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Results of more than 11,000 scans with weightbearing CT — Impact on costs, radiation exposure, and procedure time

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ABSTRACT

Background: Weightbearing CT (WBCT) has been proven to more precisely measure bone position than conventional weightbearing radiographic series (R) and conventional CT (CT). The purpose of this study was to assess the benefit of using WBCT instead of R and/or CT as the standard imaging modality, evaluating image acquisition time, radiation dose, and cost-effectiveness.
Methods: All patients who obtained a WBCT as part of standard of care from July 1, 2013 until March 15, 2019 were included in the study. Image acquisition time (T), radiation dose (RD) per patient, and cost-effectiveness were analyzed and compared between the time period using WBCT (yearly average) and the parameters from 2012, i.e. before the availability of WBCT (RCT group).
Results: 11,009 WBCT scans were obtained from 4987 patients (4,987 scans (45%) before treatment; 6,022 scans (55%) at follow-up). On a yearly average, 1,957 WBCTs (bilateral scans) and an additional 10.6 CTs (bilateral feet and ankles) were obtained (WBCT group). In 2012, 1,850 Rs (bilateral feet, dorsoplantar and lateral, metatarsal head skyline view) and 254 CTs were obtained from 885 patients (RCT group). The mean yearly RD was 4.3/4.8uSv for the WBCT/RCT groups (mean difference of .5 uSv; a decrease of 10% for the WBCT group; $p < .01$). Yearly mean T was 114/493 h in total (3.3/16.0 min per patient) for WBCT/RCT groups (mean difference of 379 h; a 77% decrease for the WBCT group; $p < .01$). Yearly cost-effectiveness was a mean profit of 43,959/−723 Euros for WBCT/RCT groups.
Conclusions: 11,009 WBCT scans from 4,987 patients over a period of 5.6 years at a foot and ankle department resulted in 10% decreased RD, 77% decreased T, and increased financial profit (51 Euros per patient) for the institution.

1. 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) [1–7]. These improvements are attributed to the absence of superimposition and the possibility to account for rotational errors after the image process [5,8]. Time spent on image acquisition (T) has shown to be lower for WBCT than for R and CT [5]. Radiation dose (RD) for WBCT has also shown to be lower than for CT [5]. 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.

2. Methods

2.1. 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

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ankle department. All patients who obtained WBCT (bilateral scan) and/or CT from July 1, 2013 until March 15, 2019 were included in the study (WBCT group).

2.1.1. Control group

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

2.2. 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.

2.2.1. 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 s; CT (bilateral feet and ankle), 415 s; WBCT (bilateral), 207 s [5].

2.2.2. 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 [9].

2.2.3. 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 Euros acquisition cost with a 5-year asset depreciation range (40,000 Euros yearly) and an annual 5,000 Euros maintenance cost, i.e. 45,000 Euros 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 Euros 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 Euros for each R series and 300 Euros 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).

2.3. Data analysis/control group

All parameters were compared between WBCT and R/CT group.

2.4. 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. SPSS (20.0.0, SPSS, Inc., Chicago, IL, USA) was used.

Table 1
Epidemiology and pathology location RCT and WBCT groups.

	RCT		WBCT		Test; p
Age (mean, range)	52.4 (8–92)		53.8 (6–91)		t-test; .7
Gender (male n, %)	2045 (49%)		779 (42%)		Chi^2; .9
Pathology location	n	%	n	%	
Ankle	603	12.1	104	11.8	Chi^2; .8
Hindfoot	480	10.1	98	11.1	
Midfoot	457	9.2	78	8.8	
Forefoot	987	19.8	182	11.8	
Multiple locations	2,423	48.6	423	47.8	

RCT group, group from 2012 with conventional radiographs and optional CT; WBCT group, group July 1, 2013 until, March 12, 2019 with WBCT and additional conventional radiographs and CT.

3. Results

11,009 WBCT scans were obtained from 4,987 patients (WBCT group). 4987 (45%) scans were performed before treatment, and 6,022 (55%) at follow-up between 3 months and 5 years after operative treatment. 1,957 WBCT scans and 10.6 CTs (all before treatment) were obtained on average yearly. The mean age of the scanned patients was 52.4 years (range, 8–92), and 41% were male. Table 1 shows the pathology location. The most common single location was forefoot (19.8%). In 2012, 1850 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 .5 uSv; a 10% decrease for the WBCT group, $p < .01$) (Table 2). The mean yearly T was 114 h in total (3.3 min per patient) for the WBCT group and 493 h in total (16.0 min per patient) for the RCT group (mean difference of 379 h; a 77% decrease for the WBCT group, $p < .01$) (Table 2). The mean yearly cost-effectiveness was a profit of 43,959/−723 Euros for WBCT/RCT groups, respectively 50.3/−.82 Euros per patient (Table 2). Consequently, there is an overall profit increase of 44,682 Euros (51.12 Euros per patient) for the institution.

4. 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.

So far, 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 [1–5,8,10–57]. 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 [58]. Also, most institutions have already installed R and/or CT devices and are thus reluctant to additionally invest in a WBCT device. To the best of our knowledge, this is the first study to investigate and compare RD as benefit for the patient and cost-effectiveness as benefit for the institution of WBCT use as standard of care in a large number of foot and ankle patients. The study's setting was an institution with existing R and CT devices that installed a WBCT device in 2013. After using the device alongside R and CT for a comparative study, WBCT replaced R and CT as the standard imaging in this clinic a few months after installation [5]. Radiographs were limited to early postoperative (one to four days) imaging for patients without weightbearing, initial or better preoperative radiographs and CT were limited to

Table 2
Data comparison WBCT and RCT groups.

Parameter	RCT	WBCT	T-test; p
Patient number	885	873.6 ± 53	
Radiographs (series, n per year)	1.85		
WBCT (n per year)		1,957 ± 87	
CT (n per year)	254	10.6 ± 2.4	
Radiation dose per patient (uSv)	4.8 ± 4.3	4.3 ± 1.5	<.01
Time spent radiology technician (hours in total per year)	493	114 ± 14.5	<.01
Time spent radiology technician (minutes.seconds per patient)	15.59 ± 8.04	3.29 ± 2.56	<.01
Private insurance / self-payers (%)	15.1	15.5	
Profit (Euros in total per year)	−723	43,959 ± 6512	<.01
Profit (Euros per patient)	.82	50.3 ± 10.9	<.01

RCT group, group from 2012 with conventional radiographs and optional CT; WBCT group, group July 1, 2013 until, March 12, 2019 with WBCT and additional conventional radiographs and CT. Numbers for WBCT group are average yearly numbers.

trauma cases that comprised around 3% in the local setting. Radiographs were indicated for initial assessment and CT when weightbearing was not possible and 3D-imaging was indicated (e.g. calcaneal fractures). In the control group (RCT) the imaging for early postoperative and trauma cases was the same. As the indication for initial radiographs in trauma cases and early postoperative radiographs was similar in WBCT and RCT groups, this imaging was excluded from the comparative study. Thus, the CT imaging in the WBCT group as described above was not excluded because it was also considered as 3D-imaging (as WBCT). However, with 10 CTs on average yearly, the effect of the CT in the WBCT group on the comparison is minimal. In the RCT group, a high rate of CT (29% of all patients) was observed. CT was indicated in addition to radiographs with weightbearing for (complex) deformities or other pathologies in the hindfoot, midfoot or in multiple locations. The high rate for CT is consequently based on the high rate of pathologies in the hindfoot (10%), midfoot (9%) and multiple locations (49%) (Table 1).

This study was not focused on the type of pathology, type of treatment, or accuracy/sensitivity/specificity of the imaging. In this study, we found a substantial decrease in R and CT use for the WBCT group as expected. The decrease of CT use from more than 250 per year (RCT group) to 10 per year (WBCT group) influenced the finding of decreased RD for the entire WBCT group. RD for CT (25 uSv) is more than 5 times higher than for WBCT (4.2 uSv) which overcompensates for the 3 times higher RD of WBCT relative to R (1.4 uSv). While the RD for WBCT is often argued to be greater, RD is definitively shown to decrease (10%) [59]. Other centres with low usage of CT might not decrease RD by substituting R alone with WBCT. When analysing cost-effectiveness, the initial cost for device acquisition and the absence of specific reimbursement are usually taken into consideration as the main factors against WBCT device profitability. While purchasing cost does not significantly differ between device types or countries, the reimbursement situation can vary drastically. Our calculation is just one example in a special setting, and the numbers might differ in other countries with different insurance settings. 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. Privately insured patients pay themselves and get reimbursement from their private insurance, whereas self-payers pay themselves without reimbursement. 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. 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). 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. 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. This effect might also differ in other settings. However, cone beam technology (as in WBCT) is currently being developed to scan knees, hands, and elbows. 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.

4.1. Shortcomings of the study

There are numerous shortcomings of the study. Specific diagnosis for multiple foot and ankle pathologies was not analysed. The indication for the imaging was not analysed and could differ in other institutions. Preoperative and follow-up imaging were included in the analysis because this was found to reflect the local situation most appropriately. For both groups, early postoperative radiographs without weightbearing were not registered and included in the further analysis. This could be considered as a shortcoming because not all radiographs were included in the study. However, the indication and frequency for these radiographs did not differ between RCT and WBCT groups and were therefore not included. The same is true for initial radiographs in trauma patients as discussed above. RD was not measured but projected with data from an earlier phantom measurement [9]. For this phantom study, the same WBCT device was used, but R and CT devices differed [9]. Consequently, the real RD might differ in our setting. However, we are not aware of any other comparable study that measured RD in such a large patient series. With later device generations (WBCT, CT and R), RD might differ. 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. We are aware all authors have a conflict of interest because all authors use WBCT in their institutions and are consultants for one of the device manufacturers and board members of the International WBCT Society. This might cause bias in the data interpretation. However, we want to stress that this conflict of interest did not influence data collection (T, RD, cost/reimbursement) or statistical analysis.

In conclusion, 11,009 WBCT scans for 4987 patients as the prevailing substitution for R and CT over a 5.6-year period at a foot and ankle centre resulted in a 10% decreased RD (−.5 uSV on average per patient) as benefit for the patients. Yearly T decreased by 439 h (77%) in total (12.30 min s per patient) as benefit for patients and institution. Yearly financial profit for imaging increased by more than 44,000 Euros in total (51 Euros per patient) as benefit for the institution.

Conflict of interest

None of the authors or the authors' institution received funding in relation to this study. 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 of Curvebeam and Ossio, Alexej Barg is consultant of Medartis, Arne Burssens is consultant of Curvebeam. All authors are board member of the International WBCT Society. The International WBCT Society is financially supported by Curvebeam, Carestream and Planmed.

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