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Original Article

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

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KEYWORDS
Weightbearing CT;
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Radiographs;
Radiation dose;
Time spent

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

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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.

SCHLÜSSELWÖRTER
Weightbearing CT;
WBCT;
Digitale Volumentomographie (DVT);
Strahlendosis;
Zeitaufwand
Bildgebung

Zusammenfassung

Hintergrund: Ziel dieser Studie war die Analyse der Auswirkungen von 3D-Röntgenbildgebung 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 Studien 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; 7.558 (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 authoŕs 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.

	RCT		WBCT		Test; p
Age (mean, range)	53.8 (6-91)		52.2 (8-92)		t-test; 0.7
Gender (male n, %)	779 (42%)		2,667 (49%)		Chi2; 0.6
Pathology location	n	%	n	%	
Ankle	104	11.8	832	14.3	Chi2; 0.1
Hindfoot	98	11.1	765	13.2	
Midfoot	78	8.8	523	9.0	
Forefoot	182	11.8	1189	20.5	
Multiple locations	423	47.8	2489	42.9	

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.

Parameter	RCT	WBCT	T-test; p
Patient number	885	853 ± 68	
Radiographs (series, n per year)	1,85		
WBCT (n per year)		1,935 ± 94	
CT (n per year)	254	10.7 ± 2.9	
Radiation dose per patient (uSv)	4.8 ± 4.3	4.3 ± 1.5	< .01
Time spent radiology technician (hours in total per year)	493	113 ± 19.6	< .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	53,543 ± 6,834	< .01
Profit (Euros per patient)	.82	57.26 ± 12.34	< .01

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 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[44]. The study's setting was an institution with existing R and CT devices that installed a WBCT device in 2013[44]. 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[44,46]. 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 trauma cases that comprised around 3% in the local setting[44]. Radiographs were indicated for initial assessment and CT when weightbearing was not possible and 3D-imaging was indicated (e.g. calcaneal fractures)[44]. In the control group (RCT) the imaging for early postoperative and trauma cases was the same[44]. 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[44]. Thus, the CT imaging in the WBCT group as described above was not excluded because it was also considered as 3D-imaging (as WBCT)[44]. However, with 10 CTs on average yearly, the effect of the CT in the WBCT group on the comparison is minimal[44]. In the RCT group, a high rate of CT (29% of all patients) was observed[44]. CT was indicated in addition to radiographs with weightbearing for (complex) deformities or other pathologies in the hindfoot, midfoot or in multiple locations[44]. 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)[44]. 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[44]. 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[44]. RD for CT (25uSv) is more than 5 times higher than for WBCT (4.2uSv) which overcompensates for the 3 times higher RD of WBCT relative to R (1.4uSv)[44]. While the RD for WBCT is often argued to be greater, RD is definitively shown to decrease (10%)[21]. Other centres with low usage of CT might not decrease RD by substituting R alone with WBCT[44]. 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[44]. While purchasing cost does not significantly differ between device types or countries, the reimbursement situation can vary drastically[44]. Our calculation is just one example in a special setting, and the numbers might differ in other countries with different insurance settings[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[44]. Privately insured patients pay themselves and get reimbursement from their private insurance, whereas self-payers pay themselves without reimbursement[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[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) [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[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[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[44].

Shortcomings of the study

There are numerous shortcomings of the study[44]. Specific diagnosis for multiple foot and ankle pathologies was not analysed[44]. The indication for the imaging was not analysed and could differ in other institutions[44]. Preoperative and follow-up imaging were included in the analysis because this was found to reflect the local situation most appropriately[44]. For both groups, early postoperative radiographs without weightbearing were not registered and included in the further analysis[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 AOFAS 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.

References

[1] An TW, Michalski M, Jansson K, Pfeffer G. Comparison of Lateralizing Calcaneal Osteotomies for Varus Hindfoot Correction. Foot Ankle Int 2018;39(10):1229–36.
[2] Barg A, Bailey T, Richter M, de Cesar Netto C, Lintz F, Burssens A, Phisitkul P, Hanrahan CJ, Saltzman CL. Weightbearing Computed Tomography of the Foot and Ankle: Emerging Technology Topical Review. Foot Ankle Int 2018;39(3):376–86.
[3] Burssens A, Peeters J, Buedts K, Victor J, Vandeputte G. Measuring hindfoot alignment in weight bearing CT: A novel clinical relevant measurement method. Foot Ankle Surg 2016;22(4):233–8.
[4] Burssens A, Peeters J, Peiffer M, Marien R, Lenaerts T, Vandeputte G, Victor J. Reliability and correlation analysis of computed methods to convert conventional 2D radiological hindfoot measurements to a 3D setting using weightbearing CT. International journal of computer assisted radiology and surgery 2018;13(12):1999–2008.
[5] Burssens A, Van Herzele E, Leenders T, Clockaerts S, Buedts K, Vandeputte G, Victor J, Weightbearing CT. in normal hindfoot alignment - Presence of a constitutional valgus? Foot Ankle Surg 2018;24(3):213–8.
[6] Burssens A, Vermue H, Barg A, Krahenbuhl N, Victor J, Buedts K. Templating of Syndesmotic Ankle Lesions by Use of 3D Analysis in Weightbearing and Nonweightbearing CT. Foot Ankle Int 2018;39(12):1487–96.
[7] Cheung ZB, Myerson MS, Tracey J, Vulcano E, Weightbearing CT. Scan Assessment of Foot Alignment in Patients With Hallux Rigidus. Foot Ankle Int 2018;39(1):67–74.
[8] Cody EA, Williamson ER, Burket JC, Deland JT, Ellis SJ. Correlation of Talar Anatomy and Subtalar Joint Alignment on Weightbearing Computed Tomography With Radiographic Flatfoot Parameters. Foot Ankle Int 2016;37(8):874–81.
[9] Colin F, Horn Lang T, Zwicky L, Hintermann B, Knupp M. Subtalar joint configuration on weightbearing CT scan. Foot Ankle Int 2014;35(10):1057–62.
[10] Collan L, Kankare JA, Mattila K. The biomechanics of the first metatarsal bone in hallux valgus: a preliminary study utilizing a weight bearing extremity CT. Foot Ankle Surg 2013;19(3):155–61.
[11] de Cesar Netto C, Bernasconi A, Roberts L, Pontin PA, Lintz F, Saito GH, Roney A, Elliott A, O'Malley M. Foot Alignment in Symptomatic National Basketball Association Players Using Weightbearing Cone Beam Computed Tomography. Orthopaedic journal of sports medicine 2019;7(2), http://dx.doi.org/10.1177/2325967119826081, 2019 Feb 21;7(2).
[12] de Cesar Netto C, Schon LC, Thawait GK, da Fonseca LF, Chinanuvathana A, Zbijewski WB, Siewerdsen JH, Demehri S. Flexible Adult Acquired Flatfoot

Deformity: Comparison Between Weight-Bearing and Non-Weight-Bearing Measurements Using Cone-Beam Computed Tomography. J Bone Joint Surg Am 2017;99(18):e98.
[13] de Cesar Netto C, Shakoor D, Dein EJ, Zhang H, Thawait GK, Richter M, Ficke JR, Schon LC, Demehri S. Influence of investigator experience on reliability of adult acquired flatfoot deformity measurements using weightbearing computed tomography. Foot Ankle Surg 2018, 10.1016/j.fas.2018.03.001 epub /10/17.
[14] de Cesar Netto C, Shakoor D, Roberts L, Chinanuvathana A, Mousavian A, Lintz F, Schon LC, Demehri S. Hindfoot alignment of adult acquired flatfoot deformity: A comparison of clinical assessment and weightbearing cone beam CT examinations. Foot Ankle Surg 2018.
[15] Ferri M, Scharfenberger AV, Goplen G, Daniels TR, Pearce D, Weightbearing CT. scan of severe flexible pes planus deformities. Foot Ankle Int 2008;29(2):199—204.
[16] Godoy-Santos AL, Cesar CN. Weight-Bearing Computed Tomography of the Foot and Ankle: an Update and Future Directions. Acta ortopedica brasileira 2018;26(2):135—9.
[17] Ha AS, Cunningham SX, Leung AS, Favinger JL, Hippe DS. Weightbearing Digital Tomosynthesis of Foot and Ankle Arthritis: Comparison With Radiography and Simulated Weightbearing CT in a Prospective Study. AJR American journal of roentgenology 2019;212(1):173—9.
[18] Hirschmann A, Pfirrmann CW, Klammer G, Espinosa N, Buck FM. Upright cone CT of the hindfoot: comparison of the non-weight-bearing with the upright weight-bearing position. European radiology 2014;24(3):553—8.
[19] Hoogervorst P, Working ZM, El Naga AN, Marmor M, In Vivo CT. Analysis of Physiological Fibular Motion at the Level of the Ankle Syndesmosis During Plantigrade Weightbearing. Foot Ankle Spec 2018, http://dx.doi.org/10.1177/1938640018782602 [Epub ahead of print].
[20] Jeng CL, Rutherford T, Hull MG, Cerrato RA, Campbell JT. Assessment of Bony Subfibular Impingement in Flatfoot Patients Using Weight-Bearing CT Scans. Foot Ankle Int 2019;40(2):152—8.
[21] Kang DH, Kang C, Hwang DS, Song JH, Song SH. The value of axial loading three dimensional (3D) CT as a substitute for full weightbearing (standing) 3D CT: Comparison of reproducibility according to degree of load. Foot Ankle Surg 2017.
[22] Kennelly H, Klaassen K, Heitman D, Youngberg R, Platt SR. Utility of weight-bearing radiographs compared to computed tomography scan for the diagnosis of subtle Lisfranc injuries in the emergency setting. Emergency medicine Australasia: EMA 2019. Feb 19. doi: 0.1111/742-6723.13237.
[23] Kim JB, Yi Y, Kim JY, Cho JH, Kwon MS, Choi SH, Lee WC. Weight-bearing computed tomography findings in varus ankle osteoarthritis: abnormal internal rotation of the talus in the axial plane. Skeletal radiology 2017;46(8):1071—80.
[24] Kimura T, Kubota M, Suzuki N, Hattori A, Marumo K. Comparison of Intercuneiform 1-2 Joint Mobility Between Hallux Valgus and Normal Feet Using Weightbearing Computed Tomography and 3-Dimensional Analysis. Foot Ankle Int 2018;39(3):355—60.
[25] Kimura T, Kubota M, Taguchi T, Suzuki N, Hattori A, Marumo K. Evaluation of First-Ray Mobility in Patients with Hallux Valgus Using Weight-Bearing CT and a 3-D Analysis System: A Comparison with Normal Feet. J Bone Joint Surg Am 2017;99(3):247—55.
[26] Kleipool RP, Dahmen J, Vuurberg G, Oostra RJ, Blankevoort L, Knupp M, Stufkens SAS. Study on the three-dimensional orientation of the posterior facet of the subtalar joint using simulated weight-bearing CT. J Orthop Res 2019;37(1):197—204.
[27] Krahenbuhl N, Bailey TL, Presson AP, Allen CM, Henninger HB, Saltzman CL, Barg A. Torque application helps to diagnose incomplete syndesmotic injuries using weight-bearing computed tomography images. Skeletal radiology 2019.
[28] Krahenbuhl N, Bailey TL, Weinberg MW, Davidson NP, Hintermann B, Presson AP, Allen CM, Henninger HB, Saltzman CL, Barg A. Impact of Torque on Assessment of Syndesmotic Injuries Using Weight-bearing Computed Tomography Scans. Foot Ankle Int 2019;40(5):710—9.
[29] Krahenbuhl N, Tschuck M, Bolliger L, Hintermann B, Knupp M. Orientation of the Subtalar Joint: Measurement and Reliability Using Weightbearing CT Scans. Foot Ankle Int 2016;37(1):109—14.
[30] Kunas GC, Probasco W, Haleem AM, Burket JC, Williamson ERC, Ellis SJ. Evaluation of peritalar subluxation in adult acquired flatfoot deformity using computed tomography and weightbearing multiplanar imaging. Foot Ankle Surg 2018;24(6):495—500.
[31] Lawlor MC, Kluczynski MA, Marzo JM. Weight-Bearing Cone-Beam CT Scan Assessment of Stability of Supination External Rotation Ankle Fractures in a Cadaver Model. Foot Ankle Int 2018;39(7):850—7.
[32] Lepojarvi S, Niinimaki J, Pakarinen H, Koskela L, Leskela HV. Rotational Dynamics of the Talus in a Normal Tibiotalar Joint as Shown by Weight-Bearing Computed Tomography. J Bone Joint Surg Am 2016;98(7):568—75.
[33] Lepojarvi S, Niinimaki J, Pakarinen H, Leskela HV. Rotational Dynamics of the Normal Distal Tibiofibular Joint With Weight-Bearing Computed Tomography. Foot Ankle Int 2016;37(6):627—35.
[34] Lintz F, de Cesar Netto C, Barg A, Burssens A, Richter M. Weight-bearing cone beam CT scans in the foot and ankle. EFORT open reviews 2018;3(5): 278—86.
[35] Lintz F, de Cesar Netto C, Burssens A, Barg A, Richter M. The value of axial loading three dimensional (3D) CT as a substitute for full weightbearing (standing) 3D CT: Comparison of reproducibility according to degree of load. Foot Ankle Surg 2018;24(6):553—4.
[36] Lintz F, Welck M, Bernasconi A, Thornton J, Cullen NP, Singh D, Goldberg A. 3D Biometrics for Hindfoot Alignment Using Weightbearing CT. Foot Ankle Int 2017;38(6):684—9.

[37] Ludlow BW, Ivanovic M. Weightbearing CBCT MDCT, and 2D imaging dosimetry of the foot and ankle. International Journal of Diagnostic Imaging 2014;1(2):1—9.

[38] Malhotra K, Welck M, Cullen N, Singh D, Goldberg AJ. The effects of weight bearing on the distal tibiofibular syndesmosis: A study comparing weight bearing-CT with conventional CT. Foot Ankle Surg 2018;piiS1268—7731(18), 30114-0. doi: 10.1016/j.fas.2018.03.006. [Epub ahead of print].

[39] Marzo J, Kluczynski M, Notino A, Bisson L. Comparison of a Novel Weightbearing Cone Beam Computed Tomography Scanner Versus a Conventional Computed Tomography Scanner for Measuring Patellar Instability. Orthopaedic journal of sports medicine 2016;4(12):1—7.

[40] Marzo JM, Kluczynski MA, Clyde C, Anders MJ, Mutty CE, Ritter CA. Weight bearing cone beam CT scan versus gravity stress radiography for analysis of supination external rotation injuries of the ankle. Quantitative imaging in medicine and surgery 2017;7(6):678—84.

[41] Osgood GM, Shakoor D, Orapin J, Qin J, Khodarahmi I, Thawait GK, Ficke JR, Schon LC, Demehri S. Reliability of distal tibio-fibular syndesmotic instability measurements using weightbearing and non-weightbearing cone-beam CT. Foot Ankle Surg 2018;piiS1268-7731(18):30469—77, http://dx.doi.org/10.1016/j.fas.2018.10.003 [Epub ahead of print].

[42] Patel S, Malhotra K, Cullen NP, Singh D, Goldberg AJ, Welck MJ. Defining reference values for the normal tibiofibular syndesmosis in adults using weight-bearing CT. The bone & joint journal 2019;101-b(3):348—52.

[43] Richter M, Zech LF, Meissner SSA. Combination of PedCAT Weight Bearing CT with Pedography Shows Relationship between Anatomy Based Foot Center (FC) and Force/Pressure Based Center of Gravity (COG). Foot Ankle Int 2018;39(3):361—8.

[44] Richter M, Lintz F, de Cesar Netto C, Barg A, Burssens A. Results of more than 11,000 scans with weightbearing CT - Impact on costs, radiation exposure, and procedure time. Foot Ankle Surg 2019.

[45] Richter M, Lintz F, Zech S, Meissner SA. Combination of PedCAT Weightbearing CT With Pedography Assessment of the Relationship Between Anatomy-Based Foot Center and Force/Pressure-Based Center of Gravity. Foot Ankle Int 2018;39(3):361—8.

[46] Richter M, Seidl B, Zech S, Hahn S. PedCAT for 3D-Imaging in Standing Position Allows for More Accurate Bone Position (Angle) Measurement than Radiographs or CT. Foot Ankle Surg 2014;20:201—7.

[47] Richter M, Zech S, Hahn S, Naef I, Merschin D. Combination of pedCAT for 3D Imaging in Standing Position With Pedography Shows No Statistical Correlation of Bone Position With Force/Pressure Distribution. J Foot Ankle Surg 2016;55(2):240—6.

[48] Richter M, Hahn ZSS. PedCAT for Radiographic 3D-Imaging in Standing Position. Fuss Sprungg 2015;13:85—102.

[49] Segal NA, Bergin J, Kern A, Findlay C, Anderson DD. Test-retest reliability of tibiofemoral joint space width measurements made using a low-dose standing CT scanner. Skeletal radiology 2017;46(2):217—22.

[50] Segal NA, Frick E, Duryea J, Nevitt MC, Niu J, Torner JC, Felson DT, Anderson DD. Comparison of tibiofemoral joint space width measurements from standing CT and fixed flexion radiography. J Orthop Res 2017;35(7):1388—95.

[51] Segal NA, Frick E, Duryea J, Roemer F, Guermazi A, Nevitt MC, Torner JC, Felson DT, Anderson DD. Correlations of Medial Joint Space Width on Fixed-Flexed Standing Computed Tomography and Radiographs With Cartilage and Meniscal Morphology on Magnetic Resonance Imaging. Arthritis care & research 2016;68(10):1410—6.

[52] Segal NA, Nevitt MC, Lynch JA, Niu J, Torner JC, Guermazi A. Diagnostic performance of 3D standing CT imaging for detection of knee osteoarthritis features. The Physician and sportsmedicine 2015;43(3):213—20.

[53] Shakoor D, Osgood GM, Brehler M, Zbijewski WB, de Cesar Netto C, Shafiq B, Orapin J, Thawait GK, Shon LC, Demehri S. Cone-beam CT measurements of distal tibio-fibular syndesmosis in asymptomatic uninjured ankles: does weight-bearing matter? Skeletal radiology 2019;48(4):583—94.

[54] Thawait GK, Demehri S, AlMuhit A, Zbijweski W, Yorkston J, Del Grande F, Zikria B, Carrino JA, Siewerdsen JH. Extremity cone-beam CT for evaluation of medial tibiofemoral osteoarthritis: Initial experience in imaging of the weight-bearing and non-weight-bearing knee. European journal of radiology 2015;84(12):2564—70.

[55] Tuominen EK, Kankare J, Koskinen SK, Mattila KT, Weight-bearing CT. imaging of the lower extremity. AJR American journal of roentgenology 2013;200(1):146—8.

[56] Welck MJ, Myerson MS. The value of Weight-Bearing CT scan in the evaluation of subtalar distraction bone block arthrodesis: Case report. Foot Ankle Surg 2015;21(4):e55—9.

[57] Welck MJ, Singh D, Cullen N, Goldberg A. Evaluation of the 1st metatarso-sesamoid joint using standing CT - The Stanmore classification. Foot Ankle Surg 2018;24(4):314—9.

[58] Yoshioka N, Ikoma K, Kido M, Imai K, Maki M, Arai Y, Fujiwara H, Tokunaga D, Inoue N, Kubo T. Weightbearing three-dimensional computed tomography analysis of the forefoot in patients with flatfoot deformity. J Orthop Sci 2016;21(2):154—8.

[59] Zhang JZ, Lintz F, Bernasconi A, Zhang S. 3D Biometrics for Hindfoot Alignment Using Weightbearing Computed Tomography. Foot Ankle Int 2019:684—9.

[60] Zhang Y, Xu J, Wang X, Huang J, Zhang C, Chen L, Wang C, Ma X. An in vivo study of hindfoot 3D kinetics in stage II posterior tibial tendon dysfunction (PTTD) flatfoot based on weight-bearing CT scan. Bone & joint research 2013;2(12):255—63.