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Reference:
Vanhoenacker Filip, Desimpel Julie.- Cone beam CT of trauma of small bones and joints
Seminars in musculoskeletal radiology - ISSN 1089-7860 - 21:3(2017), p. 290-302
Full text (Publisher's DOI): https://doi.org/10.1055/S-0037-1602405
To cite this reference: http://hdl.handle.net/10067/1435550151162165141

Cone Beam CT of trauma of small bones and joints

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Abstract

Evaluation of trauma of small bones or joints is traditionally done by conventional radiographs (CR). Although MDCT has a better sensitivity than CR in fracture detection and evaluation of complex fractures, high radiation prevents systematic use of MDCT in fracture evaluation. CBCT combines a high spatial resolution and relatively low radiation dose and is therefore a very valuable technique for evaluation of trauma of small bones and joints in patients with negative or doubtful radiographs and a high clinical suspicion for fractures or when complex fractures are suspected.

CBCT may also be useful for evaluation of chronic trauma or follow-up of fractures.

Key-words

▸ Small bones ▸ Trauma ▸ Cone Beam CT

Introduction

Cone Beam Computed Tomography (CBCT) was first introduced in the early 1980's as a new technique for dental imaging and preoperative evaluation of dental implants[1,2]. Although initially used in the clinical practice of dentists and oral surgeons, it is currently installed in many radiology departments and is used for the evaluation of a variety of dental and nondental applications[3]. The potential musculoskeletal applications of this technique have been recently reported[4,5,6,7,8,9,10,11,12] and dedicated CBCT equipment for musculoskeletal application has been developed[4,5]. Current high-end CBCT equipment allows multifunctional use for imaging of the teeth, temporal bone, sinuses and various musculoskeletal applications[3]. In our department, we use a CBCT with a gantry of 58 cm patient aperture and a movable table. Its design resembles a small MDCT and allows the extremities (upper arm and leg) to be put in **(▸ Fig. 1)**. This renders our CBCT machine suitable to study peripheral joints (knee, ankle, foot, elbow, wrist and hand). Horizontal scan positioning allows to examine trauma patients who are unable to remain stationary in a vertical position during the scan.

The purpose of this paper is to present a pictorial overview of the clinical usefulness of this technique of evaluation of trauma of small bones and joints.

Basic principles

Technique

The major differences in imaging acquisition between CBCT and "conventional" multidetector CT (MDCT) are summarized in **Fig. 2.** CBCT uses a cone shaped beam and a flat panel detector, whereas in MDCT a fan shaped beam moves helically around the patient and falls on a linear detector.

The software reconstructs 2 D images into a 3D volume dataset of images.

Advantages

The acquisition of the entire scan volume in only one rotation in CBCT results in a lower radiation dose compared to MDCT[6,7]

In a previous study on CBCT of small joints, the effective dose (ED) ranged between 1 to 15,3 µSv applying a conversion factor of 0.01 mSv/Gy x cm² for peripheral joints, which is far below reported values for MDCT. However, these values are still considerably higher than the ED for the conventional radiographs (0.07 to 5 µSv)[7].

As the dose depends on field-of-view (FOV), it would be possible to further diminish the ED by decreasing the FOV. Ideally, the area of interest has to be predefined by meticulous clinical examination before the acquisition starts in order to avoid unnecessary irradiation[7].

Other advantages of CBCT include higher spatial resolution ranging between 300µm (standard scan) to 75µm (high resolution), reduction of metal artefacts (e.g. for postoperative assessment of osteosynthesis)[3] and the relatively low cost of the equipment compared to MDCT.

Disadavantages

Disadvantages of CBCT compared to MDCT are the lack of contrast resolution hampering the use of this technique for visualization of soft tissue abnormalities[11,13] and limited scan volume/surface (limited to the size of the flat panel detector)[14]. With the equipment used in our department, the programmable Field of View (FOV) ranges from 6 x 6 cm to 18 x 16 cm.

As a consequence, CBCT is restricted to examine small bones and joints and lacks overview a large area compared to conventional radiography.

Another major drawback is the relatively long acquisition time of 30 to 40 seconds, resulting in increased susceptibility to motion artefacts. Therefore, the technique is less appropriate for patients that cannot be immobilized properly, such as young children or elderly with tremor[3,7]. Advantages and disadvantages of the musculoskeletal CBCT are summarized in (▸ **Table 1).**

Acute trauma

Although CR remains the primary modality to evaluate fracture, it is a two-dimensional projection imaging technique which may result in underestimation of fracture lines that are not in line with the incident X-ray beam[10]. In our series, CBCT has proven to detect up to 28% more fractures compared to CR[7]. Moreover, CBCT is particularly valuable in diagnosing complex (intra-articular or comminuted) fractures[7] and is therefore a valuable tool for evaluation of the local extent of the fracture. Other authors reported 45% additional information of CBCT compared to CR[10]. CBCT also enables an improved visualization of open fractures compared to CR[10].

In our series, CBCT-examination was generally more time-consuming than CR for the radiology technician (more precise patient positioning, longer scan time and post-processing and reconstruction)[7]. On the contrary, Huang A.J. et al. reported less imaging time of CBCT compared to CR and MDCT, thus not impeding normal clinical workflow[10]. For the radiologist, CBCT burden on the workflow is relatively limited as it takes on average only 30 to 50 seconds longer to interpret a CBCT examination (consisting of a data-set of multiple images) than to evaluate a conventional radiographic examination (2 up to 6 radiographs)[7].

Elbow

CBCT is particularly useful to detect radiographically subtle and non-displaced radial head fractures **(▸ Fig. 3)** and for staging of intra-articular fractures with entrapment of fragments fragment within the elbow joint[7,10].

Wrist and hand

CBCT is a superior alternative to radiography, allowing more accurate diagnoses of wrist **(▸ Figs. 4-5),** carpal **(▸ Figs. 6- 7- 8))** and finger fractures[8,9,12] **(▸ Fig. 9)**. However, CBCT cannot completely exclude occult scaphoid fractures and MRI is most sensitive for this purpose[8].

Knee

The overall gain of increased fracture detection in the knee joint has to be further examined, as there are relatively few data on the knee joint[7]. CBCT seems useful for evaluation of non-displaced patellar fractures and differential diagnosis with normal developmental variant such as multipartite patella **(▸ Fig. 10)**.

Ankle and foot

The ankle and particularly the Chopart and Lisfranc joints consist of a complex anatomical area, in which overlapping bones causes underestimation of fractures on CR **(▸ Fig. 11)**. In case of unexplained soft tissue swelling in the ankle and foot, we highly recommend a more liberate use of CBCT for detection of fractures that are not clearly visible on CR **(▸ Fig. 12)** **(▸ Figs. 13-14).** In addition, evaluation of fracture extension and complexity is definitively improved[15] **(▸ Fig. 15)**.

Chronic trauma

Magnetic Resonance Imaging is definitively the gold standard for early detection of stress reaction and fractures **(▸ Fig. 16)**. Because CBCT is a quick technique that is readily available, CBCT may have a role in evaluation of overuse of sesamoid bones of the hallux **(▸ Fig.17)** and assessment of painful accessory bones **(▸ Fig. 18)**.

Due to its exquisite high spatial resolution, CBCT combined with arthrography (CBCT-arthrography) is very accurate for staging of cartilage lesions **(▸ Fig. 19)**, osteochondritis disseccans, osteochondral fractures [3] **(▸ Fig. 20)**, evaluation of (posttraumatic) loose bodies [16] **(▸ Fig**. **21**) and tears of wrist ligaments[17,18] **(▸ Fig. 22)**. In claustrophobic patients or for evaluation of potential retears in the postoperative meniscus, it may be an alternative for MRI of the knee, particularly in patients with equivocal findings on MRI **(▸ Fig. 23)**.

In complex anatomic areas, such as the tarsal bones, CBCT allows a precise evaluation of the extent of premature posttraumatic osteo-arthritis **(▸ Fig. 24)**

Follow-up of trauma

Compared to CR, CBCT enables a better evaluation of fracture healing and the degree of surgical fusion. Overlapping bones and casts, splints and hard-ware may obscure correct interpretation of subtle callus formation on CR. Cross-sectional imaging may be very helpful in this scenario[10]. Compared to MRI, there is no disturbance of surrounding bone by metal artefacts and in this regard CBCT is suited for follow-up of subtle bone lesions adjacent to the fracture site[3,4] **(▸ Fig. 25)**. CBCT is also a promising technique for monitoring fracture healing in the long bones[19] and scaphoid fractures[3,20] **(▸ Fig. 26)**.

Conclusion

Compared to conventional radiography (CR), CBCT has an increased sensitivity in detecting small bone and joint lesions, particularly complex (intra-articular or comminuted) fractures. Despite its higher radiation dose than CR and the longer interpretation time, CBCT is a very valuable technique for evaluation of trauma of small bones and joints in patients with negative radiographs or doubtful fractures and a high clinical suspicion for fractures or when complex fractures are suspected.

In addition, CBCT may be useful for evaluation of chronic trauma or follow-up of fractures, although less sensitive than MRI.

Disadvantages of the technique are the high sensitivity of CBCT to motion artifacts and its limited capabilities in evaluation of soft tissue abnormalities.

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Table 1 Advantages and disadvantages of CBCT

ADVANTAGES	DISADVANTAGES
Relative low dose	***Higher dose than plain films***
No metal artefacts • Useful for postoperative follow-up	***Motion artefacts: less suitable for*** • Young children • Patients with tremor
More accurate than plain films • Acute trauma (detection and complexity) • Staging of cartilage lesions in combination with arthrography	***Limitations*** • Small field of view, no overview • Limited information on soft tissues
Relative low cost of equipment compared to MDCT	

Captions to figures

Fig. 1 CBCT equipment with gantry, movable table allowing horizontal positioning and multifunctional use in a department of medical imaging (Newton 5 G, QR systems, Verona, Italy).

Fig. 2 Major differences of CBCT versus MDCT. CBCT uses a cone shaped beam and a flat panel detector. The imaging data-set is acquired in one single rotation. The software reconstructs 2 D images into a 3D volume dataset of images.
In MDCT, a fan shaped beam turns helically around the patient and falls on a linear detector.

Fig. 3 Subtle radial head fracture. Lateral (A) and AP (B) radiograph of the left elbow in a 79-year-old female presenting after a fall show minor joint effusion, but no obvious fracture. On sagittal (C) reformatted CBCT, there is a subtle fracture at the radial head (black arrows).

Fig. 4 Additional fracture detection by CBCT. PA (A) radiograph of the left wrist in a 50-year-old male mountainbiker after a FOOSH trauma, showing degenerative changes of the left ulna and a small fleck of bone at the distal radio-ulnar joint (arrows). On plain films, the traumatic origin of this bony fragment was not clear. Axial (B) and sagittal (C) reformatted CBCT in the same patient shows an additional fracture on the ventral aspect of the radius (arrows), in keeping with a Barton fracture. Note also the small fracture fragment at the distal radioulnar joint on coronal (D reformatted CBCT (arrow).

Fig. 5 Distal radial fracture with intra-articular extension. PA (A) and lateral (B) radiograph of the right wrist reveal a distal radius fracture and avulsion of the styloid process of the ulna (arrows). Coronal (C) and sagittal (D) reformatted CBCT better shows the complexity of fracture of the distal radius with intra-articular extension in the radiocarpal joint (arrows).

Fig. 6 Fracture of capitate bone. PA (A) and lateral (B) radiograph of the right wrist shows no evidence of fracture. Coronal (C) and sagittal (D) reformatted CBCT clearly shows a fracture at the proximal pole of the capitate bone (arrows)**.**

Fig. 7 Scaphoid fracture. PA with ulnar deviation (A) and lateral (B) radiograph of the right wrist shows no evidence of fracture. Sagittal (C) reformatted CBCT reveals a fracture at the volar aspect of the scaphoid bone (arrow).

Fig. 8 Hamate fracture. 57-year-old recreational golf player with pain at the palm of the hand. Axial (A) and coronal FS T2-WI (B) showed subtle bone marrow edema at the hook of the hamate (arrows), suspicious for a fracture of the hook of the hamate. Axial CBCT (C) confirms the fracture at the hook of the hamate (arrows).

Fig. 9 Salter Harris 2 fracture-epiphysiolysis. Lateral radiograph of the left index (A) reveals no fracture. Coronal reformatted (B) and axial (C) CBCT shows a Salter-Harris fracture at the epiphysis of the first phalanx of the index (arrows).

Fig. 10 Patella fracture mimicking bipartite patella on plain films. Radiographs of the left knee (A) show a lucent line at the superolateral patella (arrow). Note also joint effusion within the suprapatellar bursa (asterisk). Axial (B), coronal reformatted (C) and sagittal reformatted (D) CBCT confirms a sharply delineated radiolucent line at the superolateral aspect of the patella (arrows). The sharp delineation and the absence of marginal sclerosis argues against a bipartite patella.

Fig. 11 Non-displaced calcaneus fracture in a patient presenting with persisting pain after a trauma (fall) 6 months previously. At the time of the trauma, no imaging was done. Lateral radiographs of the right calcaneus (A) show a heterogeneous bone texture of the calcaneus and a potential step-off at the cortical lining of the posterior subtalar joint (arrow). Sagittal reformatted (B) CBCT confirms a fracture line in the calcaneus with extension into the subtalar joints (arrows). On sagittal T1-WI (C), the fracture line is hypointense (arrow). Axial FS T2-WI (D) shows surrounding bone marrow edema (asterisk).

Fig. 12 Radiographically doubtful fracture of the navicular bone. 75-year-old-male presenting with posttraumatic soft tissue swelling at the dorsal aspect of the right foot. Plain radiographs (A) confirm a soft tissue swelling at the dorsal aspect of the navicular bone (arrow) and a doubtful lucent line at the navicular bone. Sagittal reformatted CBCT (B) clearly shows a slightly displaced fracture fragment (arrows) at the dorsal aspect of the navicular bone.

Fig. 13 Radiographically occult fracture of the medial cuneiforme bone of the left foot. Plain radiographs (A) fails to reveal a fracture line. Sagittal (B) and coronal (C) shows a non-displaced fracture in the medial cuneiforme bone (arrows) with proximal and distal extension into the joint between the navicular bone and medial cuneiforme bone and the first tarsometatarsal joint respectively.

Fig. 14 Additional fractures detected on CBCT compared to CR. Plain radiographs (A) shows a fracture line at the base of the navicular bone. Axial reformatted (B) CBCT image confirms the fracture line at the navicular bone (arrows). Sagittal reformatted (C) CBCT shows additional fractures at the lateral cuneiforme bone, base of the third metatarsal and cuboid (arrows) with extension into the adjacent joints.

Fig. 15 Triplane fracture of the left ankle in a 13-year-old girl. The precise extent of the fracture (arrows) is better seen on the CBCT (C-D-E) than on the plain radiographs (arrows) (A-B).

Fig. 16 Stress reaction of the second metatarsal base. Plain films (A) and axial CBCT (B) reveal no abnormalities. FS-T2-WI MRI (C) shows bone marrow edema at the base of the second metatarsal, in keeping with a stress reaction (asterisk).

Fig. 17 Sesamoid stress fracture. Axial FS T2-WI MR (A) and sagittal reformatted CBCT image (B) in a 21-year-old soccer player with sesamoid stress fracture at the medial sesamoid bone of the hallux. There is bone marrow edema on FS T2-WI (arrow), fragmentation and sclerosis on CBCT.

Fig. 18 Painful Os Peroneum Syndrome (POPS). Sagittal (A) and coronal (B) reformatted CBCT image in a patient with chronic plantar pain. Note fragmentation and sclerosis of the os peroneum (arrows). Sagittal T1-WI (C) and FS T2-WI (D) in the same patient. The os peroneum is hypointense compared to fatty bone marrow on T1-WI (arrow).

Fig. 19 Cartilage lesions of the patella on CBCT arthrography. Note filling with contrast of multiple focal defects in the retropatellar articular cartilage (black arrows).

Fig. 20 Osteochondral fracture of the talar dome. Plain radiograph (A) of the right ankle joint shows a subchondral lucency at the lateral aspect of the talar dome, in keeping with a non-displaced subchondral osteochondral fracture (arrow). Coronal FS T2-Weighted Images (WI) (B) shows bone marrow edema within the lateral talus and suspicion of an osteochondral fracture with focal cartilage defect at the margins of the osteochondral fracture (arrow). Sagittal (C) and coronal (D) reformatted CBCT confirm the bony fragment at the talar dome (arrows) with subtle overlying cartilage lesion.

Fig. 21 Progressive synovial osteochondromatosis of the elbow.
Lateral radiograph (A) of the right elbow showing multiple loose bodies anteriorly (thick arrow) and osteophyte formation posteriorly (thin black arrow). Lateral radiograph (B) of the right elbow 3 years later shows increased loose bodies at the ventral (thick arrow) and dorsal aspect (thin white arrow) of the elbow. CBCT arthrography confirms the presence of multiple intra-articular loose bodies (solid white arrow) (C).

Fig. 22 Tear of the scapholunate tear in a recreational tennis player. Coronal FS T2-WI (A) shows discontinuity of the scapholunate ligament (white arrow). Coronal reformatted CBCT arthrography confirms discontinuity of the scapholunate ligament with filling of the radiocarpal compartment after injection of the midcarpal ligament (black arrow).

Fig. 23 Recurrent tear of the medial meniscus after previous medial menisectomy. Sagittal reformatted CBCT arthrography shows shortening of the posterior horn of the medial meniscus and contrast-filled retear (black arrow).

Fig. 24 Posttraumatic osteoarthritis of the talonavicular joint.
Plain radiograph (A) of a 37-year-old male pain at the medial aspect of the right tarsus and a history of previous foot trauma. Note degenerative changes (osteoarthritis) at the talonavicular joint (arrows). Sagittal (B) and axial (B) reformatted CBCT shows better extensive subchondral cyst formation at the distal articular surface of the talus resulting in collapse (arrows). Note also vacuum phenomenon within the talonavicular joint.

Fig. 25 Cartilage lesion of the talus better seen on CBCT than on MRI due to the absence of metal artefacts. Radiograph (A) of a 51-year-old male with a history of ankle fracture after screw placement at medial malleolus and clinical suspicion of cartilage lesion. Coronal proton density (C) and FS T2-WI MRI (C) showing a subchondral bone marrow lesion at the medial talar dome (arrows). Assessment of the overlying cartilage was not possible due to metal artefacts. CBCT-arthrography (D) of the same patient showing subtle fissure of the overlying cartilage (arrow).

Fig. 26 Follow-up of scaphoid fracture. 18-year-old-male with persistent pain one month after a FOOSH trauma. Initial radiograph was interpreted as normal (not shown). Current radiograph (A) shows subtle sclerosis at the proximal pole of the scaphoid bone (arrow). CBCT (B) of the same patient 3 month after the initial trauma. Note pseudo-arthrosis at the waist of scaphoid (short arrow) and sclerosis at the proximal pole of the scaphoid bone (long arrow), in keeping with AVN.