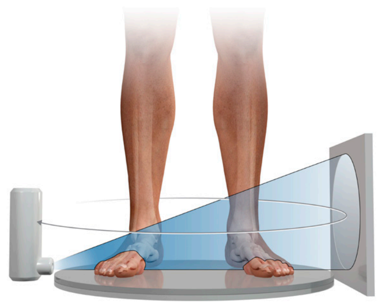
CONE BEAM CT:
A TECHNICAL EXPLANATION OF IMAGE QUALITY CHARACTERISTICS

WHITE PAPER

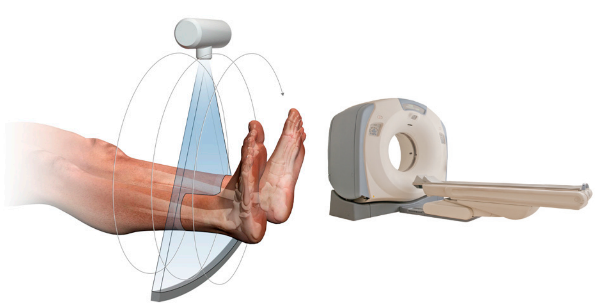
By Dr. John Carrino, MD, MPH & Dr. Eric Bogner, MD

Introduction to Cone Beam CT

Cone Beam Computed Tomography (CBCT) Advanced Imaging Systems are designed to capture three-dimensional weight bearing and non-weight bearing volumetric images of the body extremities. CBCT images are initially acquired as two-dimensional projections, using a rotating gantry with a relatively low power X-Ray source, a pulsed X-Ray beam, and a flat panel detector.



Cone Beam CT *employs a wide, cone shaped beam that captures the entire region of interest in a single 360° pass.*



Conventional CT *systems employ a narrow X-Ray beam and a detector array. Patients are always in a supine position during scan.*

The first commercial CBCT systems were designed for dental/maxillofacial applications in the early 2000s. Current applications for diagnostic CBCT systems extend to ENT (ear, nose & throat), orthopedics, and breast imaging.

The evolution of weight bearing CBCT imaging for the lower extremities has immense potential in the orthopedic realm. Weight-bearing CBCT facilitates the diagnosis of functional injury and deformity with more accuracy than conventional 2D weight-bearing radiographs. In addition, non-weight bearing CBCT imaging of complex structures such as the hand & wrist offers vastly superior visualization of intricate bone details compared to traditional X-Rays and conventional CTs. The scans are lower dose, have 3x - 10x higher resolution, and isotropic voxels in all 3 dimensions.

(Above) CurveBeam's CBCT systems are designed to image the distal extremities for musculoskeletal and orthopedic evaluation.

Extremity CBCT systems are utilized as a point-of-care modality to improve workflow and have been widely accepted by the Orthopedic community: They are compact and fit in a typical exam room, are low weight, and require minimal X-Ray isolation.

General Advantages of Cone Beam CT Image Quality

CBCT is optimized for three-dimensional radiographic imaging. The osseous (high contrast) details in CBCT datasets are at par with or close to conventional multi-detector CT (MDCT). This is the primary diagnostic objective for CBCT scans.

Voxel sizes in CurveBeam systems range from 0.2mm to 0.37mm. All CurveBeam datasets have isotropic voxels, hence any orthogonal/oblique reformats or volume renderings created from the original axial slice stack are undistorted and have the same resolution as the original axial slices.

Dr. John Carrino, MD, MPH

Dr. Carrino is an internationally renowned radiologist with particular expertise in diagnostic imaging and percutaneous image-guided intervention. He is a coauthor on over 200 peer reviewed publications in a variety of areas.

CurveBeam

WHITE PAPER

CONE BEAM CT:
A TECHNICAL EXPLANATION OF IMAGE QUALITY CHARACTERISTICS

CurveBeam systems provide a field-of-view of 20 cm(height) x 35 cm(diameter), and can accommodate most entire adult feet. This custom multi-planar reformat was created in CubeVue, Curvebeam's custom visualization software.

CurveBeam's weight bearing CT systems offer the largest field-of-view in their class, with a 20 cm (height) and a 35 cm (diameter). The voxel size at this setting is 0.3mm. The large field of view allows for a patient's entire foot from the distal calcaneus to the distal phalanges be scanned in a single study. The LFOV also accommodates a bilateral scan of both entire feet or knees, which is useful for assessing pathologies that are typically bilateral conditions, such as flat feet; or for a contralateral comparison to healthy anatomy to verify a perceived deformity is not a natural patient-specific anatomical variation.

Cone Beam CT:
Bilateral Advantage

Another advantage of CurveBeam's bilateral scan capability, both limbs are scanned at a significantly reduced dose compared to when each side is scanned separately. Additionally, time savings are realized by scanning both feet in a single scan session since the technologist only needs to complete the acquisition set-up once, the feet do not have to be repositioned, and only one scan needs to be reconstructed and post-processed.

There is no loss of image resolution when both feet or knees are scanned simultaneously. However, the X-Ray beam indeed suffers greater attenuation when traversing 2 limbs instead of 1, reducing the signal to noise ratio to some extent. This primarily impacts the aesthetics with a slightly noisier looking scan, but the anatomy's structures and relevant diagnostic details are still clearly visible.

Cone Beam CT:
Image Quality Characteristics

Several concurrent technologies have facilitated a significant enhancement in image quality for CBCT systems. These include improved flat panel detector technology, advanced reconstruction algorithms, and data-based models to predict and correct for scatter radiation.

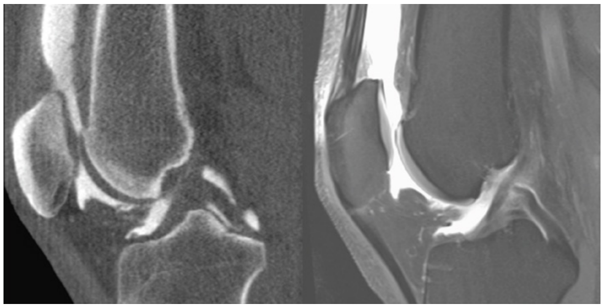
The coronal plane provides unobstructed alignment views. (To the left) Alignment of the subtalar joint can be assessed.

The active components of the LineUP's Complementary Metal-Oxide-Semiconductor (CMOS) flat panels are smaller than traditional amorphous silicon detectors, allowing for more densely placed pixels for higher resolution imaging. The higher charge mobility in CMOS detector crystalline silicon also results in lower noise, higher Detective Quantum Efficiency (DQE), and faster readout time. Faster readout permits a shorter scan, resulting in reduced likelihood of blurring caused by patient movement(1). In terms of reconstruction, CurveBeam utilizes a new-generation proprietary weighted back projection technique with a non-linear filtering scheme. This technique identifies areas of high (bone) and low (soft tissue) density and treats them differently during reconstruction, allowing for more accurate representation of areas potentially affected by reconstruction artefacts. Currently under development is a technique that uses materials-based information to model the scanned object and predict the X-Ray scatter generated so

Dr. Eric Bogner, MD

Dr. Bogner is a board certified radiologist specializing in musculoskeletal radiology for the last 15 years and the division head of Computed Tomography. He has a keen interest in the development of MSK CT imaging helping multiple vendors advance their imaging toward the cutting edge.

that it can be effectively compensated. Most current methods estimate scatter using a water phantom instead of the actual object scanned. The new object-based scatter correction offers significantly better accuracy, resulting in higher contrast and sharper details throughout the image.



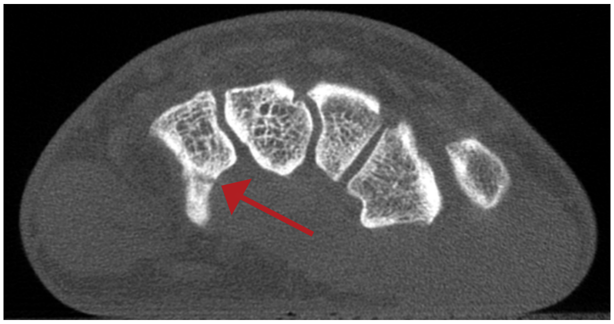
(Above) The sagittal reformatted weight bearing CT arthrogram (left) and MRI (right) both demonstrate outstanding delineation between cartilage and subchondral bone.

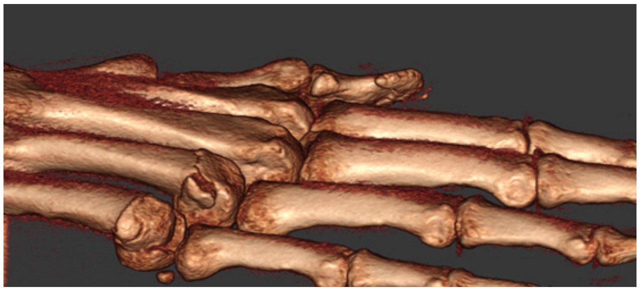
Advantages of CBCT: Bone Trabeculation

Cone Beam CT imaging produces clear images of highly contrasted structures, making it extremely useful for evaluating bone. CurveBeam systems' kVp and mA settings are optimized to depict trabecular architecture at a high resolution.

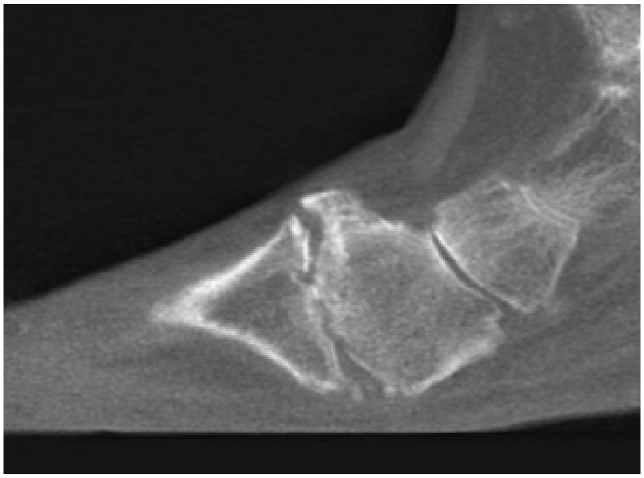
CurveBeam employs a new-generation proprietary reconstruction algorithm that provides the characteristic sharp edges of Feldcamp-Kress reconstructions with noise reduction often seen in most recent & advanced iterative reconstruction methods.

(Below)This subtle hamate fracture was detected due to the fine trabecular detail provided by CBCT. Sagittal MPR reveals conspicuous breach of bony trabeculae indicating fracture. This finding would not be any more apparent on a "traditional" MDCT exam.





(Above) 3D surface rendered image provides clear assessment of the relationship of the fracture fragments of the ring finger metacarpal and small finger metacarpal similar to what a surgeon would encounter during operation. This allows better pre-operative view of the osteoarticular architecture.



(Above) The Sagittal MPR clearly depicts the degree of joint degeneration (joint space loss, subchondral sclerosis, and osteophyte formation), which may be difficult to ascertain on projection radiography because of overlapping anatomical structures.

(Left) This post-operative scan depicts a mal-union of the tibia and talus. Surgeons can assess the degree of osseous healing at frequent intervals.

CONE BEAM CT:

A TECHNICAL EXPLANATION OF IMAGE QUALITY CHARACTERISTICS

WHITE PAPER

Advantages of Cone Beam CT: Hight Contrast Imaging

CurveBeam employs a proprietary reconstruction kernel to enhance the soft tissue contrast and reduce noise levels while preserving bone trabeculation details. In this kernel, which has been implemented on CurveBeam's LineUP system, the detector pixel size is reduced to 0.297mm to increase spatial resolution. The implemented algorithm exclusively features an inherant automatic marker and phantom-free "dejittering", aimed at compensating stochastic mechanical inaccuracies, impossible to calibrate away with any other existing approach in the market.

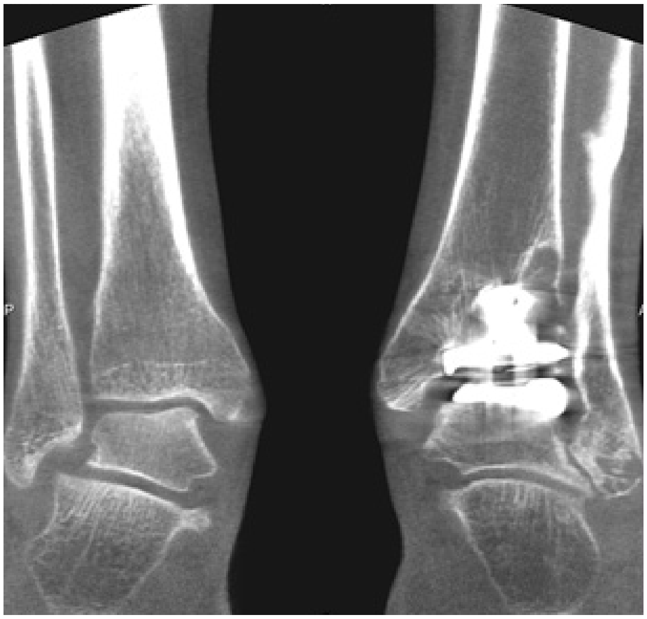
(Above) The same dataset displayed with soft tissue enhancement algorithm off (left) and on (right).

CurveBeam Metal Suppression Techniques (MAR)

CurveBeam's proprietary metal artefact reduction (MAR) algorithm employs a high-density detection filter, which enables more authentic reconstructions in the vicinity of metal hardware. The option to apply metal artefact reduction can be activated at any time, i.e. before or after completing each scan.

Any other Metal Suppression algorithms reduce streaks and voids caused by metal objects, but do not accurately depict the anatomical detail immediately surrounding the metal. Rather, they depict metal surrounded by an extrapolated layer of blur. In the reconstruction implemented in CurveBeam scanners, even in anatomy with large quantities of metal such as total ankle replacements, anatomy in close proximity to metal is preserved with an unmatched degree of authenticity compared to any other commercial system.

The above image shows a post-MAR slice.



The above image shows a normal slice without application of MAR.

Conclusion: Cone beam CT imaging holds immense potential as a routine diagnostic tool in orthopedic medicine. CurveBeam's CBCT systems provide three-dimensional, high-contrast trabecular detail for definitive diagnosis of fractures and dislocations. The ability to scan in weight bearing position, coupled with the stellar image quality characteristics and isotropic resolution, makes CBCT a key modality in a musculoskeletal imaging suite.

(1) Zentai, George. "Comparison of CMOS and a-Si Flat Panel Imagers for X-Ray Imaging." Comparison of CMOS and a-Si Flat Panel Imagers for X-Ray Imaging, 29 July 2011, ieeexplore.ieee.org/abstract/document/5962217.