White paper

Multitom Rax Real 3D for musculoskeletal imaging

Imaging technique and clinical application

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siemens-healthineers.com/robotic-x-ray

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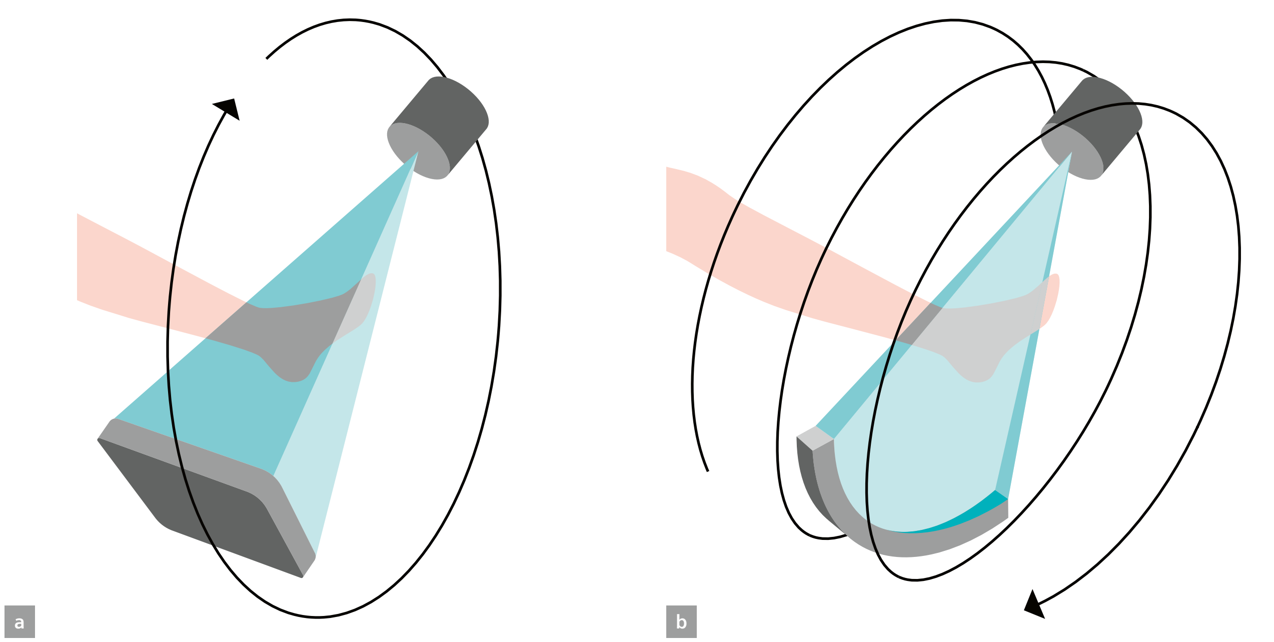
Contents

Real 3D: the technique

Real 3D is an option on the Twin-Robotic X-ray system Multitom Rax, developed for the requirements of a musculoskeletal or trauma department. Due to its modular design, Multitom Rax enables conventional radiography, fluoroscopic examinations for functional assessment as well as 3D bone imaging on the same system. Real 3D 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.

Image acquisition

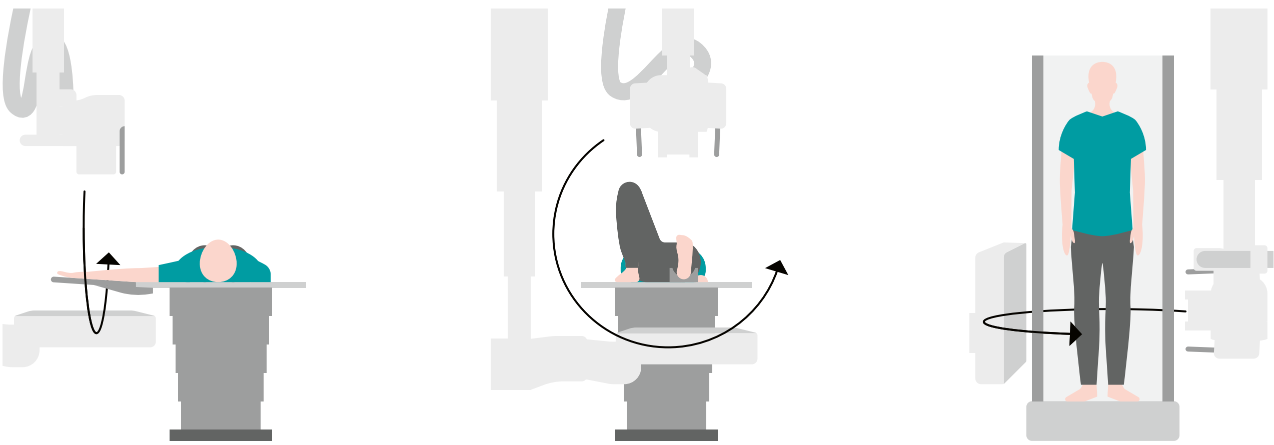
Real 3D uses a flat panel detector for image acquisition resulting in a cone geometry of the X-ray beam (Figure 1). During a scan, tube and detector rotate around the patient and a certain number of projection images are taken, depending on the particular application. The projection data is then used to calculate a 3D dataset as it is known and well-established from computed tomography (CT). In contrast to Real 3D, multidetector 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 carried out in a spiral or helical fashion to cover the entire region of interest [1,2].



1 X-ray geometry in Real 3D (a) and multidetector CT (b)

For the Real 3D image acquisition, Multitom Rax uses both a ceiling-mounted tube (voltage: 40 kV to 150 kV; current: 0.5 mAs to 800 mAs) and a ceiling-mounted amorphous silicon flat panel detector (with an active area of 42.0 cm x 42.5 cm and a cesium iodide scintillator). Tube and detector both move on rails with three translational and two rotational degrees of freedom[1]. They can move on defined paths (trajectories) around the patient to acquire the projections.

Three types of trajectories are installed in the system, enabling imaging of different body parts with the patient either in supine or upright position (Figure 2). Depending on the trajectory, tube and detector capture projection data over an angular range of between 180° and 200° around the patient with a scan duration of between 10 and 20 seconds. Noo et al. [3] showed that these angular ranges can be sufficient for an exact and stable reconstruction of a region of interest in an object.



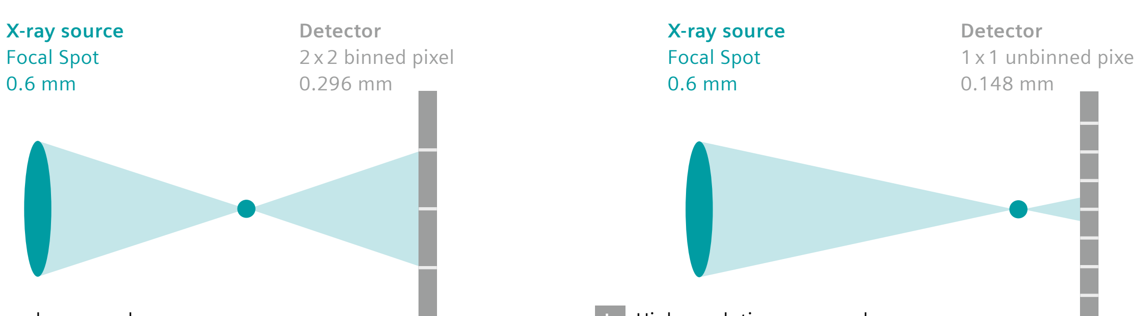
a Tableside trajectory for hand and elbow examinations

b Table trajectory for knee and foot examinations

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

2 Different trajectories for Multitom Rax Real 3D

The maximum volume that can be imaged using Multitom Rax Real 3D is a cylinder with a diameter and a height of approximately 24 cm at an isotropic spatial resolution of up to 16 lp/cm. For higher spatial resolution of up to 32 lp/cm, a cylinder with a diameter and a height of 16 cm can be reconstructed. This additional scanning mode is called Real 3D Hi-Res. The high-resolution scan mode works with an un-binned partial detector readout, in contrast to the normal mode of 2 x 2 binned full readout mode. In order to fully exploit the smaller pixel size, the circular trajectory is modified such that the examined body part is closer to the detector (Figure 3). This reduces the limiting effect of the focal spot size on the spatial resolution of the X-ray system.



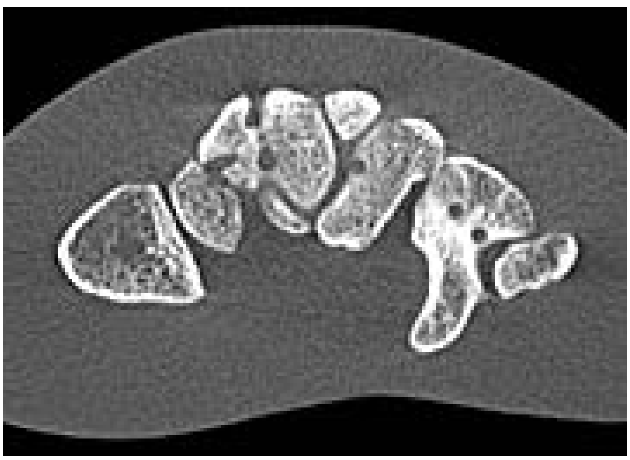
a Normal scan mode

b High-resolution scan mode

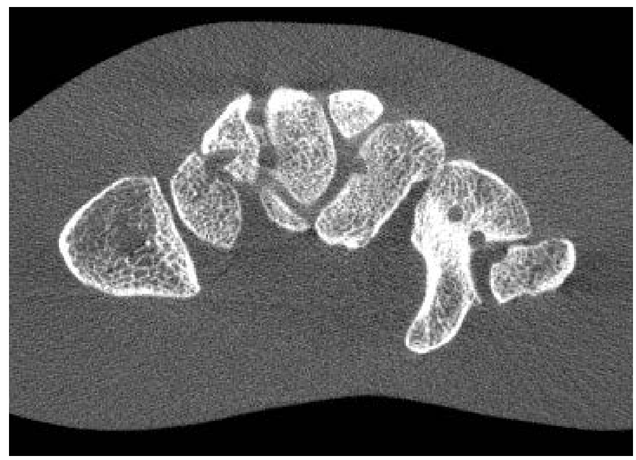
3 X-ray source and detector for the two different scan modes of Real 3D

[1] *Datasheet Multitom Rax, Siemens Healthineers*

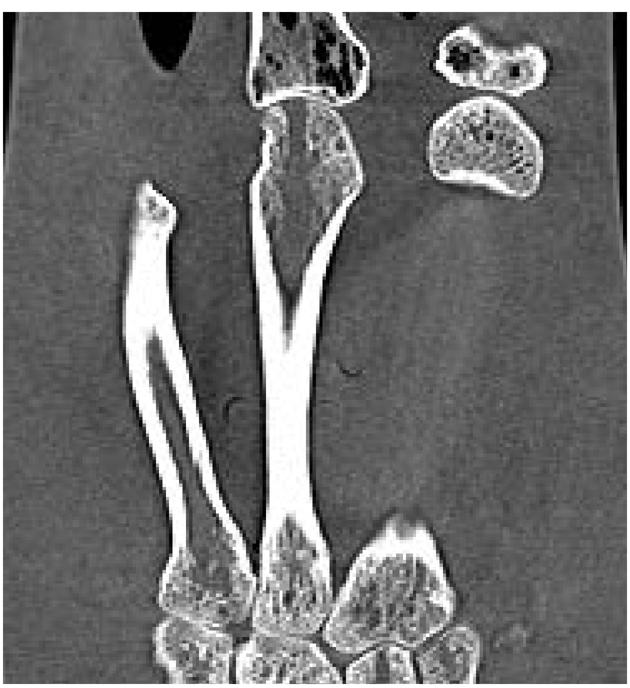
Using the high-resolution scan mode, the better spatial resolution shows advantages in assessing anatomical structures. The visualization of the bone and its trabeculae is sharper and more precise than in the normal scan mode (Figure 4).



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

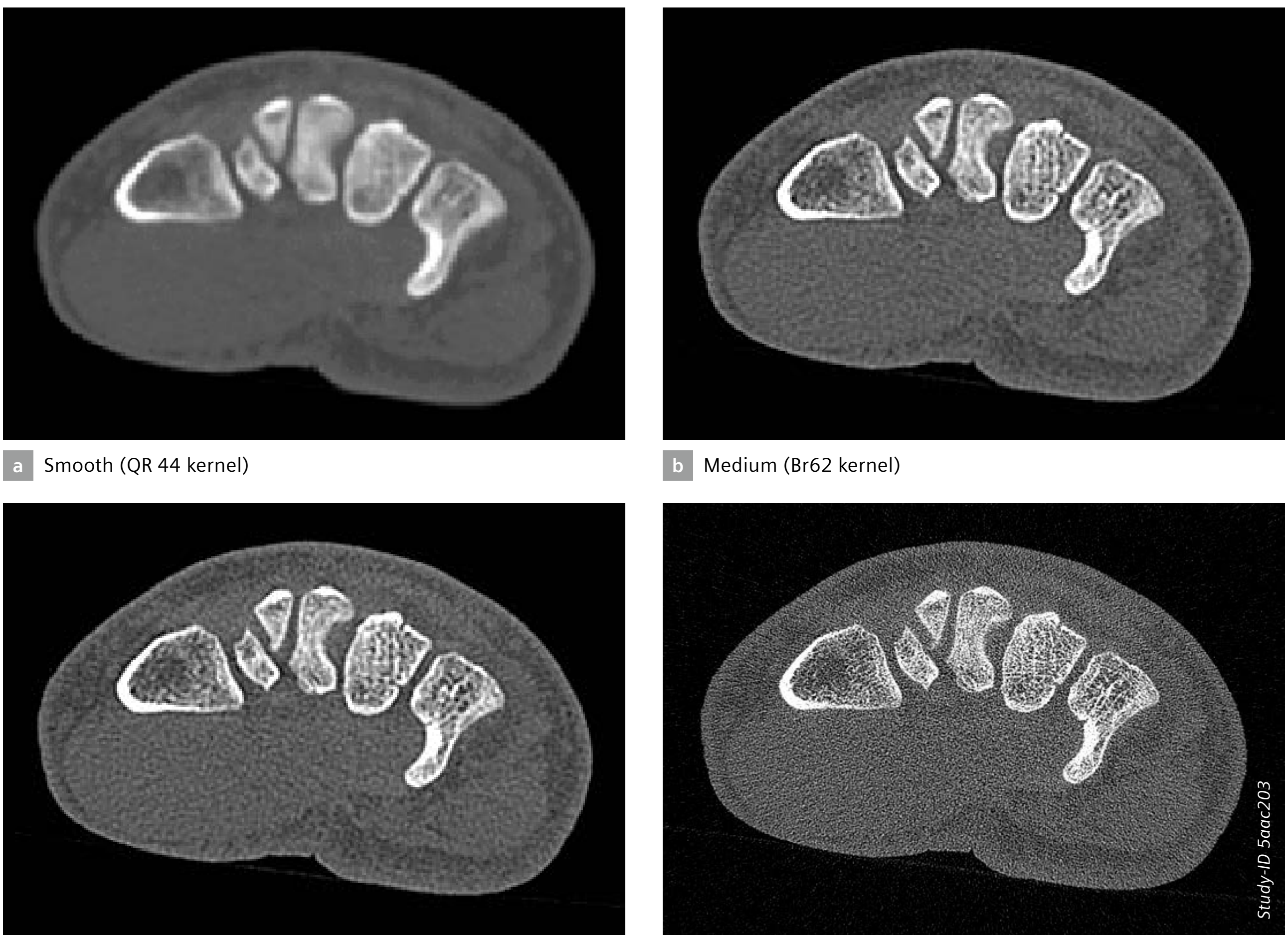
4 Real 3D phantom examination of a hand

Image reconstruction

For diagnostic evaluations, the radiologist can use multiplanar reconstruction (MPR) views in sagittal, coronal, and axial planes, similar to MDCT (Figure 5). A 3D view using volume rendering technique (VRT) enables an additional assessment of anatomical structures.

5 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 between four different image impressions for the generated Real 3D slices: smooth, medium, sharp, and very sharp. The image impression is mainly influenced by the underlying reconstruction kernels which are chosen to be identical to the ones used in the clinical MDCT systems of Siemens Healthineers, which enables Real 3D on Multitom Rax to have a matched image resolution and impression. The smooth impression is mainly intended for VRT renderings, while the medium impression is a good balanced choice for diagnosis of both bone and soft tissue. The sharp and very sharp image impressions are intended for diagnosis of fractures and fine bone structures (Figure 6).



a Smooth (QR 44 kernel)

b Medium (Br62 kernel)

c Sharp (Br69 kernel)

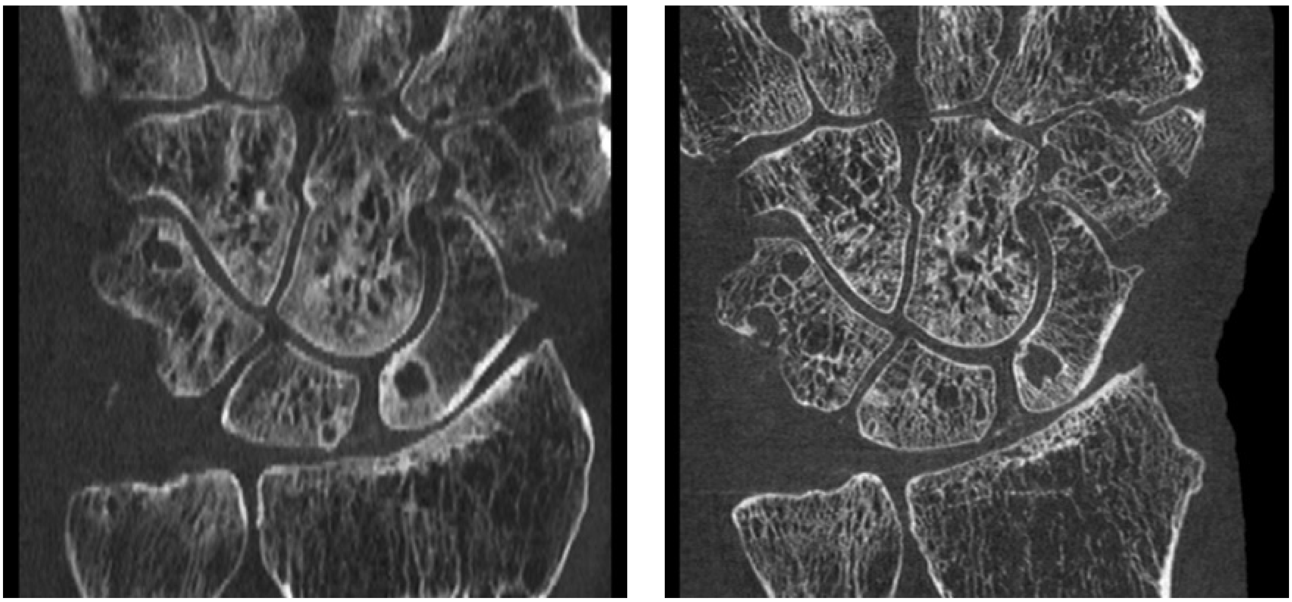
d Very sharp (Ur77 kernel)[2]

6 Real 3D image impressions including underlying resolution-matched MDCT reconstruction kernels

(Courtesy of Krankenhaus der Augustinerinnen, Cologne, Germany)

[2] *Only available for Real 3D Hi-Res*

In particular, the coronal image resolution in the z-direction is higher in Real 3D, compared to MDCT, due to the isotropic smaller pixels of the flat panel of Multitom Rax (Figure 7).



a High-resolution MDCT scanner using Ur77 kernel

b Real 3D Hi-Res using very sharp image impression

7 Coronal slices of a hand examination *(Courtesy of University Hospital Wuerzburg, Germany)*

For body parts with metallic implants, markers or external fixators Real 3D offers specialized acquisition modes with adapted parameters, which automatically trigger an iterative metal artifact reduction method during the computation of the slice images. The advanced interpolation method in combination with a preservation of high frequency details is able to reduce the number of streaks and very bright and dark areas surrounding metallic implants in the image to a large degree. In Figure 8 you can see an image example of an ankle examination with and without metal artifact reduction: Dark streaks close to the visible screw as well as three dark phantom holes caused by out-of-plane screws are strongly reduced by Real 3D's metal artifact reduction.

This artifact reduction method is optionally available even if a regular acquisition mode was used, e.g. if the presence of the metal was unknown to the user before the acquisition. Conversely it is still possible to turn off the artifact reduction even if an acquisition mode for metal implants was used for the data acquisition.

a Without Metal Artifact Reduction

b With Metal Artifact Reduction

8 Sagittal slice of an ankle examination with a bone fracture plate and multiple fixation screws

(Courtesy of Krankenhaus der Augustinerinnen, Cologne, Germany)

Applied radiation dose

For evaluating a modality, the applied radiation dose plays an important role. The dose specification relates to 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 enable an evaluation of the potential damage that the ionizing radiation can cause in the patient's body, but rather depicts the radiation of the respective X-ray beams.

Dose Area Product for 2D radiography

According to IEC 60601-2-54, a device for conventional X-ray examinations measures or calculates a value for the dose area product (DAP) in Gy·m². 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. A value for $CTDI_{vol}$ must be derived including information about the CTDI phantom used as the object – a cylinder with 16 cm or 32 cm diameter. The DLP can also be calculated as the product of the $CTDI_{vol}$ value and the scan length.

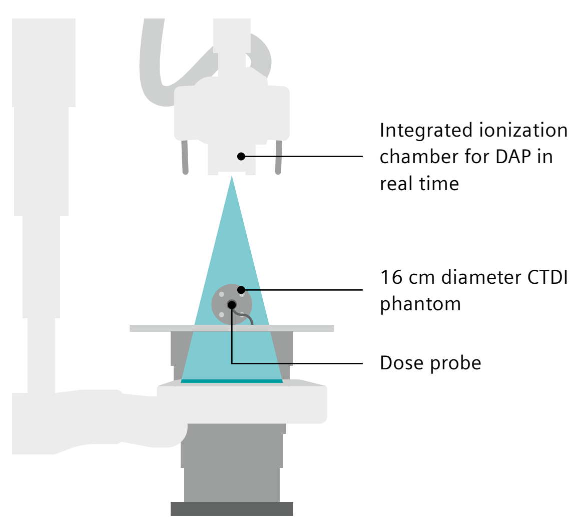
For conventional X-ray examinations a value for the dose area product (DAP) is documented. Due to the different acquisition technique compared to 2D radiography, for MDCT examinations a dose length product (DLP) and a Computed Tomography Dose Index (CTDI) are documented.

As described above, Real 3D captures a high number of projection images using a fluoroscopy acquisition mode. Consequently, the dose for each image is measured as DAP using an ionization chamber at the X-ray source (Figure 9). For the entire Real 3D dataset, the applied dose is stated as the DAP sum of the individual projection images.

In addition, Real 3D offers computed values for DLP and $CTDI_{vol,16cm}$ (see description above). As a basis for calculating these values, conversion factors were determined in dose measurements with a 16 cm CTDI phantom (Figure 9).[3] The Lund University in Malmö has independently validated this calculation and confirmed the high accuracy of the method implemented on Multitom Rax [4].

The $CTDI_{vol,16cm}$ of Real 3D and MDCT scanners could serve as a basis for comparing the applied radiation dose between both systems. Unlike the DAP, the DLP takes the actual source-to-object-distance of the acquisition into account that varies across different trajectory types of Real 3D as well as across different MDCT models.

The dose declarations of Real 3D therefore enables a comparison to both conventional X-ray devices and MDCT scanners. Nevertheless, it should be considered that the dose comparison of different modalities is subject to a certain degree of inaccuracy due to different measurement possibilities.



9 Measuring positions for DAP and for calculation of DLP and $CTDI_{vol,16cm}$

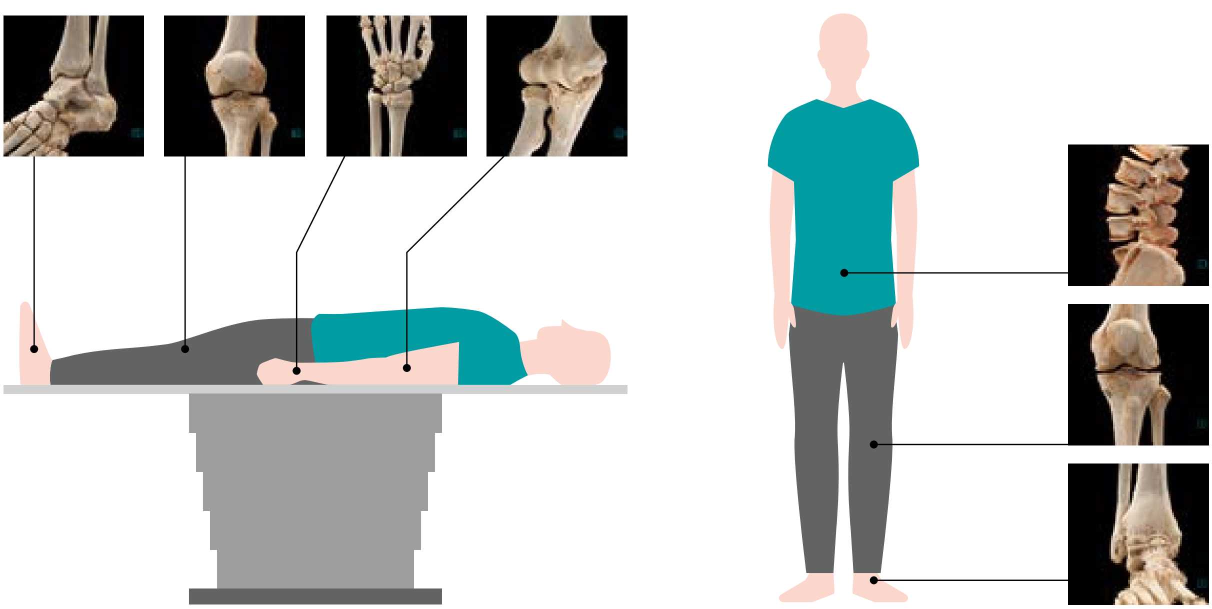
[3] The measurements are derived from IEC 60601-2-44. Due to the different aquisition methods of Real 3D and MDCT, the measurements cannot be adopted exactly as described in IEC 60601-2-44.

Real 3D: clinical application in musculoskeletal imaging

Real 3D for musculoskeletal imaging focuses on two fields of application: trauma evaluation of upper and lower extremities and weight-bearing imaging of the lower extremities as well as the lumbar spine.

For trauma imaging Real 3D can add a diagnostic value in comparison to 2D X-ray examinations, especially for the assessment of complex anatomies with much superposition of adjacent bony structures such as joints. The 3D information might enable the radiologist to detect and rule out extremity fractures and fracture-related findings more reliably than conventional radiography [5].

Real 3D offers examinations of the foot, knee, elbow, and hand with the patient in a lying position (Figure 10a), as well as weight-bearing imaging for foot, knee and lumbar spine (Figure 10b). Images that are scanned with the patient in an upright position may provide additional information for diagnosis and treatment planning, such as exact positioning of the joints for implant and prosthesis planning, or malposition of anatomical structures [6].



a Scanned in a lying patient position

b Scanned in a weight-bearing patient position

10 Recommended body regions for Real 3D[3] *(Courtesy of Krankenhaus der Augustinerinnen, Cologne, Germany)*

[3] *Images reprocessed on syngo.via with cinematic VRT. Cinematic VRT is recommended for communication, education, and publication purposes and not intended for diagnostic reading*

Trauma evaluation of extremities

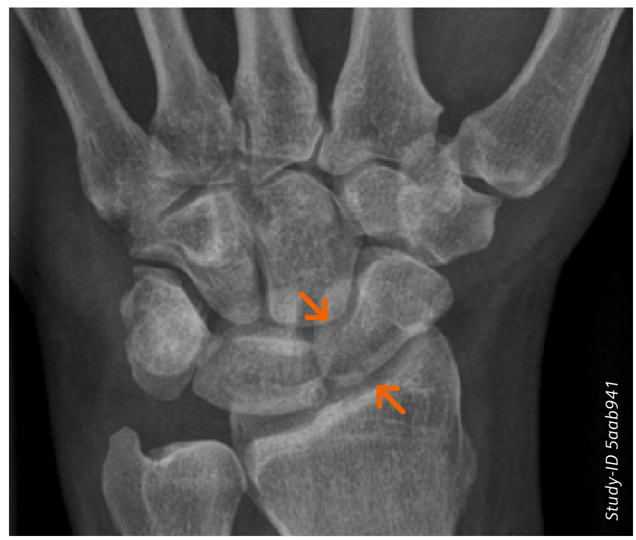
Additional 3D information compared to conventional radiography

In contrast to conventional 2D radiography, Real 3D provides additional 3D information. For body regions with much superposition of bony structures, such as wrist or ankle, Real 3D may enable the evaluation of acute small bone and joint trauma by detecting and excluding extremity fractures and fracture-related findings more reliably than radiographs [5]: In a study including 92 patients – 76 wrist, hand or finger and 16 ankle, foot or toe trauma scans – the influence of Real 3D on diagnosis and patient treatment were analyzed. After the conventional radiographs were done, the patients had a Real 3D scan. On Real 3D images the radiologists detected a statistically significant higher number of fractures, joint involvements, and multi-fragment situations than on conventional X-ray images (Table 1). Therefore, the diagnostic confidence of the radiologists was superior for Real 3D than for conventional radiography [5]. The orthopedic surgeon changed the treatment decision based on radiological reports after the Real 3D scan compared to the radiological report after the radiograph for 31.5% of the patients [5].

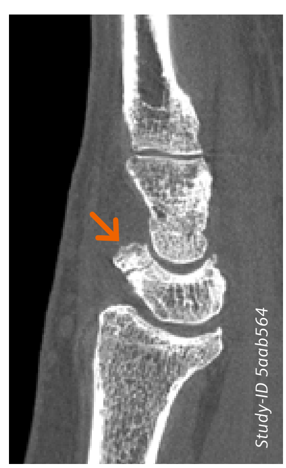
The clinical case in Figure 11 illustrates the potentially additional diagnostic value of Real 3D compared to conventional radiography. The patient had fallen onto his extended left wrist and reported pain over the dorsoradial side of the carpus. Physical examination detected slight swelling with no hint of carpal instability. A non-displaced fracture of the scaphoid waist was suspected in radiography (Figure 11a). A 3D scan was requested to detect additional fractures and evaluate the scapholunate gap. In contrast to the suspected scaphoid waist fracture, the Real 3D images displayed a non-displaced fracture of the dorsal lunate (Figure 11b and c). While the lunate fracture explained the patient's wrist pain, the most important finding of the Real 3D examination was the lack of a scaphoid fracture. A surgical therapy was not necessary, as the suspected and potentially unstable scaphoid waist fracture could be ruled out in the Real 3D examinations. The non-displaced dorsal lunate fracture was deemed stable and well suited for conservative treatment. Therefore, cast immobilization for six weeks was advised.

	Real 3D	X-ray
Fractures	83	64
Joint Involvements	69	53
Multi-Fragment situations	68	50

Table 1: Diagnostic findings for Real 3D and X-ray scans [5]



a X-ray examination

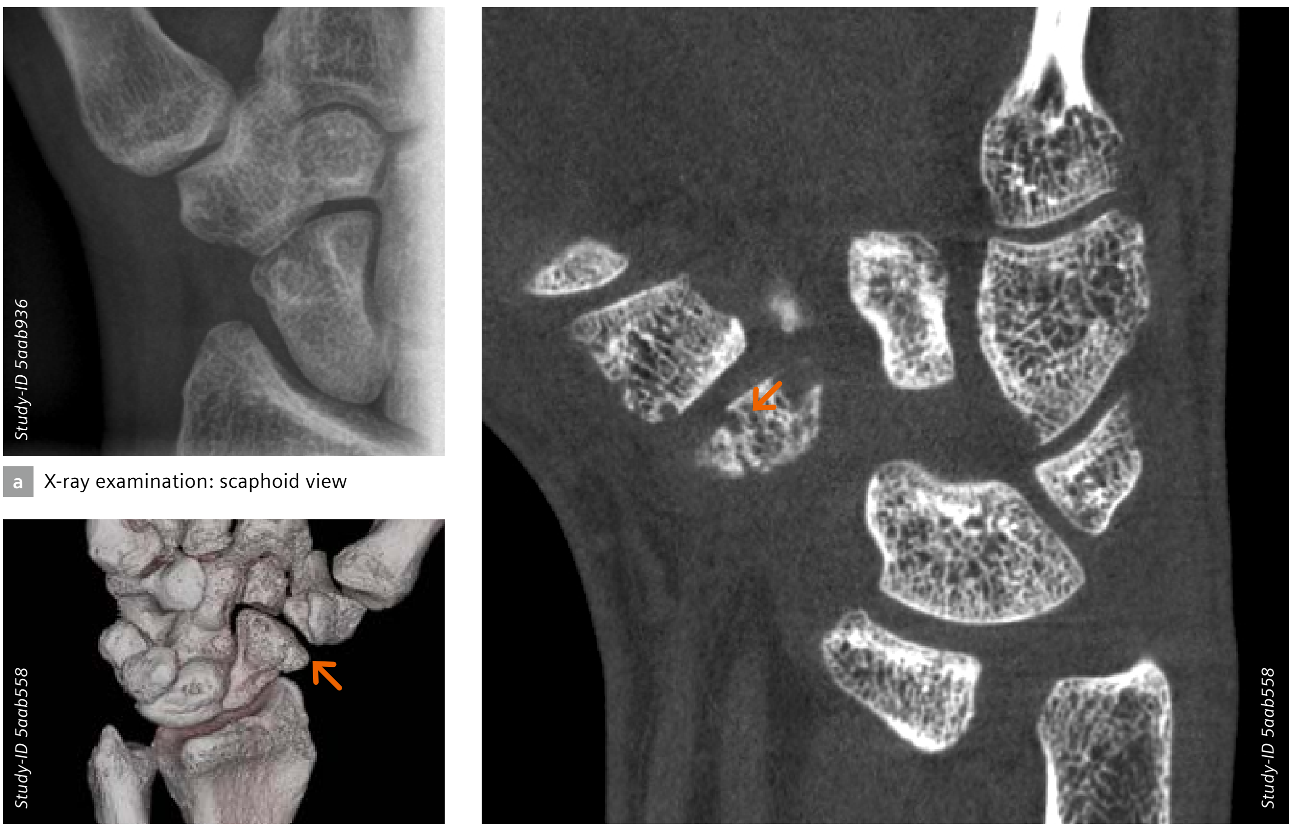


b Real 3D Hi-Res sagittal view

c Real 3D Hi-Res coronal view

11 Multitom Rax examinations of a lunate fracture
(Courtesy of University Hospital Wuerzburg, Germany)

Figure 12 depicts a further clinical case in which a scaphoid fracture could not be detected in the radiographic image but was clearly revealed in the Real 3D image data. For the patient shown, the anterior-posterior and lateral radiographs as well as dedicated scaphoid view did not provide fracture-related findings. But the patient reported persisting pain over the radial side of the carpus after having fallen on the dorsally outstretched hand during construction work two weeks earlier. The Real 3D Hi-Res images displayed a subtle, non-displaced fracture of the scaphoid's tubercle. This kind of fracture does not require a surgical treatment, but a cast immobilization for six weeks. In this case a diagnosis was only possible due to having 3D information available.*



a X-ray examination: scaphoid view

b Real 3D Hi-Res VRT view

c Real 3D Hi-Res coronal view

12 Multitom Rax examinations of a scaphoid fracture *(Courtesy of University Hospital Wuerzburg, Germany)*

* *The statements by Siemens' Healthineers customers described herein are based on results that were achieved in the customer's unique setting. Because there is no "typical" hospital or laboratory and many variables exist (e.g., hospital size, samples mix, case mix, level of IT and/or automation adoption) there can be no guarantee that other customers will achieve the same results.*

Real 3D compared to multidetector CT

Using MDCT, 3D information in the form of sectional views is already well established in musculoskeletal imaging. Therefore, it is important that Real 3D offers comparable image impression with regard to skeletal structures to the radiologist. Different studies on human specimens demonstrated comparable image quality of Real 3D to MDCT for the normal scan mode, and an even superior image quality for the high-resolution scan mode [7,8,9,10].

For the comparison of Real 3D to a conventional MDCT scanner, 16 cadaveric wrists and ankles were examined and assessed regarding different image characteristics [7,8]. While the overall image quality was rated higher for Real 3D than for MDCT for the wrist, it was slightly lower for imaging of the ankle. Artifacts and image noise in bone were comparable for wrist imaging and slightly more prominent for ankle. The assessment of artifacts and image noise in soft tissue was inferior compared to MDCT. It was concluded that Real 3D is particularly suitable for evaluating bone cortex and trabeculae, and therefore for fracture diagnosis and the healing process.

For wrist and elbow imaging, the image quality of the Real 3D high-resolution scan mode was analyzed compared to a high-resolution MDCT scanner, as shown in a study with 16 wrists and elbows of body donors [9,10]. The overall image quality of Real 3D Hi-Res was rated similar to a high-resolution MDCT scanner. Artifacts in bone of Real 3D Hi-Res were considered minimal or little – comparable to high-resolution MDCT – and image noise in bone slightly inferior than for high-resolution MDCT. Corresponding to the results of the normal scan mode, artifacts and noise in soft tissue was rated inferior for Real 3D Hi-Res than high-resolution MDCT. So it was concluded, using Real 3D Hi-Res an even better image quality for evaluating bony structures could be achieved compared to the normal scan mode in the same way as a high-resolution MDCT scanner compared to a conventional MDCT scanner.

All four studies concluded that Real 3D offered substantial dose savings compared to conventional and high-resolution MDCT scanners. In Table 2 you can see the $CTDI_{vol,16cm}$ values for the presented cadaveric studies. For the comparison of the normal Real 3D scan mode to a conventional MDCT scanner the applied radiation dose of the MDCT scanner was five to eight times higher than Real 3D. And the high-resolution MDCT scanner applied a radiation dose four times higher than Real 3D Hi-Res. Both scan modes showed similar image quality for Real 3D regarding bone imaging as the respective MDCT scanner. This indicates that substantial dose savings using Real 3D for extremity imaging might be possible depending on the clinical question [7,8,9,10].

	Normal scan mode				High-resolution scan mode			
	Wrist [7]		Ankle [8]		Wrist [9]		Elbow [10]	
	Real 3D	MDCT	Real 3D	MDCT	Real 3D Hi-Res	High-resolution MDCT	Real 3D Hi-Res	High-resolution MDCT
$CTDI_{vol,16cm}$ (mGy)	1.8±0.2	15.0	2.9±0.6	15.0	3.3	13.8	3.3	13.8

Table 2: Applied radiation dose for cadaveric studies

Multifunctionality of Multitom Rax: Radiography, fluoroscopy, and Real 3D

The combination of different functionalities of Multitom Rax may offer an improved patient workflow and thereby potential time savings. For example, after the conventional X-ray examination the patient might stay at Multitom Rax for the Real 3D scan and might not have to change room for an MDCT examination.

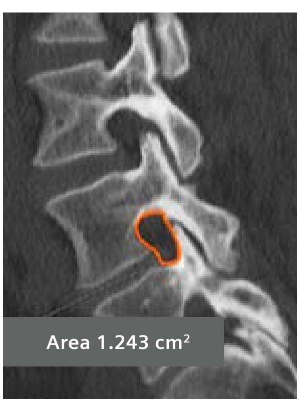
With Multitom Rax, arthrographies can be performed that enable the simultaneous evaluation of chondral injuries, surrounding cartilage, and subchondral bone. After the injection of the contrast medium with the fluoroscopy functionality of the system, the Real 3D scan can be done immediately, without changing the room.

Weight-bearing imaging for new approaches in orthopedics

The examination of disorders in a natural weight-bearing condition is well established in 2D radiography. Real 3D also opens up this approach for 3D imaging. The Real 3D 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 under weight-loading, a Real 3D scan with the patient in an upright position may make a difference in diagnosis and treatment planning compared to supine imaging, e.g. 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 [6].

For lumbar spine imaging, first clinical results showed that the lumbar foramina were smaller in a weight-bearing position compared with a supine patient position (Figure 13) [11]. Two readers compared the neuroforaminal size – the cross-sectional areas, the cranio-caudal and the ventro-dorsal diameters of the foramina – of 48 patients scanned in an upright and a supine position. There was a statistically significant decrease in neuroforaminal size for all parameters for both readers from the supine to the weight-bearing position. In addition, the patients that showed a narrower foraminal size had a higher decrease of the intervertebral disc in the upright position. Both results may indicate an added value of the weight-bearing 3D information for diagnosis and treatment planning [11]. The depiction of osseous structures for the lumbar spine using Real 3D was comparable to MDCT scanners in patients with a body mass index of 30 kg/m² or less, although the imaging technique of Real 3D at the body trunk is at a disadvantage compared to MDCT due to higher scattered radiation.

The static forces that apply in weight-bearing conditions and the resulting changes in anatomical sizes 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, but future clinical research is still necessary to investigate how patients can profit in their clinical outcome from these measured differences [12].



a MDCT slice acquired in a supine patient position

b Real 3D slice acquired in a weight-bearing patient position

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

a Ankle – sagittal view

b Knee – sagittal view

14 Real 3D examinations of ankle and knee
(Courtesy of Krankenhaus der Augustinerinnen, Cologne, Germany)

Beside the unique application on the lumbar spine, Multitom Rax Real 3D offers weight-bearing 3D examinations for ankle and knee (Figure 14), similar to other systems that use the cone-beam technique for computed tomography. Clinical results with the use of such devices for the ankle showed application fields for weight-bearing imaging in the investigation of the normal anatomy and dynamics of the hindfoot or in the assessment of forefoot and hindfoot alignment [13].

For the knee, diagnosis and treatment of osteoarthritis and patellofemoral diseases can be affected by the circumstance that femorotibial rotation, tibial tuberosity-trochlear groove, and medial joint space width differ between weight-bearing and non-weight-bearing images [14]. As well as for the lumbar spine, the application fields of weight-bearing foot and knee examinations require further clinical research to standardize approaches for diagnosis and treatment planning.

Real 3D: conclusion

The Multitom Rax integrates three different image modalities in one room and even one system: radiography, fluoroscopy, and Real 3D. In particular the Real 3D functionality can be a useful enhancement for the musculoskeletal imaging department, as it provides tomographic information of the scanned anatomical region. In first publications, Real 3D showed a similar image quality for the evaluation of bony structures in 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 – especially in z-direction due to the used detector technology – can be achieved.

Weight-bearing examinations with Real 3D offer new approaches with the potential to enhance diagnosis and sustainably improve patient treatment. Establishing weight-bearing 3D imaging in clinical routine remains an important research topic for orthopedic imaging.

Abbreviations

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
MPR	Multiplanar Reconstruction
VRT	Volume Rendering Technique

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