Results from more than 13,000 Weight-Bearing CT scans over 6.8 years. Impact on costs, radiation exposure and time spent

Ergebnisse von mehr als 13.000 Scans einer 3D-Röntgenbildgebung mit Belastung über 6,8 Jahre. Auswirkungen auf Strahlenbelastung, Zeitbedarf und Kosten

Martinus Richter a, b, *, Francois Lintz a, c, Cesar de Cesar Netto a, d, Alexej Barg a, e, Arne Burssens a, f, Scott Ellis a, g

E-Mail: martinus.richter@sana.de (M. Richter).

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Abstract

Background: The purpose of this study was to assess the benefit of using Weight-Bearing CT (WBCT) instead of radiographs (R) and/or CT in a foot and ankle center regarding time spent for image acquisition, radiation dose, and cost effectiveness.

Material and Methods: All patients who obtained WBCT (PedCAT) from July 1, 2013 until March 15, 2020 were included in the study. Age, sex, primary pathology were analyzed. All parameters were compared between the time period using WBCT (yearly average) with the parameters from 2012, i.e. before availability of WBCT. The time spent for image acquisition (T) and radiation dose (RD) was calculated.
based on measured values from previous studies. For analysis cost effectiveness, device cost, reimbursement and working time cost of radiology technicians were taken into consideration within the local circumstances.

**Results:** 13,156 WBCT scans were obtained in 5,798 patients (5,798 (44%) before treatment; 7,358 (56%) follow-up; mean age, 52.2; 46% male). Primary pathologies were forefoot deformities (n = 1,189 (21%)) and ankle instability/cartilage defect (n = 832 (14%)), and hindfoot deformity (n = 765 (13%)). 1,935 WBCT scans were obtained on average yearly, and 10.2 CTs (WBCT group). In 2012, 1,850 R and 254 CTs were obtained (R(+CT) group). Yearly RD was 4.3 uSv for WBCT group and 4.8 uSv for R(+CT) group (difference 0.5 uSv decrease with WBCT 10%, p < 0.01). Yearly T was 113 hours in total (3.5 minutes per patient) for WBCT group and 493 hours in total (16.0 minutes per patient) for R(+CT) group (difference, 380 hours, decrease with WBCT, 77%, p < 0.01). Yearly profit was 53,543 Euro for WBCT group, -723 Euro for R(+CT) group.

**Conclusions:** 13,156 WBCT scans in 5,798 patients as substitution of R(+CT) over a 6.8 year period at a foot and ankle center resulted in 10% decreased RD (minus 0.5 uSv on average per patient). Yearly T decreased 380 hours (77%) in total (12.0 minutes per patient). Yearly financial income increased more than 54,000 Euro in total (58 Euro per patient). RD decreased despite higher radiation dose for WBCT than for R alone, based on substitution of a high number of CTs by WBCT. Other centers with low usage of CT might not decrease RD by substituting R alone by WBCT.

**Zusammenfassung**

**Hintergrund:** Ziel dieser Studie war die Analyse der Auswirkungen von 3D-Röntgenbildung mit Belastung (WBCT) anstatt von konventionellen Röntgenbildern (R) und/oder CT in einem Zentrum für Fuß- und Sprunggelenkchirurgie der Maximalversorgung hinsichtlich Strahlenbelastung, Zeitbedarf und Kosteneffektivität.

**Material und Methoden:** Alle Patienten bei denen WBCT (PedCAT, Curvebeam, Hatfield, PA, USA) von 01.01.2013 bis 15.03.2020 wurden als WBCT Gruppe in die Studie eingeschlossen, und alle Patienten bei denen R und/oder CT 2012 erfolgte (RCT Gruppe). Alter, Geschlecht, primäre Pathologie, Zeitaufwand Bildakquisition (T) und Strahlenbelastung (RD) wurden zwischen den Gruppen verglichen. Für T und RD wurden Messwerte aus einer früheren Studie zugrunde gelegt. Für die Analyse der Kosteneffektivität wurde die Gerätekosten für WBCT (nicht für RCT, da bereits früher vorhanden) inkl. Unterhaltskosten, Erlös und Personalkosten der röntgentechnischen Assistenten einbezogen.

**Ergebnisse:** 13,156 WBCT Scans wurden bei 5,798 Patienten durchgeführt (5,798 (44%) präoperativ; 7,358 (57%) Nachuntersuchung(en); Durchschnittsalter, 52,2 Jahre; 46% männlich. Primäre Pathologien waren Vorfußdeformitäten (n = 1,189 (21%)), OSG Instabilität/Knorpelschaden (n = 832 (14%)) und Rückfußdeformitäten (n = 765 (13%)). In der WBCT Gruppe wurden 1,935 WBCT Scans und 10,7 CTs im Durchschnitt pro Jahr durchgeführt. In der RCT Gruppe erfolgen 1,850 R und 254 CTs. Die jährliche RD betrug im Durchschnitt 4,3/4,8uSv pro Patient WBCT/RCT Gruppe. Die jährliche T betrug im Durchschnitt 113 h (3,5 Minuten/Patient)/493 h (16,0 Minuten/Patient) für WBCT/RCT Gruppe. Der jährlich finanzielle Profit betrug im Durchschnitt pro Jahr 53,543/-723 Euro für WBCT/RCT Gruppe.

**Schlussfolgerungen:** 13,156 WBCT Scans bei 6,798 Patienten über einen Zeitraum von 6,8 Jahren als Substitution für R (+CT) führten zu einer reduzierten RD für das gesamte Patientenkollektiv von 10% (0,5uSv pro Patient) trotz höherer RD für WBCT als für R aufgrund der deutlich geringeren Anzahl von CTs. Die jährliche T verringerte sich um 380 h (77%) gesamt (12 Minuten pro Patient). Der jährlich finanzielle Profit stieg um mehr als 54.000 Euro (58 Euro/Patient).
Introduction

Weightbearing CT (WBCT) has been proven to more precisely measure bone position than conventional sequencing including systematic weightbearing radiograph series (R) and optional conventional CT without weightbearing (CT)\[4,13,36,43,44,46,47,59\]. These improvements are attributed to the absence of superimposition and the possibility to account for rotational errors after the image process\[2,44,46\]. Time spent on image acquisition (T) has shown to be lower for WBCT than for R and CT\[46\]. Radiation dose (RD) for WBCT has also shown to be lower than for CT\[44,46\]. The cost-effectiveness of using WBCT clinical settings is questionable. As far as we know, T, RD and especially cost-effectiveness have not been investigated in a high number of patients so far. The purpose of this study was to assess the potential benefits of using WBCT instead of R and/or CT in a foot and ankle department, regarding RD, T, and cost-effectiveness.

Methods Study design

A WBCT device (PedCAT, Curvebeam, Warrington, PA, USA) was put into operation from July 1, 2013 in the first author’s foot and ankle department. All patients who obtained WBCT (bilateral scan) and/or CT from July 1, 2013 until March 15, 2020 were included in the study (WBCT group).

Control group

All patients who obtained radiographs and/or CT from January 1 to December 31, 2012 were included in the control group (RCT group).

No exclusion criteria for patients were defined (both groups). Initial radiographs in trauma patients and early postoperative (one to four days) radiographs were excluded from the study (both groups).

Data acquisition

Age, gender, primary pathology location, and additional CT (bilateral feet and ankles) were registered. Pathology location was differentiated in ankle, hindfoot, midfoot, forefoot, and multiple other locations based on anatomy as follows: hindfoot between ankle and Chopart joint, midfoot between Chopart and Lisfranc joints, and forefoot distal to Lisfranc joint. Involvement of the joints were defined relative to the main neighbouring location or, when unclear, as multiple location.

Imaging time (T)

T was calculated based on an analysis of previous studies as follows: R (bilateral feet dorsoplantar and lateral, metatarsal head skyline view), 902 seconds; CT (bilateral feet and ankle), 415 seconds; WBCT (bilateral), 207 seconds\[46\].

Radiation dose (RD)

RD per patient was calculated based on previous phantom measurements as part of obligatory standard periodic quality assurance protocols: R, 1.4 uSv; CT, 25 uSv; and WBCT 4.2 uSv\[37\].

Cost-effectiveness

For analysis of cost-effectiveness, device cost, working time cost of radiology technicians (similar to T), and reimbursement in the local setting were taken into consideration for the WBCT group. The total device cost was calculated at a 200,000 Euro acquisition cost with a 5-year asset depreciation range (40,000 Euro yearly) and an annual 5,000 Euro maintenance cost, i.e. 45,000 Euro yearly cost for the WBCT group. No device costs were included for the RCT group since the R and CT devices were already installed. Staff costs were calculated by multiplication of T with 20 Euro per hour (based on local practice fares). The only reimbursement that could be considered was the one generated by privately insured patients or self-payers which corresponded to 15.5/15.1% of WBCT/RCT groups at a rate of 30 Euro for each R series and 300 Euro for each CT/WBCT. Vice versa, no reimbursement was achieved and considered for the study for all other patients (with public insurance). The potential profit was then considered in total and per patient (Table 2).

Data analysis / control group

All parameters were compared between WBCT and RCT group.

Statistics

Either a Student’s T-test or Chi-square test were used for comparison between groups with normal distributed and binomial data, respectively. P-values were considered significant when lower than .05. IBM SPSS Statistics 25 (SPSS, Inc., Chicago, IL, USA) was used.
Table 1  Epidemiology and pathology location RCT and WBCT groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RCT (mean, range)</th>
<th>WBCT (mean, range)</th>
<th>Test; p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean, range)</td>
<td>53.8 (6-91)</td>
<td>52.2 (8-92)</td>
<td>t-test; 0.7</td>
</tr>
<tr>
<td>Gender (male n, %)</td>
<td>779 (42%)</td>
<td>2,667 (49%)</td>
<td>Chi2; 0.6</td>
</tr>
<tr>
<td>Pathology location</td>
<td>n</td>
<td>n</td>
<td></td>
</tr>
<tr>
<td>Ankle</td>
<td>104</td>
<td>832</td>
<td></td>
</tr>
<tr>
<td>Hindfoot</td>
<td>98</td>
<td>765</td>
<td></td>
</tr>
<tr>
<td>Midfoot</td>
<td>78</td>
<td>523</td>
<td></td>
</tr>
<tr>
<td>Forefoot</td>
<td>182</td>
<td>1,189</td>
<td></td>
</tr>
<tr>
<td>Multiple locations</td>
<td>423</td>
<td>2,489</td>
<td></td>
</tr>
</tbody>
</table>

RCT group, group from 2012 with conventional radiographs and optional CT; WBCT group, group July 1, 2013 until, March 15, 2020 with WBCT and additional conventional radiographs and CT.

Table 2  Imaging data RCT and WBCT groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RCT (mean, range)</th>
<th>WBCT (mean, range)</th>
<th>T-test; p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient number</td>
<td>885</td>
<td>853±68</td>
<td></td>
</tr>
<tr>
<td>Radiographs (series, n per year)</td>
<td>1,85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WBCT (n per year)</td>
<td></td>
<td>1,935±94</td>
<td></td>
</tr>
<tr>
<td>CT (n per year)</td>
<td>254</td>
<td>10.7±2.9</td>
<td></td>
</tr>
<tr>
<td>Radiation dose per patient (uSv)</td>
<td>4.8±4.3</td>
<td>4.3±1.5</td>
<td>.01</td>
</tr>
<tr>
<td>Time spent radiology technician</td>
<td>493</td>
<td>113±19.6</td>
<td>.01</td>
</tr>
<tr>
<td>Time spent radiology technician</td>
<td>15.59±8.04</td>
<td>3.29±2.56</td>
<td>.01</td>
</tr>
<tr>
<td>Private insurance / self-payers</td>
<td>15.1</td>
<td>15.5</td>
<td></td>
</tr>
<tr>
<td>Profit (Euro per patient)</td>
<td>-723</td>
<td>53,543±6,834</td>
<td>.01</td>
</tr>
<tr>
<td>Profit (Euro per patient)</td>
<td>.82</td>
<td>57.26±12.34</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>

RCT group, group from 2012 with conventional radiographs and optional CT; WBCT group, group July 1, 2013 until, March 15, 2020 with WBCT and additional conventional radiographs and CT. Numbers for WBCT group are average yearly numbers.

Results

13,156 WBCT scans were obtained in 5,798 patients (WBCT group). 5,798 (44%) scans were performed before treatment, and 7,358 (56%) at follow-up between 3 months and 6.8 years after operative treatment. 1,935 WBCT scans and 10.7 CTs (all before treatment) were obtained on average yearly. The mean age of the scanned patients was 52.2 years (range, 8-92), and 46% were male. Table 1 shows the pathology location. The most common single location was forefoot (21%). In 2012, 1,850 Rs and 254 CTs were obtained from 885 patients (RCT group). The yearly average RD was 4.3 uSv for WBCT group and 4.8 uSv for RCT group (mean difference of 0.5 uSv; a 10% decrease for the WBCT group, p<0.01) (Table 2). The mean yearly T was 113 hours in total (3.5 minutes per patient) for the WBCT group and 493 hours in total (16.0 minutes per patient) for the RCT group (mean difference of 380 hours; a 77% decrease for the WBCT group, p<0.01) (Table 2). The mean yearly cost-effectiveness was a profit of 53,543/-723 Euros for WBCT/RCT groups, respectively 57.26/-82 Euros per patient (Table 2). Consequently, there is an overall profit increase of 54,267 Euros (58.1 Euros per patient) for the institution.

Discussion

This study confirmed WBCT use as standard of care resulted in lower radiation dosage and procedure time and was financially profitable. In our experience, these benefits offset costs within the first year of introduction, despite a very unfavourable local reimbursement situation; no specific code existed for patients without private insurance or self-payers. The current results confirm the results from an earlier study with 11,000 WBCT scans over 5.8 years[44].

Before, all studies analysing WBCT focused on bone position measurement accuracy and/or pathology detection, leaving little room to investigate the technical superiority and cost-effectiveness of WBCT relative to R and CT[1–20,22–36,38–42,45,46,49–60]. Despite these advantages, WBCT has yet to replace R and CT sequences in the standard assessment of foot and ankle patients. Arguments like higher RD in relation to R and device costs have hindered the broader distribution of WBCT[44,48]. Also, most institutions have already installed R and/or CT devices and are thus reluctant to additionally invest in a WBCT device[44]. To the best of our knowledge, this is the first study to investigate
Results might differ between device types or countries, the reimbursement situation can vary drastically\textsuperscript{[44]}. Our calculation is just one example in a special setting, and the numbers might differ in other countries with different insurance settings\textsuperscript{[44]}. The special situation here was that only patients with private insurance or self-payers (around 15\% of all patients in WBCT and RCT groups) were charged at all for the imaging\textsuperscript{[44]}. Privately insured patients pay themselves and get reimbursement from their private insurance, whereas self-payers pay themselves without reimbursement\textsuperscript{[44]}. So, this is a profit for the institution and cost for the private insurance. In the case of self-payers without private insurance, it is profit for the institution and cost for the patient. In all these considerations, the potential cost or profit of further treatment on the basis of 2D- or 3D-imaging is unclear and debateable\textsuperscript{[44]}. A higher percentage of self-payers or privately insured would increase the reimbursement more in the WBCT group than in the RCT group, because the reimbursement is higher for WBCT/CT (300 Euros) than for radiographs (30 Euros)\textsuperscript{[44]}. The situation has already evolved in many countries, such as the United States, UK, and Belgium, where authorities have recognized the general usefulness and benefits of WBCT for patients and institutions relative to the traditional RCT sequence\textsuperscript{[44]}. We found the 77\% decrease in image acquisition time for the WBCT group relative to the RCT group to be the main factor for increased profit\textsuperscript{[44]}. This effect might also differ in other settings. However, cone beam technology (as in WBCT) is currently being developed to scan the entire body. This expanded application may possibly increase indications and usability of WBCT scans in institutions which are not specialized in foot and ankle surgery or with a more restricted flow of patients needing regular CT scans\textsuperscript{[44]}. 

**Shortcomings of the study**

There are numerous shortcomings of the study\textsuperscript{[44]}. Specific diagnosis for multiple foot and ankle pathologies was not analysed\textsuperscript{[44]}. The indication for the imaging was not analysed and could differ in other institutions\textsuperscript{[44]}. Preoperative and follow-up imaging were included in the analysis because this was found to reflect the local situation most appropriately\textsuperscript{[44]}. For both groups, early postoperative radiographs without weight-bearing were not registered and included in the further analysis\textsuperscript{[44]}. This could be considered as
a shortcoming because not all radiographs were included in the study[44]. However, the indication and frequency for these radiographs did not differ between RCT and WBCT groups and were therefore not included[44]. The same is true for initial radiographs in trauma patients as discussed above[44]. RD was not measured but projected with data from an earlier phantom measurement[37,44]. For this phantom study, the same WBCT device was used, but R and CT devices differed[37]. Consequently, the real RD might differ in our setting[44]. However, we are not aware of any other comparable study that measured RD in such a large patient series[44]. With later device generations (WBCT, CT and R), RD might differ[44]. To the best of our understanding, it would be more probable that newer WBCT technology would decrease RD more than the much longer available and further developed R and CT technology[44]. We expect the same for T that is influenced by the scanning time. We are aware all authors have a conflict of interest because all authors use WBCT in their institutions and some are consultants for one of the device manufacturers and board members of the International WBCT Society[44]. This might cause bias in the data interpretation[44]. However, we want to stress that this conflict of interest did not influence data collection (T, RD, cost/reimbursement) or statistical analysis[44].

In conclusion, 13,156 WBCT scans in 5,798 patients as substitution of R(+CT) over a 6.8 year period at a foot and ankle center resulted in 10% decreased RD (minus 0.5 uSV on average per patient). Yearly T decreased 380 hours (77%) in total (12.0 minutes per patient). Yearly financial income increased more than 54,000 Euro in total (58 Euro per patient). RD decreased despite higher radiation dose for WBCT than for R alone, based on substitution of a high number of CTs by WBCT. Other centers with low usage of CT might not decrease RD by substituting R alone by WBCT.

Conflict of interest

Martinus Richter is consultant of Curvebeam, Ossio, Geistlich and Intercus, and proprietor of R-Innovation. Francois Lintz is consultant of Curvebeam, Follow and Newclip Technics and proprietor of L-Innov. Cesar de Cesar Netto is consultant for Curvebeam, Ossio and Paragon 28. Alexej Barg is consultant of Medartis, Arne Burssens is consultant of Curvebeam. Scott Ellis is consultant for Paragon 28 and Wright Medical, and currently serves as the President of the AOAFS Foundation. All authors are board member of the International WBCT Society. The International WBCT Society is financially supported by Curvebeam, Carestream, Paragon 28 and Footinnovate.

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