Chapter 20
Weight Bearing Computed Tomography Devices

Beginning of Weight Bearing Computed Tomography Devices

The necessity for weight bearing computed tomography (CT) devices has already been demonstrated in the mid-1990s by Greisberg et al. [1]. This pivotal paper reported on the peritalar subluxation occurring in flatfoot deformities using a simulated weight bearing CT device containing a custom-built loading frame with the patient positioned supine. It soon became a stepping stone for other reports to follow, incorporating a similar setup [2, 3]. Despite these important findings, limitations regarding patient positioning, amount of load, and a high radiation dose were inevitable [4]. This advocated the development toward the weight bearing CT devices currently used in clinical practice.

Foot and Ankle Weight Bearing Computed Tomography Devices

The first weight bearing CT devices were available beginning of the 2010s [5–7]. They incorporate cone beam CT technology, which in essence uses a rotating X-ray to obtain the field of view. It was initially popularized in the dental area, but technical improvements caused it to be widely used across the majority of medical disciplines. The main advantages include a low radiation dose, the absence of superimposition, and a high image resolution. One of the first applications of weight bearing musculoskeletal scanning was dedicated to the foot and ankle [8, 9].

Currently, three companies are on the market offering weight bearing CT devices in this area (in alphabetical order): Carestream (Rochester, NY, USA), CurveBeam (Philadelphia, PA, USA) and Planmed (Helsinki, SF, FI). Their physical properties as well as the concomitant landmark studies will be discussed for each device (Figs. 20.1, 20.2, and 20.3).

M. Richter et al., *Weight Bearing Cone Beam Computed Tomography (WBCT) in the Foot and Ankle*, https://doi.org/10.1007/978-3-030-31949-6_20

Fig. 20.1 Onsight 3D Extremity System® (Carestream, Rochester, NY, USA). Physical dimensions of this device are as follows (in transport mode): length, 78.8″; width, 32″; and height, 76″. The gantry can be moved upward and turned 90°. This allows additional non-weight bearing imaging of the lower limb, as well as imaging of the upper extremities: the hand, wrist, and elbow. The first version of this device was described in one of the most early technical reports on musculoskeletal weight bearing CT imaging [10]. The first clinical applications were demonstrated in the alignment of flatfoot deformities [6]. Full technical details can be found on the website: https://www.carestream.com/en/us/medical/products/carestream-onsight-3d-extremity-system

Fig. 20.2 PedCAT® (CurveBeam, Philadelphia, PA, USA). Physical dimensions of this device are as follows: length, 58″; width, 28.5″; and height, 51″. Imaging of the foot and ankle can be performed both during weight bearing, physiological bipedal stance, as well as non-weight bearing while seated. The first study using this device included both technical details as well as clinical applications. In this pivotal report, a comparison was made toward non-weight bearing CT regarding radiation dose and accuracy of measurements commonly used in clinical foot and ankle practice [5]. Full technical details can be found on the website: https://www.curvebeam.com/products/pedcat/

Fig. 20.3 Verity® (Planmed, Helsinki, SF, FI). Physical dimensions of this device are as follows: length, 73″; width, 30″; and height, 66″. The gantry can be moved upward and turned 90°. This allows additional non-weight bearing imaging of the lower limb, as well as imaging of the upper extremities: the hand, wrist, and elbow. In the first study using this device, technical details were analyzed and reported [11]. Clinical examples demonstrated a higher accuracy in detecting ankle and midfoot osteoarthritis [11]. Full technical details can be found on the website: https://www.planmed.com/computed-tomography/

Knee Weight Bearing Computed Tomography Devices

The numerous applications and advantages encountered during weight bearing CT imaging of the foot and ankle raised the interest toward similar investigations at the level of the knee. The same three companies as mentioned above provide weight bearing CT devices to perform knee imaging. Their technical details will be described as well as their reports in clinical practice (Figs. 20.4, 20.5, and 20.6).

The Future of Weight Bearing Computed Tomography Devices

Weight bearing CT imaging is expected to extend towards the hip, allowing a complete analysis of the entire lower limb. This advancement will provide additional data over full leg radiographs, as 3D measurements will be possible. These data will increase our understanding of different types of deformities and their relation toward joint preserving as well as replacing procedures.

Fig. 20.4 Onsight 3D Extremity System® (Carestream, Rochester, NY, USA). Physical dimensions of this device are described above. The gantry can be moved upward to allow weight bearing CT imaging of the knee. It can be turned 90°, in the case non-weight bearing CT imaging is preferred [12]. The first version of this device was described in one of the most early technical reports on musculoskeletal weight bearing CT imaging [10]. The first clinical applications were demonstrated in patients with knee osteoarthritis quantifying joint space with and meniscal extrusion [6]

Fig. 20.5 LineUp® (CurveBeam, Philadelphia, PA, USA). Physical dimensions of this device are as follows: length, 48″; width, 28.5″; and height, 51.3″. Weight bearing CT imaging of the knee is achieved by elevation of the gantry while the patient is in physiological bipedal stance. Non-weight bearing CT imaging is also available but requires the patient to be seated in a chair. The first study using this device included both technical details and clinical applications [13]. In comparison with MRI and X-rays, weight bearing CT imaging was more sensitive and accurate to detect knee osteoarthritis. Full technical details can be found on the website: https://www.curvebeam.com/products/lineup/

Fig. 20.6 Verity® (Planmed, Helsinki, SF, FI). Physical dimensions of this device are described above. The gantry can be moved upward to allow weight bearing CT imaging of the knee. It can be turned 90°, in the case non-weight bearing CT imaging is preferred. In the first study using this device, technical details were analyzed and reported [11]. Clinical examples demonstrated advantages toward metal artifact reduction of prosthetic components and alignment of the knee [11]

Another area that could benefit from weight bearing CT imaging is the axial skeleton, particularly in the case of scoliosis. This 3D deformity is difficult to understand on 2D radiographs and substantially influenced by weight bearing conditions. A full-bodyweight bearing CT is expected to be developed for this process. However, such devices face technical difficulties as the gantry needs to turn horizontally, meaning perpendicularly to the direction of gravity. A future engineering and multidisciplinary approach will be required to succeed in this challenging process.

References

1. Greisberg J, Hansen ST Jr, Sangeorzan B. Deformity and degeneration in the hindfoot and midfoot joints of the adult acquired flatfoot. Foot Ankle Int. 2003;24(7):530–4.
2. Kido M, Ikoma K, Imai K, Maki M, Takatori R, Tokunaga D, et al. Load response of the tarsal bones in patients with flatfoot deformity: in vivo 3D study. Foot Ankle Int. 2011;32(11):1017–22.
3. Zhang Y, Xu J, Wang X, Huang J, Zhang C, Chen L, et al. 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 Res. 2013;2(12):255–63.
4. Al-Rawi B, Hassan B, Vandenberge B, Jacobs R. Accuracy assessment of three-dimensional surface reconstructions of teeth from cone beam computed tomography scans. J Oral Rehabil. 2010;37(5):352–8.
5. 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(3):201–7.

6. de Cesar Netto C, Schon LC, Thawait GK, da Fonseca LF, Chinanuvathana A, Zbijewski WB, et al. 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.
7. Lepojärvi S, Niinimäki J, Pakarinen H, Koskela L, Leskelä H-V. 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.
8. Barg A, Bailey T, Richter M, de Cesar Netto C, Lintz F, Burssens A, et al. Weightbearing computed tomography of the foot and ankle: emerging technology topical review. Foot Ankle Int. 2018;39(3):376–86.
9. Lintz F, de Cesar Netto C, Barg A, Burssens A, Richter M, Weight Bearing CT International Study Group. Weight-bearing cone beam CT scans in the foot and ankle. EFORT Open Rev. 2018;3(5):278–86.
10. Zbijewski W, De Jean P, Prakash P, Ding Y, Stayman JW, Packard N, et al. A dedicated cone-beam CT system for musculoskeletal extremities imaging: design, optimization, and initial performance characterization. Med Phys. 2011;38(8):4700–13.
11. Tuominen EK, Kankare J, Koskinen SK, Mattila KT. Weight-bearing CT imaging of the lower extremity. Am J Roentgenol. 2013;200(1):146–8.
12. Thawait GK, Demehri S, AlMuhit A, Zbijweski W, Yorkston J, Del Grande F, et al. Extremity cone-beam CT for evaluation of medial tibiofemoral osteoarthritis: initial experience in imaging of the weight-bearing and non-weight-bearing knee. Eur J Radiol. 2015;84(12):2564–70.
13. 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. Phys Sportsmed. 2015;43(3):213–20.