White paper

Multitom Rax Real3D for musculoskeletal and trauma imaging

Imaging technique and clinical application

Anna Rasche, PhD; Marcel Beister, PhD

siemens-healthineers.com/robotic-x-ray

SIEMENS Healthineers

Contents

1. Real3D: The technique and its added value 3

3D imaging in supine and natural weight-bearing patient positions 3
High spatial resolution for bony structures 5
Dose-saving potential for extremities 9

2. Real3D: Applications in clinical practice 11

Trauma evaluation of extremities: Fracture detection and surgical follow-up 11
Arthrography: Taking advantage of Multitom Rax's multifunctionality 15
Weight-bearing imaging for new approaches in orthopedics 17

3. Conclusion: Shaping the future of orthopedic and trauma imaging with Real3D 20

Abbreviations 20

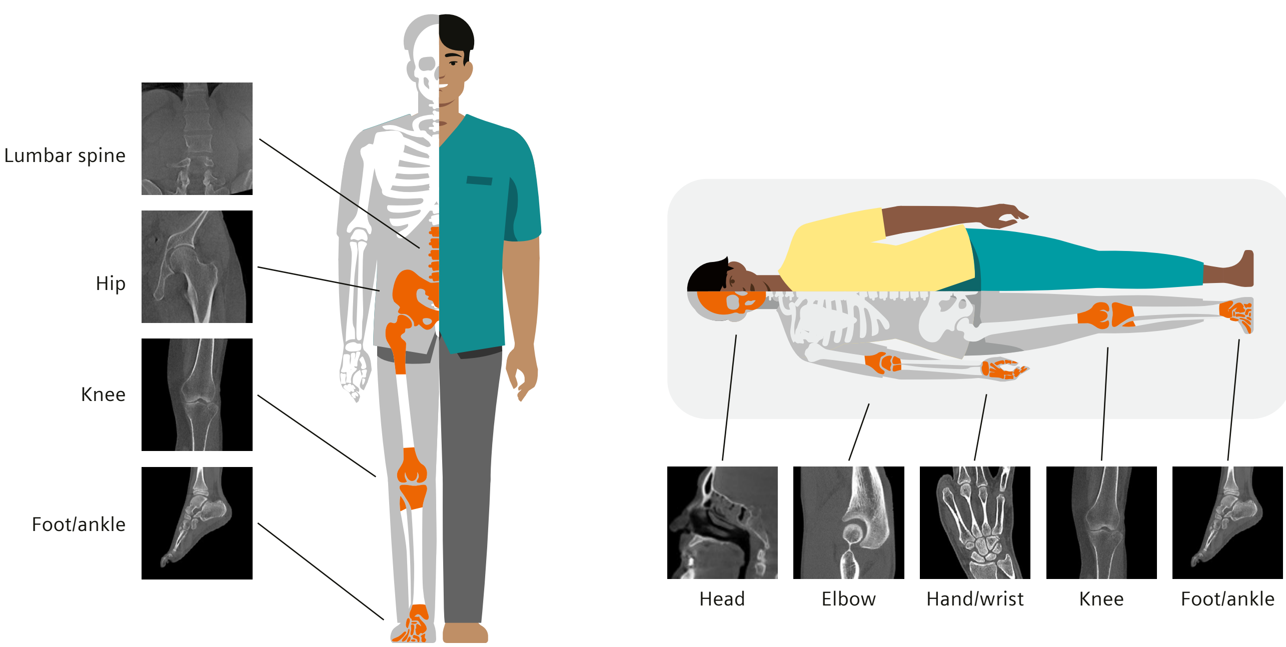
References 21

1. Real3D: The technique and its added value

The Twin Robotic X-ray system Multitom Rax provides conventional radiography, fluoroscopic examinations for functional assessment, the slot scanning function True2scale Body Scan for extended orthopedic examinations, and Real3D as cone-beam computed tomography on the same system. The focus of this white paper is on Real3D that offers three-dimensional information on the scanned body region – free from magnification and distortion – in sagittal, coronal, and axial views as well as a rendered bone volume to meet the requirements of musculoskeletal and trauma departments.

3D imaging in supine and natural weight-bearing patient positions

Real3D enables examinations of different body regions with the patient in a supine or weight-bearing position as shown in Figure 1.



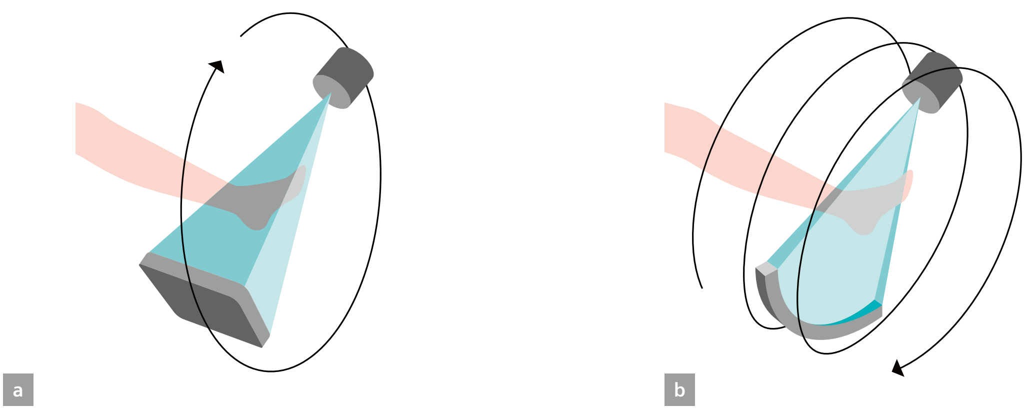
a Scanned in a weight-bearing patient position

b Scanned in a supine patient position

1 Recommended body regions for Real3D

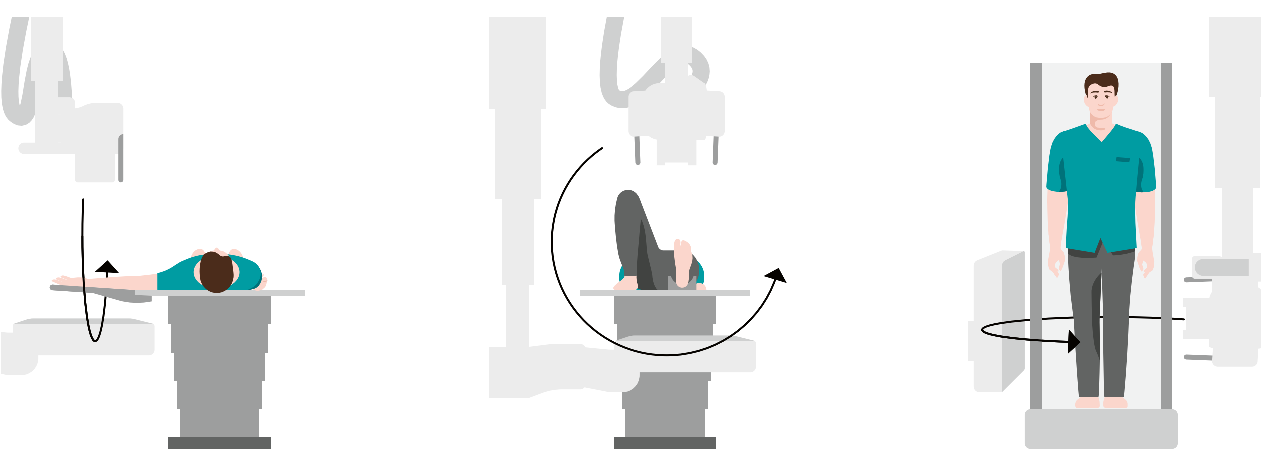
To capture 3D information, Real3D uses a flat panel detector for image acquisition that results in a cone geometry of the X-ray beam (Figure 2a). During a scan, tube and detector rotate around the patient and a specific number of projection images are taken depending on the application. The projection data is used to calculate 3D datasets that are familiar and well-established in computed tomography (CT).

In contrast to Real3D, multi-detector computed tomography (MDCT) uses a combination of a fan-beam X-ray configuration and multiple detector rows for image acquisition to subsequently reconstruct a volume dataset. Because of the much smaller cone angle, multiple rotations around the patient are performed in a spiral or helical pattern to cover the entire region of interest.[1],[2]



2 X-ray geometry in Real3D (a) and multi-detector CT (b)

Multitom Rax uses a ceiling-mounted tube and a ceiling-mounted amorphous silicon flat-panel detector for Real3D image acquisition (with an active area of 42.0 cm x 42.5 cm and a cesium iodide scintillator). Tube and detector both have three translational and two rotational degrees of freedom for moving on defined paths (trajectories) around the patient and acquiring the projections. Three types of trajectories are installed in the system to enable imaging of different body parts with the patient in either a supine or an upright position (Figure 3). Depending on the trajectory, tube and detector capture projection data over an angular range of between 171° and 200° around the patient with a scan duration of between 12 and 16 seconds. For a precise and stable reconstruction of a region of interest, angular ranges of less than 360° are sufficient.[3]



a Tableside trajectory for hand and elbow examinations

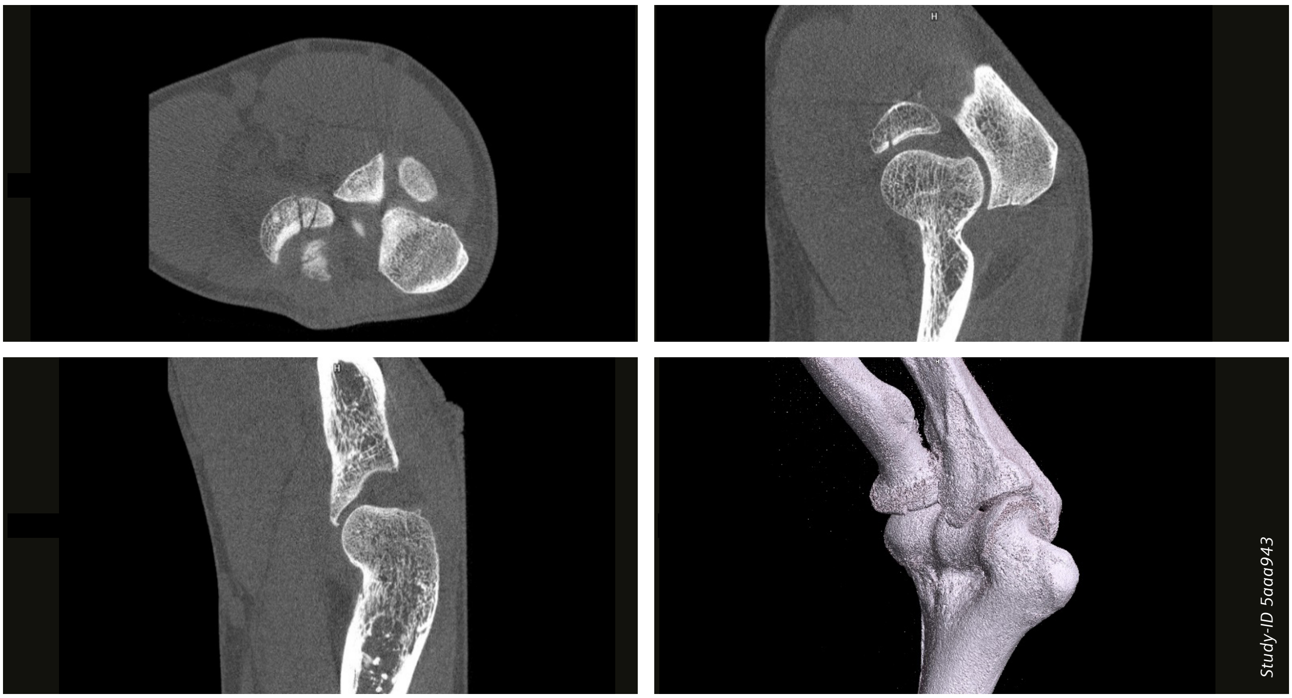
b Table trajectory for head, foot, and knee examinations

c Upright trajectory for foot, knee, hip, and lumbar spine examinations

3 Different trajectories for Multitom Rax Real3D

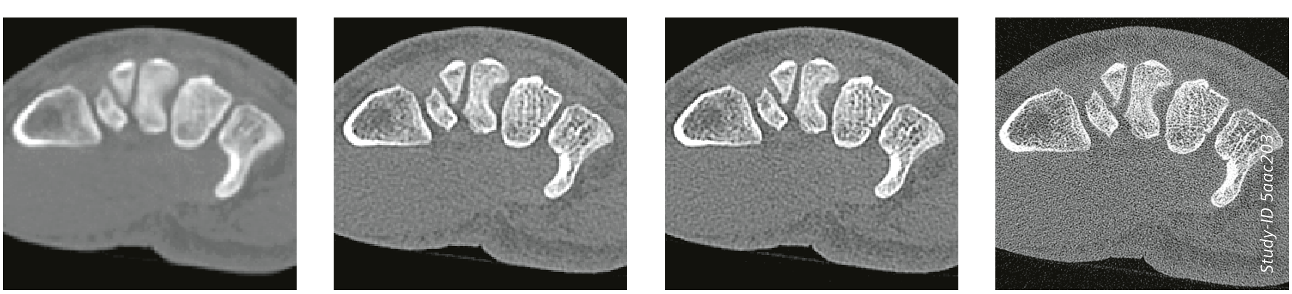
High spatial resolution for bony structures

For diagnostic evaluations, the radiologist can use multi-planar reconstruction (MPR) views in sagittal, coronal, and axial planes, corresponding to MDCT (Figure 4). A 3D view using a volume-rendering technique (VRT) allows for an additional assessment of anatomical structures.



4 MPR and VRT of an elbow: axial, sagittal, coronal, and VRT view of a fracture of the radial head
(Courtesy of Krankenhaus der Augustinerinnen, Cologne, Germany)

The user can choose up to four different image impressions for the generated Real3D slices: smooth, medium, sharp, and very sharp. The image impression is influenced primarily by the underlying reconstruction kernels. These are chosen to be similar to the ones used in Siemens Healthineers' clinical MDCT systems, which enables Real3D on Multitom Rax to provide a comparable image impression. The smooth impression is mainly intended for VRT renderings, while the medium impression is a good, balanced choice between image resolution and noise. The sharp and very sharp image impressions with a higher image resolution are intended for diagnosing fractures and fine bony structures (Figure 5).

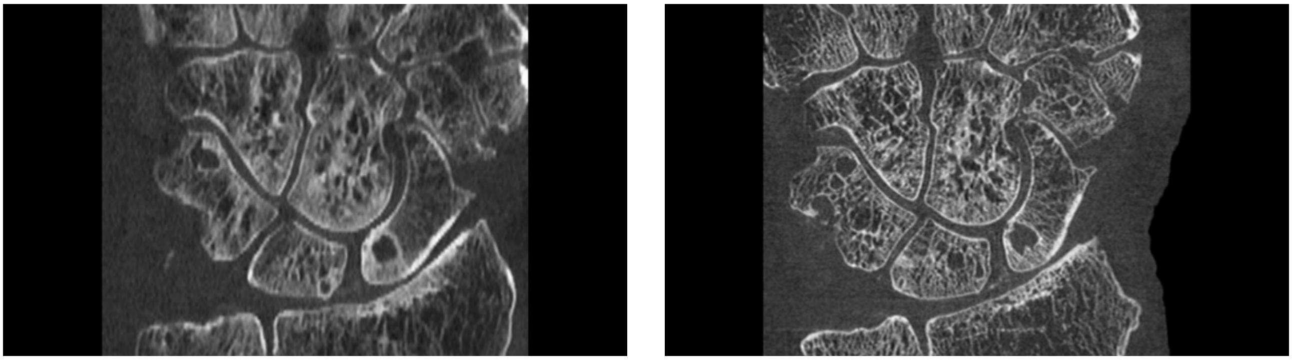


a Smooth **b** Medium **c** Sharp **d** Very sharp[1]

5 Real3D image impressions
(Courtesy of Krankenhaus der Augustinerinnen, Cologne, Germany)

[1] *Only available for Real3D Hi-Res*

The maximum volume that can be imaged using Multitom Rax Real3D is a cylinder with a diameter and height of approximately 23 to 26 cm at an isotropic spatial resolution of up to 15 lp/cm, depending on the trajectory and image impression selected for reconstruction. The coronal image resolution in the z-direction is higher in Real3D than in MDCT due to the isotropic smaller pixels of Multitom Rax's flat panel detector (Figure 6).



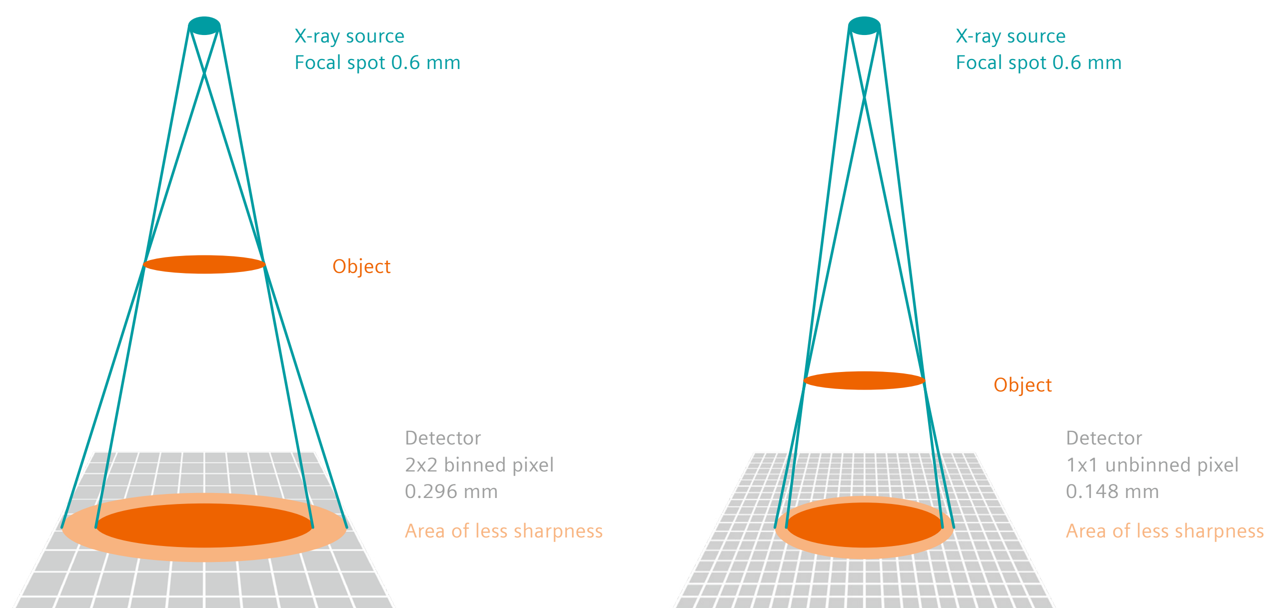
a High-resolution MDCT scanner using an ultra-high-resolution, sharp reconstruction kernel (Ur77)

b Real3D Hi-Res using the image impression "very sharp"

6 Coronal slices of a wrist examination
(Courtesy of University Hospital Wuerzburg, Germany)

Real3D Hi-Res is an additional scan mode with a higher spatial resolution of up to 25 lp/cm, that allows a reconstruction of a cylinder with a diameter and height of 15 cm. The high-resolution scan mode works with an un-binned partial detector readout, in contrast to the normal mode of 2 x 2 binned readout mode.

To fully exploit the smaller pixel size, the circular trajectory is modified so that the examined body part is closer to the detector. This reduces the limiting effect of the focal spot size on the spatial resolution of the X-ray system (Figure 7).

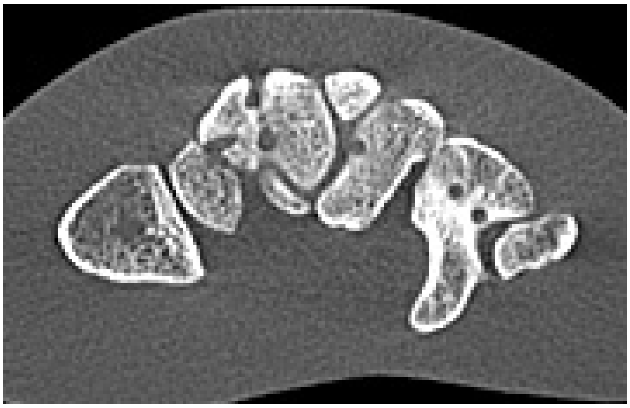


a Normal scan mode

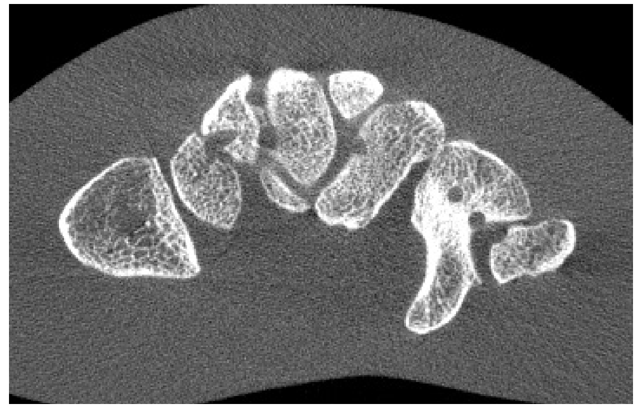
b High-resolution scan mode

7 X-ray source and detector for the Real3D scan modes

The higher spatial resolution when using the high-resolution scan mode has advantages for assessing anatomical structures. The visualization of the bone and its trabeculae is sharper than the normal scan mode and reveals more details (Figure 8). Table 1 shows an overview of the differences between both scan modes implemented in Multitom Rax.



a Axial slice in normal scan mode



b Axial slice in high-resolution scan mode

c Coronal slice in normal scan mode

d Coronal slice in high-resolution scan mode

8 Real3D phantom examination of a hand

	Normal scan mode Real3D	**High-resolution scan mode Real3D Hi-Res**
Spatial resolution	15 lp/cm	25 lp/cm
Reconstructable volume	Cylinder with diameter and height of 23 to 26 cm	Cylinder with diameter and height of 15 cm
Body regions	Hand/wrist, elbow, head, hip, lumbar spine, knee, foot/ankle	Hand/wrist, elbow

Table 1: Differences between Real3D's normal and high-resolution scan modes

! Even higher spatial resolution using Real3D Hi-Res: 32 lp/cm compared with 16 lp/cm in the normal scan mode.

Metal artifact reduction for excellent bone visualization in the presence of implants

For body parts containing metallic implants, markers, or external fixators, Real3D offers dedicated acquisition modes with modified parameters that automatically trigger a metal artifact reduction method during the computation of the slice images and the VRT. The advanced interpolation method in conjunction with the preservation of high-frequency details can reduce the number of streaks and very bright and dark areas surrounding metallic implants in the image to a large extent. In Figure 9, you can see an example of an ankle examination with and without metal artifact reduction: Dark streaks close to the visible screw and three dark phantom holes created by out-of-plane screws are substantially reduced by Real3D's metal artifact reduction. A study of cadaveric wrist scans confirmed that Real3D Hi-Res with metal artifact reduction implemented "Facilitates excellent visualization of the appendicular skeleton in the presence of metal implants."[4]

The artifact reduction method can be chosen for reconstruction even if a regular acquisition mode was used: for example, if the presence of the metal was unknown to the user before the acquisition. Conversely, it is possible to turn off the artifact reduction for reconstruction even if an acquisition mode for metal implants was used for the data acquisition.

a Without metal artifact reduction

b With metal artifact reduction

9 Sagittal slice of a foot examination with a bone fracture plate and multiple fixation screws

(Courtesy of Krankenhaus der Augustinerinnen, Cologne, Germany)

Dose-saving potential for extremities

Dose declaration

The applied radiation dose plays an important role in evaluating modalities. The dose specification describes the energy that the patient is exposed to. The unit for this dose is Gray (1 Gy = 1 J/kg). In contrast to the effective dose – which is specified in the unit Sievert (Sv) – the applied dose does not provide an evaluation of the potential damage that the ionizing radiation can cause in the patient's body; rather, it describes the radiation of the X-ray beams.

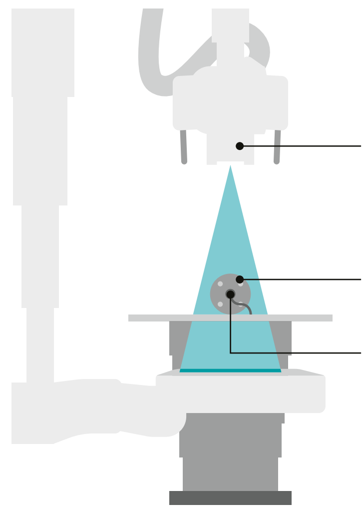
A value for the dose area product (DAP) is documented in conventional X-ray examinations. Due to its different acquisition technique compared to 2D radiography, in MDCT examinations a dose length product (DLP) and a computed tomography dose index (CTDI) are documented.

As described above, Real3D captures a number of projection images using a fluoroscopy acquisition mode. As a result, the dose for each image is measured as DAP using an ionization chamber at the X-ray source (Figure 10). The applied dose is stated as the DAP sum of the individual projection images for the entire Real3D dataset.

In addition, Real3D offers computed values for DLP, $CTDI_{vol16}$, and $CTDI_{vol32}$ (see description above). As a basis for calculating these values, conversion factors were determined in dose measurements with a 16-cm CTDI phantom, because this entire phantom fits inside the Real3D beam path (Figure 10).[2] Lund University in Malmö has independently validated this calculation and confirmed the accuracy of the method implemented on Multitom Rax.[5] A calculated value for $CTDI_{vol32}$ based on simulations can also be displayed by the system.

The DLP takes the actual source-to-object-distance of the acquisition into account, which varies across different trajectory types in Real3D and across different MDCT models. That is why we recommend $CTDI_{vol16}$ and $CTDI_{vol32}$ of Real3D and MDCT scanners to serve as a basis for comparing the applied radiation dose between both systems.

The dose declaration values from Real3D allow for a comparison of conventional X-ray devices with MDCT scanners. Nevertheless, users should take into account the fact that comparing the dose delivered by different modalities is subject to a certain degree of inaccuracy due to different measurement methods, and this will impact the desired image quality. The radiation dose cannot be considered separately, but only in the context of the achieved image quality.



10 Measuring positions for DAP and for calculation of DLP and $CTDI_{vol16}$

! Dose area product for 2D radiography
According to IEC 60601-2-54, conventional X-ray devices measure or calculate a value for the dose area product (DAP) in Gy·m^2. The DAP is the surface integral of the air kerma – the kinetic energy released in air – along a sectional plane through the radiation field.

! Dose length product for 3D computed tomography
According to IEC 60601-2-44, a value for the dose length product (DLP) in mGy·cm and a computed tomography dose index (CTDI) in mGy must be specified for CT scanners. The DLP is calculated as the line integral of the air kerma along the system axis of the computer tomograph. The $CTDI_{vol}$ represents the average energy dose (expressed as air kerma) within a phantom, a PMMA cylinder with a diameter of 16 or 32 cm, aligned with the scanner axis and centered in the scan plane. A value for $CTDI_{vol}$ must be derived that includes information about the CTDI phantom. The DLP can also be calculated as the product of the $CTDI_{vol}$ value and the scan length.

[2] *The measurements are derived from IEC 60601-2-44. Due to the different acquisition methods of Real3D and MDCT, the measurements cannot be adopted exactly as described in IEC 60601-2-44.*

Applied radiation dose at the extremities

Several studies of human specimens compared the applied radiation dose and the achieved image quality of Real3D to MDCT scanners when imaging extremities. All publications conclude that there were substantial dose savings using Real3D compared to MDCT scanners at a comparable image quality for bony structures. [6],[7],[8],[9]

Table 2 shows the $CTDI_{vol16}$ values from cadaveric studies. In the normal Real3D scan mode, the applied radiation dose from the MDCT scanner was five to eight times higher than from Real3D – and the high-resolution MDCT scanner applied a radiation dose four times higher than Real3D Hi-Res. The results of another study of cadaveric wrist and elbow scans indicate a further dose-saving potential using Real3D Hi-Res at a low dose compared to the standard protocol while maintaining the desired diagnostic image quality.[10]

As stated above, the radiation dose affects the achieved image quality. Looking at the results of Real3D in normal scan mode for the wrist, the overall image quality was rated higher for Real3D than for MDCT and slightly lower for images of the ankle. Artifacts and image noise in bone were comparable in the wrist images and slightly more prominent in the ankle images. The assessment of artifacts and image noise in soft tissue was inferior compared to MDCT. It was concluded that Real3D is especially suitable for evaluating bone cortex and trabeculae and therefore for fracture diagnosis and during the healing process.[6],[7]

The image quality of the Real3D high-resolution scan mode was analyzed compared to a high-resolution MDCT scanner for wrist and elbow imaging. The overall image quality of Real3D Hi-Res was rated as similar to a high-resolution MDCT scanner. Artifacts in bone using Real3D Hi-Res were considered minimal or few – comparable to high-resolution MDCT – and image noise in bone was inferior to high-resolution MDCT. Similar to the results from normal scan mode, artifacts and noise in soft tissue were rated lower in Real3D Hi-Res compared to high-resolution MDCT. It was concluded that by using Real3D Hi-Res, an even better image quality for evaluating bony structures could be achieved compared to the normal scan mode, similar to comparing a high-resolution MDCT scanner to a conventional MDCT scanner.[8],[9]

The normal scan mode of Real3D produces a similar image quality for bone visualization while applying less radiation dose compared to a conventional MDCT scanner and the Hi-Res scan mode compared to high-resolution MDCT scanner. This indicates that substantial dose savings using Real3D for extremity imaging may be possible depending on the clinical situation.

	Normal scan mode				High-resolution scan mode				
	Wrist [6]		Ankle [7]		Wrist [8]		Elbow [9]		Wrist / Elbow [10]
	Real3D	MDCT	Real3D	MDCT	Real3D Hi-Res	High-resolution MDCT	Real3D Hi-Res	High-resolution MDCT	Real3D Hi-Res Low Dose
$CTDI_{vol16}$ (mGy)	1.8±0.2	15.0	2.9±0.6	15.0	3.3	13.8	3.3	13.8	1.2

Table 2: Applied radiation dose in cadaveric studies

! Real3D offers a dose-saving potential for the evaluation of bony structures in the upper and lower extremities.

Applied radiation dose at the body trunk

The applied radiation dose is different when imaging extremities than it is using the cone-beam imaging technique at the body trunk. More tissue is present in the beam path, which causes more scattered radiation. That is why a higher radiation dose is needed to achieve an adequate image quality at the body trunk than at the extremities. The applied radiation dose for imaging the lumbar spine at the body trunk was analyzed in a study of human specimens. The authors proposed a protocol with a $CTDI_{vol32}$ of 11.9 ± 2.6 mGy for clinical use, which was the most balanced choice after considering the overall image quality, the clarity of the posterior wall, the applied radiation dose, and noise. When the radiation dose used in the proposed Real3D protocol was compared to values from multi-detector CT, similar or even higher dose levels are reported in the literature.[11]

2. Real3D: Application in clinical practice

Multitom Rax offers diverse clinical applications of Real3D that range from trauma and functional evaluation of extremities to the assessment of joints in a natural weight-bearing patient position.

Trauma evaluation of extremities: Fracture detection and surgical follow-up

For trauma imaging, Multitom Rax and its Real3D functionality can add diagnostic value compared to 2D X-ray examinations, especially for the assessment of complex anatomies with high superposition of adjacent bony structures like joints. Real3D can be used right after the 2D image if required or instead of a 2D examination to evaluate traumas to the extremities and their surgical follow-up. When evaluating small bone and joint trauma, Real3D may help physicians by detecting and excluding extremity fractures, fracture-related findings, and post-surgical complications more reliably than 2D radiographs, as shown in Table 3.[12],[13],[14],[15]

It has been reported that there are a larger number of fractures, joint involvement, and multi-fragment injuries being assessed using Real3D compared to conventional X-ray images. The orthopedic surgeon changed the treatment decision based on radiological reports after the Real3D scan was compared to the report from the radiograph for 31.5 percent of the patients, and six fractures suspected in radiographs were ruled out by the Real3D information.[12]

Comparable benefits can be shown for Real3D Hi-Res. In a study of severe wrist trauma, Real3D Hi-Res was superior for imaging scaphoid fractures, multi-fragment radius injuries, articular affliction, proximal pole or waist involvement, and comminuted patterns.[13]

For acute elbow traumas, Real3D Hi-Res allowed for a greater sensitivity compared to radiography in the assessment of fractures, articular surface involvement, and multi-fragment patterns.[14]

The diagnostic accuracy for detecting various post-surgical complications, screw dislocation, implant loosening, fragment displacement, and delayed healing was superior for Real3D compared to X-ray examinations in a study that included patients after osteoplasty of hand/wrist, elbow, and ankle/foot. In addition, the post-operative management decision changed in 23.8 percent of patients with Real3D images compared to X-ray information. In one case, the Real3D image showed no intra-articular positions of four screws – thanks to reducing over-projection of anatomical structures compared to conventional X-ray – and this prevented unnecessary surgeries.[15]

The studies of fracture detection presented had a higher sensitivity for detecting fractures and fracture-related findings using Real3D compared to conventional radiography; they also confirmed the readers' greater diagnostic confidence when reading Real3D images, as shown in Table 4.

! Physicians ruled out more fractures, fracture-related findings, and post-surgical complications at extremities using Real3D compared to conventional radiography.

! Higher diagnostic confidence for physicians for ruling out fractures and fracture-related findings at extremities using Real3D compared to conventional radiography.

	Real3D/ Real3D Hi-Res	X-ray
Diagnostic accuracy of upper/lower extremity traumas [12]:		
Fractures	98%	71%
Joint involvement	98%	79%
Multi-fragment injuries	98%	76%
Diagnostic accuracy of wrist traumas [13]:		
Radius fracture	100%	100%
Articular affliction	99%	84%
Multi-fragment situation in radius	100%	92%
Scaphoid fracture	100%	70%
Waist or proximal pole involvement	100%	68%
Multi-fragment injury in scaphoid	100%	73%
Sensitivity of elbow traumas [14]:		
Fracture	96%	75%
Articular involvement	95%	79%
Multi-fragment injury	96%	71%
Diagnostic accuracy of post-surgical complications [15]:		
Articular screw position	99%	84%
Screw loosening	99%	86%
Implant failure	100%	96%
Fragment dislocation	99%	85%
Delayed healing / non-union	98%	89%

Table 3: Average diagnostic accuracy/sensitivity of findings among different readers

	Real3D	X-ray	p value
Diagnostic confidence: traumas of the upper and lower extremities [12]	5	4	< 0.001
Diagnostic confidence: wrist traumas [13]	5	4	< 0.001
Diagnostic confidence: elbow traumas [14]	5	4	< 0.001

Table 4: Median diagnostic confidence when reading Real3D compared to conventional X-ray examinations from “1 = no” to “5 = absolute” among different readers

Clinical cases: Trauma evaluation of extremities and post-surgical follow-up

The following presents two examples from clinical routine that show the benefits of Real3D compared to conventional 2D radiographs.

Figure 11 illustrates the clinical case of a radial head fracture. The patient fell from an e-scooter onto his right elbow. He presented to the trauma surgery department with pressure pain, especially over the radial head, and extensive swelling that resulted in limited motion range. No bony injury could be ascertained in the initial X-ray scans. However, a subtle anterior fat pad sign in the lateral radiogram (arrow) suggested the presence of joint effusion (Figure 11a). When the second set of radiographs six days later did not display any fracture line (Figure 11b), Real3D was requested to exclude a radiographically occult fracture of the radial head (Figure 11c).

Multitom Rax Real3D was able to depict a non-displaced fracture in the anterior portion of the radial head (Mason type I). Aside from the radial head injury, other fractures were excluded in the Real 3D examination. Surgical therapy was not required, because the elbow joint showed no signs of instability. Instead, the patient was given conservative treatment that included temporary immobilization and subsequent physical therapy.

a X-ray examinations on date of injury

b X-ray examinations six days later

c Axial, sagittal, and coronal view of Real3D Hi-Res examination using standard protocol (tube voltage 80 kV, $CTDI_{vol32}$ 1.9 mGy, $CTDI_{vol16}$ 5.5 mGy, scan time 14 sec)

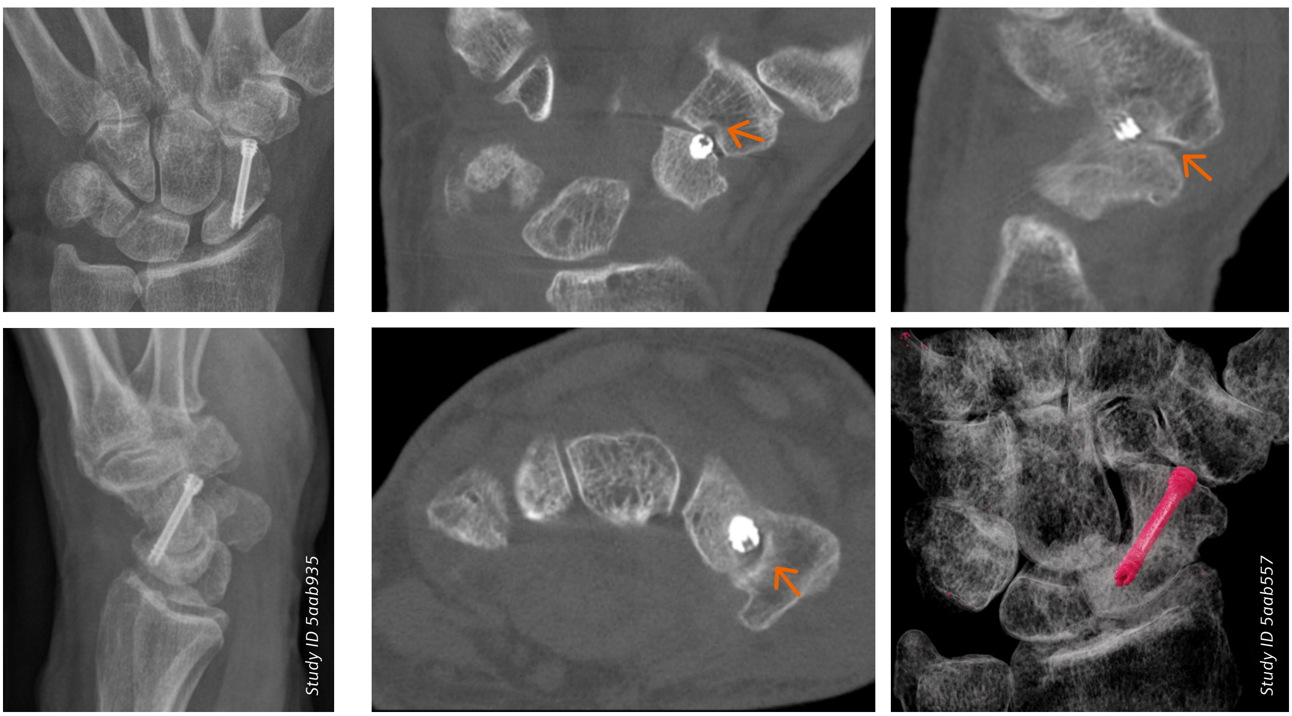
11 Multitom Rax examinations of a radial head fracture

(Courtesy of University Hospital Wuerzburg, Germany)[3]

[3] *Please visit our Clinical Case Library to explore more applications of Multitom Rax Real3D*

The clinical case of a scaphoid screw dislocation demonstrates the clinical use of Real3D for surgical follow-up (Figure 12). The patient fell on her left wrist three months before the present examination and suffered a scaphoid waist fracture (Herbert B2). Conventional screw osteosynthesis was performed with subsequent cast immobilization for six weeks. The patient reported subtle pressure pain over the radial side of the distal carpal row. The 2D radiography (Figure 12a) was unable to visualize accurate screw placement and remained inconclusive with regard to fracture healing, so that a Real3D scan was ordered (Figure 12b).

In addition to the complete fracture healing, Real3D images with metal artifact reduction revealed screw displacement into the scaphotrapezial joint. The proximal articular surface of the trapezium displayed a small notch (arrow on the coronal view) congruent to the distal portion of the dislocated screw. Signs of secondary osteoarthritis were visible (joint space narrowing, subchondral sclerosis).



a X-ray examinations

b Coronal, sagittal, axial, and MIP (maximum intensity projection) view of Real3D Hi-Res examination using dedicated metal protocol (tube voltage 116 kV, $CTDI_{vol32}$ 5.0 mGy, $CTDI_{vol16}$ 18.0 mGy, scan time 14 sec)

12 Multitom Rax examinations of a scaphoid screw dislocation
(Courtesy of University Hospital Wuerzburg, Germany)[4]

[4] *Please visit our Clinical Case Library to explore more applications of Multitom Rax Real3D*

Arthrography: Taking advantage of Multitom Rax's multifunctionality

The combination of its different functionalities means that Multitom Rax offers the potential for an improved patient workflow and associated time savings. With Multitom Rax, arthrographies can be performed for a simultaneous evaluation of chondral injuries, surrounding cartilage, and subchondral bone. After the injection of the contrast medium using the fluoroscopy functionality of the system, the Real3D scan can be performed immediately without changing rooms.

A study of human specimens proved the feasibility of Multitom Rax for 3D arthrography of the wrist in a "one-stop shop" approach without repositioning the region of interest by using fluoroscopy to inject the contrast medium and Real3D Hi-Res to create the tomography. The median examination time for 3D arthrography was 5.4 min from contrast injection to finishing the Real3D scan.[16]

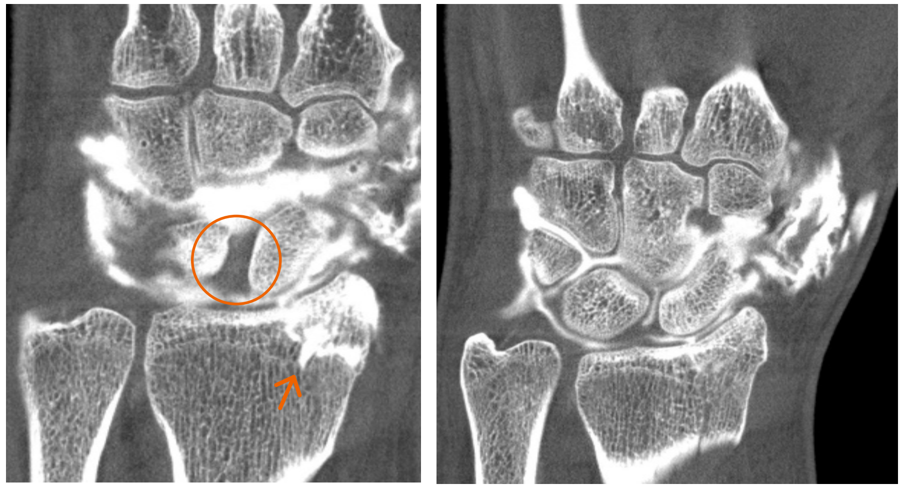
! With its fluoroscopic and Real3D functionalities, Multitom Rax offers a one-stop shop approach for 3D arthrography.

Clinical case: Arthrography

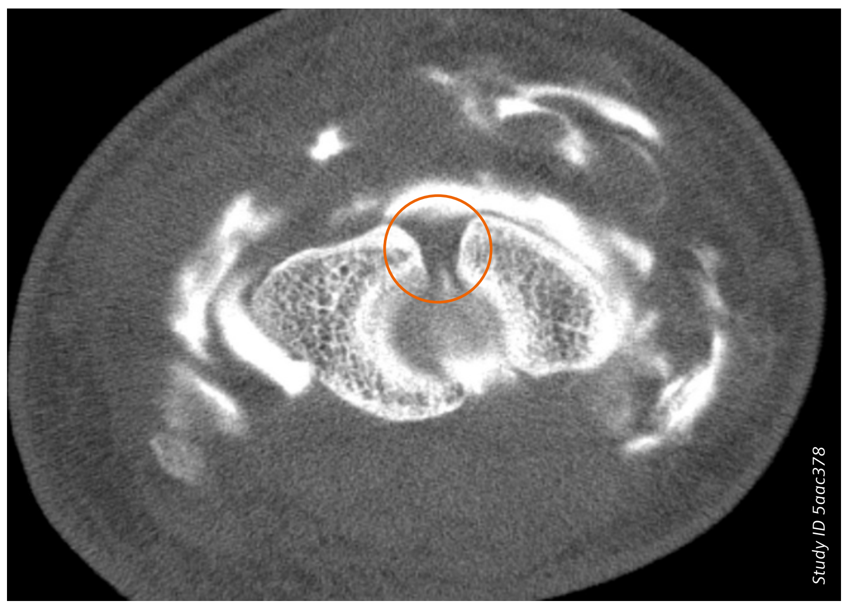
The case shown in Figure 13 shows this application in clinical routine. The patient presented with pain and swelling over the radial side of the wrist after falling on his outstretched left hand in a bicycle accident. With the 2D radiography (Figure 13a), a slightly displaced fracture of the radial styloid process was ascertained (marked with an arrow on the X-ray examination).
Before beginning surgical treatment of this Chauffeur-type fracture, trauma surgeons requested a pre-operative assessment of scapholunate ligament integrity. To assess the anatomical structure, an arthrography using Multitom Rax was performed with the patient remaining in the same position for the fluoroscopy and Real3D imaging using the tableside scan trajectory for wrist imaging.

Fluoroscopy-guided two-compartment wrist arthrography (midcarpal, radiocarpal) depicted no communicating lesions of the intrinsic carpal ligaments (Figure 13b). Subsequent Real3D imaging (Figure 13c) visualized the Chauffeur fracture of the distal radius (arrow), while ruling out any discontinuity of the scapholunate interosseous ligament (marked with a circle on the coronal view). Axial reformatting supported the presumed integrity of the scapholunate interosseous ligament. Its dorsal segment in particular, which functions as one of the key stabilizers of the proximal carpal row, appeared intact (marked with a circle on the axial view). The lunotriquetral ligament displayed a subtle discontinuity in its proximal membranous portion. However, this finding is mainly associated with degenerative alterations and insignificant for carpal stability.

While the patient had surgery for re-fixation of the distal radius, the need for additional treatment of the scapholunate ligament was ruled out in a minimally invasive procedure using Multitom Rax Real3D arthrography.



a X-ray examination



b Fluoroscopy-guided injection

c Coronal and axial views of Real3D Hi-Res examination using standard protocol (tube voltage 80 kV, $CTDI_{vol32}$ 1.6 mGy, $CTDI_{vol16}$ 4.5 mGy, scan time 14 sec)

13 Multitom Rax examinations of a wrist arthrography
(Courtesy of University Hospital Wuerzburg, Germany)[5]

[5] *Please visit our Clinical Case Library to explore more applications of Multitom Rax Real3D*

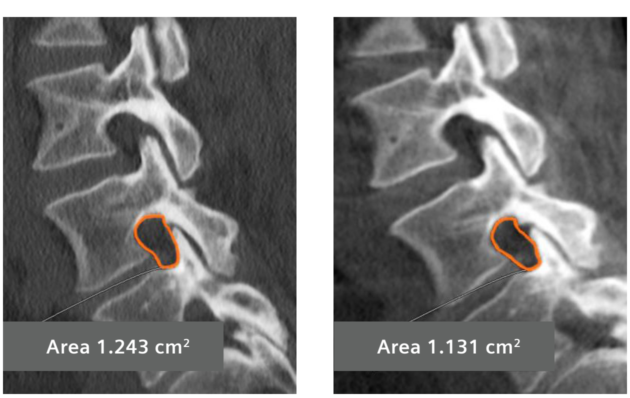
Weight-bearing imaging for new approaches in orthopedics

The examination of disorders in a natural weight-bearing position is well established in 2D radiography. Now Real3D makes this approach possible for 3D imaging. A Real3D scan with the patient in a natural weight-bearing position may provide additional information for the evaluation of osteoarticular deformities. Because the position of certain anatomical structures, especially complex joints, changes with weight loading, a Real3D scan with the patient in an upright position could make a difference in diagnosis and treatment planning compared to supine imaging: for example, for an improved prosthesis or surgery planning and for patients who have pain in a weight-bearing position, and for whom a scan in a supine position does not provide a finding.[17]

Weight-bearing imaging of the lumbar spine

With its Real3D functionality, Multitom Rax is the only generally available scanner that enables weight-bearing CT imaging of the lumbar spine.

The first clinical results show a valid use case for this kind of examination in the assessment of the lumbar foramina. A study of 48 patients confirmed that the lumbar foramina were smaller in a weight-bearing position compared to a supine patient position (Figure 14). There was a statistically significant decrease in neuroforaminal size – the cross-sectional areas as well as the cranio-caudal and ventro-dorsal diameters of the foramina – from the supine to the weight-bearing position. These results may indicate the added value of the weight-bearing 3D information for diagnosis and treatment planning.[18]



a MDCT slice acquired in a supine patient position

b Real3D slice acquired in a weight-bearing patient position

14 Marked neural foramina in the lumbar spine
(Courtesy of University Hospital Basel, Switzerland)

Another scientific publication analyzed the spinal stability of six patients in a weight-bearing, neutral standing position and with flexion and extension using Real3D. The Real3D scan in a functional physiological standing position offered three-dimensional information with no geometric distortion compared to conventional radiographs of fractures, spinal canal, exit foramina, facet joints, and implanted metal. In one of the patients, this information prevented fusion surgery by showing spinal stability. The authors conclude that neutral, flexion, and extension imaging using Real3D allows for an accurate assessment of spinal instabilities. For patients for whom no diagnosis was possible using a supine 3D imaging modality, weight-bearing Real3D examinations offered new opportunities to identify the cause of occult back and leg pain.[19]

When combining the advantages of cross-sectional and weight-bearing imaging of the lumbar spine, it is found that Real3D offers a promising alternative for imaging diseases of the lumbar spine. The static forces that apply in weight-bearing conditions and the resulting changes in anatomical size are believed to be the main reason for an often recognizable mismatch between clinical and magnetic resonance imaging findings for the diagnosis of lower back pain. However, future clinical research is needed to investigate how patients' clinical outcomes can be improved by these differences.[20]

! Weight-bearing Real3D examinations of the lumbar spine show a decrease in the neuroforaminal size compared to supine patient position.

Weight-bearing imaging of the lower extremities

In addition to its unique application for the lumbar spine, Multitom Rax Real3D offers weight-bearing examinations of the lower extremities similar to other systems that use the cone-beam technique for computed tomography. This type of imaging offers quantification of biomechanical parameters, including the relative positions of bones, angles, and ligaments as well as joint space width.[21]

For the knee, the diagnosis and treatment of osteoarthritis and patellofemoral diseases can be impacted by the fact that femorotibial rotation, the tibial tuberosity-trochlear groove, and medial joint space width differ between weight-bearing and non-weight-bearing images.[22]

Foot and ankle examinations that are performed in a weight-bearing position can add clinical value when evaluating complex deformities, joint alignment, congruence and coverage of articulating facets, impingement, joint degeneration, and decreases in joint space width when standing.[21]

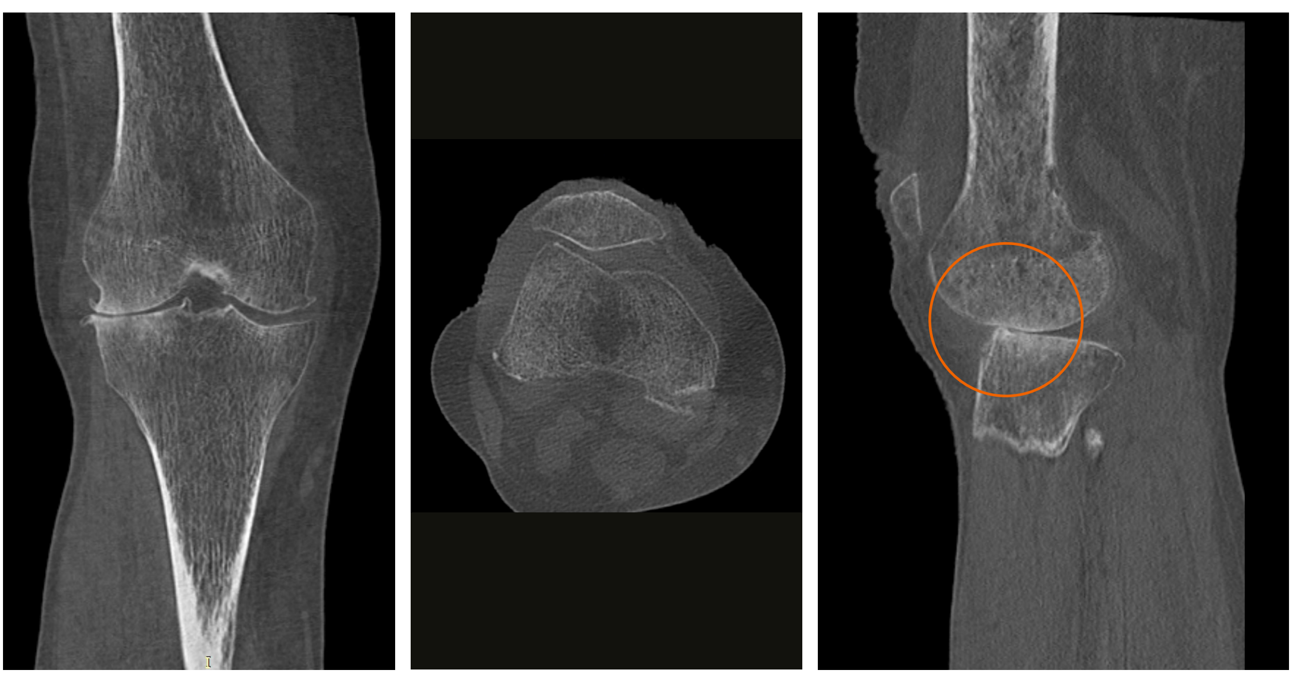
A growing number of international studies of weight-bearing 3D examinations of the lower extremities has been observed in recent years, which has led to a better understanding of the anatomy and biomechanics of scans performed in a natural weight-bearing position.[21]

Similar to the lumbar spine, the application fields for weight-bearing foot, knee, or hip examinations using Real3D open the door for more clinical research: for example, to standardize approaches for diagnosis and treatment planning.

Clinical cases: Weight-bearing imaging

An example of Real3D in clinical routine for osteoarthritis of the knee scanned with the patient in a natural weight-bearing patient position is shown in Figure 15. The patient had lateral knee pain for several years, and the symptoms increased significantly under weight load, especially when walking and climbing stairs. A Real3D scan was performed to look for degenerative changes and the position of the bones and to assess the situation under weight-bearing conditions.

The 3D examination under weight load shows that the lateral joint space has completely closed up (marked with a circle in the sagittal view). In addition, there are signs of activated osteoarthritis of the knee: spotty, periarticular osteopenia that most resembles inactivity osteopenia; lateralized patella with incipient retropatellar arthrosis; and concomitant joint effusion. The option to implant a knee endoprosthesis was discussed with the patient.



Coronal, axial, and sagittal views of Real3D examination using standard protocol (tube voltage 117 kV, $CTDI_{vol32}$ 4.6 mGy, $CTDI_{vol16}$ 9.5 mGy, scan time 16 sec)

15 Multitom Rax examinations of an osteoarthritis of the knees under weight-bearing conditions

(Courtesy of Artemed Hospital Munich, Germany)[6]

[6] *Please visit our Clinical Case Library to explore more applications of Multitom Rax Real3D*

The following clinical case shows a perfect example of the clinical value of weight-bearing Real3D for foot and ankle examinations in clinical routine. In Figure 16, weight-bearing examinations of both of the patient's feet are shown. The patient suffered a calcaneus fracture of the left foot 12 years previously, with several surgeries and subtalar arthrodesis that resulted in a rotational error of the foot. In particular, the supination error bothered him when walking and made it hard to place his foot straight on the ground. To compensate, the patient had to perform an internal rotation of the entire leg of 20 to 25°. The Real3D examination (Figures 16b and c) was needed to analyze the subtalar position under weight-bearing conditions in both feet in order to find rotational differences after the trauma and surgeries.

The physiological angle between talus and calcaneus (kite angle) of the left foot was 13°. On the right side, the kite angle was reduced by 3°, which presumably resulted from compensating for the angle deformity of the lower leg. Additional rotational differences were found in the rotation measurements of both legs. The new information led to a re-evaluation of the previous imaging of the lower leg, which revealed a rotational error on the left lower leg of 25° and a varus deformity of the knee. The mobile right foot could compensate for some of the changes, whereas the left foot was fixated by subtalar arthrodesis. The treatment required a rotation-correcting osteotomy of the left tibia and fibula.

a X-ray examination

b Sagittal views of both feet in a Real3D examination using dedicated metal protocol for left and right foot (tube voltage per scan 117 kV, $CTDI_{vol32}$ as sum of both scans 19.1 mGy, $CTDI_{vol16}$ 32.0 mGy, scan time per scan 16 sec)

c Axial views of both feet in a Real3D examination

16 Multitom Rax examinations of both feet under weight-bearing conditions

(Courtesy of University Hospital Carl Gustav Carus, Dresden, Germany)[7]

[7] *Please visit our Clinical Case Library to explore more applications of Multitom Rax Real3D*

3. Conclusion: Shaping the future of orthopedic and trauma imaging with Real3D

The Real3D functionality in the Multitom Rax Twin-Robotic X-ray system can be a useful enhancement for musculoskeletal and trauma departments, because it provides tomographic information on the scanned anatomical region.

In the initial publications, Real3D showed a similar image quality in the evaluation of bony structures in the extremities compared to conventional MDCT scanners – and a dose-saving potential at the same time. Using the high-resolution scan mode, an even higher resolution can be achieved. The 3D information can allow the radiologist to detect and rule out extremity fractures, fracture-related findings, and post-surgical complications more reliably than conventional radiography.[12]

Multitom Rax's multifunctionality provides integrated fluoroscopic and Real3D imaging, offering a one-stop shop approach for 3D arthrography – from contrast injection under fluoroscopy to the Real3D examination – without repositioning the patient.[16]

Weight-bearing examinations with Real3D offer new options and the potential to enhance diagnosis and achieve a sustainable improvement in patient treatment. Images that are taken with the patient in an upright position may provide more information for diagnosis and treatment planning, for example, precise positioning of the joints for implant and prosthesis planning and malposition of anatomical structures.[17]
Weight-bearing 3D imaging in clinical routine remains an important research topic for orthopedic imaging.

Abbreviations

BMI	Body mass index
CT	Computed tomography
CTDI	Computed-tomography dose index
DAP	Dose area product
DLP	Dose length product
Hi-Res	High-resolution
MAR	Metal artifact reduction
MDCT	Multi-detector computed tomography
MIP	Maximum-intensity projection
MPR	Multi-planar reconstruction
VRT	Volume-rendering technique

References

[1] Scarfe WC. Clinical applications of cone-beam computed tomography in dental practice. J Can Dent Assoc 2006; 72(1):75–80. PMID: 16480609.

[2] Scarfe WC and Farman AG. What is cone-beam CT and how does it work? Dent Clin North Am 2008; 52(4):707-30. doi: 10.1016/j.cden.2008.05.005. PMID: 18805225.

[3] Noo F, Defrise M, Clackdoyle R, Kudo H. Image reconstruction from fan-beam projections on less than a short scan. Phys. Med. Biol. 2002; 47(14):2525–46.

[4] Kunz AS, Patzer TS, Grunz JP, Luetkens KS, Hartung V, Hendel R, Fieber T, Genest F, Ergün S, Bley TA, Huflage H. Metal artifact reduction in ultra-high-resolution cone-beam CT imaging with a twin robotic X-ray system. Sci Rep. 2022 Sep 16;12(1):15549. doi: 10.1038/s41598-022-19978-9. PMID: 36114270.

[5] Fransson V, Tingberg A. Dose length product determination in cone-beam computed tomography through experimental measurements and dose area product conversion. Proc. SPIE 11595, Medical Imaging 2021: Physics of Medical Imaging, 115952Y. 2021 Feb 15

[6] Grunz JP, Gietzen CH, Kunz AS, Weng AM, Veyhl-Wichmann M, Ergün S, Bley TA, Schmitt R, Gassenmaier T. Twin robotic X-ray system for 3D cone-beam CT of the wrist: An evaluation of image quality and radiation dose. AJR Am J Roentgenol. 2020 Feb;214(2):422-427.

[7] Grunz JP, Kunz AS, Gietzen CH, Weng AM, Veyhl-Wichmann M, Ergün S, Schmitt R, Bley TA, Gassenmaier T. 3D cone-beam CT of the ankle using a novel twin robotic X-ray system: Assessment of image quality and radiation dose. Eur J Radiol. 2019 Oct;119:108659.

[8] Grunz JP, Weng AM, Gietzen CH, Veyhl-Wichmann M, Pennig L, Kunz A, Schmitt R, Ergün S, Bley TA, Gassenmaier T. Evaluation of ultra-high resolution cone-beam CT prototype of twin robotic radiography system for cadaveric wrist imaging. Acad Radiol. 2020 Jul 9:S1076-6332(20)30368-8.

[9] Grunz JP, Weng AM, Kunz AS, Veyhl-Wichmann M, Schmitt R, Gietzen CH, Pennig L, Herz S, Ergün S, Bley TA, Gassenmaier T. 3D cone-beam CT with a twin robotic X-ray system in elbow imaging: Comparison of image quality to high-resolution multidetector CT. Eur Radiol Exp. 2020 Sep 8;4(1):52.

[10] Luetkens KS, Ergün S, Huflage H, Kunz AS, Gietzen CH, Conrads N, Pennig L, Goertz L, Bley TA, Gassenmaier T, Grunz JP. Dose reduction potential in cone-beam CT imaging of upper extremity joints with a twin robotic X-ray system. Sci Rep. 2021 Oct 11;11(1):20176. doi: 10.1038/s41598-021-99748-1. PMID: 34635787; PMCID: PMC8505435.

[11] Feldle P, Grunz JP, Kunz AS, Patzer TS, Huflage H, Hendel R, Luetkens KS, Ergün S, Bley TA, Conrads N. Weight-bearing gantry-free cone-beam CT of the lumbar spine: Image quality analysis and dose efficiency. Eur J Radiol. 2023 Aug;165:110951. doi: 10.1016/j.ejrad.2023.110951. Epub 2023 Jun 25. PMID: 37379623.

[12] Grunz JP, Pennig L, Fieber T, Gietzen CH, Heidenreich JF, Huflage H, Gruschwitz P, Kuhl PJ, Petritsch B, Kosmala A, Bley TA, Gassenmaier T. Twin robotic X-ray system in small bone and joint trauma: Impact of cone-beam computed tomography on treatment decisions. Eur Radiol. 2020 Dec 5.

[13] Grunz JP, Jordan MC, Schmitt R, Luetkens KS, Huflage H, Meffert RH, Bley TA, Kunz AS. Gantry-free high-resolution cone-beam CT: Efficacy for distal radius and scaphoid fracture detection and characterization. Acad Radiol. 2023 Jul;30(7):1358-1366. doi: 10.1016/j.acra.2022.08.030. Epub 2022 Sep 25. PMID: 36167629

[14] Kunz AS, Schmalzl J, Huflage H, Luetkens KS, Patzer TS, Kuhl PJ, Gruschwitz P, Petritsch B, Schmitt R, Bley TA, Grunz JP. Twin robotic gantry-free cone-beam CT in acute elbow trauma radiology. 2023 Mar;306(3):e221200. doi: 10.1148/radiol.221200. Epub 2022 Nov 8. PMID: 36346312.]

[15] Patzer TS, Grunz JP, Huflage H, Conrads N, Veldhoen S, Schmalzl J, Pennig L, Bley TA, Luetkens KS, Kunz AS. Combining gantry-free cone-beam computed tomography with iterative metal artefact reduction for surgical follow-up imaging of the appendicular skeleton. Eur J Radiol. 2022 Oct;155:110465. doi: 10.1016/j.ejrad.2022.110465. Epub 2022 Aug 10. PMID: 35973302.

[16] Luetkens KS, Grunz JP, Paul MM, Huflage H, Conrads N, Patzer TS, Gruschwitz P, Ergün S, Bley TA, Kunz AS. One-stop shop CT arthrography of the wrist without subject repositioning by means of gantry-free cone-beam CT. Sci Rep. 2022 Aug 24;12(1):14422. doi: 10.1038/s41598-022-18395-2. PMID: 36002544; PMCID: PMC9402709.

[17] Benz RM, Hirschmann A. 3D Imaging of joints in the upright weight-bearing position using Multitom Rax. J Trauma Treat 2016; 5:291.

[18] Falkowski AL, Kovacs BK, Benz RM, Tobler P, Schön S, Stieltjes B, Hirschmann A. In vivo 3D tomography of the lumbar spine using a twin robotic X-ray system: Quantitative and qualitative evaluation of the lumbar neural foramina in supine and upright position. Eur Radiol. 2020 Oct 29.

[19] Winn N, Kaur S, Cassar-Pullicino V, Ockendon M. A novel use of cone beam CT: Flexion and extension weight-bearing imaging to assess spinal stability. Eur Spine J. 2022 Jul;31(7):1667-1681. doi: 10.1007/s00586-022-07233-8. Epub 2022 May 19. PMID: 35585251.

[20] Benz RM, Harder D, Amsler F, Voigt J, Fieselmann A, Falkowski AL et al. Initial assessment of a prototype 3D cone-beam computed tomography system for imaging of the lumbar spine, evaluating human cadaveric specimens in the upright position. Investigative Radiology 2018; 53(12):714-9.

[21] Brinch S, Wellenberg RHH, Boesen MP, Maas M, Johannsen FE, Nybing JU, Turmezei T, Streekstra GJ, Hansen P. Weight-bearing cone-beam CT: The need for standardized acquisition protocols and measurements to fulfill high expectations: A review of the literature. Skeletal Radiol. 2023 Jun;52(6):1073-1088. doi: 10.1007/s00256-022-04223-1. Epub 2022 Nov 9. Erratum in: Skeletal Radiol. 2023 Jul;52(7):1431. PMID: 36350387.

[22] Hirschmann A, Buck FM, Fucentese SF, Pfirrmann CWA. Upright CT of the knee: The effect of weight-bearing on joint alignment. Eur Radiol 2015; 25(11):3398–404

On account of certain regional limitations of sales rights and service availability, we cannot guarantee that all products / services / features included in this brochure are available through the Siemens Healthineers sales organization worldwide. Availability and packaging may vary by country and are subject to change without prior notice.

The information in this document contains general descriptions of the technical options available and may not always apply in individual cases.

Siemens Healthineers reserves the right to modify the design and specifications contained herein without prior notice. Please contact your local Siemens Healthineers sales representative for the most current information.

In the interest of complying with legal requirements concerning the environmental compatibility of our products (protection of natural resources and waste conservation), we may recycle certain components where legally permissible. For recycled components we use the same extensive quality assurance measures as for factory-new components.

Any technical data contained in this document may vary within defined tolerances. Original images always lose a certain amount of detail when reproduced.

Siemens Healthineers Headquarters
Siemens Healthineers AG
Siemensstr. 3
91301 Forchheim, Germany
Phone: +49 9191 180
siemens-healthineers.com

Published by Siemens Healthineers AG · 13865 0623 online ·