EOS | A radically new vision in orthopedic imaging

Main publications about EOS And sterEOS

Summary

I. Publications

1 Key articles

The EOS SYSTEM

1.1 Evaluation of a new low-dose digital X-ray device: first dosimetric and clinical results in children. Kalifa G, Charpak Y, Maccia C, Fery-Lemonnier E, Bloch J, Boussard JM, Attal M, Dubousset J, Adamsbaum C. Pediatr Radiol. 1998

Abstract: BACKGROUND: A new low-dose digital X-ray device, based on Charpak's Nobel prize-winning multiwire chamber, enables the production of images at very low doses. Objectives. To present the first dosimetric and clinical results. MATERIALS AND METHODS: The analysis was performed on 93 children with scoliosis and 47 undergoing pelvic radiography. The comparative study between conventional X-ray and the new technique focused on three points: (1) the dose delivered by each system (2) the diagnostic information provided by each system and (3) comparison of image quality criteria with European guidelines. RESULTS: The mean ratio of conventional dose to that of the low-dose technique was 13.1 for the spinal examination and 18.8 for the pelvis. There was no significant difference in diagnostic information available from each modality, but there was a slight difference in quality criteria in favour of the conventional technique. CONCLUSION: This new device allows spectacular dose reduction, consistent with adequate clinical information. Improvements of the prototype will lead to extension of potential indications and industrial development.

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Take Away & Results : First evaluation of the Charpak system. This device will afterwards be called the EOS system. Comparing radiation dose with respect to a conventional radiography system, the Charpak system allowed a dose reduction 13.1 times lower for the spine and 18.8 times lower for the pelvis.

1.2. The EOS imaging system and its uses in daily orthopaedic practice.
Illes T, Somoskeoy S. Int Orthop2012 Feb 28.

Abstract: BACKGROUND: The EOS X-ray machine, based on a Nobel prize-winning invention in physics in the field of particle detection, is capable of a simultaneous capture of biplanar X-ray images by slot scanning of the whole body in an upright, physiological load-bearing position, using ultra-low radiation doses. The simultaneous capture of spatially calibrated anterioposterior and lateral images provides a three-dimensional (3D) surface reconstruction of the skeletal system using a special software. Parts of the skeletal system in X-ray images and 3D-reconstructed models appear in true

1:1 scale for size and volume, thus spinal and vertebral parameters, lower limb axis lengths and angles, as well as any relevant clinical parameters in orthopaedic practice can be very precisely measured and calculated. Visualisation of 3D reconstructed models in various views by sterEOS 3D software enables presentation of top view images to help analyse rotational conditions of lower limbs, joints and spine deformities in the horizontal plane, providing revolutionary novel possibilities in orthopaedic surgery, especially in spine surgery. APPROACH AND CONCLUSIONS: Our department has been extensively using the very first commercially available EOS imaging system worldwide for routine orthopaedic diagnostics since June 2007. During this period of about 4.5 years, more than 5,700 standard examinations have been carried out, about a third of them in spine deformity cases and the rest in lower limb orthopaedic cases. In this mini-review, general principles and uses of this groundbreaking integrated orthopaedic solution is reviewed with a few highlighted examples from our own clinical practice.

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Take Away & Results: General principles and uses of the EOS system is reviewed with a few highlighted examples from the site's clinical practice, based on more than 5,700 examinations.

1.3. The EOS imaging system.

Wybier M, Bossard P. Joint Bone Spine2012 Nov 21.

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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Take Away & Results: The main indications of this new imaging technology are assessment and follow-up of balance disorders of the spine and of the lower limbs.

Dose

1.4. Diagnostic imaging of spinal deformities: reducing patients radiation dose with a new slot-scanning X-ray imager.

Deschenes S, Charron G, Beaudoin G, Labelle H, Dubois J, Miron MC, Parent S. Spine (Phila Pa 1976)2010 Apr 20;35(9):989-94.

Abstract: STUDY DESIGN: Clinical trial comparing image quality and entrance dose between Biospace EOS system, a new slot-scanning radiographic device, and a Fuji FCR 7501S computed radiography (CR) system for 50 patients followed for spinal deformities. OBJECTIVE: Based on their physical properties, slot-scanners show the potential to produce image quality comparable to CR systems using less radiation. This article validates this assertion by comparing a new slot-scanner to a CR system through a wide-ranging evaluation of dose and image quality for scoliosis examinations. SUMMARY OF BACKGROUND DATA: For each patient included in this study, lateral and posteroanterior images were acquired with both systems. For each system, entrance dose was measured for different anatomic locations. METHODS: Dose and image quality being directly related, comparable images were obtained using the same radiograph tube voltage on both systems while tube currents were selected to match signal-to-noise ratios on a phantom. Different techniques were defined with respect to patient's thickness about the iliac crests. Given dose amplitudes expected for scoliosis examinations, optically stimulated luminescence dosimeters were chosen as optimal sensors. Two radiologists and 2 orthopedists evaluated the images in a randomized order using a questionnaire targeting anatomic landmarks. Visibility of the structures was rated on a 4 level scale. Image quality assessment was analyzed using a Wilcoxon signed-rank tests. RESULTS: Average skin dose was reduced from 6 to 9 times in the thoracoabdominal region when using the slot-scanner instead of CR. Moreover, image quality was significantly better with EOS for all structures in the frontal view ($P < 0.006$) and lateral view ($P < 0.04$), except for lumbar spinous processes, better seen on the CR ($P < 0.003$). CONCLUSION: We established that the EOS system offers overall enhanced image quality while reducing drastically the entrance dose for the patient.

Results & Take away : Average **skin dose was reduced from 6 to 9 times** in the thoracoabdominal region when using the slot-scanner instead of CR. Moreover, **image quality was significantly better with EOS** for all structures in the frontal view ($P < 0.006$) and lateral view ($P < 0.04$), except for lumbar spinous processes, better seen on the CR ($P < 0.003$).

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1.5. Ionizing radiation doses during lower limb torsion and anteversion measurements by EOS stereoradiography and computed tomography. Delin C, Silvera S, Bassinet C , Thelen P, Rehel JL, legmann P, Folinais D. Eur J Radiol. 2013.

Abstract: Objectives: To calculate and compare the doses of ionizing radiation delivered to the organs by computed tomography (CT) and stereoradiography (SR) during measurements of lower limb torsion and anteversion. Materials and methods:A Rando anthropomorphic phantom (Alderson RANDO phantom, Alderson Research Laboratories Inc., Stanford, Conn) was used for the dose measurements. The doses were delivered by a Somatom 16-slice CT-scanner (Siemens, Erlangen) and an EOS stereoradiography unit (EOS-Imaging, Paris) according to the manufacturers' acquisition protocols. Doses to the surface and deeper layers were calculated with thermoluminiscent GR207P dosimeters. Dose uncertainties were evaluated and assessed at 6% at k=2 (that is, two standard deviations). Results: The absorbed doses for the principal organs assessed were as follows: for the ovaries, 0.1 mGy to the right ovary and 0.5 mGy to the left ovary with SR versus1.3 mGy and 1.1 mGy with CT, respectively; testes, 0.3 mGy on the right and 0.4 mGy on the left with SR versus 8.5 mGy and 8.4 mGy with CT; knees, 0.4 mGy to the right knee and 0.8 mGy to the left knee with SR versus 11 mGy and 10.4 mGy with CT; ankles, 0.5 mGy to the right ankle and 0.8 mGy to the left with SR versus 15 mGy with CT. Conclusion: The SR system delivered substantially lower doses of ionizing radiation doses than CT to all the organs studied: CT doses were 4.1 times higher to the ovaries, 22.9 times higher for the testicles, and 13 to 30 times higher for the knees and ankles. The use of the SR system to study the torsion of lower limbs makes it possible to reduce the amount of medical irradiation that patients accumulate.

Results & Take away : The authors compare EOS vs CT radiation dose. **EOS radiation dose was lower with respect to CT: 4.1 times for ovaries, 22.9 times for testicles, 13-30 times for knees and ankles.**

1.6. Occupational and patient exposure as well as image quality for full spine examinations with the EOS imaging system. Damet J, Fournier P, Monnin P, Sans-Merce M, Ceroni D, Zand T, Verdun FR, Baechler S.. Medical physics. 2014

Abstract: EOS (EOS imaging S.A, Paris, France) is an x-ray imaging system that uses slot-scanning technology in order to optimize the trade-off between image quality and dose. The goal of this study was to characterize the EOS system in terms of occupational exposure, organ doses to patients as well as image quality for full spine examinations. METHODS: Occupational exposure was determined by measuring the ambient dose equivalents in the radiological room during a standard full spine examination. The patient dosimetry was performed using anthropomorphic phantoms representing an adolescent and a five-year-old child. The organ doses were measured with thermoluminescent detectors and then used to calculate effective doses. Patient exposure with EOS was then compared to dose levels reported for conventional radiological systems. Image quality was assessed in terms of spatial resolution and different noise contributions to evaluate the detector's performances of the system. The spatial-frequency signal transfer efficiency of the imaging system was quantified by the detective quantum efficiency (DQE).

RESULTS: The use of a protective apron when the medical staff or parents have to stand near to the cubicle in the radiological room is recommended. The estimated effective dose to patients undergoing a full spine examination with the EOS system was 290 µSv for an adult and 200 µSv for a child. MTF and NPS are nonisotropic, with higher values in the scanning direction; they are in addition energy-dependent, but scanning speed independent. The system was shown to be quantum-limited, with a maximum DQE of 13%. The relevance of the DQE for slot-scanning system has been addressed.
CONCLUSIONS: As a summary, the estimated effective dose was 290 µSv for an adult; the image quality remains comparable to conventional systems.

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Take Away & Results : EOS image quality remains comparable to conventional systems while providing lower radiation dose.

SPINE

Pediatric Spine

1.7. Adolescent idiopathic scoliosis treated with posteromedial translation: radiologic evaluation with a 3D low-dose system. Ilharreborde B, Sebag G, Skalli W, Mazda K. Eur Spine J. 2013 Apr 12.

Abstract: PURPOSE: Computed tomography can be used for three-dimensional (3D) evaluation of adolescent idiopathic scoliosis (AIS) patients, but at the expense of high radiation exposure, and with the limitation of being performed in the supine position. These drawbacks can now be avoided with low-dose stereoradiography, even in routine clinical use. The purpose of this study was to determine the 3D postoperative correction of AIS patients treated by posteromedial translation. METHODS: Forty-nine consecutive patients operated for AIS (Lenke 1-4) using posteromedial translation were included. Corrections were evaluated preoperatively, postoperatively and after at least 2 years using the EOS imaging system. 3D angles were measured in the plane of maximum deformity. RESULTS: Mean number of levels fused and operative time were 13.5 ± 1 and 215 ± 25 min, respectively. Main thoracic, proximal thoracic, and lumbar curves corrections averaged 64.4 ± 18, 31 ± 10 and 69 ± 20 %, respectively. Mean T4-T12 kyphosis increased 18.8° ± 9° in the subgroup of hypokyphotic patients. Mean apical vertebral rotation reduction was 48.3 ± 20 %. Trunk height gain averaged 27.8 ± 14 mm. There was no pseudarthrosis or significant loss of correction in any plane during follow-up. Two patients (4 %) developed asymptomatic proximal junctional kyphosis, despite having normal thoracic kyphosis. Their sagittal balance was shifted posteriorly by 36 and 47 mm, respectively, by the operation, but revision surgery was not performed. CONCLUSIONS: Low-dose stereoradiography provided 3D reconstructions of the fused and unfused spine in routine clinical use. Postoperative 3D analysis showed that posteromedial translation enhanced sagittal balance correction, without sacrificing frontal or axial correction of the deformity.

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Results & Take away : EOS allows for 3D reconstructions of the **fused and unfused spine in routine clinical use.**

1.8. Computer-Generated Three-Dimensional Spine Model From Biplanar Radiographs: A Validity Study in Idiopathic Scoliosis Curves Greater than 50 degrees.

Carreau J, Bastrom T, Petcharaporn M, Schulte C, Marks M, Illés T, Somoskëoy S, Newton P. Spine Deformity. March 2014.

Abstract: Study Design: Reproducibility study of SterEOS 3-dimensional (3D) software in large, idiopathic scoliosis (IS) spinal curves.
Objective: To determine the accuracy and reproducibility of various 3D, software-generated radiographic measurements acquired from a 2-dimensional (2D) imaging system.
Summary of Background Data: SterEOS software allows a user to reconstruct a 3D spinal model from an upright, biplanar, low-dose, X-ray system. The validity and internal consistency of this system have not been tested in large IS curves.
Methods: EOS images from 30 IS patients with curves greater than 50_ were collected for analysis. Three observers blinded to the study protocol conducted repeated, randomized, manual 2D measurements, and 3D software generated measurements from biplanar images acquired from an EOS Imaging system. Three-dimensional measurements were repeated using both the Full 3D and Fast 3D guided processes. A total of 180 (120 3D and 60 2D) sets of measurements were obtained of coronal (Cobb angle) and sagittal (T1-T12 and T4-T12 kyphosis; L1-S1 and L1-L5; and pelvic tilt, pelvic incidence, and sacral slope) parameters. Intra-class correlation coefficients were compared, as were the calculated differences in values generated by SterEOS 3D software and manual 2D measurements. The 95% confidence intervals of the mean differences in measures were calculated as an estimate of reproducibility.
Results: Average intra-class correlation coefficients were excellent: 0.97, 0.97, and 0.93 for Full 3D, Fast 3D, and 2D measures, respectively (p= .11). Measurement errors for some sagittal measures were significantly lower with the 3D techniques. Both the Full 3D and Fast 3D techniques provided consistent measurements of axial plane vertebral rotation.
Conclusions: SterEOS 3D reconstruction spine software creates reproducible measurements in all 3 planes of deformity in curves greater than 50°. Advancements in 3D scoliosis imaging are expected to improve our understanding and treatment of idiopathic scoliosis.

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Results & Take away: SterEOS 3D reconstruction spine software creates reproducible measurements in all 3 planes of deformity in large, idiopathic scoliosis curves.

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Adult Spine

1.9. Standardized way for imaging of the sagittal spinal balance. Morvan G, Mathieu P, Vuillemin V, Guerini H, Bossard P, Zeitoun F, Wybier M. Eur Spine J2011 Sep;20 Suppl 5:602-8.

Abstract: Nowadays, conventional or digitalized teleradiography remains the most commonly used tool for the study of the sagittal balance, sometimes with secondary digitalization. The irradiation given by this technique is important and the photographic results are often poor. Some radiographic tables allow the realization of digitalized spinal radiographs by simultaneous translation of X-ray tube and receptor. EOS system is a new, very low dose system which gives good quality images, permits a simultaneous acquisition of upright frontal and sagittal views, is able to cover in the same time the spine and the lower limbs and study the axial plane on 3D envelope reconstructions. In the future, this low dose system should take a great place in the study of the pelvispinal balance. On the lateral view, several pelvic (incidence, pelvic tilt, sacral slope) and spinal (lumbar lordosis, thoracic kyphosis, Th9 sagittal offset, C7 plumb line) parameters are drawn to define the pelvispinal balance. All are interdependent. Pelvic incidence is an individual anatomic characteristic that corresponds to the "thickness" of the pelvis and governs the spinal balance. Pelvis and spine, in a harmonious whole, can be compared to an accordion, more or less compressed or stretched.

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Take Away & Results : Digitalized teleradiography in standing position allows a good evaluation of the sagittal balance and is the most commonly used system today, but the EOS X-rays brought a real progress for the study of the pelvispinal balance **avoiding vertical parallax distortion** with a very **low dose of radiation**.

1.10. Breakthrough in three-dimensional scoliosis diagnosis: significance of horizontal plane view and vertebra vectors. Illes T, Tunyogi-Csapo M, Somoskeoy S. Eur Spine J2011 Jan;20(1):135-43.

Abstract: Scoliosis is a multifactorial three-dimensional (3D) spinal deformity with integral and directly related vertebral deviations in the coronal, sagittal and horizontal planes. Current classification and diagnostic methods rely on two-dimensional (2D) frontal and lateral X-ray images; no routine methods are available for the visualization and quantitative evaluation of deviations in the horizontal plane. The EOS 2D/3D system presented here is a new, low-dose, orthopedic radiodiagnostic device based on Nobel prize-winning X-ray detection technology with special software for 3D surface reconstruction capabilities that finally led to a breakthrough in scoliosis diagnosis with high-quality, realistic 3D visualization and accurate quantitative parametric analysis. A new concept introducing vertebra vectors and vertebra vector parametric calculations is introduced that furnishes simplified visual and intelligible mathematical information facilitating interpretation of EOS 2D/3D data, especially with regard to the horizontal

plane top view images. The concept is demonstrated by a reported scoliotic case that was readily characterized through information derived from vertebra vectors alone, supplemented with the current angulation measurement methods in the coronal and sagittal planes and axial vertebral rotation measurements in the horizontal plane, with a calibrated 3D coordinate system suitable for inter-individual comparisons. The new concept of vertebra vectors may serve as a basis for a truly 3D classification of scoliosis.

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Results & Take away : Vertebra vectors afford a simple, intelligible means visualizing and describing the essential features of the information provided by the EOS 2D/3D system concerning the scoliotic spine. The vertebra vector concept provides a solid basis for a truly 3D scoliosis classification

1.11. Evidence showing the relationship between sagittal balance and clinical outcomes in surgical treatment of degenerative spinal diseases: a literature review. Le Huec JC, Faundez A, Dominguez D, Hoffmeyer P, Aunoble S. Int Orthop. 2014.

Abstract: Study Design: Reproducibility study of SterEOS 3-dimensional (3D) software in large, idiopathic scoliosis (IS) spinal curves.
Objective: To determine the accuracy and reproducibility of various 3D, software-generated radiographic measurements acquired from a 2-dimensional (2D) imaging system.
Summary of Background Data: SterEOS software allows a user to reconstruct a 3D spinal model from an upright, biplanar, low-dose, X-ray system. The validity and internal consistency of this system have not been tested in large IS curves.
Methods: EOS images from 30 IS patients with curves greater than 50_ were collected for analysis. Three observers blinded to the study protocol conducted repeated, randomized, manual 2D measurements, and 3D software generated measurements from biplanar images acquired from an EOS Imaging system. Three-dimensional measurements were repeated using both the Full 3D and Fast 3D guided processes. A total of 180 (120 3D and 60 2D) sets of measurements were obtained of coronal (Cobb angle) and sagittal (T1-T12 and T4-T12 kyphosis; L1-S1 and L1-L5; and pelvic tilt, pelvic incidence, and sacral slope) parameters. Intra-class correlation coefficients were compared, as were the calculated differences in values generated by SterEOS 3D software and manual 2D measurements. The 95% confidence intervals of the mean differences in measures were calculated as an estimate of reproducibility.
Results: Average intra-class correlation coefficients were excellent: 0.97, 0.97, and 0.93 for Full 3D, Fast 3D, and 2D measures, respectively (p= .11). Measurement errors for some sagittal measures were significantly lower with the 3D techniques. Both the Full 3D and Fast 3D techniques provided consistent measurements of axial plane vertebral rotation.
Conclusions: SterEOS 3D reconstruction spine software creates reproducible measurements in all 3 planes of deformity in curves greater than 50°. Advancements in

3D scoliosis imaging are expected to improve our understanding and treatment of idiopathic scoliosis.

Results & Take away: Clinical evidence show that measurement of sagittal balance parameters is correlated to clinical outcomes.

Lower limbs (hip, knee and ankle)

1.12. Femoral and Tibial Torsion Measurements With 3D Models Based on Low-Dose Biplanar Radiographs in Comparison With Standard CT Measurements.

Buck FM, Guggenberger R, Koch PP, Pfirrmann CW. AJR Am J Roentgenol2012 Nov;199(5):W607-12.

Abstract : OBJECTIVE: The purpose of this study was to evaluate the interchangeability of femoral and tibial torsion measurements obtained with 3D models based on low-dose biplanar radiographs and standard CT measurements by testing the following two hypotheses: that there is excellent agreement between the two methods and that there is excellent interreader agreement. MATERIALS AND METHODS: Two independent readers used 3D models based on low-dose simultaneous biplanar radiographs and axial CT images to measure femoral and tibial torsion in 35 patients (mean age, 65 years; range, 46-89 years) with osteoarthritis of the knee who were to undergo prosthesis insertion. The two measurements were compared by means of Bland-Altman plots and descriptive statistics. Interreader agreement was quantified with intraclass correlation coefficients. RESULTS: The average differences between readers on the CT measurements were 1.3 degrees (range, 0 degrees -11 degrees) for the femur and 1.5 degrees (range, 0 degrees -12 degrees) for the tibia. The average differences for the measurements obtained with the 3D model were 0.1 degrees (range, 0 degrees -9 degrees) for the femur and 0.8 degrees (range, 0 degrees -10 degrees) for the tibia. The average differences between the two methods were 0 degrees (range, -5 degrees to 7 degrees) for the femoral measurements and 3 degrees (range, -12 degrees to 5 degrees) for the tibial measurements. Bland-Altman plots showed no relevant differences between the results of the two measurement modalities. Except for one measurement of femoral torsion and one measurement of tibial torsion, all results based on the 3D models were within the 95% limit of agreement (mean +/- 1.96 SD). Interreader agreement was statistically significant ($p < 0.001$) for all measurements with high intraclass correlation coefficients (> 0.9). CONCLUSION: Femoral and tibial torsion measurements obtained with 3D models based on biplanar radiographs are interchangeable with standard CT measurements in patients with osteoarthritis of the knee.

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Results & Take away : Femoral and tibial torsion measurements obtained with 3D models based on biplanar radiographs are **interchangeable** with standard CT measurements.

1.13. Measuring femoral and rotational alignment: EOS system versus computed tomography.

Folinais D, Thelen P, Delin C, Radier C, Catonne Y, Lazennec JY. Orthop Traumatol Surg Res2013 Jul 19.

Abstract: INTRODUCTION: Computed tomography (CT) is currently the reference standard for measuring femoral and tibial rotational alignment. The EOS System is a new biplanar low-dose radio-graphic device that allows 3-dimensional lower-limb modelling with automated measurements of femoral and tibial rotational alignment (torsion). HYPOTHESIS: Femoral and tibial torsion measurements provided by the EOS System are equivalent to those obtained using CT. MATERIALS AND METHODS: In a retrospective analysis of 43 lower limbs in 30 patients, three senior radiologists measured femoral and tibial torsion on both CT and EOS images. Agreement between CT and EOS values was assessed by computing Pearson's correlation coefficient and interobserver reproducibility by computing the intraclass correlation coefficient (ICC). RESULTS: Femoral torsion was 13.4◦by EOS vs. 13.7◦by CT (P = 0.5) and tibial torsion was 30.8◦ by EOS vs. 30.3◦ by CT (P = 0.4). Strong associations were found between EOS and CT values for both femoral torsion (P = 0.93) and tibial torsion (P = 0.89). With EOS, the ICC was 0.93 for femoral torsion and 0.86 for tibial torsion; corresponding values with CT were 0.90 and 0.92. DISCUSSION: The EOS system is a valid alternative to CT for lower-limb torsion measurement. EOS imaging allows a comprehensive evaluation in all three planes while substantially decreasing patient radiation exposure.

Link to Pubmed

Results & Take away : The EOS system is a **valid alternative to CT for lower-limb torsion measurement,** while decreasing patient radiation exposure.

1.14. Three-dimensional measurements of the lower extremity in children and adolescents using a low-dose biplanar X-ray device.

Gheno R, Nectoux E, Herbaux B, Baldisserotto M, Glock L, Cotten A, Boutry N. Eur Radiol2011 Oct 20.

Abstract: OBJECTIVE: To evaluate three-dimensional (3D) measurements of the lower extremity using a biplanar low-dose X-ray device in children and adolescents. METHODS: Firstly, 3D measurements of eight dried bones were analysed by a biplanar low-dose X-ray device (LDX) using stereoscopic software and compared with 3D computed tomography (CT). Secondly, 47 lower limbs of children and adolescents were studied using LDX two-dimensional (2D) and 3D measurements. Both parts were evaluated for femoral and tibial lengths and mechanical angles, frontal and lateral knee angulations, and the femoral neck-shaft angle. between LDX and CT measurements showed no significant differences: femoral length (P = 0.069), tibial length (P = 0.059), femoral mechanical angle (P = 0.475), tibial mechanical angle (P = 0.067), frontal knee angulation (P = 0.198), lateral knee angulation (P = 0.646) and femoral neck-shaft angle (P = 0.068). The comparison between LDX 2D and 3D measurements showed significant differences in tibial length (P = 0.003), femoral mechanical angle (P ‹ 0.001) and femoral neck-shaft angle (P = 0.001); other parameters were unremarkable. CONCLUSIONS: The 3D LDX system presented reliable measurements compared with 3D CT. Differences between LDX 2D and 3D measurements were noted in the femoral mechanical angle,

femoral neck-shaft angle and tibial length. Moderate to good interobserver agreement for the 3D LDX measurements were found. potential lower extremity discrepancies discrepancies in children/adolescents prevalent practice LDX measurements carry good overall interobserver agreement.

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Take Away & Results : Low radiation dose is essential when assessing potential lower extremity discrepancies. A new biplanar low-dose X-ray device can assess such discrepancies in children/adolescents. This LDX device provides equally reliable 3D measurements as prevalent practice LDX measurements and carry good overall interobserver agreement.

1.15. EOS low-dose radiography: a reliable and accurate upright assessment of lower-limb lengths. Escott BG, Ravi B, Weathermon AC, Acharya J, Gordon CL, Babyn PS, Kelley SP, Narayanan UG. J Bone Joint Surg Am. 2013 Dec.

Abstract: BACKGROUND: Children with lower-limb-length discrepancy require repeated radiographic assessment for monitoring and as a guide for management. The need for accurate assessment of length and alignment is balanced by the need to minimize radiation exposure. We compared the accuracy, reliability, and radiation dose of EOS, a novel low-dose upright biplanar radiographic imaging system, at two different settings, with that of conventional radiographs (teleoroentgenograms) and computed tomography (CT) scanograms, for the assessment of limb length.

METHODS: A phantom limb in a standardized position was assessed ten times with each of four different imaging modalities (conventional radiographs, CT scanograms, EOS-Slow, EOS-Fast). A radiation dosimeter was placed on the phantom limb, on a portion closest to the radiation source for each modality, in order to measure skin-entrance radiation dose. Standardized measurements of bone lengths were made on each image by consultant orthopaedic surgeons and residents and then were assessed for accuracy and reliability.

RESULTS: The mean absolute difference from the true length of the femur was significantly lower (most accurate) for the EOS-Slow (2.6 mm; 0.5%) and EOS-Fast (3.6 mm; 0.8%) protocols as compared with CT scanograms (6.3 mm; 1.3%) ($p < 0.0001$), and conventional radiographs (42.2 mm; 8.8%) ($p < 0.0001$). There was no significant difference in accuracy between the EOS-Slow and EOS-Fast protocols ($p = 0.48$). The mean radiation dose was significantly lower for the EOS-Fast protocol (0.68 mrad; 95% confidence interval [CI], 0.60 to 0.75 mrad) compared with the EOS-Slow protocol (13.52 mrad; 95% CI, 13.45 to 13.60 mrad) ($p < 0.0001$), CT scanograms (3.74 mrad; 95% CI, 3.67 to 3.82 mrad) ($p < 0.0001$), and conventional radiographs (29.01 mrad; 95% CI, 28.94 to 29.09 mrad) ($p < 0.0001$). Intraclass correlation coefficients showed excellent

(>0.90) agreement for conventional radiographs, the EOS-Slow protocol, and the EOS-Fast protocol.
CONCLUSIONS: Upright EOS protocols that utilize a faster speed and lower current are more accurate than CT scanograms and conventional radiographs for the assessment of length and also are associated with a significantly lower radiation exposure. In addition, the ability of this technology to obtain images while subjects are standing upright makes this the ideal modality with which to assess limb alignment in the weight-bearing position. This method has the potential to become the new standard for repeated assessment of lower-limb lengths and alignment in growing children.
CLINICAL RELEVANCE: This study assesses the reliability and accuracy of a diagnostic test used for clinical decision-making.

Link to Pubmed

Take Away & Results: Upright EOS protocols that utilize a faster speed and lower current are more accurate than CT scanograms and conventional radiographs for the assessment of length and also are associated with a significantly lower radiation exposure.

1.16. Offset and anteversion reconstruction after cemented and uncemented total hip arthroplasty: an evaluation with the low-dose EOS system comparing two- and three-dimensional imaging. Lazennec JY, Brusson A, Folinais D, Rousseau M, Pour AE. Int Orthop Dec 2014.

Abstract: Accurate evaluation of femoral offset is difficult with conventional anteroposterior (AP) X-rays. The EOS imaging system is a system that makes the acquisition of simultaneous and orthogonal AP and lateral images of the patient in the standing position possible. These two-dimensional (2D) images are equivalent to standard plane X-rays. Three-dimensional (3D) reconstructions are obtained from these paired images according to a validated protocol. This prospective study explores the value of the EOS imaging system for comparing measurements of femoral offset from these 2D images and the 3D reconstructions. METHODS: We included 110 patients with unilateral total hip arthroplasty (THA). The 2D offset was measured on the AP view with the same protocol as for standard X-rays. The 3D offset was calculated from the reconstructions based on the orthogonal AP and lateral views. Reproducibility and repeatability studies were conducted for each measurement. We compared the 2D and 3D offset for both hips (with and without THA). RESULTS: For the global series (110 hips with and 110 without THA), 2D offset was 40 mm (SD 7.3; 7-57 mm). The standard deviation was 6.5 mm for repeatability and 7.5 mm for reproducibility. Three-dimensional offset was 43 mm (SD 6.6; 22-62 mm), with a standard deviation of 4.6 for repeatability and 5.5 for reproducibility. Two-dimensional offset for the hips without THA was 40 mm (SD 7.0; 26-56 mm), and 3D offset 43 mm (SD 6.6; 28-62 mm). For THA side, 2D offset was 41 mm (SD 8.2; 7-57 mm) and 3D offset 45 mm (SD 4.8; 22-61 mm). Comparison of the two protocols shows a significant difference between the 2D and 3D measurements, with the 3D offset having higher values. Comparison of the side with and without surgery

for each case showed a 5-mm deficit for the offset in 35 % of the patients according to the 2D measurement but in only 26 % according to the 3D calculation. CONCLUSIONS: This study points out the limitations of 2D measurements of femoral offset on standard plane X-rays. The reliability of the EOS 3D models has been previously demonstrated with CT scan reconstructions as a reference. The EOS imaging system could be an option for obtaining accurate and reliable offset measurements while significantly limiting the patient's exposure to radiation.

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Take Away & Results: This study points out the limitations of 2D measurements of femoral offset on standard plane X-rays. The EOS imaging system could be an option for obtaining accurate and reliable offset measurements while significantly limiting the patient's exposure to radiation.

Workflow

1.17. Comparison of radiation dose, workflow, patient comfort and financial break-even of standard digital radiography and a novel biplanar low-dose X-ray system for upright full-length lower limb and whole spine radiography. Dietrich TJ, Pfirrmann CW, Schwab A, Pankalla K, Buck FM. Skeletal Radiol. 2013.

Abstract: OBJECTIVE: To compare the radiation dose, workflow, patient comfort, and financial break-even of a standard digital radiography and a biplanar low-dose X-ray system. MATERIALS AND METHODS: A standard digital radiography system (Ysio, Siemens Healthcare, Erlangen, Germany) was compared with a biplanar X-ray unit (EOS, EOS imaging, Paris, France) consisting of two X-ray tubes and slot-scanning detectors, arranged at an angle of 90° allowing simultaneous vertical biplanar linear scanning in the upright patient position. We compared data of standing full-length lower limb radiographs and whole spine radiographs of both X-ray systems. RESULTS: Dose-area product was significantly lower for radiographs of the biplanar X-ray system than for the standard digital radiography system (e.g. whole spine radiographs; standard digital radiography system: 392.2 ± 231.7 cGy*cm2 versus biplanar X-ray system: 158.4 ± 103.8 cGy*cm2). The mean examination time was significantly shorter for biplanar radiographs compared with standard digital radiographs (e.g. whole spine radiographs: 449 s vs 248 s). Patients' comfort regarding noise was significantly higher for the standard digital radiography system. The financial break-even point was 2,602 radiographs/year for the standard digital radiography system compared with 4,077 radiographs/year for the biplanar X-ray unit. CONCLUSION: The biplanar X-ray unit reduces radiation exposure and increases subjective noise exposure to patients. The biplanar X-ray unit demands a higher number of examinations per year for the financial break-even point, despite the lower labour cost per examination due to the shorter examination time.

Link to Pubmed

Take Away & Results : EOS allows an **over 2 x dose reduction with an acquisition time divided** by two for full spine and lower limb examinations when compared to DR.

2 More about pediatric spine

2.1 Three dimensional analysis of brace biomechanical efficacy for patients with AIS.

Lebel DE, Al-Aubaidi Z, Shin EJ, Howard A, Zeller R. Eur Spine J. 2013 Jul 20.

Abstract: PURPOSE: Corrective three dimensional (3D) effect of different braces is debatable. We evaluated differences in in-brace radiographic correction comparing a custom thoracic-lumbo-sacral-orthosis (TLSO) (T) brace to a Chêneau type TLSO (C) brace using 3D EOS reconstruction technology. Our primary research question was the 3D effect of brace on the spine and in particularly the apical vertebra rotation (AVR). METHODS: This was a retrospective comparative analysis of patients with adolescent idiopathic scoliosis who had orthogonal AP and lateral X-rays with and without brace. A 3D image of the spine was reconstructed. Coronal, sagittal and axial spine parameters were measured before bracing and then on the first post-brace X-ray. Brace efficacy in controlling coronal, sagittal and axial parameters was evaluated. RESULTS: Eighteen patients treated with the C brace and ten patients treated with the T brace were included. No difference was found regarding patients' age, gender, magnitude of Cobb angle, sagittal parameters or AVR at inclusion. Following bracing, AVR was significantly reduced by the C brace compared to the T brace [average correction of 8.2° vs. 4.9° (P = 0.02)]. Coronal and sagittal correction did not differ significantly between the two groups. CONCLUSIONS: By utilizing a novel 3D reconstruction technology, we were able to demonstrate that braces differ in their immediate effects on the spine. Although clinical relevance should be evaluated in a future trial we feel that the ability to measure treatment effects in 3D, and especially the transverse plane, is an important tool when evaluating different treatments.

Link to Pubmed

Results & Take away : By **using the 3D reconstructions provided by SterEOS** it has been demonstrated that **braces differ in their immediate effects on the spine**.

2.2 Comparison of 3D Spinal Reconstruction Accuracy: Biplanar Radiographs with EOS Versus Computed Tomography.

Glaser DA, Doan J, Newton PO. Spine (Phila Pa 1976)2012 Mar 13.

Abstract: STRUCTURED ABSTRACT: Study Design. Experimental study for systematic evaluation of 3D reconstructions from low-dose digital stereoradiography.Objectives. To assess the accuracy of EOS 3-dimensional (3D) reconstructions compared to 3D

computed tomography (CT) and the effect spine positioning within the EOS unit has on reconstruction accuracy.Summary of Background Data. Scoliosis is a 3D deformity, but 3D morphological analyses are still rare. A new low-dose radiation digital stereoradiography system (EOS) was previously evaluated for intra/interobserver variability, but data are limited for 3D reconstruction accuracy.Methods. Three synthetic scoliotic phantoms (T1-pelvis) were scanned in upright position at 0, +/-5, and +/-10deg of axial rotation within EOS and in supine position using CT. 3D EOS reconstructions were superimposed on corresponding 3D CT reconstructions. Shape, position and orientation accuracy were assessed for each vertebra and the entire spine. Additional routine planer clinical deformity measurements were compared: Cobb angle, kyphosis, lordosis, and pelvic incidence.Results. Mean EOS vertebral body shape accuracy was 1.1+/-0.2 mm (max 4.7mm) with 95%CI of 1.7mm. Different anatomical vertebral regions were modeled well with root mean square(RMS) values from 1.2 to 1.6 mm. Position and orientation accuracy of each vertebrae were high: RMS offset was 1.2 mm (max 3.7 mm) and RMS axial rotation was 1.9deg (max 5.8deg). There was no significant difference in each of the analyzed parameters (p›0.05) associated with varying the rotational position of the phantoms in EOS machine. Planer measurements accuracy was ‹1deg mean difference for pelvic incidence, Cobb angle (mean 1.6deg/max 3.9deg) and sagittal kyphois (mean ‹1deg, max 4.9deg).Conclusions. The EOS image acquisition and reconstruction software provide accurate 3D spinal representations of scoliotic spinal deformities. The results of this study provide spinal deformity surgeons evidence pertaining to this new upright 3D imaging technology that may aid in the clinical diagnosis and decision making of patients with scoliosis.

Link to Pubmed

Results & Take away: Mean EOS vertebral body shape accuracy is 1.1+/-0.2 mm with 95%CI of 1.7mm. Different anatomical vertebral regions are modeled well with root mean square (RMS) values from 1.2 to 1.6 mm. The results of this study provide spinal deformity surgeons evidence pertaining to this new upright 3D imaging technology that may aid in the clinical diagnosis and decision making of patients with scoliosis.

2.3 Angle measurement reproducibility using EOS three-dimensional reconstructions in adolescent idiopathic scoliosis treated by posterior instrumentation.

Ilharreborde B, Steffen JS, Nectoux E, Vital JM, Mazda K, Skalli W, Obeid I. Spine (Phila Pa 1976)2011 Sep 15;36(20):E1306-13.

Abstract: STUDY DESIGN: A reproducibility study was conducted in preoperative and postoperative three-dimensional (3D) measurements for patients operated for adolescent idiopathic scoliosis (AIS). OBJECTIVE: To assess the reliability of preoperative and postoperative 3D reconstructions using EOS in patients operated for AIS. SUMMARY OF BACKGROUND DATA: No prior reliability study of 3D measurements has been performed in the literature for severe scoliosis and for operated patients. METHODS: This series included 24 patients (62 degrees +/- 11) operated for Lenke 1 or 2 AIS, using either all-pedicle screw constructs (group 1) or hybrid constructs, with universal clamps at thoracic levels (group 2). All patients underwent low-dose standing biplanar radiographs,

pre- and postoperatively. Three operators performed the 3D reconstruction process two times preoperatively and two times postoperatively (total 288 reconstructions). Intraoperator repeatability and interoperator reproducibility were calculated and compared between groups. RESULTS: The preoperative reproducibility was between 4 degrees and 6.5 degrees for parameters dedicated to scoliosis (Cobb and apical vertebral rotation), between 4 degrees and 7 degrees for kyphosis and lordosis values, and between 1 degrees and 5 degrees for pelvic measurements. The postoperative reproducibility was between 5 degrees and 8 degrees for values of kyphosis and lordosis, between 1 degrees and 5.5 degrees for pelvic parameters, and between 6.5 degrees and 10.5 degrees for the scoliotic parameters. The reproducibility of the scoliotic parameters was slightly better in the hybrid construct group, but the difference was not significant (P = 0.8). No difference was found between groups for the other parameters. CONCLUSION: 3D postoperative reconstructions are as reproducible as preoperative ones. The reproducibility is not influenced by the type of implant used for correction. Mean difference between operator was higher than previously reported for the apical rotation measurement, but this difference can be explained by the severity of the curves and the lower visibility of the anatomical landmarks due to the implants.

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Take Away & Results : 3D postoperative reconstructions are as reproducible as preoperative ones. The reproducibility is not influenced by the type of implant used for correction. Mean difference between operator was higher than previously reported for the apical rotation measurement, but this difference can be explained by the severity of the curves, and the lower visibility of the anatomical landmarks due to the implants.

2.4 Idiopathic scoliosis in children and adolescents: assessment with a biplanar x-ray device. Amzallag-Bellenger E, Uyttenhove F, Nectoux E, Moraux A, Bigot J, Herbaux B, Boutry N. Insights Imaging. 2014 Sep 13.

Abstract: Idiopathic scoliosis is one of the most common conditions encountered in paediatric practice. It is a three-dimensional (3D) spinal deformity. Conventional radiography is still the modality of choice for evaluation of children and adolescents with idiopathic scoliosis, but it requires repeat radiographs until skeletal maturity is reached and does not provide information about spinal deformity in all three planes. A biplanar X-ray device is a new technique that enables standing frontal and lateral radiographs of the spine to be obtained at lowered radiation doses. With its specific software, this novel vertical biplanar X-ray unit provides 3D images of the spine and offers the opportunity of visualising the spinal deformity in all three planes. This pictorial review presents our experience with this new imaging system in children and adolescents with idiopathic scoliosis.

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Results & Take away: Radiography plays a pivotal role in the evaluation of children and adolescents with idiopathic scoliosis. However, it is limited to 2D measurements of frontal and sagittal spinal curves, and regular follow-up until skeletal maturity requires repeated X-ray exposure. **The EOS 2D/3D system** is a biplanar X-ray system that appeared in 2005 **to overcome these drawbacks**.

3 More about adult spine

3.1 Accuracy and reliability of coronal and sagittal spinal curvature data based on patient-specific three-dimensional models created by the EOS 2D/3D imaging system. Somoskeoy S, Tunyogi-Csapo M, Bogyo C, Illes T. Spine J2012 Oct 23.

Abstract : BACKGROUND CONTEXT: Three-dimensional (3D) deformations of the spine are predominantly characterized by two-dimensional (2D) angulation measurements in coronal and sagittal planes, using anteroposterior and lateral X-ray images. For coronal curves, a method originally described by Cobb and for sagittal curves a modified Cobb method are most widely used in practice, and these methods have been shown to exhibit good-to-excellent reliability and reproducibility, carried out either manually or by computer-based tools. Recently, an ultralow radiation dose-integrated radioimaging solution was introduced with special software for realistic 3D visualization and parametric characterization of the spinal column. PURPOSE: Comparison of accuracy, correlation of measurement values, intraobserver and interrater reliability of methods by conventional manual 2D and sterEOS 3D measurements in a routine clinical setting. STUDY DESIGN/SETTING: Retrospective nonrandomized study of diagnostic X-ray images created as part of a routine clinical protocol of eligible patients examined at our clinic during a 30-month period between July 2007 and December 2009. PATIENT SAMPLE: In total, 201 individuals (170 females, 31 males; mean age, 19.88 years) including 10 healthy athletes with normal spine and patients with adolescent idiopathic scoliosis (175 cases), adult degenerative scoliosis (11 cases), and Scheuermann hyperkyphosis (5 cases). Overall range of coronal curves was between 2.4 degrees and 117.5 degrees . Analysis of accuracy and reliability of measurements were carried out on a group of all patients and in subgroups based on coronal plane deviation: 0 degrees to 10 degrees (Group 1, n=36), 10 degrees to 25 degrees (Group 2, n=25), 25 degrees to 50 degrees (Group 3, n=69), 50 degrees to 75 degrees (Group 4, n=49), and more than 75 degrees (Group 5, n=22). METHODS: Coronal and sagittal curvature measurements were determined by three experienced examiners, using either traditional 2D methods or automatic measurements based on sterEOS 3D reconstructions. Manual measurements were performed three times, and sterEOS 3D reconstructions and automatic measurements were performed two times by each examiner. Means comparison t test, Pearson bivariate correlation analysis, reliability analysis by intraclass correlation coefficients for intraobserver reproducibility and interrater reliability were performed using SPSS v16.0 software (IBM Corp., Armonk, NY, USA). No funds were received in support of this work. No benefits in any form have been or will be received from a

commercial party related directly or indirectly to the subject of this article. RESULTS: In comparison with manual 2D methods, only small and nonsignificant differences were detectable in sterEOS 3D-based curvature data. Intraobserver reliability was excellent for both methods, and interrater reproducibility was consistently higher for sterEOS 3D methods that was found to be unaffected by the magnitude of coronal curves or sagittal plane deviations. CONCLUSIONS: This is the first clinical report on EOS 2D/3D system (EOS Imaging, Paris, France) and its sterEOS 3D software, documenting an excellent capability for accurate, reliable, and reproducible spinal curvature measurements.

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Results & Take away : When compared to conventional 2D measurements, **interrater reproducibility of sterEOS 3D modeling was consistently higher**. 3D parameters were found to be **unaffected** by the magnitude of coronal curves or sagittal plane deviations.

3.2 Sagittal alignment of the cervical spine in adolescent idiopathic scoliosis treated by posteromedial translation. Ilharreborde B, Vidal C, Skalli W, Mazda K. Eur Spine J2012 Sep 11.

Abstract: PURPOSE: To analyze postoperative changes in the cervical sagittal alignment (CSA) of patients with AIS treated by posteromedial translation. METHODS: 49 patients with thoracic AIS underwent posterior arthrodesis with hybrid constructs, combining lumbar pedicle screws and thoracic universal clamps. Posteromedial translation was the main correction technique used. 3D radiological parameters were measured from low-dose biplanar radiographs. CSA was assessed using the C2C6 angle, and the central hip vertical axis (CHVA) was used as a reference axis to evaluate patients' balance. RESULTS: Preoperatively, 58 % of patients had thoracic hypokyphosis, and 79 % had a kyphotic CSA. Significant correlation was found (r = 0.45, P = 0.01) between thoracic hypokyphosis and cervical kyphosis. Increase in T4-T12 thoracic kyphosis (average 14.5 degrees +/- 10 degrees) was associated with significant decrease in cervical kyphosis in the early postoperative period. The CSA further improved spontaneously during follow-up by 7.6 degrees (P ‹ 0.0001). Significant positive correlation (r = 0.32, P = 0.03) was found between thoracic and cervical improvements. At latest follow-up, 94 % of the patients were normokyphotic and 67 % had a CSA in the physiological range. Sagittal balance of the thoracolumbar spine was not significantly modified postoperatively. However, the procedure significantly changed the position of C2 in regard to the CHVA (C2-CHVA), which reflects headposition (P = 0.012). At last follow-up, the patients sagittal imbalance was not significantly different from the preoperative imbalance (P = 0.34). CONCLUSIONS: Thoracic hypokyphosis and cervical hypolordosis, observed in AIS, can be improved postoperatively, when the posteromedial translation technique is used for correction. The cervical spine remains adaptable in most patients, but the proportion of patients with physiological cervical lordosis at final follow-up remained low (24.5 %).

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Results & Take away : Because of its ability to perform a **complete evaluation of spinal alignment before and after surgery**, EOS showed that thoracic hypokyphosis and cervical hypolordosis, observed in AIS, can be improved postoperatively, when the posteromedial translation technique is used for correction.

3.3 3D reconstruction of the spine from biplanar X-rays using parametric models based on transversal and longitudinal inferences. Humbert L, De Guise JA, Aubert B, Godbout B, Skalli W. Med Eng Phys2009 Jul;31(6):681-7.

Abstract: Reconstruction methods from biplanar X-rays provide 3D analysis of spinal deformities for patients in standing position with a low radiation dose. However, such methods require an important reconstruction time and there is a clinical need for fast and accurate techniques. This study proposes and evaluates a novel reconstruction method of the spine from biplanar X-rays. The approach uses parametric models based on longitudinal and transversal inferences. A first reconstruction level, dedicated to routine clinical use, allows to get a fast estimate (reconstruction time: 2 min 30 s) of the 3D reconstruction and accurate clinical measurements. The clinical measurements precision (evaluated on asymptomatic subjects, moderate and severe scolioses) was between 1.2 degrees and 5.6 degrees. For a more accurate 3D reconstruction (complex pathologies or research purposes), a second reconstruction level can be obtained within a reduced reconstruction time (10 min) with a fine adjustment of the 3D models. The mean shape accuracy in comparison with CT-scan was 1.0 mm. The 3D reconstruction method precision was 1.8mm for the vertebrae position and between 2.3 degrees and 3.9 degrees for the orientation. With a reduced reconstruction time, an improved accuracy and precision and a method proposing two reconstruction levels, this approach is efficient for both clinical routine uses and research purposes.

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Results & Take away : With a **reduced reconstruction time**, an **improved accuracy and precision** and a method proposing two reconstruction levels, this approach is **efficient for both clinical routine uses and research purposes**.

4 More about lower limbs (hip, knee and ankle)

4.1 Three-dimensional hindfoot alignment measurements based on biplanar radiographs: comparison with standard radiographic measurements. Sutter R, Pfirrmann CW, Espinosa N, Buck FM. Skeletal Radiol2012 Nov 20.

Abstract : OBJECTIVE: To establish a hindfoot alignment measurement technique based on low-dose biplanar radiographs and compare with hindfoot alignment measurements on long axial view radiographs, which is the current reference standard. MATERIALS AND

METHODS: Long axial view radiographs and low-dose biplanar radiographs of a phantom consisting of a human foot skeleton embedded in acrylic glass (phantom A) and a plastic model of a human foot in three different hindfoot positions (phantoms B1-B3) were imaged in different foot positions (20 degrees internal to 20 degrees external rotation). Two independent readers measured hindfoot alignment on long axial view radiographs and performed 3D hindfoot alignment measurements based on biplanar radiographs on two different occasions. Time for three-dimensional (3D) measurements was determined. Intraclass correlation coefficients (ICC) were calculated. RESULTS: Hindfoot alignment measurements on long axial view radiographs were characterized by a large positional variation, with a range of 14 degrees /13 degrees valgus to 22 degrees /27 degrees varus (reader 1/2 for phantom A), whereas the range of 3D hindfoot alignment measurements was 7.3 degrees /6.0 degrees to 9.0 degrees /10.5 degrees varus (reader 1/2 for phantom A), with a mean and standard deviation of 8.1 degrees +/- 0.6/8.7 degrees +/- 1.4 respectively. Interobserver agreement was high (ICC = 0.926 for phantom A, and ICC = 0.886 for phantoms B1-B3), and agreement between different readouts was high (ICC = 0.895-0.995 for reader 1, and ICC = 0.987-0.994 for reader 2) for 3D measurements. Mean duration of 3D measurements was 84 +/- 15/113 +/- 15 s for reader 1/2. CONCLUSION: Three-dimensional hindfoot alignment measurements based on biplanar radiographs were independent of foot positioning during image acquisition and reader independent. In this phantom study, the 3D measurements were substantially more precise than the standard radiographic measurements.

Link to Pubmed

Results & Take away : Three-dimensional hindfoot alignment measurements based on biplanar radiographs were **independent of foot positioning** during image acquisition and **reader independent.**

4.2 New method for measuring acetabular component positioning with EOS imaging: feasibility study on dry bone. Journe A, Sadaka J, Belicourt C, Sautet A. Int Orthop2012 Sep 5.

Abstract: PURPOSE: Malposition of the acetabular cup is the most common cause of total hip arthroplasty (THA) dislocation. The position of a total hip implant is usually analysed on computed tomography (CT) scan. We aim to prove it is possible to measure, with good accuracy, the position of an acetabular cup using the low-dose irradiation (EOS) imaging. MATERIAL AND METHODS: We implanted an acetabular cup in a pelvic dry bone and easured cup anteversion and inclination with scanography. We performed 14 series of EOS acquisitions with different inclination, rotation and pelvic tilt, which were analysed by five observers. Two observers repeated angle measurements. We then calculated measurement inter- and intrareproducibility and accuracy. RESULTS: Using a confidence interval (CI) of 95 %, inter- and intra-observer reproducibility were ±1.6, and ±1.4°, respectively, for cup inclination; accuracy in comparison with CT was ±2.6°. Using a 95 % CI, inter- and intra-observer reproducibility for cup anteversion were ±2.5° and ±2.3°, respectively. Measurement accuracy compared with CT was ±3.9°. CONCLUSION: EOS

imaging system is superior to standard radiography in terms of measuring acetabular anteversion and inclination.

Link to Pubmed

Take Away & Results : EOS imaging system is **superior to standard radiography** in terms of measuring acetabular anteversion and inclination.

4.3 Reliability of a new method for lower-extremity measurements based on stereoradiographic three-dimensional reconstruction. Guenoun B, Zadegan F, Aim F, Hannouche D, Nizard R. Orthop Traumatol Surg Res2012 Jul 31.

Abstract : INTRODUCTION : Several clinical and radiological techniques have been described to assess lower limb length and angle measurements. None of them has yet met the ideal criteria for a reliable, reproducible, safe, and inexpensive system. In this context, a new biplanar X-ray system (EOS™, EOS imaging, Paris, France) makes it possible to obtain a 3D reconstruction of the lower extremities from two 2D orthogonal radiographic images, with associated calculation of 3D measurements. The reliability of this technique has never been documented on adults. HYPOTHESIS: Lower limb measurements produced by the 3D EOS™ reconstruction system are reproducible regarding inter- and intraobserver assessment and more reliable with this 3D technique than when they are obtained from 2D measurements. MATERIALS AND METHODS: This study included 25 patients awaiting total hip arthroplasty (50 lower limbs). Two independent observers made all measurements twice, both on the 2D frontal radiograph and using 3D reconstructions (femoral measurements of length, offset, neck shaft angle, neck length, and head diameter, as well as the tibia length, limb length, HKA and HKS). Reproducibility was estimated by intraclass correlation coefficients. RESULTS: Both the inter- and intraobserver reproducibility of the EOS™ measurements was excellent; more specifically inter- and intraobserver reproducibility was 0.997 and 0.997 for femoral length, 0.996 and 0.995 for tibial length, 0.999 and 0.999 for limb length, 0.894 and 0.891 for HKS, 0.993 and 0.994 for HKA, 0.870 and 0.845 for femoral offset, and 0.765 and 0.851 for neck shaft angle. For most of the variables, the interobserver correlations were statistically better with the EOS™ 3D reconstruction. DISCUSSION: Our results show that the EOS™ systems allow reproducible lower limb measurements. Furthermore, 3D EOS™ reconstructions offer better reproducible measures for most of the parameters than radiographic 2D projection. Its use before deciding on surgery and during planning for lower limb arthroplasty appears essential to us. LEVEL OF EVIDENCE: Level III: diagnostic prospective study on consecutive patients.

Link to Pubmed

Take Away & Results : The EOS systems allows **reproducible lower limb measurements** in 3D.

4.4 Evaluation of a new low-dose biplanar system to assess lower-limb alignment in 3D: a phantom study. Thelen P, Delin C, Folinais D, Radier C. Skeletal Radiol2012 Jun 9.

Abstract : Objective : Knee coronal alignment is routinely assessed on a full-length radiograph of the lower limbs. However, poor positioning of the knee during the procedure affects the accuracy of this kind of measurement, particularly in cases combining knee rotation and flexion. The purpose of this study was to assess the value of a three-dimensional assessment of the hip-knee-ankle (HKA) angle based on a biplanar radiographic system. Material and methods : A biplanar slot scanning system was used to take radiographs of three lower-limb synthetic models with similar frontal deviation (5°valgus) but different flexion angulations (0°, 9°, and 18°). Biplane acquisitions were done with lower-limb axial rotations ranging from 20° of internal rotation to 20° of external rotation on each of the lower limb models. Three independent observers performed standard 2D measurements of the HKA angle from each anteroposterior (AP) image and also modeled the lower limb in 3D for each biplane acquisition with dedicated software. The HKA angle was automatically calculated from the 3D models. The results of the 2D and 3D techniques were compared. Results : Axial rotation provoked 2D HKA measurement errors up to, respectively, 1.4°, 4.7°, and 6.8° for the lower extremities with 0°, 9°, and 18° flexion, while it never affected the 3D HKA measurement for more than 1.5°. Interobserver errors were 0.7° (SD = 0.5°) for the 2D measurements and 0.6° (SD = 0.4°) for the 3D measurements. Conclusions : The 3D modeling allows for a more accurate evaluation of coronal alignment compared to 2D, eliminating bias due to wrong knee positioning.

Link to article

Take Away & Results : The 3D modeling allows for a **more accurate evaluation of coronal alignment** compared to 2D, eliminating bias due to wrong knee positioning.

4.5 Does Standing Affect Acetabular Component Inclination and Version After THA? Clin Orthop Relat Res. Polkowski GG, Nunley RM, Ruh EL, Williams BM, Barrack RL. 2012 May 19.

Abstract : BACKGROUND : Avoiding complications after hip arthroplasty with hard-on-hard bearings, especially metal-on-metal, correlates with the position of the acetabular component. Supine imaging with conventional radiography has traditionally been utilized to assess component inclination (abduction), as well as anteversion, after THA and surface replacement arthroplasty (SRA). However, most adverse events with hard bearings (excessive wear and squeaking) have occurred with loading. Standing imaging, therefore, should provide more appropriate measurements. QUESTIONS/PURPOSES: We determined whether standing changed standard measurements of acetabular component position using a novel biplanar imaging system compared to traditional supine imaging. METHODS: We performed simultaneous biplanar standing imaging of the lower extremity with a novel imaging system using low radiation collimated beam on 46 patients who underwent THA (23) or SRA (23). Patients who had previously undergone

THA had standard CT scans performed. For patients who underwent SRA, we compared acetabular inclination in the supine versus double-limb and single-limb standing. RESULTS: Standing anteversion differed from supine anteversion by greater than 5° for 12 of 23 patients who underwent THA (range, 5°-16°). For patients who underwent SRA, 13 of 23 patients exhibited a difference of greater than 3° in inclination between supine and double-limb standing images, and six of 23 patients exhibited a difference of greater than 3° in inclination between supine and single-limb standing images. CONCLUSIONS: Standing changed the acetabular inclination and version in a substantial percentage of patients undergoing hip arthroplasty.
Link to article

Take Away & Results : Standing anteversion differed from supine anteversion by greater than 5° for 12 of 23 patients who underwent THA (range, 5°-16°). For patients who underwent SRA, 13 of 23 patients exhibited a difference of greater than 3° in inclination between supine and double-limb standing images, and six of 23 patients exhibited a difference of greater than 3° in inclination between supine and single-limb standing images. **Standing changed the acetabular inclination and version in a substantial percentage of patients undergoing hip arthroplasty.**

4.6 Geometrical values of the normal and arthritic hip and knee detected with the EOS imaging system. Than P, Szuper K, Somoskeoy S, Warta V, Illes T. Int Orthop2011 Nov 18.

Abstract: PURPOSE: EOS 2D/3D is an integrated, low-dose orthopedic digital radioimaging solution, which, due to its groundbreaking properties, has recently shown an increasing application in scoliosis surgery. Its integrated sterEOS 3D software allows creation of patient-specific three-dimensional (3D) lower limb models, and can produce geometrical parameters in 3D. Currently there are a limited number of reports on EOS for lower limb applications. of 256 hip and knee joints of 128 healthy subjects, as well as 53 hips and 46 knees of 69 patients with hip or knee arthritis, were evaluated based on orthogonal EOS two-dimensional (2D) images. Measurements for hips included femur and tibia length, total length of the extremity, femoral antetorsion and offset, femoral neck length, neck-shaft and hip-knee-shaft (HKS) angles. Lower limb alignment in both frontal and sagittal planes were determined in normal and arthritic knees. Values were compared with those obtained by standard methods published by others. geometrical parameters were found in our healthy subjects. In osteoarthritic cases, values for neck-shaft angle, femoral antetorsion, femur length and total length of the extremity were shown to decrease non-significantly. Evaluation of lower limb alignment in healthy and arthritic knees showed normal values in healthy subjects apart from three cases with an average six degrees varus. Arthritic knees were most frequently found to have a varus angulation, with the exception of 11 cases with normal or valgus alignment. reconstruction is useful for a comprehensive 3D examination of the lower limb. In the near future it may be suitable for daily routine diagnostics of orthopedic lower limb deformities as a primary examination method.

Link to Pubmed

Take Away & Results : EOS 2D/3D with its sterEOS 3D reconstruction is useful for a comprehensive 3D examination of the lower limb. In the near future it may be suitable for daily routine diagnostics of orthopedic lower limb deformities as a primary examination method.

4.7 Fast 3D reconstruction of the lower limb using a parametric model and statistical inferences and clinical measurements calculation from biplanar X-rays. Chaibi Y, Cresson T, Aubert B, Hausselle J, Neyret P, Hauger O, de Guise JA, Skalli W. Comput Methods Biomech Biomed Engin2011 Jan 1:1.

Abstract: In clinical routine, lower limb analysis relies on conventional X-ray (2D view) or computerised tomography (CT) Scan (lying position). However, these methods do not allow 3D analysis in standing position. The aim of this study is to propose a fast and accurate 3D-reconstruction-method based on parametric models and statistical inferences from biplanar X-rays with clinical measurements' (CM) assessment in standing position for a clinical routine use. For the reproducibility study, the 95% CI was under 2.7 degrees for all lower limbs' angular measurements except for tibial torsion, femoral torsion and tibiofemoral rotation (< 5 degrees). The 95% CI were under 2.5 mm for lower limbs' lengths and 1.5 to 3 degrees for the pelvis' CM. Comparisons between X-rays and CT-scan based 3D shapes in vitro showed mean differences of 1.0 mm (95% CI = 2.4 mm). Comparisons of 2D lower limbs' and 3D pelvis' CM between standing 'Shifted-Feet' and 'Non-Shifted-Feet' position showed means differences of 0.0 to 1.4 degrees . Significant differences were found only for pelvic obliquity and rotation. The reconstruction time was about 5 min.

Link to Pubmed

Results & Take away : Using a specific radiographic protocol, a 'Fast-3DReconstruction' method and/or a 'Full-3D-Reconstruction' method of the lower limb provides accurate full lower limb shape and the most pertinent lower limbs' clinical measurements used in clinical routine including FNSA, tibial torsion, femoral torsion and tibiofemoral rotation, in a fast way and with a good reproducibility.

4.8 THA Patients in Standing and Sitting Positions: A Prospective Evaluation Using the Low-Dose "Full-Body" EOS® Imaging System. Jean Yves Lazennec, Adrien Brusson, Marc-Antoine Rousseau. Seminars in arthroplasty Dec 2012.

Abstract: Variations in pelvic tilt according to the patient's posture may significantly modify the cup orientation and the prosthetic hip biomechanics. This study reports the "functional" positions of a 150 THA cohort using exclusively the novel EOS technology with a specific interest on the radiation dose delivered. The average dose for full-body acquisition was between 0.50 and 1.54 mGy. Globally, an 18° decrease of sacral slope is observed from the standing to the sitting position. A significant increase of cup frontal

and sagittal inclination and anteversion were observed in the sitting position. The slot-scanning radiography provides direct numerical descriptors of the pelvic/hip functional relationships.

Link to publication

Take Away & Results: EOS provides direct numerical descriptors of the pelvic/hip functional relationships with a very low dose.

4.9 Three-dimensional quantitative analysis of the proximal femur and the pelvis in children and adolescents using an upright biplanar slot-scanning X-ray system.

Szuper K, Schlégl AT, Leidecker E, Vermes C, Somoskeöy S, Than P. Pediatric radiology 2014 Aug 26.

Abstract: Background The anatomy and biomechanics of the pelvis and lower limbs play a key role in the development of orthopaedic disorders. Objective This study aimed to establish normal reference standards for the measurement of gender-specific pelvic and femoral parameters in children and adolescents with the EOS 2-D/3-D system. Materials and methods EOS 2-D images of 508 individuals (ages 4-16 years) were obtained as part of routine diagnostics. Patients with lower limb abnormalities were excluded. Pelvic and femoral surface 3-D models were generated and clinical parameters calculated by sterEOS 3-D reconstruction software. Data were evaluated using Spearman correlation, paired-samples and independent-samples t-test and linear regression analysis. Results Changes in anatomical parameters were found to correlate with age and gender in 1) femoral mechanical axis length: 27.3-43.7 cm (males), 25.5-41.2 cm (females), 2) femoral head diameter: 29.4-46.1 mm (males), 27.7- 41.3 mm (females), 3) femoral offset: 26.8-42.4 mm (males), 25.5-37.9 mm (females) and 4) femoral neck length: 35.1- 52.9 mm (males), 32.8-48.1 mm (females). There was no gender-specific correlation for the neck shaft angle with values from 130.4° to 129.3°, for femoral torsion (22.5°- 19.4°), for sacral slope (39.0°-44.4°) and for lateral pelvic tilt (5.1 mm-6.2 mm). Sagittal pelvic tilt exhibited no significant correlation with age showing average values of 6.5°. Conclusions The EOS 2-D/3-D system proved to be a valuable method in the evaluation of female and male developmental changes in pelvic and lower limb anatomical parameters, in normal individuals younger than 16 years of age.

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Take Away & Results: femoral and pelvic parameters in children and adolescents measured in our study using the EOS 2-D/3-D system seem to be consistent with previously reported data, and also provide new data on specific pelvic parameters that are currently lacking in the scientific literature.

4.10 Low-dose biplanar radiography can be used in children and adolescents to accurately assess femoral and tibial torsion and greatly reduce irradiation.

Meyrignac O, Moreno R, Baunin C, Vial J, Accadbled F, Sommet A, de Gauzy JS, Sans N. European Radiology. Dec 2014.

Abstract: To evaluate in children the agreement between femoral and tibial torsion measurements obtained with low-dose biplanar radiography (LDBR) and CT, and to study dose reduction ratio between these two techniques both in vitro and in vivo. MATERIALS AND METHODS: Thirty children with lower limb torsion abnormalities were included in a prospective study. Biplanar radiographs and CTs were performed for measurements of lower limb torsion on each patient. Values were compared using Bland-Altman plots. Interreader and intrareader agreements were evaluated by intraclass correlation coefficients. Comparative dosimetric study was performed using an ionization chamber in a tissue-equivalent phantom, and with thermoluminescent dosimeters in 5 patients. RESULTS: Average differences between CT and LDBR measurements were -0.1° ±1.1 for femoral torsion and -0.7° ±1.4 for tibial torsion. Interreader agreement for LDBR measurements was very good for both femoral torsion (FT) (0.81) and tibial torsion (TT) (0.87). Intrareader agreement was excellent for FT (0.97) and TT (0.89). The ratio between CT scan dose and LDBR dose was 22 in vitro (absorbed dose) and 32 in vivo (skin dose). CONCLUSION: Lower limb torsion measurements obtained with LDBR are comparable to CT measurements in children and adolescents, with a considerably reduced radiation dose.

Take Away & Results: Lower limb torsion measurements obtained with sterEOS are comparable to CT measurements in children and adolescents, with a considerable reduced radiation dose.

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II. Communications

1 Dose

1.1 Dose and Scoliosis Radiographic Examination: How Can a Slot-scanning System Reduce Considerably Irradiation by Managing Scatter Reduction? Sylvain Deschênes, Guy Charron, Josee Dubois,Gilles Beaudoin. Communication at RSNA 2011.

Abstract: PURPOSE: To evaluate the physical performance and clinical dose benefits of a slit-scanning X-ray imaging system compared to full-field systems. METHOD AND MATERIALS: A slit-scanner (EOS Imaging, Paris, France) is compared to DR systems using Trixell flat panel detectors on the basis of Effective Detective Quantum Efficiency (DQEeff). This metric adjusts the standard DQE of the systems by discarding the scattered radiation and keeping only the part of the signal coming from primary photons. Scatter fraction is evaluated by measuring signal intensity in images of a RANDO anthropomorphic phantom (Phantom Laboratory, Salem, NY) before and after placing a lead shield where apertures (3mm diameter) are aligned with different anatomical regions. For full-field systems, the scatter fraction is assessed with and without the anti-scatter grid in place. To correlate the DQEeff results with dose, equivalent technical parameters are estimated for scoliosis X-rays on the slit-scanner and the DR. This is done by analysing signal-to-noise ratios and contrast-to-noise ratios computed on images of a step phantom made of PMMA and Aluminum. Then, using entrance air kerma for the matching techniques, effective dose is computed by Monte Carlo simulation for each system. RESULTS: For an x-ray spectrum equivalent to scoliosis examination (RQA7), DQE for DR (0.47) is more than twice as large as for slit-scanner (0.22). However, for a region along the thoracic spine, the slit-scanner has a DQEeff (0.20) three times higher than DR with anti-scatter grid (0.06). This correlates with a substantial dose reduction in scoliosis examination, effective dose being seven times lower for the slit-scanner (55 µSv) compared to DR(386 µSv). CONCLUSION: When considering its efficacy to block scatter radiation, the slit-scanner offers higher performances than DR. This allows substantial dose reductions without compromising image quality.

Take Away & Results : EOS allows a substantial dose reduction in scoliosis examination, effective dose being **seven** times lower for the slit-scanner compared to DR.

1.2. Ultra low dose imaging for the follow up of idiopathic scoliosis: How low is reasonably achievable with new slot-scan technology? Alison M, Ferrero E, Tanase A, Rega A, Ilharreborde B, Mazda K, Sebag G. Communication at RSNA 2013.

Abstract: PURPOSE: For the follow up of spinal deformities, a novel biplanar slot scanning system has been shown to allow significant dose reduction. Further dose reduction can be obtained with recent technical advances (copper filtration and

dedicated image processing) and with the optimization of the acquisition parameters (kV, mA and scan speed). Our aim was to assess the image quality as well as the reproducibility of clinical parameter measurements using an optimized ultra low dose protocol for scoliosis examinations. METHOD AND MATERIALS: 23 patients (mean age: 12.4 yo ± 3.3, range 5-18yo) with mild or moderate idiopathic scoliosis were imaged with an ultra low dose protocol optimized according to the body mass index, following the ALARA concept. Dose Area product (DAP) and entrance dose (kerma) were quantified for each examination. Image quality was rated on a 5-point scale based on the visibility of the edges of the vertebrae of 5 different anatomical areas (cervical, superior and inferior thoracic and lumbar spine), 5 corresponding to the highest quality. Cobb angle, cervical and lumbar lordosis, thoracic kyphosis, pelvic parameters (pelvic incidence, sacral slope) were measured by two independent operators (radiologist and orthopedist). The intraclass correlation coefficient (ICC) was used to assess interobserver agreement of the measurements. RESULTS: Mean (±SD) Cobb angle was 22.3 (± 13)°. Mean DAP was 39.5 (± 17.1) and 87.9 (± 31.7) mGy.cm2 for the antero posterior (AP) and the lateral view respectively. Mean entrance doses was 17.6 (±6.4) and 42.1(±12.8) µGy for the AP and the lateral view respectively. This dose corresponds to approximately 10 days of background radiation. Image quality was graded 3 in 11/23 (48%) cases, 4 in 11/23 (48%) cases and 5 in 1/23 (4%) case. Interoberver agreement was very high for Cobb angle (ICC 0.92), T1-T12 kyphosis (ICC 0.90) and L1-S1 lordosis (ICC 0.90) and high for cervical lordosis (ICC 0.89), T4-T12 kyphosis (ICC 0.89), pelvic incidence (ICC 0.88) and sacral slope (ICC 0.83). CONCLUSION: Ultra low dose imaging is achievable for the follow up of idiopathic scoliosis, with acceptable image quality and high reproducibility of the measurements. CLINICAL RELEVANCE/APPLICATION: Ultra low dose protocol using biplanar slot scanning system with optimized acquisition parameters can be used for the monitoring of idiopathic scoliosis, allowing further dose reduction.

Take Away & Results : Ultra low dose (microdose) imaging can be used for the monitoring of idiopathic scoliosis. The average dose/examination is equivalent to 10 days of background radiation.

2 Spine

2.1 The Use of 3D Spinal Parameters to Differentiate between Progressive and Non-Progressive AIS Curves at the First Visit.

Marie-Lyne Nault, MD, MSc; Jean-Marc Mac-Thiong, MD, PhD; Marjolaine Roy-Beaudry, MSc; Isabelle Turgeon; Hubert Labelle, MD; Jacques de Guise, PhD; Stefan Parent, MD, PhD. Communication at SRS annual meeting 2012.

Abstract: SUMMARY: Based on a prospective cohort of 134 patients followed for a mean of 37 months, 3D parameters of the spine calculated at the first visit were identified as being different between the evolutive and the non evolutive patients. Parameters were

torsion, plane of maximal curvature orientation, hypokyphosis and apical vertebra axial rotation.
INTRODUCTION: Prediction of curve progression remains challenging in adolescent idiopathic scoliosis (AIS) at the first visit. The objective of this study was to compare 3D morphologic parameters of the spine at the first visit between a non-progressive and a progressive group of immature patients with AIS. METHODS: This is a single-center prospective series of 134 consecutive patients with a diagnosis of AIS followed from their first visit to maturity (mean 37 months). The first group was made of AIS patients with a minimum of 6° progression of the major curve between the first and last follow up (P) (n=53) and the second group was composed of non progressive patients that reached maturity with less than 6° of progression (n=81). 3D reconstructions of the spine at the initial visit were obtained using EOS™ images and 3D parameters calculated automatically. There were 6 categories of measurements: angle of plane of maximum curvature, Cobb angles (kyphosis, lordosis), 3D wedging (apical vertebra, apical disks), rotation (upper and lower junctional vertebra, apical vertebra, thoracolumbar junction), torsion and slenderness (height/width ratio). RESULTS: There was no statistical difference between the two groups for age and initial Cobb angle. Four distinct parameters were found to be significantly different and clinically significant by being greater than the measurement error. The significant parameters included spinal torsion, the rotation of the plane of maximal curvature, hypokyphosis and apical vertebral rotation (table). CONCLUSION: This study confirms that even at the initial visit, 3D morphologic differences exist between progressive and non-progressive curves in AIS, in particular parameters linked to rotation, hypokyphosis, plane of maximal curvature and torsion of the spine. These findings underscore the importance of the torsional aspect of the deformity occurring in the junctional zone under the main curve. Wedging doesn't seem to be related to progression at this early stage. It supports the use of 3D reconstructions of the spine in the initial evaluation of AIS to help predict the outcome.

Take Away & Results : Even at the initial visit, **3D morphologic differences exist between progressive and non-progressive curves in AIS**, in particular parameters linked to rotation, hypokyphosis, plane of maximal curvature and torsion of the spine.