arrow). On the right, patient being allowed to stand against the wall, since only one incidence is requested (frontal, in this case).

- at each step of the course of the X-ray tube/detector pair, the X-ray beam is orthogonal to the radiographed object, avoiding any parallax deformation of the image;
- at each step of the course of the X-ray beam/detector pair, the radiation dose is automatically regulated in accordance with the thickness and density of the radiographed tissues;
- the pixels size is as low as 254 μM;
- 30,000 gray levels allow tissues of different thickness and density to be simultaneously disclosed in an appropriate image.

Digital image quality is optimally enhanced on the workstation, with appropriate landmarks (Fig. 7), until the image is sent to impression or digital recording.

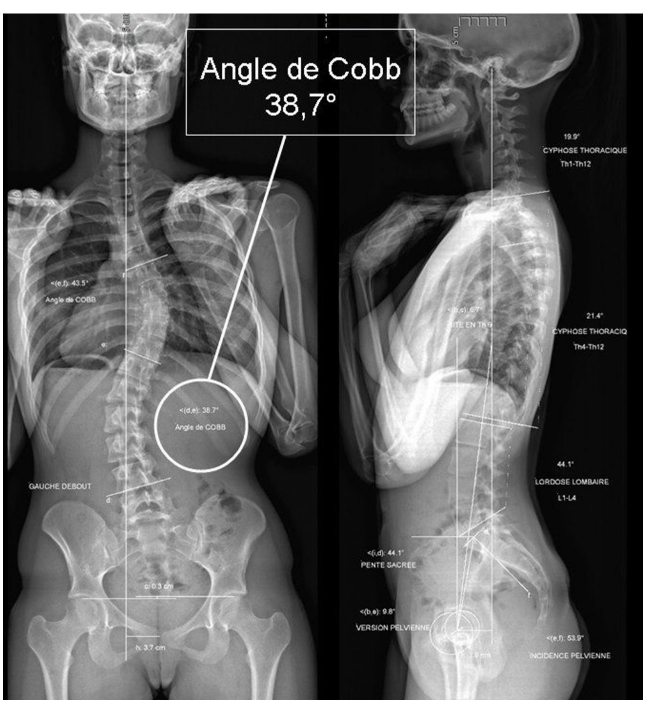

Fig. 7. Full spine and pelvis frontal and lateral 2D-EOS radiographs, with appropriate manually placed landmarks and automatically provided angles. The result of the measurement of one angle has been enlarged in the caption on purpose to illustrate the type of results obtained from the drawings.

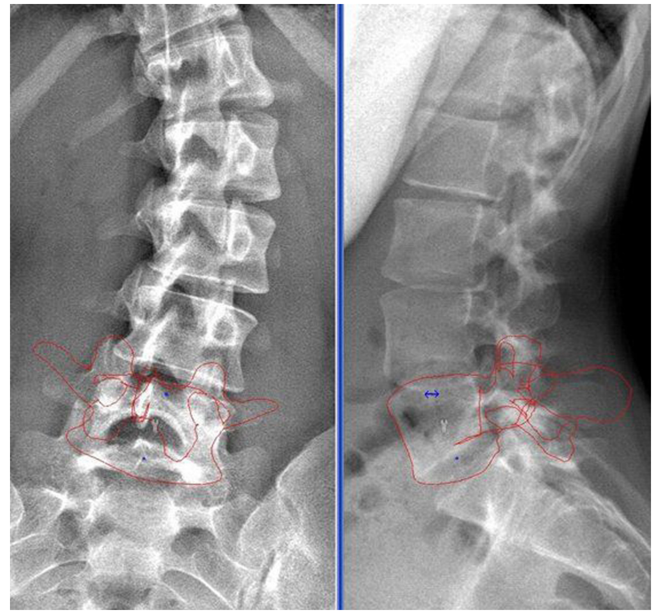

Fig. 8. 3D-EOS reformatted images of the spine. Semi-automatic contouring (red lines) of the L5 vertebra on paired frontal and lateral views.

When 3D reformation is necessary, each selected part of the skeleton is semi-automatically contoured on the workstation (Fig. 8), thanks to a dedicated software (sterEOS®, Biospace med, France) based on recorded radio-anatomic digital models. Such reformation is however time-consuming, as far as 15 min for the whole spine (Fig. 9). A fast 3D-reformation software, now available, should shorten this important step of the process [6].

3D reformatted images accuracy is about 2.3–3.9° in determining vertebrae orientation and is similar to that of CT imaging in measuring lengths [7,9–11,14].

4. Current clinical applications

4.1. Spine measurements

On both frontal and lateral spine 2D images disclosed on the workstation, specific landmarks and axes are drawn, so that the software provides the different angles and distance values (Fig. 7).

In addition, EOS imaging commonly displays a high quality lateral image of the pelvic girdle, which was almost impossible to obtain from conventional X-ray. Consequently, the pelvic

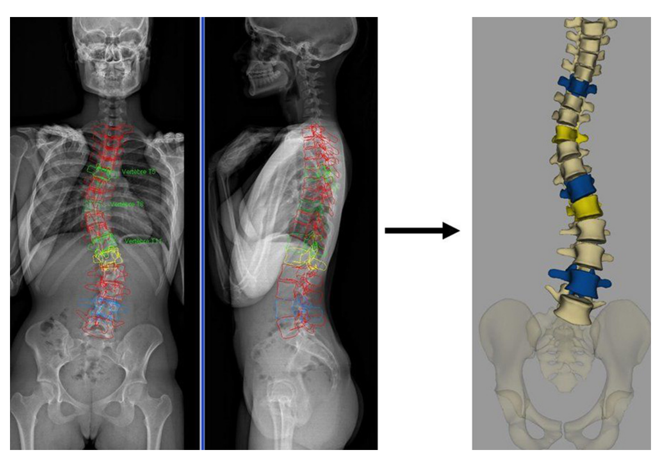

Fig. 9. Full spine contouring on paired frontal and lateral views (left) and volumic resulting image (right).

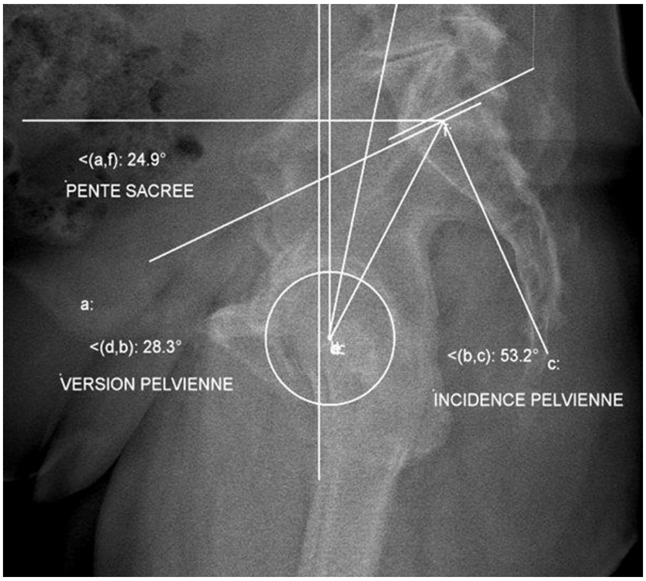

Fig. 10. Lateral 2D-EOS image of the pelvis with appropriate landmarks and resulting angles.

parameters being also systematically studied (Fig. 10), EOS imaging dramatically enhanced our knowledge of the pelvic-spinal balance.

Since scoliosis is mainly an axial plane imbalance, the EOS study of currently or potentially severe juvenile scolioses systematically includes a 3D-reformation of each vertebra, especially at the first radiological examination (Fig. 11). For each vertebra, the sterEOS® software now provides its positions in the frontal, sagittal and axial planes, as well as the diagrammatic vector resulting from these three parameters.

In the elderly, the lower limbs balance is also commonly assessed, the field of view of the EOS image being usually wide enough to cover both the pelvic-spinal area and that of the lower limbs (Fig. 12). The 3D reformation of elderly vertebrae is not systematic, depending on clinical pre-therapeutic requirements.

4.2. Lower limbs measurements

Gonometry (knee measurements) is now performed through EOS imaging. The linked frontal and lateral images of the lower limbs allow measuring 2D-angles in each plane. In case of severe 2D-deformation in any of these planes, complimentary

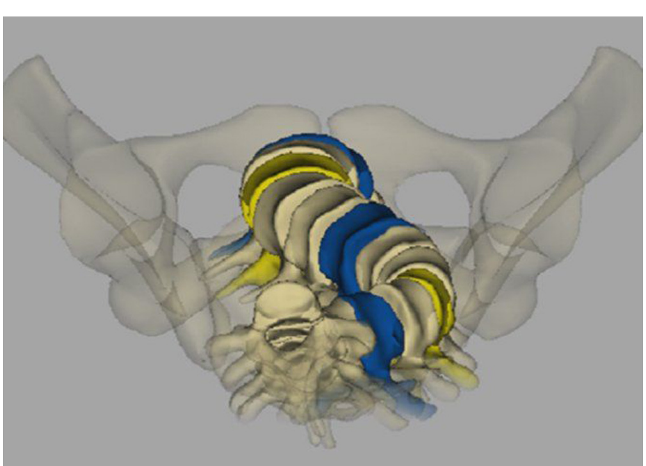

Fig. 11. 3D-EOS image of the full scoliotic spine presented from above.

Fig. 12. Lateral 2D-EOS image of an old patient. Severe flessum of hips and knees (red circles) is the counterpart of an apparent sagittal balance of the operated on spine.

3D-reformatted images directly provide integrated values of the angles, their values in one plane being modulated by those in the orthogonal one (Fig. 13).

Coxometry (hip measurements) is also obtained on EOS images. In addition, 3D-reformatted images of femora and tibiae directly provide the angle values of their axial torsion (Fig. 14). 3D-EOS measurements of axial torsion of femora in cadaveric specimens are in accordance with those of 2D-CT [12], while measurements of the tibial axial torsion significantly differ from one method to the other [15].

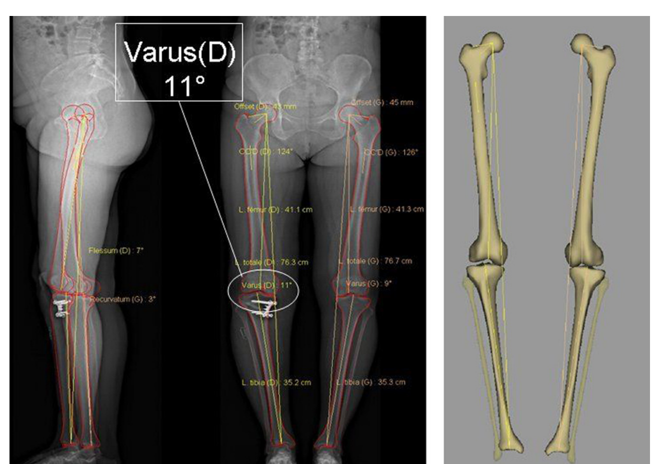

Fig. 13. 3D-EOS reformatted images of the lower limbs. On the left, full contouring (in red) of the femora and the tibiae on paired AP and lateral views. On the right, volumic resulting image. The result of the measurement of one angle has been enlarged in the caption on purpose to illustrate the type of results obtained from the drawings.

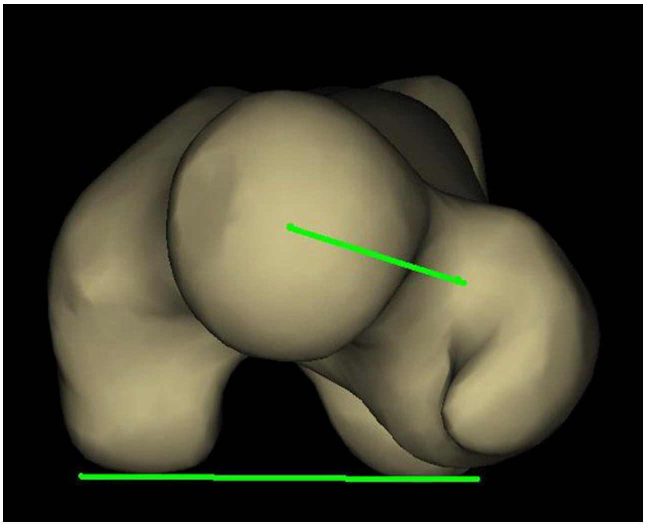

Fig. 14. 3D-EOS image of a femur, presented from above. The sterEOS[R] software automatically provides the angle value of torsion, even when no landmark is placed.

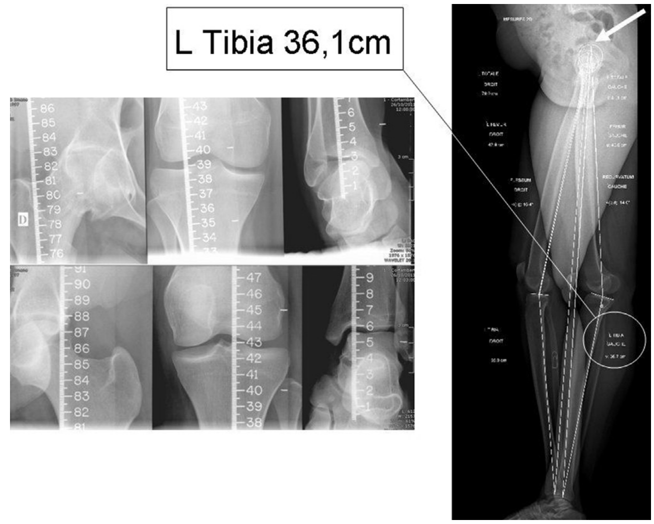

Fig. 16. Lower limbs length assessment. On the left, conventional radiographs performed with the Bell's ruler placed under the patient laying supine. On the right, 2D-EOS sagittal view, with appropriate landmarks and resulting distance values. The result of the measurement of one length has been enlarged in the caption on purpose to illustrate the type of results obtained from the drawings.

Through EOS imaging of hip arthroplasty, acetabular cup inclination and anteversion can be also assessed both in the upright and in the sitting positions and compared to the anterior pelvic plane inclination [8] (Fig. 15). Conversely, no 3D-EOS assessment of hip arthroplasty is available with the current sterEOS® software. Axial position of prosthesis components can be provided only by CT scans.

Lower limbs length is mainly assessed on 2D-EOS sagittal images, to the best of our knowledge: we found no discrepancy between 2D-EOS imaging and conventional radiographs obtained with Bell's ruler superimposition (unpublished data) (Fig. 16).

Fig. 15. 2D-EOS assessment of the acetabular cup of hip arthroplasty. The cup (arrows) position is studied frontally (left) and laterally (right) in the upright (up) and sitting (down) patient positions. (*kindly released by Alain Sautet et al.*).

4.3. Bone structure analysis

In 31 cadaveric specimens, several features, namely disc narrowing, osteophytes of vertebral plates, were found to correspond on EOS and MR images [13].

However, only rough assessment of bone and soft tissues structure may be currently expected from EOS imaging. EOS imaging sensibility to subtle changes like small areas of bone defect or sclerosis or mild joint space narrowing has not been yet studied.

5. Potential clinical indications

The wide field of view of EOS imaging should favor the assessment of polyostotic diseases with elementary lesions of sufficient size, such as fibrous dysplasia of bones, multiple exostoses disease, osteogenesis imperfecta, as well as multiple vertebral collapse.

Experimental studies of bone density found no sufficient accuracy of the EOS system [10].

6. EOS imaging limitations

Movement artifacts due to the long lasting time of acquisition may lead to the repeat of the examination, resulting in radiation dose increase.

Since there is no television to check the patient's positioning, a different frontal projection of the pelvis from one examination to the following one would induce variations in the projection of the vertebrae, therefore errors in angle values determination. More devices inside the cabin are expected, in order to ascertain and maintain the correct placement of the patient.

To avoid superimposition of the lower limbs in the lateral examination, a mild sagittal gap between feet is necessary (Fig. 17). This position may induce artificial anterior knee flessum and posterior knee recurvatum (personal unpublished data).

In case of severe scoliosis combined with osteoporosis in the elderly, contouring the vertebrae for 3D-imaging purpose may be challenging.

3D-EOS measurements may be different from those obtained in a 2D-conventional fashion, in particular in knee frontal deformation. Even if the first ones might reflect anatomy more faithfully, they have to meet the traditional 2D experience of clinicians. During

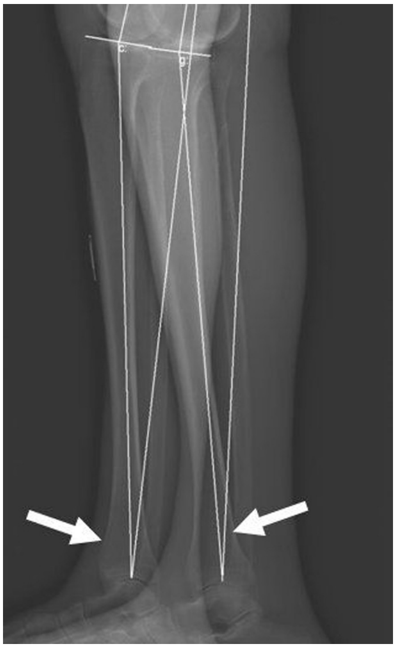

Fig. 17. Slight anterior positioning of one foot in 2D-EOS lateral image of the lower limbs.

the current transitory period of time, it is therefore still necessary to provide 2D-imaging results together with 3D-imaging ones, until a new 3D experience will take place into clinicians mind.

EOS imaging can provide no study in the supine position, which is however requested in some scoliosis pre-operative assessments.

7. Conclusion

EOS imaging is the new gold standard for the assessment of skeletal deformations, due to its multiplanar capabilities combined to the dramatic decrease in radiation dose when compared to conventional radiography or CT imaging, particularly welcome in young patients follow-up.

Further technological improvements might result in other clinical indications of EOS imaging, namely a better sensibility to skeletal structure changes.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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