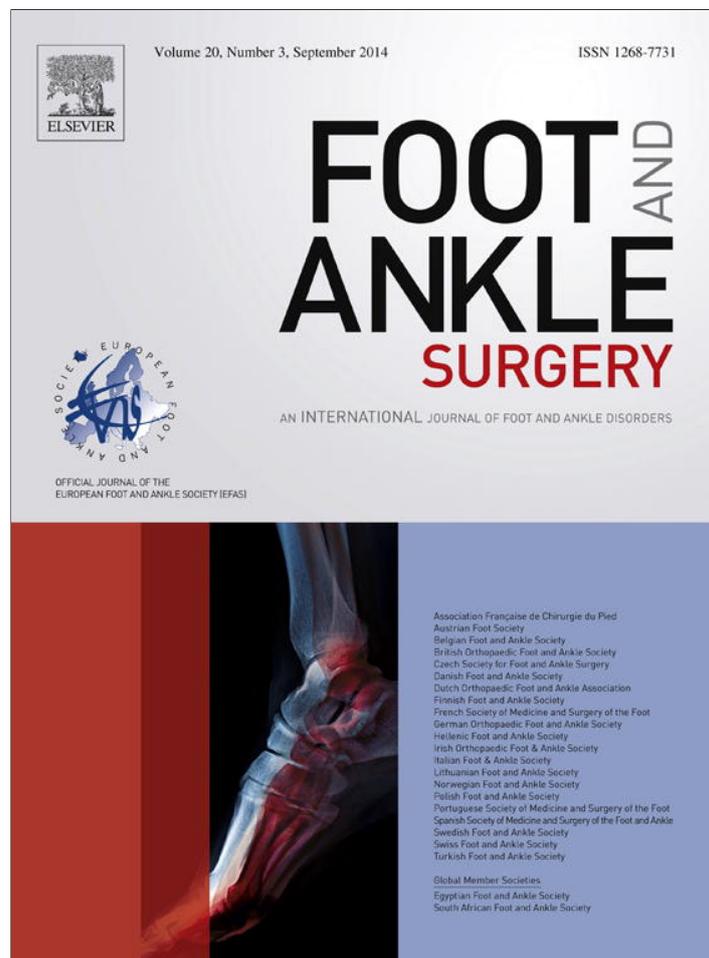


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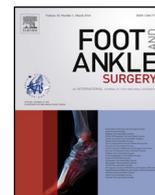
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PedCAT for 3D-imaging in standing position allows for more accurate bone position (angle) measurement than radiographs or CT



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ABSTRACT

Background: PedCAT (Curvebeam, Warrington, USA) is a new technology that allows 3D-imaging with full weight bearing which is not influenced by projection and/or foot orientation (as radiographs). The aim of this study was to compare time spent of the image acquisition, and comparison of specific bone position (angle) measurements between three imaging methods (radiographs, CT, pedCAT), and to analyze and compare measurement differences and inter- and intraobserver reliability.

Methods: In a prospective consecutive controlled study, 30 patients in which standard digital radiographs with full weight bearing in standing position (feet bilateral dorsoplantar and lateral views and Saltzman hindfoot view), CT without weight bearing, and pedCAT scan with full weight bearing in standing position were included, starting July 1, 2013. The following angles were measured for the right foot by three different investigators three times: 1st – 2nd intermetatarsal angle, talo-metatarsal 1-angle (TMT) both dorsoplantar and lateral projection, hindfoot angle, calcaneal pitch. The angles were digitally measured and compared (ANOVA with Post Hoc Scheffe test).

Results: The angles differed between radiographs, CT and pedCAT (ANOVA, all $p \leq .01$). The angles differed between pedCAT and both radiographs and CT (Post Hoc Scheffe test, each $p \leq .05$ except for TMT dorsoplantar and calcaneal pitch angles versus radiographs).

Conclusions: The angles differed between radiographs, CT and pedCAT, indicating that only pedCAT is able to detect the correct angles. PedCAT includes weight bearing in contrast to CT. PedCAT prevents inaccuracies of projection and foot orientation in contrast to radiographs due to the 3D dataset which is principally independent from projection and foot orientation.

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1. Introduction

The standard for diagnostic radiographic imaging in foot and ankle surgery is radiographs with full weight bearing [5]. The three-dimensional relationships of the bones in the foot are difficult to assess with standard radiographs due to superimposition of the different bones [1]. Angle measurements with standard radiographs could be inaccurate due to inaccuracies of the projection (orientation of (central) beam) and/or foot orientation [2,6,7]. 3D-imaging with conventional computed tomography (CT)

allows for exact analysis within the 3D-data that is not influenced by projection and/or foot orientation but lacks weight bearing [1,3]. PedCAT (Curvebeam, Warrington, USA) is a new technology that allows 3D-imaging with full weight bearing which should be not influenced by projection and/or foot orientation (Figs. 1 and 2).

The aim of this study was to compare time spent of the image acquisition, and comparison of specific angle measurements between the three methods (radiographs, CT, pedCAT), and to analyze and compare inter- and intraobserver reliability.

2. Methods

In a prospective consecutive study, 30 patients in which standard digital radiographs with full weight bearing in standing position, CT without weight bearing in supine position, and pedCAT with full weight bearing in standing position were included, starting July 1, 2013. The potential pathologies of the feet were registered but not further analyzed.

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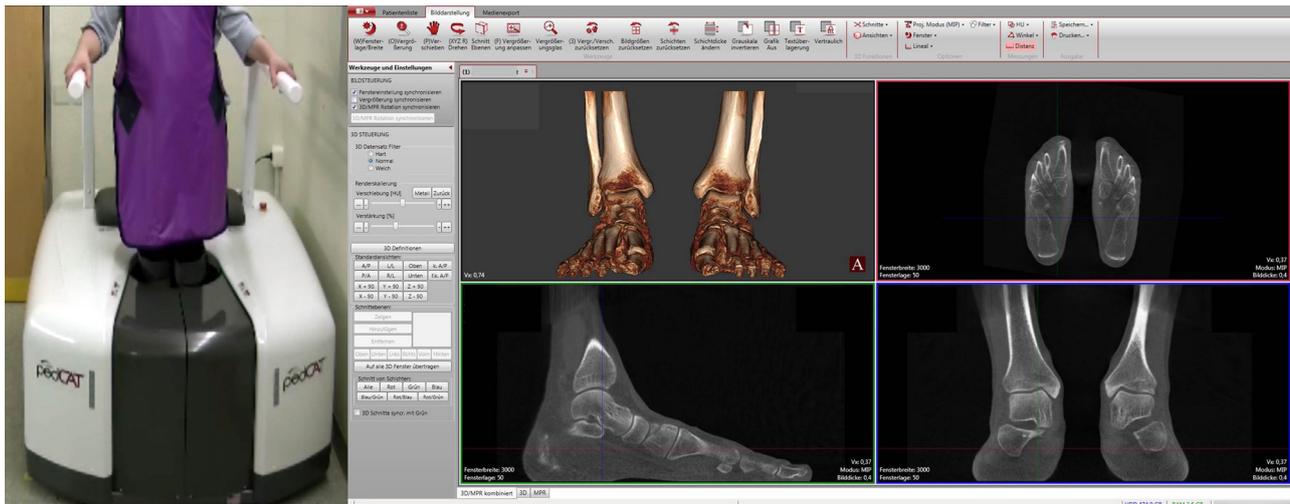


Fig. 1. pedCAT-scan and software screen. An X-ray emitter and a flat-panel-sensor on the opposite side are rotating horizontally around the feet. Resolution and contrast which are the principal parameters for image quality are comparable with modern conventional CT. Left, patient positioned in pedCAT[®] during scan. Sitting position is also possible for patients that are not allowed or able to stand. The grey part is a sliding door that is opened before and after the scan. The patient can walk into the device when the door is open. Right, software screen view with 3D-reformation (top left), axial reformation (top right, red frame), parasagittal reformation (bottom left, green frame) and coronal reformation (bottom right, blue frame). The standard view is with 1 mm slice thickness, shown by the red, green and blue lines. The red lines are corresponding to the axial reformation in the red frame, the green lines are corresponding to the parasagittal reformation in the green frame, and the blue lines are corresponding to the coronal reformation in the blue frame.

2.1. Inclusion and exclusion criteria, ethics

The inclusion criteria were age ≥ 18 years, presentation at the local foot and ankle outpatient clinic, and indication for radiographs and 3D-imaging (CT, pedCAT). The indication for Radiograph and 3D-imaging (CT, pedCAT) was defined following the local standard. For example no indication for 3D imaging (CT, pedCAT) was given for isolated forefoot deformities, whereas indication for 3D imaging (CT, pedCAT) was given for deformities in the midfoot and/or hindfoot region.

The exclusion criteria were age < 18 years, no indication for radiograph and/or 3D imaging (CT, pedCAT), and participation in other studies.

All three methods (Radiographs, CT, pedCAT) were approved by the relevant authority for diagnostic use at the local institution. Approval from the local ethical committee was proposed for simultaneous use of all three methods (Radiograph, CT, pedCAT) based on the indications as described above. Informed consent was obtained from all subjects.

2.2. Image acquisition

The radiographic image acquisition followed a standardized protocol with a fully digital device (Model Buck Diagnost, Philips, Hamburg, Germany) [5,10]. The patient was positioned on a special step with a holding apparatus for the digital film, the X-ray emitter

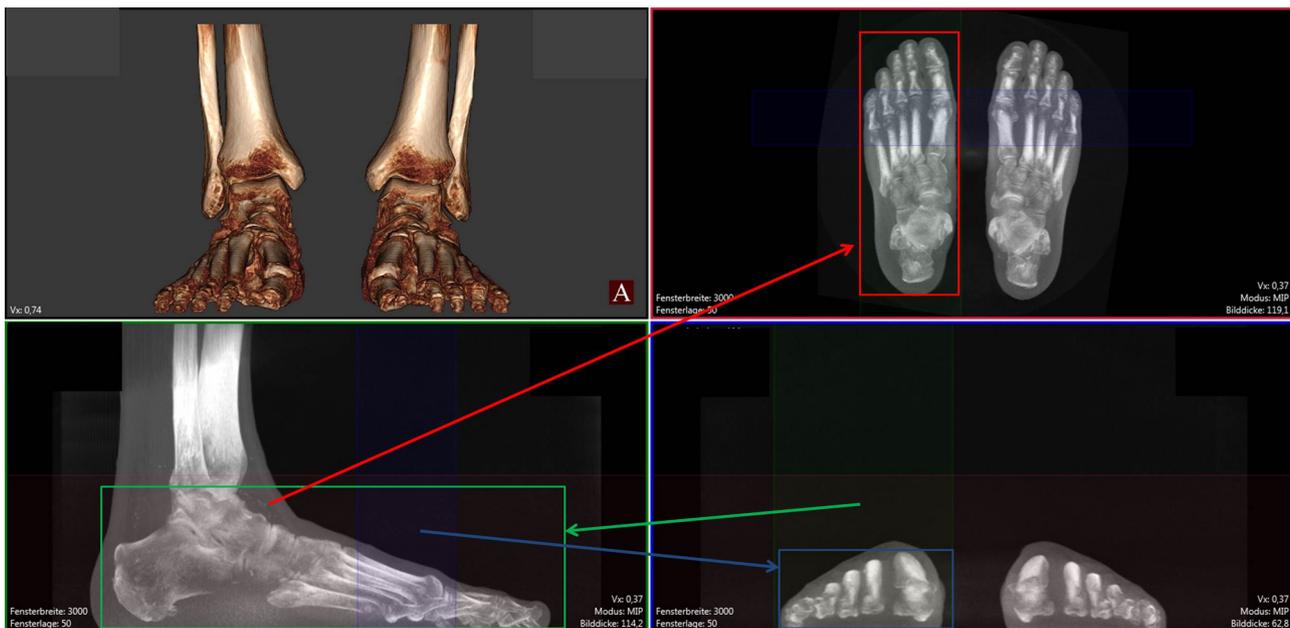


Fig. 2. pedCAT software screen view with increased slice thickness to create virtual radiographs. Top right, in red frame, virtual dorsoplantar radiograph created by increased slice thickness that contains entire foot (red arrow). Bottom left, in green frame, virtual lateral radiograph created by increased slice thickness that contains entire foot (green arrow). Bottom right, in blue frame, virtual metatarsal head skyline view radiograph created by increased slice thickness that contains the metatarsal heads (blue arrow).

was adjusted and the images were taken (feet bilateral dorsoplantar and lateral views and Saltzman hindfoot view [10]). The radiation exposure time was approximately 1/10th of a second for each image. For CT (Model Optima 520, General Electric Healthcare, Solingen, Germany; helical technique, 20 lines), the patient was positioned in supine position, and the feet were placed in a special holding device to ensure neutral foot and ankle position [8]. Both feet and ankles were scanned from 10 cm proximal to the ankle level. The slice thickness was adjusted to 1 mm and the pure scanning time was 60 s. For pedCAT (Model pedCAT, Curvebeam, Warrington, USA), the patient walked into the device, and was positioned in bipedal standing position as shown in Fig. 1. Technically, an X-ray emitter and a flat-panel-sensor on the opposite side are rotating horizontally around the feet. Resolution and contrast which are the principal parameters for image quality are comparable with modern conventional CT. The scanning time was 68 s.

2.3. Time spent

The time spent of the image acquisition was registered. Time spent was defined as the sum of the time needed for positioning the patient for the imaging and the time needed for the imaging as such as described above. The time for epidemiological data entry was not included. For the radiograph group the times for all four images (feet bilateral dorsoplantar, right foot lateral, left foot lateral, Saltzman hindfoot view bilateral) were added up to a total time.

2.4. Angle measurements

The angles were digitally measured with specific software (Radiographs, Jivex, Visus, Bochum, Germany; CT, Syngo XS version VE31GSL19P21VC10ASL129P167SP1, Siemens, Erlangen, Germany; pedCAT, Cubeview, version 2.4.0.5, Curvebeam, Warrington, USA).

The following angles were measured for the right foot by three different investigators three times: 1st – 2nd intermetatarsal angle, talo-metatarsal 1-angle (TMT) dorsoplantar and lateral projection, hindfoot angle, calcaneal pitch angle [9,10].

The 1st – 2nd intermetatarsal angle was defined as the angle created between the axis of the 1st and the 2nd metatarsal in the dorsoplantar view (Radiograph) or axial/horizontal reformation (CT, pedCAT). For CT and pedCAT the plane for the measurement was virtually rotated within the 3D-dataset to achieve an exact congruency to the bone axes of 1st and 2nd metatarsals.

The TMT angle was defined as the angle created between the axis of the 1st metatarsal and the talus [9] (Fig. 3). The dorsoplantar TMT angle was measured in the dorsoplantar view (Radiograph) or axial/horizontal reformation (CT, pedCAT) (Fig. 3, image top right). The lateral TMT angle was measured in the lateral view (Radiograph) or parasagittal reformation (CT, pedCAT) (Fig. 3, image bottom left). For CT and pedCAT the plane for the measurement was virtually rotated within the 3D-dataset to achieve an exact congruency to the bone axis of talus and 1st metatarsal.

The hindfoot angle was defined as the angle created between the axis of the distal tibia and the line between the centre of the talar dome and the posterior calcaneal process (Fig. 3). This angle is defined to be positive for hindfoot valgus and negative for hindfoot varus. It is measured in the Saltzman view (Radiograph) or coronal reformation (CT, pedCAT) (Fig. 3). For CT and pedCAT the plane for the measurement was virtually rotated within the 3D-dataset to achieve an exact congruency to the bone axis of the tibia and the axis of the hindfoot (Fig. 3, image bottom right). This was typically the case when this plane was congruent with the axis of the ankle, i.e. a line between medial and lateral malleolus comparable to a Mortise orientation but within a 3D-space. Fig. 3 (image bottom right) shows the orientation within the 3D dataset as described above with the adjusted rotation with the fibula and tibia aligned in the same virtual plane comparable to a Mortise view.



Fig. 3. PedCAT software screen showing an example of some angle measurements. The 3D-reformation (top left), shows how the 3D-dataset was virtually rotated to allow for exact congruency of the plane of the reformations with the bone axes as described in the methods section. Top right, measurement of the dorsoplantar TMT angle (-9.2° in this example); bottom left, measurement of the lateral TMT angle (-12.2° in this example); bottom right, measurement of the hindfoot angle also as described in the methods section (17.3° in this example). The hindfoot angle measurement was typically performed in another plane which cannot be displayed simultaneously with planes for the dorsoplantar and lateral TMT angles. This modified presentation was chosen for this figure for to allow simultaneous presentation of three angles within one figure. The lines that define the centres of the bones proximally or distally are exactly 50% of the measured entire bone thickness, i.e. the center of the diameter.

The calcaneal pitch angle was defined as the angle created between line between the lowest part of the posterior calcaneal process and the lowest part of the anterior calcaneal process, and a horizontal line. The calcaneal pitch was measured in the lateral view (Radiograph) or parasagittal reformation (CT, pedCAT). For CT and pedCAT the plane for the measurement was virtually rotated within the 3D-dataset to achieve an exact congruency to an exactly parasagittal plane.

All bone axes (Tibia, talus, metatarsals) were defined as the straight line between the centres of the bones proximally and distally. These bone centres were defined by linear measurements (Fig. 3). The TMT angles were defined to be negative for abduction in the dorsoplantar radiograph and for dorsiflexion in the lateral radiographs [9].

2.5. Statistics

The parameters were compared intra- and interobserver, and between the different methods (Radiograph, CT, pedCAT) (ANOVA with Post Hoc Scheffe test). The null hypothesis at a significant level of 0.05 was formulated that the different angles did not differ between the three methods. For non-significant findings, a power analysis was indicated. Sufficient power was defined as ≥ 8 .

3. Results

3.1. Time spent

The time spent for the image acquisition was 902 ± 70 s for radiographs, 415 ± 46 s for CT and 270 ± 44 s for pedCAT on average (ANOVA, $p < .001$).

3.2. Angle measurement – differences between methods

The angles differed between radiographs, CT and pedCAT (ANOVA, all $p \leq .01$) (Table 1). The angles differed between pedCAT and both radiographs and CT (Post Hoc Scheffe test, each $p \leq .05$) except for TMT dorsoplantar and calcaneal pitch angles for pedCAT versus radiographs). The null hypothesis was rejected for all angles

Table 1
ONEWAY ANOVA radiographs versus CT versus PedCAT and Post Hoc Test PedCAT versus radiographs and CT.

ONEWAY ANOVA							
Parameter	Radiographs		CT		PedCAT		p
	Mean	STD	Mean	STD	Mean	STD	
IM-angle	7.7	3.3	7.8	3.9	9.3	3.5	<0.001
TMT dorsoplantar	-6.2	12.4	4.3	10.0	-5.0	12.0	<0.001
TMT lateral	-5.2	8.2	0.5	8.4	-7.6	8.2	<0.001
Hindfoot angle	2.4	6.9	5.4	5.6	10.1	7.1	<0.001
Calcaneal pitch angle	17.5	6.3	16.5	5.0	17.8	5.4	0.01
Post Hoc Scheffe Test							
Parameter	PedCAT vs.						p
IM-angle	Radiographs						<0.001
	CT						<0.001
TMT dorsoplantar	Radiographs						0.561
	CT						<0.001
TMT lateral	Radiographs						0.003
	CT						<0.001
Hindfoot angle	Radiographs						<0.001
	CT						<0.001
Calcaneal pitch angle	Radiographs						0.701
	CT						0.013

IM, 1st – 2nd intermetatarsal angle; TMT, talo – 1st metatarsal – angle; STD, standard deviation.

except for TMT dorsoplantar and calcaneal pitch angles between pedCAT and radiographs.

3.3. Angle measurement – intra- and interobserver reliability

Regarding intraobserver reliability, the angles did not differ between measurement 1, measurement 2 and measurement 3 for all three investigators and for all three methods (Radiograph, CT, pedCAT) (ANOVA, each $p > .9$, power > 8).

Regarding interobserver reliability, the angles did not differ between the three investigators for measurement 1, measurement 2 and measurement 3 for all three methods (Radiograph, CT, pedCAT) (ANOVA, each $p > .9$, power $> .8$).

4. Discussion

This is the first study comparing bone position (bone axis angle) measurements between standard radiographs with weight bearing, standard CT without weight bearing and 3D imaging with weight bearing (PedCAT).

4.1. Time spent

The image acquisition with pedCAT (270 s) is 70% faster than with radiographs (902 s) and 35% faster than with CT (270). This difference is not caused by the scanning time as such which is much lower for radiographs (4 times 1/10 of a second) than for CT (60 s) or pedCAT (68 s). The positioning of the patient and the adjustment of the X-ray emitter comprises the time spent for radiographs and the positioning of the patient and the adjustment of the device with specifying the scan area and sliding the patient to the correct position for the scan for CT. For the pedCAT the patient positioning is the fastest and no further adjustments are needed so that only pressing a button is necessary to perform the scan.

4.2. Angle measurement – differences between methods

The angles differed between radiographs, CT and pedCAT. The difference as such is a fact but the difference does not if one of the methods measures correct and which one. However, when considering technical issues it is obvious that the pedCAT is able to detect the correct angles because pedCAT scans under weight bearing and obtains a 3D-dataset which is independent of foot position and projection. Consequently, the significant different angles (Table 1) measured with radiographs or CT in comparison with pedCAT imply that radiographs or CT do not allow for correct angle measurement (except radiographs for calcaneal pitch angle and TMT dorsoplantar). The incorrect angles measured with radiographs are probably caused by inaccuracies of projection and foot orientation, and the incorrect angles measured with CT by missing weight bearing (see detailed discussion below). PedCAT includes weight bearing in contrast to CT. PedCAT countervails inaccuracies of projection and foot orientation in contrast to radiographs due to the 3D-dataset which is principally independent from projection and foot orientation. If a malposition of the foot during image acquisition exists, the planes of the pedCAT-reformations (also CT) could be rotated as described above to ensure exact angle measurement despite foot malposition. We did not quantitatively assess the extent of plane rotation needed but the investigators' interpretation was that the least plane rotation was needed for dorsoplantar TMT and calcaneal pitch angles and more plane rotation for the other angles. This reflects the results that radiographs were not different for calcaneal pitch angles and dorsoplantar TMT that are obviously less likely to be influenced by inaccurate foot position, and/or projection which is also an issue

for radiographs. Inaccuracy of the projection, i.e. the (central) beam(s), is obviously an underestimated problem for radiographic imaging. We were not able to isolate the factors inaccurate foot position or inaccurate projection. The resulting different angles in comparison with pedCAT reflect probably a combination of both inaccuracies.

4.2.1. 1st – 2nd intermetatarsal angle

This angle was lower for radiographs (7.7) and CT (7.8) than for pedCAT (9.3). We believe that the different angles for radiographs in comparison with pedCAT reflect a combination of both factors inaccurate foot position and inaccurate projection of the radiographic image acquisition. A slight supination of the foot might cause this as well as the bilateral dorsoplantar imaging that is performed with a central beam in the center of the image and between both feet resulting in minimally oblique (non-perpendicular in relation to the film) beams at both feet. For CT, the missing weight bearing will probably cause a true lower angle because CT is independent of foot position and projection as pedCAT.

4.2.2. TMT dorsoplantar

This angle was lower for radiographs (–6.2) and pedCAT (–5.0) than for CT (4.3). The higher or better less negative angles for CT than for radiographs and pedCAT are obviously caused by the missing weight bearing. For radiographs, inaccuracies of foot position and projection are either not relevant or might abrogate each other. We believe that these inaccuracies are more likely not relevant because the investigators' interpretation was that the least plane rotation for measurement within the pedCAT data was needed for this angle (see above).

4.2.3. TMT lateral

This angle was higher for radiographs (–5.2) and much higher for CT (0.5) than for pedCAT (–7.6). The much higher or better much less negative angles for CT than for pedCAT are obviously caused by the missing weight bearing. For radiographs, a slight supination of the foot could possibly increase the angle or better decrease the negative value of this angle. More probable seems to be that the axis of the talus is "sticking out" of the plane of the 2D-radiograph based on the abduction of the mid- and forefoot in a flatfoot which is then positioned with the mid- and forefoot parallel to the film but the talus in slight internal rotation and not parallel to the film.

4.2.4. Hindfoot angle

This angle was lower for radiographs (2.4) and CT (5.4) than for pedCAT (10.1). Again, the higher angles for CT than for pedCAT are obviously caused by the missing weight bearing. For radiographs, the foot position with both feet parallel to each other and the longitudinal foot axes perpendicular to the film might be the most important reason for the lower angles. This position is typically not a Mortise view which would be more internal rotation of the ankle and foot. For pedCAT the plane for the measurement was virtually rotated within the 3D-dataset to achieve an exact congruency to the bone axis of the tibia and the axis of the hindfoot. This was typically the case when this plane was congruent with the axis of the ankle, i.e. a line between medial and lateral malleolus comparable to a Mortise orientation but within a 3D-space. This is virtually more internally rotated than in the radiograph group resulting in a higher angle at least for all hindfeet with valgus position which were the majority of the cases as shown by the positive values on average (Median also positive, 5.6).

4.2.5. Calcaneal pith angle

This angle was higher for radiographs (17.5) and pedCAT (17.8) than for CT (16.5). The lower angles for CT than for radiographs and

pedCAT are obviously caused by the missing weight bearing. For radiographs, inaccuracies of foot position and projection are either not relevant or might abrogate each other. We believe that these inaccuracies are more likely not relevant because the investigators' interpretation was that the least plane rotation for measurement within the pedCAT data was needed for this angle (see above).

4.3. Angle measurement – intra- and interobserver reliability

The intra- and interobserver reliability is sufficient for all three methods. This is probably based on the digital software based measurements, and the experience of all three investigators regarding these kind of digital measurements. Based on the sufficient intra- and interobserver reliability for all three methods, differences between the methods are not influenced by differences of intra- and interobserver reliability.

4.4. Shortcomings of the study

The shortcomings of this study are not the typical ones like missing analysis of intra- and/or interobserver reliability or missing power analysis of the statistical test. The low case number might be a shortcoming. We feel that a (much) higher case number would have led to significant differences of the dorsoplantar TMT and calcaneal pitch angles when comparing radiographs with pedCAT. All other angles differed already significantly which led to the conclusions, so a higher case number would probably not change the conclusions. The angular measurement as such could possibly be influenced by the investigators in that manner that the investigators would have desired that one method, for example the pedCAT, would perform better than the other methods. However, this kind of influence principally results in a low intra- and/or interobserver reliability which were sufficient for all three methods. We did not measure how difficult and time consuming the measurements were. The reason for this is that the type of software and version and above all the experience of the investigator might influence this time much more than the method as such. Another shortcoming might be that we were not able to isolate the factors inaccurate foot position or inaccurate projection of the radiographs group. The radiographic image acquisition followed a standardized protocol which was not further assessed [5]. Finally, the potential foot pathologies of the subjects were registered but not analyzed. The pathological angles (not neutral or 0 for TMT dorsoplantar and lateral, hindfoot and calcaneal pith angle on average) imply that relevant pathologies were present which is also based on the inclusion criteria. However, we did not want to investigate different pathologies but the technical parameters of the different imaging methods.

4.5. Radiation dose

A comparison of the radiation dose of the pedCAT with radiographs and a standard CT-scan was not performed in our study. The applied energy (product of amperage, voltage and time) is typically adjusted and registered during a CT scan, radiographs or pedCAT-scan. However, the dose as such depends on the structure of the scanned object and is not measured during the imaging. Recently, the dose of foot/ankle radiographs, CT and pedCAT was *measured* and analyzed using a foot and ankle phantom [4]. The dose for adults for three radiographs from one foot (anterio-posterior/dorsoplantar + lateral + oblique) was 0.7 μ Sv, the dose for a bilateral pedCAT scan 4.3 μ Sv, and the dose for conventional CT of one foot/ankle 25 μ Sv [4]. The means that a bilateral pedCAT scan has a comparable dose as 18 unilateral radiographs of the foot, and 17% of an unilateral CT of the foot and ankle [4]. This study did also measure the dose of an unilateral

pedCAT scan which was 1.4 μ Sv comparable to 6 unilateral radiographs of the foot, and 5.6% of an unilateral CT of the foot and ankle [4]. For the later clinical use this radiation dose is relativized because virtual radiographs could be created from the pedCAT data as shown in Fig. 2. We have created the following virtual radiographs from the pedCAT-scan data: entire foot dorsoplantar and lateral views, ankle anteroposterior, Mortise and lateral views, Saltzman views, metatarsal head skyline views, Broden' views (all views bilateral).

4.6. Cost

Another issue is cost as always. A device for radiography is around 75,000 Euro, a pedCAT is 150,000 Euro and a CT is starting at 200,000 Euro (all prices exclusive VAT). However, devices for radiographs and CT can be used for other body regions also whereas the pedCAT can only be used for the foot and ankle region. The reimbursement is different for different countries and types of insurance. In the country in which this study has taken place the reimbursement for a pedCAT scan is comparable with a CT scan and 15 radiographs. Time spent is also a cost factor. In our study the time spent for the pedCAT scan was 70% faster than radiographs and 35% faster than a CT scan. Still, a pedCAT might be cost-effective for institutions with one foot and ankle surgeon but we think that group with two or more foot and ankle surgeons or foot and ankle departments might be able to run a pedCAT not only cost-effectively but also with creating profit even when the quality of the imaging is not taking into consideration. It has been demonstrated in many U.S. institutions and private practices that a single foot & ankle surgeon can operate the pedCAT cost effectively and generate a sizable surplus. The same should apply to other parts of the world. This can also be established by comparing the pedCAT's typical lease or finance cost (between 3000 and 4000 Euros per month depending on the lease terms) and reimbursement per scan (around 200 Euros). These example figures would permit a practice to justify the cost with 15–20 scans a month, which should be achievable even with a single surgeon. This model has been well established for almost similar CBCT devices for dental/maxillofacial/ENT imaging, with hundreds of such devices installed with single practitioners in Germany and across Europe.

4.7. Approval for use

Approval for imaging is specific for the pedCAT. Actually, most countries classify the device as a CT. However, a more common trend is to differentiate between conventional CT and Cone Beam CT, and apply exemptions for CBCT from typical CT requirements due to its specialized and limited applications, coupled with low dose and dramatically less complexity. This same model is very common and already established with CBCT devices for maxillofacial & ENT imaging.

In some countries like the one where the institution of authors is located, this device is not classified as a CT which allows non-radiologists to prosecute a pedCAT in their institution in contrast to CT which is mostly only approved for prosecution by radiologists. In conclusion, everybody who is approved to run his or her radiograph device will be allowed to run a pedCAT.

4.8. Standard imaging?

When considering the potential of the pedCAT as faster image acquisition and more accurate bone position representation than radiographs and CT with acceptable radiation dose and cost-effectiveness, one could conclude the pedCAT might have the potential to become the standard diagnostic imaging in foot and ankle surgery. When a pedCAT is available as in our institution, CT

which has no better image quality (resolution and contrast) but 10 times radiation dose, 1.5 times time spent for image acquisition, higher device cost, and radiologist needed is almost obsolete. Since September 2013, we limited the use of a conventional CT to patients with acute injury that are not able to stand or sit in the pedCAT. We compared the numbers of CT and pedCAT over a six month period in which both were available at our institution (September 2013–February 2014) with a six month period in which only CT was available (September 2012–February 2013). In the period with only CT, 148 CT scans were obtained, and in the period with both 16 CT scans and 135 pedCAT scans. This corresponds to a reduction of conventional CT scans of almost 90%. We are expecting the same development with conventional radiographs. We have not performed the same transposition from radiographs to pedCAT as for CT to pedCAT because we do not have enough pedCAT-workstations for creation, presentation and printout of the virtual radiographs. We do plan to switch completely from conventional radiographs to virtual radiographs when these technical requirements are fulfilled.

The results of this study call into question if the existing standard angles of angles for pathology classification are also correct for the pedCAT. The answer is no and the reason is obvious because the pedCAT measures different angles as measured with radiographs. For example the 1st – 2nd-intermetatarsal angles were 7.7° on average for radiographs and 9.3° on average for pedCAT with a difference of 1.6° (Table 1). What caused this difference? Again, we believe that the different angles of the pedCAT in comparison with radiographs reflect a combination of both factors inaccurate foot position or inaccurate projection of the radiographic image acquisition as discussed above in detail. What does this mean? Are we able to perform a distal osteotomy of the first metatarsal for hallux valgus correction in cases with 1st – 2nd-intermetatarsal angle 17.6° measured with pedCAT comparing with 16° with radiographs? What about the significant differences of the hindfoot angles? When it comes to implantation of total ankle replacements and/or surgical corrections of the hindfoot, this might be important information. We cannot answer these questions at this stage but we believe that the standard angles and angles for classification of pathologies need to be defined for pedCAT comparable technologies. Another important part of the discussion based on the results of this study is whether conventional radiographs could still serve as standard diagnostic imaging. The logical answer from a scientific point of view is no because the angles that are measured with conventional radiographs are not correct. Nevertheless, we believe that conventional devices for radiographs will not disappear for a long time and this will be the same with all the non-validated foot and ankle scores that are used again and again even though everybody knows that they are not validated, i.e. they are not correctly measuring. At the end conventional devices for radiographs might disappear as non-validated scores but nobody knows when validated scores and new imaging technologies like pedCAT might be used instead as already in our institution.

In conclusion, the bone position represented by the measured angles differed between radiographs, CT and pedCAT, indicating that only pedCAT is able to detect the correct angles. PedCAT includes weight bearing in contrast to CT. PedCAT prevents inaccuracies of projection and foot orientation in contrast to radiographs due to the 3D-dataset which is principally independent from projection and foot orientation. PedCAT or a similar technology has potential to become the standard diagnostic imaging.

Conflict of interest statement

None of the authors or the authors institution received funding in relation to this study. The corresponding author is consultant for

Curvebeam, Small Bone Innovations and Intercus, proprietor of R-Innovation, and joint proprietor of First Worldwide Orthopaedics.

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