



# Is there any use? Validity of 4D rasterstereography compared to EOS 3D X-ray imaging in patients with degenerative disk disease

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## Abstract

**Introduction** Previous studies of 4D rasterstereography show a high intra- and interday reliability. However, only few studies validate rasterstereography to conventional X-ray imaging. We utilized EOS X-ray imaging system (EOS Imaging, Paris, France) for accurate 3D spinal modeling and compared the results to parameters obtained by 4D rasterstereography. The aim of the present study was to validate 4D rasterstereography in patients with degenerative disk disease (DDD).

**Materials and method** Thirty-four individuals with DDD (female = 22 and male = 12) were included. EOS X-ray images were analyzed to determine spinal [lumbar lordosis (LL) and thoracic kyphosis (TK)] and pelvic parameters [pelvic obliquity (PO) and pelvic axial rotation (PR)]. Patients received 4D rasterstereographic measurements on the same day as EOS imaging. Parameters obtained by rasterstereography were compared to those obtained by EOS X-ray imaging. We used Bland and Altman's test as well as Pearson test to validate rasterstereography. Additionally, we calculated interrater reliability of EOS X-ray analysis using the intraclass correlation coefficient (ICC).

**Results** Our data showed only weak correlation between 4D rasterstereography and EOS X-ray imaging for spinal parameters (LL and TK). Pelvic parameters (PO and PR) showed no correlation. Interrater correlation reliability for EOS analysis was excellent (ICC > 0.8).

**Conclusion** Our data suggest that rasterstereographic systems are no reliable substitute for X-ray-based imaging systems in patients with degenerative disk disease. EOS imaging was shown to provide reliable and accurate spinal modeling. Based on our results, rasterstereographic imaging should be used with caution for evaluating spinal and pelvic parameters in patients with DDD.

## Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.

**Key points**

1. Study Aim: validate 4D-rasterstereography in patients with degenerative disc disease (DDD).
2. 4D-rasterstereography was validated against Gold Standard EOS-X-ray.
3. Pearson Correlation Coefficient, Bland-Altman Test was determined for validation. Additionally, intraclass correlation coefficient (ICC) of EOS X-ray analysis was calculated.

**Take Home Messages**

1. 4D-rasterstereographic systems are no reliable substitute for X-ray based imaging in patients with DDD.
2. EOS X-ray imaging provides reliable 3D spinal modeling in the measurement of spinal parameters.

**Figure 1: Pearson Correlation Coefficients of spinal and pelvic parameters.** The figure contains four scatter plots with regression lines and correlation coefficients (r) and p-values (p):  
- Correlation Lumbar Lordosis: r = 0.46, p < 0.001  
- Correlation Thoracic Kyphosis: r = 0.43, p < 0.001  
- Correlation Pelvic Axial Rotation: r = -0.25, p = 0.14  
- Correlation Pelvic Obliquity: r = 0.18, p = 0.29

**Keywords** EOS X-ray · Rasterstereography · Degenerative disk disease · DDD · Sagittal balance

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Extended author information available on the last page of the article

## Introduction

Diagnosis and treatment of spinal deformities rely on radiological imaging as a tool to measure the extent of spinal deformity. Radiological imaging can also be used to evaluate progression of spine deformities. In general, 2-dimensional anteroposterior and lateral full-length spine radiographs are considered as the established gold standard imaging technique. Nevertheless, the downsides of standard X-ray imaging are the availability of only 2-dimensional information as well as substantial radiation exposure. Especially in young patients who require multiple full-length X-ray examinations over the course of their medical history (e.g., patients with adolescent idiopathic scoliosis), radiation exposure can become a serious issue [1, 2]. Therefore, efforts have been made to introduce alternative noninvasive, cost-effective as well as reliable imaging techniques for diagnosis and follow-up in spine patients.

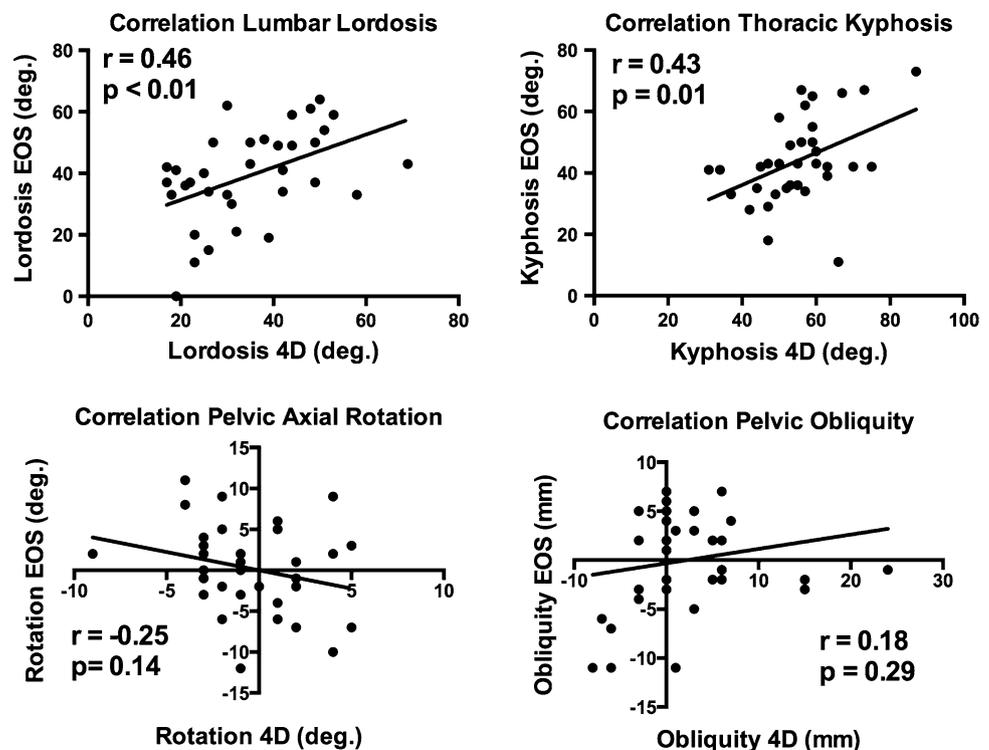
Rasterstereography was introduced by Drerup and Hierholzer 30 years ago: Spine surface curvatures were calculated from rasterstereographic surface measurements of landmarks corresponding to the vertebra prominens, the dimples of the posterior superior iliac spines and the sacrum point [3]. Due to the nature of rasterstereography, no radiation exposure exists [3]. The method was shown to be reliable in patients with scoliosis up to 90° Cobb angle both preoperative and after surgical correction and fusion

[4–6]. According to the manufacturers protocol, patients can be examined automatically standing free in what is considered to be a natural posture. Parallel light raster lines are projected onto the skin of the patients back by a slide projector and captured by a digital camera (Fig. 1a). Anatomic landmarks are identified automatically. Viewed under a known and fixed angle, the lines are distorted corresponding to the 3-dimensional surface shape of the back. By making use of modeling techniques such as active contour models, active shape models and inverse kinematic models, biomechanically relevant results such as the position of the skeletal segments are obtained.

The output data provide a 3-dimensional model of the back surface including various features such as anatomic landmarks, transverse and sagittal profiles from which thoracic kyphosis and lumbar lordosis are automatically calculated, as well as pelvic parameters as pelvic axial rotation and pelvic obliquity. The process is contactless and noninvasive, and the results are available immediately [7]. Although an abundance of the literature proves the reliability of rasterstereography, there are only limited published data showing the validity [8, 9]. Up to now, most available data provide evidence that rasterstereography can be considered reliable, but only little data validate rasterstereography to the gold standard of X-ray-imaging in certain collectives of patients [10–12].

EOS 3D X-ray imaging was developed based on the Nobel price winning discovery of Georges Chapak, using a low-dose radiation technique to acquire simultaneous 2D

**Fig. 1** Pearson correlation coefficients of spinal and pelvic parameters: Data obtained by 4D rasterstereography (4D) were plotted against data obtained by EOS X-ray (EOS) for spinal parameters [lumbar lordosis (LL) and thoracic kyphosis (TK)] as well as pelvic parameters [pelvic axial rotation (PR) and pelvic obliquity (PO)]. Values displayed for pelvic parameters are referenced to the left side

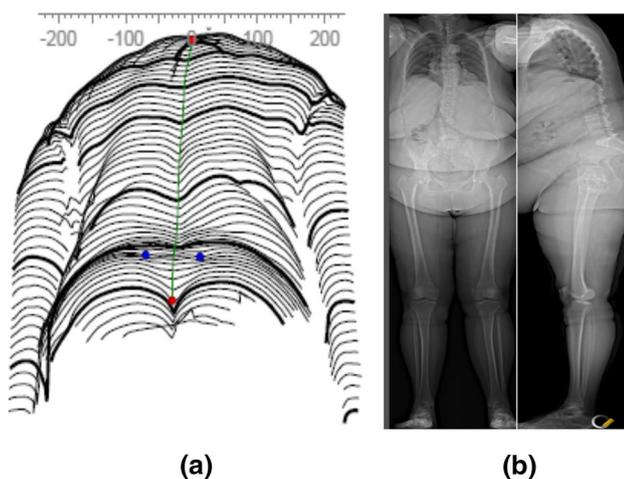


X-ray data which is used for 3D image reconstruction. The EOS examination takes place in an upright scanning cabin where the patient can either stand or sit. With a vertically traveling arm supporting two fine X-ray beams perpendicular to one another, the EOS system acquires frontal and lateral, weight-bearing images of the patient in a functional—standing or sitting—position (Fig. 2b). These biplanar images are then used to create a 3D model of the patient's skeleton. Data acquisition usually requires < 60 s for a full body scan while the patient is only exposed to approximately 1/10th of the radiation dose compared to a conventional whole spine X-ray [13, 14].

Some studies exist validating rasterstereography in patients with adolescent idiopathic scoliosis [5, 6, 15]. Tabart-Fougère et al. [8] compared rasterstereography to EOS X-ray imaging in 35 patients with adolescent idiopathic scoliosis. They found a good correlation of the scoliosis angle provided by rasterstereography and the Cobb angle of the major curve obtained by conventional radiography ( $r=0.7$ ).

However, other parameters (e.g., lumbar lordosis, thoracic kyphosis, pelvic obliquity and axial pelvic rotation) have not been validated so far. To our current knowledge, no evidence exists showing the validity of rasterstereography in the group of patients with degenerative disk disease (DDD). In our view, this is an important issue since patients with DDD represent a large proportion of patients seen in everyday practice.

Therefore, the aim of this study was to evaluate the validity of spine rasterstereography in a cohort of patients with degenerative disorders of the spine.



**Fig. 2** **a** Exemplary imaging of a patient as provided by the 4D rasterstereographic system. **b** Biplanar EOS X-ray imaging of the same patient as shown in **a**. Both 4D rasterstereographic and EOS X-ray system provide relevant pelvic and spinal analysis data in tables (not shown)

## Methods

### Participants

Patients who were treated at a single spine center for acute and chronic low back pain received conventional X-ray imaging as well as magnetic resonance imaging (MRI) of the lumbar spine. If the MRI did show degenerative disk disease, patients received EOS X-ray imaging as well as 4D rasterstereographic measurement after giving their informed consent. Thirty-four consecutive individuals (female = 22 and male = 12) diagnosed with DDD at the age between 25 and 88 years were included.

Exclusion criteria were patients with neurological pathologies (e.g., paraparesis, neuromyopathy), tumor/metastatic or infectious causes for lower back pain, and the inability of standing upright without support. Also, patients with an obesity grade II and above (BMI > 35) according to WHO were excluded from analysis [16].

A sample size of 31 participants was calculated to obtain a statistical power up to 91% and an alpha error of 5% based on the results of preliminary data.

### Data assessment

Biplanar EOS X-ray images were acquired by one senior radiology technicians according to the standard protocol specifications of EOS imaging: Patients were examined in a free-standing position with their hands on their clavicles, elbow flexed and the head looking forward.

4D rasterstereographic measurements using the Formetric 4D System (Diers, International GmbH, Schlangenbad, Germany) were taken by one single experienced technician on the same day as EOS imaging. The modality evaluated was 3D static, which allows measurements to be made based on one image in a 1-s capture. Patients were examined in a standing position with their hands on their clavicles, elbow flexed and the head looking forward. This position, which is not typically recommended for rasterstereography, was used to enable the comparison with 3D EOS imaging by ensuring similar balance and stance of the patient.

Biplanar low-dose EOS images were analyzed using the sterEOS software (EOS imaging, Paris, France).

To evaluate the interobserver reliability of the 3D EOS analysis, four equally experienced investigators separately analyzed each 3D EOS image using the sterEOS software.

### Data analysis

To evaluate the validity of 4D rasterstereography, we evaluated following parameters: lumbar lordosis (LL)

and thoracic kyphosis (TK) angle (degree) as well as pelvic obliquity (PO) (mm) and pelvic axial rotation (PR) (degree). For pelvic parameters, the obtained values were referenced to the left side: A positive value for pelvic axial rotation corresponds to a rotation to the left side. Similarly, a positive pelvic obliquity value corresponds to the left pelvis being higher than the right pelvis.

EOS X-ray images were analyzed using the sterEOS software to determine the lumbar lordosis (LL) and thoracic kyphosis (TK) angle as well as pelvic obliquity (PO) and pelvic axial rotation (PR).

For 4D rasterstereography validation, we compared and analyzed data obtained by 4D rasterstereography and EOS X-ray imaging using Bland and Altman's 95% limit of agreement (LOA) as well as Pearson correlation coefficient ( $r$ ). Bland–Altman's test and Pearson correlation test are generally described to be the proper statistical tools of analysis when validating diagnostic methods that lead to quantitative results [17].

Bland–Altman's plots are generally interpreted informally by comparing the average discrepancy between methods (the bias), as well as the limits of agreement (LOA). If LOA are wide, the results are ambiguous. If the limits are narrow (and the bias is small), then two methods can be considered as equivalent.

For Pearson's test, correlation was defined as follows:  $r > 0.7 / < -0.7$  strong correlation;  $r > 0.5 / < -0.5$  moderate correlation;  $r > 0.3 / < -0.3$  weak correlation; and  $r < 0.3 / > -0.3$  no correlation).

To assess the interobserver reliability of the 3D EOS X-ray analysis, we calculated the intraclass correlation coefficient (ICC [1, 3]) [18]. Interobserver reliability was defined as follows:  $ICC > 0.75$  excellent reliability;  $0.74 > ICC > 0.40$  good reliability; and  $ICC < 0.39$  poor reliability.

All statistics were calculated using GraphPad Prism 6 software (GraphPad, San Diego, CA, USA). For all data,  $p > 0.05$  was considered statistically significant with a 95% confidence interval.

## Results

### Participants

Thirty-four consecutive patients with diagnosed DDD were included in the study. The demographic characteristics of the 34 included patients (25–88 years, 22 females and 12 males) are depicted in Table 1. The descriptive results of the spinal and pelvic parameters measured are summarized in Table 2.

**Table 1** Demographic characteristics of included individuals with DDD

|     | Mean | Min value | Max value | SD    | 95% CI      |
|-----|------|-----------|-----------|-------|-------------|
| Age | 71   | 25        | 88        | 13.24 | 65.97–75.21 |
| BMI | 26   | 19        | 34        | 4.18  | 24.16–27.08 |

$n = 34$ , female = 22, male = 12

BMI body mass index, SD standard deviation, CI confidence interval

**Table 2** Descriptive statistics of spinal and pelvic parameters obtained by either 4D rasterstereography (4D) or EOS X-ray (X-ray)

|                    | 4D               | X-ray            |
|--------------------|------------------|------------------|
| LL (mean $\pm$ SD) | 35 $\pm$ 13      | 39 $\pm$ 15      |
| TK (mean $\pm$ SD) | 55 $\pm$ 12      | 44 $\pm$ 14      |
| PR (mean $\pm$ SD) | -0.52 $\pm$ 3.04 | 0.23 $\pm$ 5.36  |
| PO (mean $\pm$ SD) | 1.11 $\pm$ 6.52  | -0.02 $\pm$ 5.17 |

LL lumbar lordosis, TK thoracic kyphosis, PR pelvic axial rotation, PO pelvic obliquity, SD standard deviation

### Validation of 4D rasterstereography: Pearson correlation

Data of spinal and pelvic parameters obtained by 4D rasterstereography and EOS X-ray were compared to validate 4D rasterstereography. First, we calculated Pearson correlation coefficient as depicted in Table 3 and Fig. 1. The comparison of lumbar lordosis showed a weak correlation of  $r = 0.46$  ( $p = 0.005$ ); thoracic kyphosis showed a weak correlation of  $r = 0.43$  ( $p = 0.01$ ). Concerning the pelvic parameters, correlation for pelvic obliquity was  $r = 0.18$  ( $p = 0.29$ ) and correlation for pelvic axial rotation was  $r = -0.25$  ( $p = 0.14$ ). Therefore, while we found a weak correlation of spinal parameters obtained by rasterstereography compared to EOS X-ray imaging, no correlation was found comparing the pelvic parameters.

### Validation of 4D rasterstereography: Bland–Altman LOA

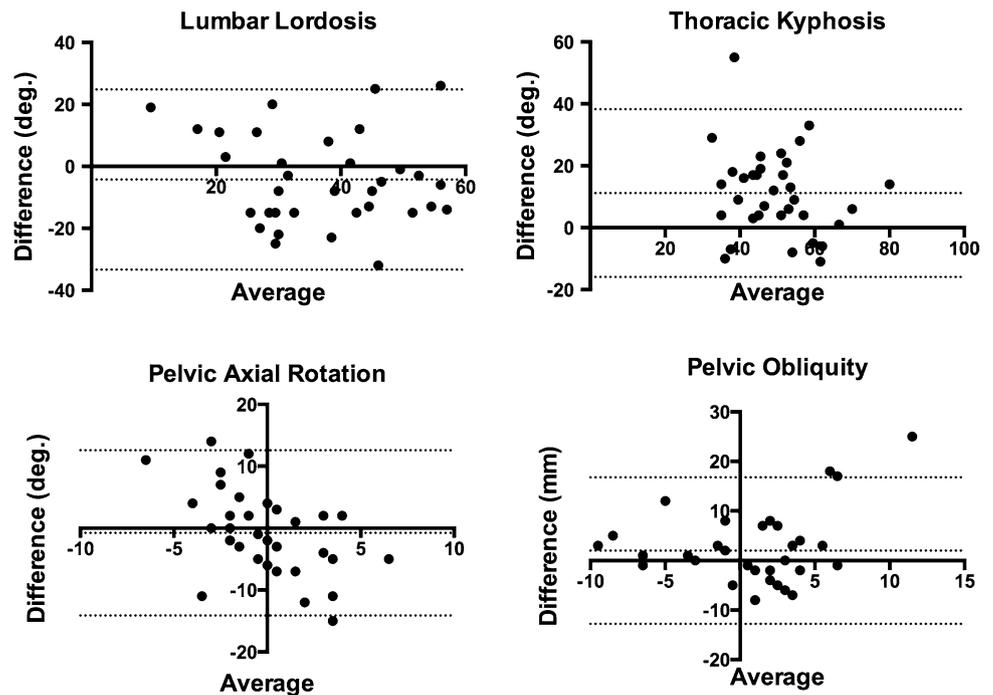
As a next step, we used Bland and Altman's limit of agreement as a tool to interpret the equivalence of 4D rasterstereography and the gold standard EOS X-ray. Figure 3 shows that for spinal parameters Bland–Altman's LOA analysis revealed a bias of  $-4.27^\circ$  for lumbar lordosis (95% limit of agreement  $-33.5^\circ$  to  $24.82^\circ$ ) and a bias of  $11.18^\circ$  (95% limit of agreement  $-15.91^\circ$  to  $38.26^\circ$ ) for thoracic kyphosis. For pelvic parameters, Bland–Altman's test revealed for pelvic axial rotation a bias of  $0.76^\circ$  (95% limit of agreement  $-14.1^\circ$  to  $12.6^\circ$ ) and a bias of 2 mm (95% limit of agreement  $-12.8$  mm to  $16.8$  mm) for pelvic obliquity. As

**Table 3** Results of statistical analysis: Results of spinal (LL, TK) and pelvic (PR, PO) parameters obtained by EOS X-ray and 4D rasterstereography were compared by Pearson correlation and Bland–Altman's limit of agreement to validate 4D rasterstereography

|    | Pearson correlation |            |                       |                | Bland–Altman's LOA |       |              |
|----|---------------------|------------|-----------------------|----------------|--------------------|-------|--------------|
|    | <i>r</i>            | 95% CI     | <i>r</i> <sup>2</sup> | <i>p</i> value | Bias               | SD    | 95% LOA      |
| LL | 0.46                | 0.15–0.69  | 0.21                  | <0.01          | −4.26              | 14.84 | −33.35–24.82 |
| TK | 0.43                | 0.11–0.67  | 0.18                  | <0.05          | 11.18              | 13.82 | −15.91–38.26 |
| PR | −0.25               | −0.54–0.09 | 0.06                  | 0.14           | −0.76              | 6.81  | −14.11–12.58 |
| PO | 0.18                | −0.16–0.49 | 0.03                  | 0.29           | 2                  | 7.54  | −12.79–16.79 |

LL lumbar lordosis, TK thoracic kyphosis, PR pelvic axial rotation, PO pelvic obliquity, CI confidence interval, SD standard deviation, LOA limit of agreement

**Fig. 3** Bland–Altman's LOA of spinal and pelvic parameters: Data obtained by 4D rasterstereography were compared to data obtained by EOS X-ray for spinal parameters lumbar lordosis (LL) and thoracic kyphosis (TK) as well as pelvic parameters pelvic axial rotation (PR) and pelvic obliquity (PO). Dotted lines indicate 95% limit of agreement (upper and lower line) as well as sample mean of differences (= bias, intermediate dotted line). Values displayed for pelvic parameters are referenced to the left side



described in the Methods section, Bland–Altman's LOA results are interpreted informally. Our data show that 4D rasterstereographic measurements tended to underestimate the amount of lumbar lordosis and overestimated thoracic kyphosis compared to the gold standard of EOS X-ray imaging. For pelvic parameters, while the bias is relatively small, the wide limits of agreement (LOA) indicate a general inaccuracy of the 4D rasterstereographic measurement compared to EOS X-ray.

### Interobserver reliability of the 3D EOS analysis

To determine the reliability of the EOS 3D analysis, we calculated the intraclass correlation coefficient (ICC [1, 3],  $n = 34$ ). The ICC for both lumbar lordosis and thoracic kyphosis was excellent [ICC = 0.9 (0.84; 0.94 95% CI)]. For pelvic obliquity, ICC was 0.89 (0.83; 0.94 95% CI). For

pelvic axial rotation, the ICC was 0.8 (0.7; 0.89 95% CI). The overall interobserver correlation was excellent for all parameters assessed.

### Discussion

4D rasterstereography was introduced as alternative imaging technique to conventional X-ray imaging. 4D rasterstereography was intended to be a noninvasive, cost-effective as well as reliable imaging technique for diagnosis and monitoring in spine patients. For these reasons, 4D rasterstereography is currently used by many as a diagnostic tool in patients with spinal deformities of different origins.

While a plethora of studies exist proving the reliability (in terms of repeatability) [5–8, 19] of 4D rasterstereography, only a minority of published papers actually show its

validity (in terms of accuracy compared to a gold standard), mostly in patients with AIS [4, 8, 20].

Guidetti et al. [19] evaluated the intra- and interday reliability of spine rasterstereographic system Formetric 4D with and without reflective markers in 26 healthy volunteers. Participants were analyzed two times at the same day and another time at a different day. Twenty different parameters including lumbar lordosis, thoracic kyphosis, lateral deviation to both sides as well as different pelvic parameters were evaluated. ICC and Cronbach's alpha were calculated. Finally, the authors concluded that "...this study validated aspects of the rasterstereographic measuring system...". This conclusion was criticized by others [10] since 4D rasterstereography was not actually validated against a gold standard method by Guidetti et al. Therefore, 4D rasterstereography was tested for reliability, but not validated.

Nevertheless, some studies actually validated 4D rasterstereography: Schroeder et al. [20] provided data to validate the 4D rasterstereographic "scoliosis angle" by means of radiographic Cobb angles. A total of 10 patients with suspected scoliosis were examined. The authors found that the scoliosis angle provided by 4D rasterstereography was similar to the radiologically evaluated Cobb angle if patients had a scoliotic deformity of Cobb > 10°. Unfortunately, the conclusion of this study was limited: While a total of 10 individuals were included in this study, the group of patients with a Cobb > 10° consisted of 4 patients only. This small number of individuals and the resulting lack of significance hinder the reasoning about the validity of 4D rasterstereography.

In a different study, Tabard-Fougère et al. [8] evaluated the validity of 4D rasterstereography in thirty-five patients with adolescent idiopathic scoliosis (AIS) with a major curve Cobb angle (CA) between 10° and 40° for frontal, sagittal and transverse parameters. They found a good correlation ( $r=0.7$ ) of 4D rasterstereographic Scoliosis angle and Cobb angle determined by conventional whole spine X-rays.

In summary, there are several issues: First, while there exist only a handful of studies that actually validate the method of 4D rasterstereography, the majority of these studies selectively include AIS patients, but not patients with other spinal disorders.

Second, some validation studies include a very limited number of individuals, therefore limiting the significance of the results.

Third, even though the manufacturer claims that 4D rasterstereography provides information about pelvic parameters, it is hard to find evidence in the literature since most validating studies only look at spinal parameters.

For this reason, we decided to validate 4D rasterstereography in patients with DDD to the gold standard of conventional EOS X-ray. In contrast to the studies mentioned above, our data show only a weak correlation of spinal parameters. Although not statistically significant

due to variation, we found no correlation of pelvic parameters obtained by 4D rasterstereography compared to data obtained by EOS X-ray. These results were also confirmed by Bland–Altman's test. Considering the growing importance of pelvic parameters in the diagnosis and therapy of sagittal imbalance, this limits the regular use of 4D rasterstereography in our point of view.

One of the factors that might explain the different outcome in validity is the BMI. 4D rasterstereography relies on the detection of anatomic landmarks that might be impaired in obese patients. In the study of Tabard-Fougère et al. [8], the mean BMI of the AIS patients evaluated was  $19 \pm 4$  (mean  $\pm$  SD) and therefore lower than in the collective of individuals included in our study (mean BMI  $26 \pm 4$ ). However, we believe that the individuals included in our study represent a more realistic collective in terms of the BMI seen in patients with spinal disorders in everyday practice. Furthermore, to limit the influence of high grade and extreme obesity on our results, we excluded individuals with a BMI > 35. According to the manufacturer's protocol, anatomical fixpoints are automatically recognized by the system. Although reflective markers can be used to increase accuracy of 4D rasterstereography, according to the manufacturer there is no need for it. The use of reflective markers is left to the decision of the experienced technician.

The lack of a clear protocol when to apply reflecting markers as well as the fact that reflective markers have to be applied manually also might increase inconsistency in data collection using 4D rasterstereography.

Naturally, our study has limitations. Even though power analysis revealed statistical significance of our data, including higher numbers of individuals would be desirable to furthermore increase the power of our study.

Additionally, we only included individuals with degenerative disk disease in our study. Further studies are needed to test whether our findings are applicable to patients with other spinal disorders than DDD, especially AIS patients.

## Conclusion

In conclusion, while 4D rasterstereography might be a useful tool in patients with AIS [8, 20], our data indicate that in patients with DDD, 4D rasterstereographic systems are no reliable substitute for X-ray-based imaging. In concordance with other studies, we show that EOS X-ray imaging provides reliable 3D spinal modeling in the measurement of spinal parameters [21, 22]. Based on our results, conclusions drawn from 4D rasterstereographic imaging should be interpreted with caution for evaluating spinal and especially pelvic parameters in patients with DDD.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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