Lower Limb Alignment and Length Measurements - Comparison of Computed Tomography, Upright Full-Length Conventional Radiography and Upright Biplanar Linear-Low Dose X-ray Scanner

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Purpose

To compare lower limb length and alignment angle measurements using computed tomography (CT), upright full-length conventional radiography (CR) and three dimensional (3D) models based on upright biplanar linear low dose radiography (EOS).
Methods and Materials

Institutional review board approval was obtained prior to the start of this study.

Patients

51 patients (22 male, 29 female; mean age 68.8 years; range 43-92 years) with severe gonarthritis scheduled for implantation of a total knee endoprosthesis were consecutively included given their informed consent. Patients younger than 18 years, with a severe lower limb deformity, paraplegic patients or patients who were unable to stand in an upright position were excluded.

As part of the study protocol EOS scans were additionally acquired on the same day.

CT-Scans

CT was performed using a 40-row multi-detector CT unit (Brilliance 40, Philips, Netherlands).

The patient was scanned in supine position with his feet first entering the gantry. Both legs were extended and care was taken to stabilize them in neutral position without any rotation. Ankle joints were flexed in 90° and the toes pointed towards the ceiling. The limb with the diseased knee was centered in the gantry. In order to allow preoperative axial axis measurements of the femur and tibia three spiral scans had to be planned on a scout view from the iliac crest to the planta pedis: first of the hip joints (from pubic joint space to proximal ¼ of the femur), second of the knee joints (15 cm above to 10 cm below joint space) and third of the ankle joints (5 cm above joint space to center of calcaneus).

Scout view, raw images and reconstructed data were eventually sent to the PACS for ensuing measurements.

CR-Scans

Full length conventional radiographs were performed immediately after CT acquisitions on an Ysio-system (Siemens Healthcare). Different presets of tube voltages were chosen by the radiology technician according to patient’s stature and weight (small, medium and large with 75-85 kV, 77-90 kV and 77-96 kV and tube currents according to automatic exposure measurements, respectively).

Three differently angulated projections of the lower limb are combined into one single "stitched" image by a specific post-processing algorithm of the unit. The stitched images were then sent to the PACS for length and angle measurements.

EOS-Scans
All scans were simultaneously performed in frontal and lateral projections in an EOS imaging unit (EOS, EOS imaging SA, 10 rue Mercœur, 75011 Paris, France).

The patient was centered in upright position in the scanner on a platform with his central axis aligned with vertical laser lights in frontal and lateral projections. Patients had to be positioned with their legs in a small step position in order to allow delineation of the contour of both limbs on the lateral projection. Tube voltage of the X-ray tubes was chosen by the radiology technician from three presets, according to the patients’ weight and stature (small, medium and large; 80-104kV with 200-320 mAs for ap-projection and 100 - 120kV with 200-320mAs for lateral projection).

The translational speed of the tubes was chosen between 4 and 6 on the vendor specific scale (ranging from 1 for fast to 8 for slow). After scanning images were sent immediately to the EOS workstation for generation of 3D models.

**Post-Processing and Measurements**
All post-processing and measurements were performed by two radiologists.

In all modalities lower limb length was defined by calculating the distance from the center of the femoral head to the center of the ankle joint space. Lower limb alignment angle was defined between a line through the center of the femoral head and the intercondylar notch of the femur and a line between the eminentia intercondylaris of the tibia and the center of the ankle joint ([Figure 1][1]).

CT and CR
Measurements on CT scout view and CR were performed in the PACS-system of our department (IMPAX 6.4.0.4551, Agfa) using the aforementioned predefined structures ([Figure 2a-c]).

EOS
EOS acquisitions were post-processed on a separate workstation of the EOS unit using vendor-specific software (sterEOS 1.4.3.5112). An idealized model of the software was fused with the frontal and lateral projection of the lower limb by manually fitting contours of the model to predefined osseous landmarks (e.g. femoral head, femoral condyles, tibial head, medial and lateral malleolus) ([Figure 3a]). A 3D model could then be generated and key measurements (limb length and limb alignment angle) were automatically calculated by the software according to the abovementioned definitions ([Figure 3b]).

**Statistical Analysis**
Descriptive statistics (mean, standard deviation (SD) and range) were calculated for both lower limb length and alignment angles of the three different modalities.

Differences between modalities were assessed by paired, two-tailed t-testing and Bland-Altman analyses.
Inter-reader agreement was assessed by calculating intraclass correlation coefficients (ICC) for all modalities. ICC values of 0.61-0.80 were interpreted as substantial, and 0.81-1 as high agreement.

A p-value of 0.05 was considered statistically significant.
**Fig. 1**: Figure 1: In all modalities lower limb length was defined by calculating the distance from the center of the femoral head to the center of the ankle joint space (left leg). Lower limb alignment angle was defined between a line through the center of the femoral head and the intercondylar notch of the femur and a line between the eminentia intercondylaris of the tibia and the center of the ankle joint (right leg).

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Fig. 2: Figure 2: Measurements of limb length and alignment angle were performed on CT scout view (a), CR (b) and EOS (c) using the aforementioned predefined structures (center femoral head, intercondylar notch of femur, eminentia intercondylaris of the tibia and the center of the ankle joint).

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Fig. 3: Figure 3: EOS acquisitions were post-processed on a separate workstation of the EOS unit using vendor-specific software (sterEOS 1.4.3.5112). An idealized model of the software was fused with the frontal and lateral projection of the lower limb by manually fitting contours of the model to predefined osseous landmarks (e.g. femoral head, femoral condyles, tibial head, medial and lateral malleolus) (a). A 3D model could then be generated and key measurements (limb length and limb alignment angle) were automatically calculated by the software according to the abovementioned definitions (b).

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Results

Mean limb lengths were 783.4mm (SD± 55.77mm, range 639-927mm), 784.7mm (SD±53.56mm, 655-924mm) and 779.4mm (SD±55.28mm, 633-921mm) for CT, CR and EOS, respectively. Mean alignment angle measurements were 2.2° (SD±5.50°, range -12°-20°), 2.5° (SD±6.89°, -17°-18°) and 3.7° (SD±6.62°, -14°-18°), respectively (Table 1).

Length and angle measurements differed significantly when comparing EOS to CT and CR by paired t-testing (p<0.001). However, no significant differences were seen between CT and CR for length and angle measurements, respectively (p= 0.328 and 0.562).

Bland-Altman analyses showed a small positive bias in length (3.94mm, SD±3.97; 5.25mm, SD±13.32) and a small negative bias in angle measurements (-1.41°, SD±2.52; -1.21°, SD±3.43) for CT and CR compared to EOS (Figure 4, Table 2).

A constant range of measurement differences and scatter in the graphs with increasing average was seen in comparisons and for both length and alignment angle measurements. Furthermore consistent variability of measurements across all graphs was seen.

ICCs for interreader agreements were 0.996, 0.996 and 0.997 for limb length and 0.949, 0.933 and 0.952 for angle measurements in CT, CR and EOS respectively (Table 3).
Table 1: Table 1: Descriptive Statistics of mean lower limb length and alignment angle measurements for different imaging modalities and both readers.

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Bland-Altman-Graphs

Fig. 4: Figure 4: Bland-Altman analysis of lower limb length (a-c) and lower limb angle alignment (d-f) measurements. Note constant range of measurement differences wh
increasing average and consistent variability across all graphs. For detailed values refer to Table 2.

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Table 2: Bland-Altman analyses of different modalities (CT vs CR, CT vs EOS and CR vs EOS) for lower limb length and alignment angle measurements.

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**Table 2:**

<table>
<thead>
<tr>
<th></th>
<th>CT vs CR</th>
<th>CT vs EOS</th>
<th>CR vs EOS</th>
</tr>
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<tbody>
<tr>
<td><strong>Lower Limb Length</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bias</td>
<td>-1.30</td>
<td>3.94*</td>
<td>5.25*</td>
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<td>SD of bias</td>
<td>13.39</td>
<td>3.97</td>
<td>13.32</td>
</tr>
<tr>
<td>95% CI</td>
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<td>3.16, 4.72</td>
<td>2.63, 7.86</td>
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<tr>
<td>lloa</td>
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<td>-3.84</td>
<td>-20.87</td>
</tr>
<tr>
<td>uloa</td>
<td>24.96</td>
<td>11.72</td>
<td>31.36</td>
</tr>
<tr>
<td><strong>Lower Limb Alignment Angle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bias</td>
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<td>-1.41*</td>
<td>-1.21*</td>
</tr>
<tr>
<td>SD of bias</td>
<td>3.58</td>
<td>2.52</td>
<td>3.43</td>
</tr>
<tr>
<td>95% CI</td>
<td>-0.91, 0.50</td>
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<td>-1.88, -0.55</td>
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<tr>
<td>lloa</td>
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<td>-7.92</td>
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<tr>
<td>uloa</td>
<td>6.81</td>
<td>3.52</td>
<td>5.51</td>
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</tbody>
</table>

SD = standard deviation  
95% CI = 95% confidence interval  
lloa = lower limit of agreement of 95% CI  
uloa = upper limit of agreement of 95% CI  
* = significant bias

**Table 3:** Intraclass correlation coefficients (ICC) of different modalities for calculation of interreader agreement between both readers.

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<table>
<thead>
<tr>
<th></th>
<th>limb length</th>
<th>limb alignment angle</th>
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<tbody>
<tr>
<td><strong>CT</strong></td>
<td>0.996</td>
<td>0.949</td>
</tr>
<tr>
<td><strong>CR</strong></td>
<td>0.996</td>
<td>0.933</td>
</tr>
<tr>
<td><strong>EOS</strong></td>
<td>0.997</td>
<td>0.952</td>
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</table>

**Table 3:**
Conclusion

Lower limb length and alignment measurements on CT, CR and EOS are comparable, however with a significant but small bias in favor of EOS scans. Interreader agreement is high for all modalities with the highest agreement in EOS.
References
