White paper

Multitom Rax – True2scale Body Scan for musculoskeletal imaging

Imaging technique and clinical applications

Karl-Philipp Kienle (MD, PhD, MBA),
Magdalena Herbst,
Marcel Beister (PhD),
Andreas Fieselmann (PhD),
Christoph Luckner (PhD),
Ludwig Ritschl (PhD),
Steffen Kappler (PhD),
Axel Hebecker (PhD)

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Introduction

True2scale Body Scan (T2S) is an option on the Twin-Robotic X-ray system Multitom Rax, developed for the requirements of a musculoskeletal department to obtain length extended images of the skeletal system. Moreover, due to its modular design, Multitom Rax enables conventional radiography, fluoroscopic examinations for functional assessment as well as 3D imaging – all on one system.

True2scale is engineered to capture geometrically accurate biplanar images of the entire body, whole spine, and long-leg. These images are intended to assess skeletal malposition, such as scoliosis[1] or osteoarthritis secondary to malalignment of the limbs[2]. Since postural dysfunctions may be influenced by the scanning position of the patient, weight-bearing radiographs are preferred for length extended imaging procedures, if the patient is able to stand during the examination[3]. Long-leg images are also used for preoperative planning for total hip or knee prostheses[4].

The first part of this white paper will provide a technical overview of length-extended imaging, with a focus on True2scale, a slot-scanning based image acquisition and reconstruction technique, in comparison to conventional radiography and stitching. The second part will provide an overview of typical clinical applications including first clinical images.

True2scale Body Scan

The technique and its added value

In this section, the acquisition technique, and its special characteristics as well as the differentiation from other techniques is introduced. The operating options and the processes are described, and necessary dose values according to the ALADA (As Low As Diagnostically Acceptable) principle are discussed.

Extended coverage & precision

The active area of flat-panel detectors used in digital radiography is usually limited to approximately 43 x 43 cm in size. Therefore, the full bone structure of the spine or leg cannot be captured in a single image. To solve this problem, different technologies have been developed to achieve length extended images that fully cover larger body parts.

Source tilt & stiching technique

In conventional source tilt & stitching imaging, e.g., implemented in the SmartOrtho/ RaxOrtho function of Multitom Rax, the source is rotated at its stationary anchorage to create multiple, slightly overlapping images, which are then joined by software (Figure 1a). The rotation is aligned with the detector so that the emitted beams always strike the entire detector during the acquisition of up to four images as it moves along the region of interest being examined. Due to the different beam angles and distances between the emitter and the detector, distortion and magnification effects occur. Especially for a small SID (source-image distance), this can result in relevant measurement deviations[5]. Thus, it is mandatory to perform calibration steps, such as placing a calibration ball in the relevant plane or measuring the table-object-distance (TOD)[5,6].

Slot scanning technique

The slot-scanning technique allows geometrically accurate imaging of larger body areas or even the whole body. Here, images are either generated from highly collimated X-ray beams captured by a linear detector entrance slit[7] (see Figure 1b), or reconstructed by a dedicated reconstruction technique taking the small but existing divergence of the beam into account, as recently introduced with True2scale imaging (see Figure 1c)[8].

For True2scale X-ray source and detector move simultaneously and parallel along the body axis (head to toe or toe to head). During this process, highly collimated images are acquired with a divergence of approximately 2° in the scan direction. The True2scale reconstruction technique takes this small divergence of the beam into account, and effectively prohibits clinically relevant distortion or magnification in this direction[8].

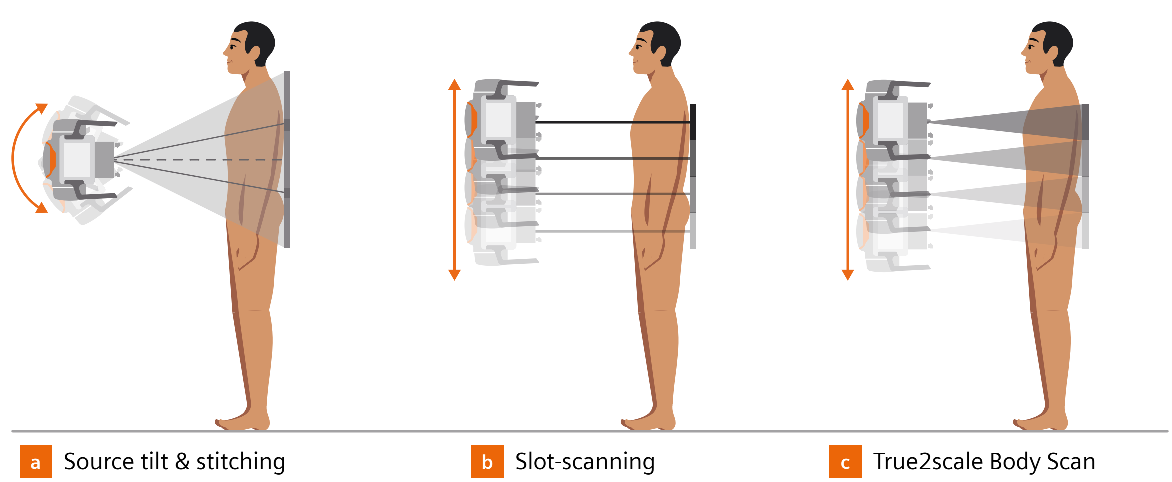

Figure 1: Illustration of the techniques of conventional source tilt & stitching (a); slot-scanning (b); True2scale slot-scanning technique (c)

In the orthogonal direction (patient left-right axis), the image still bases on a divergent beam geometry; as the patient position is defined by positioning markers, the magnification factor is known and can be corrected during reconstruction by the software. The use of calibration objects (balls, rules, etc.) is not required. Due to the nature of the True2scale imaging technique, objects, that are positioned outside the focal volume, might cause artifacts and will appear blurry.

A True2scale acquisition in natural weight-bearing position offers a scan length of up to 170 cm. In addition, True2scale can be used for examinations at the table, with the patient in a lying position, up to a scan length of 190 cm. The maximal width at patient plane is 32 cm for anterior-posterior (a.p.) images and 26.5 cm for lateral images.

A side-by-side overview of the techniques, True2scale and SmartOrtho/ RaxOrtho, as well as their functionalities, is shown in Table 1.

	True2scale Body Scan	SmartOrtho / RaxOrtho
Coverage	Length extended images 170 cm standing, 190 cm supine Width 32 cm for a.p., 26.5 cm for lateral images	Length extended images 154 cm standing, 143 cm supine Width approx. 40 cm at 3 m SID
Acquisition	Slot scanning reconstruction technique with geometrical accuracy	Source tilt & stitching technique allowing manual pixel-based optimization
Workflow	Biplanar length extended acquisition without repositioning	Monoplanar length extended acquisition
Patient positioning	Flexible positioning: standing (weight-bearing), seated or supine	Flexible positioning: standing (weight-bearing), seated or supine
Spatial resolution	Continuous acquisition in binned mode	High resolution radiographic images
Dose	Dedicated low dose imaging protocols for e.g., scoliosis	Dedicated low dose imaging protocols for e.g., scoliosis

Table 1: Comparison of the length extended imaging techniques, True2scale Body Scan and SmartOrtho/ RaxOrtho.

The True2scale reconstruction method applied on the acquired images yields geometrically accurate images in scanning direction. The user does not need to perform additional calibration steps.

Low dose

Another benefit of the high beam collimation, as described as the basis for the slot-scanning technique, is a native scatter reduction[9]. Scattered radiation impairs image quality, as it reduces the image contrast and the signal-to-noise ratio (SNR). Figure 2 illustrates how the beam collimation reduces scattered radiation in slot scan images – two patterns are mainly relevant. First, less scatter events take place, which would cause scattered photons in the relevant area. Second, an amount of the scattered photons reaches the detector outside the collimated area, and thus do not affect the acquired image.

Therefore, the method of high beam collimation creates a higher SNR, thus an image of comparable quality can be obtained with a lower radiation dose[10]. Figure 3 shows an example of the same Dose Area Product (DAP) (2.3 μGy*m²) and the respective image quality.

Luckner et al. investigated the dose saving potential on a prototype of the slot-scanning technique with a slot size of 5 x 43 cm compared to a full-field acquisition (43 x 43 cm)[9]. Two distinct acquisition settings (80 kVp without copper filtration and 120kVp with 0.3 mm copper filtration) were evaluated on two different regions of a body phantom: thoracic spine and lumbar spine.

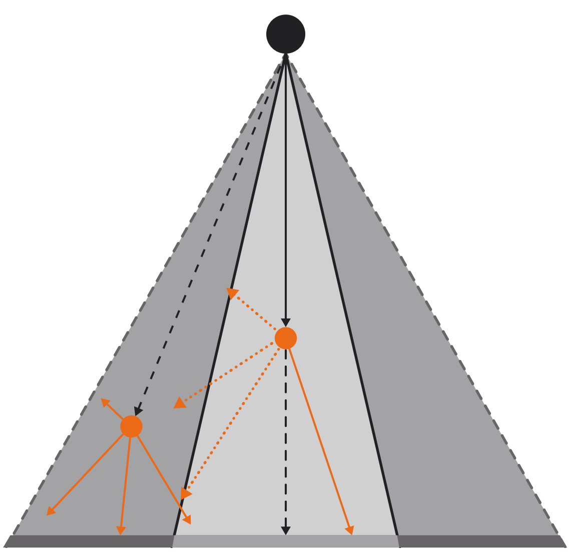

Figure 2: Beam collimation as native scatter reduction method. Due to the collimation, less scatter events take place. Furthermore, less scattered photons reach the detector in the relevant area.

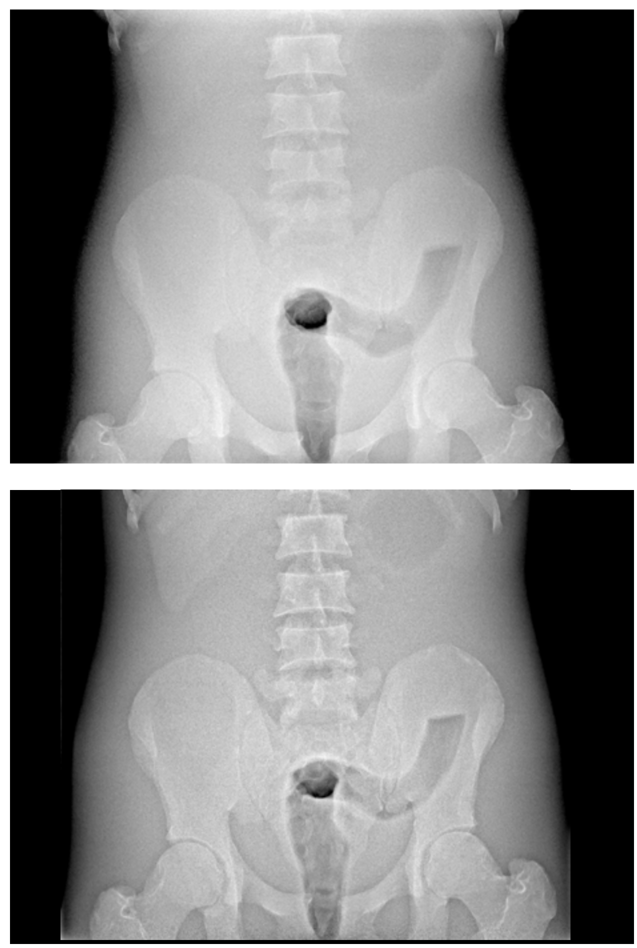

Figure 3: Phantom images acquired with conventional full-field (top) and the slot-scanning technique (bottom). DAP of both images is 2.3 μGy*m².

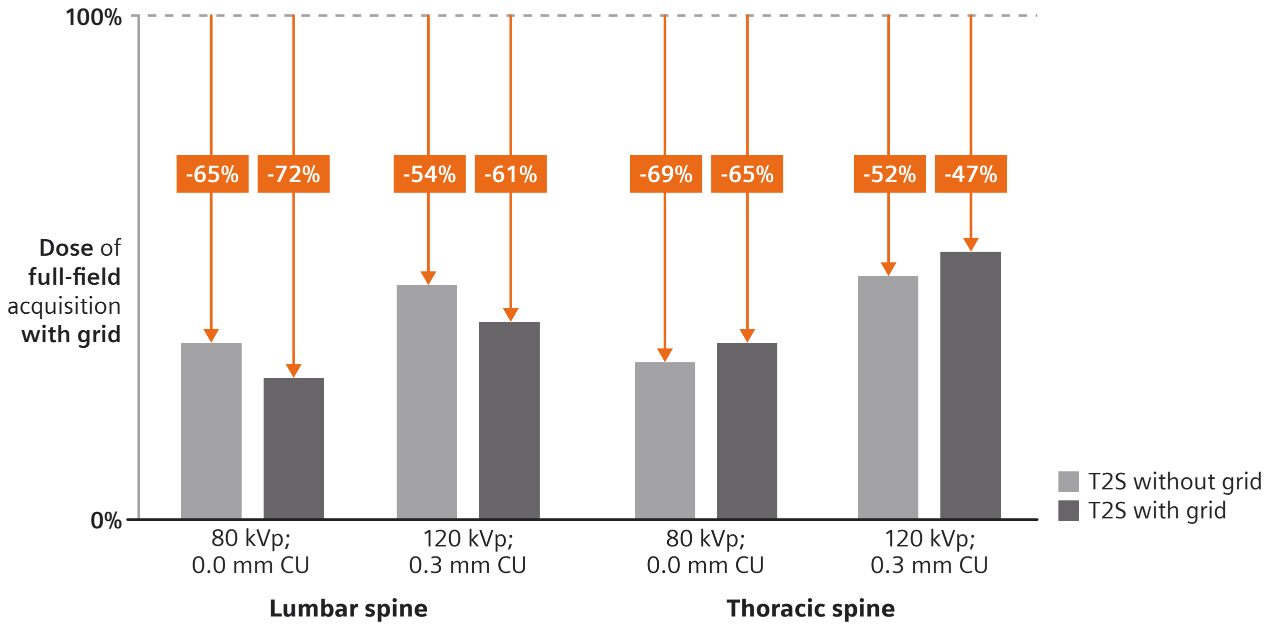

Figure 4: Dose saving potentials, comparing full-field to slot-scanning acquisition, without compromising on image quality in terms of SNR [Luckner et al. [9]]. 80kVp as a typical setting for a.p. images and 120kVp for lateral images. (CU = copper filter)

Depending on the compared acquisition settings, in the study from Luckner et al., dose savings between 47% and 72% were feasible compared to a full-field acquisition, keeping the SNR constant[9]. All results are shown in Figure 4.

The scatter-rejecting property of the True2scale acquisition technique allows to reduce dose compared to a full-field acquisition while maintaining a good SNR with a gridless acquisition, independent of the patient size.

Fast acquisition and workflows

True2scale images can be acquired in supine or upright (weight-bearing) patient position. Supine images are acquired at the table; for weight-bearing images, the patient stand of Multitom Rax is used and helps to reduce motion artifacts during image acquisition, by giving the patient a good balance with attachable handles and positioning aids for secure patient positioning.

True2scale offers acquisitions in a.p. and/or lateral orientation for three positions supine, seated or standing. As the system moves around the patient, the patient does not need to be repositioned. There is the choice between a.p., lateral, or combined a.p. and lateral scans,* where the system acquires first the a.p. and then the lateral view.

For a fast readout at 30 frames per second, the detector is operated in a 2x2 binning mode, resulting in 0.296 mm x 0.296 mm detector pixel spacing. This combination enables unilateral full-body acquisitions (170 cm) in as little as 8 seconds, and biplanar full-body acquisitions in as little as 22 seconds,depending on the patient's Body-Mass-Index (BMI).

To adapt to patient-specific conditions, e.g. pediatric imaging, obese patients, etc., True2scale can be operated in three different speeds. In the fastest acquisition mode, the system moves with 27 cm/s (0.972 km/h) along the patient. To avoid blurring of the images, as known for example from long time exposed night shots in photography, the exposure time must be adapted (shortened) accordingly. For the fastest acquisition mode, the exposure time is limited to 2 ms. During this time, the system moves approximately 0.54 mm, yielding sufficient spatial resolution. With an exposure time of 2 ms, the dose output of the tube is limited. Especially for larger patients, longer exposure times are required for adequate image quality, thus, two modes with slower acquisition speeds are offered (14 cm/s and 8 cm/s), which allow longer exposure times (4 ms and 7 ms) without affecting the spatial resolution.

Despite the 2x2 binning and the fast system movement during the scan, all True2scale scanning modes yield a spatial resolution that is sufficient for typical orthopedic examinations in terms of musculoskeletal measurements (14 lp/cm @ 10 % MTF)[11].

**The combined acquisition is available up to a patient BMI of 30 kg/m²*

The following table summarizes typical acquisition parameters:

Overview of typical acquisition parameters and image characteristics of True2scale Body Scan

Scan time	single plane 8 – 18 s biplane 22 – 34 s
Tube voltage	40 – 150kV (lower for pediatric examinations)
Source-detector distance	132 – 150 cm
Image type	frontal and lateral 2D reconstructed image
Pixel size (detector)	0.296 mm (2x2 binning, native 0.148 mm)
Pixel size (recon)	0.25 mm
Spatial resolution	up to 1.4 lp/mm ± 10% @ 10% MTF
Max. image length	170 cm standing 190 cm lying
Max. image width	32 cm for a.p. view 26.5 cm for lateral view

True2scale Body Scan

Clinical application and practice

The first section focused on the technical conditions and capabilities. In the following, clinical application areas of True2scale (whole spine, long-leg, and whole body) are specifically addressed. To make this as practical as possible, the areas of application are discussed using real case examples.

Imaging of the whole spine in two planes

The German Back Pain Study and Health Survey evaluated the lifetime prevalence of low back pain which was 85%[12]. This was increasing with age, with 11% of those under 30 years of age reporting low back pain (defined as persisting for at least three months) in the past year, compared with 30% of those aged 65 years and older[13]. Approximately one-third of sufferers are not pain-free after one year, and the relapse rate is equally high[14]. Since back pain is very nonspecific, the goal of diagnostics is to find out the causalities and to recognize emergencies. It is not generally recommended to perform imaging for episodes of low back pain, but if the pain persists for more than four to six weeks, the indication for imaging is suggested to be considered[15,16].

For imaging spinal deformities and diseases, True2scale can be a well-suited tool for the radiologist and orthopedist. In this context, the factors of high precision, described above, due to the comparability of even small progression changes, as well as the low dose play a significant factor. Furthermore, the limited mobility and the possible pain during positioning for imaging play a significant role. Therefore, it is also advantageous from the perspective of patient comfort and workflow to be able to acquire the coronary and sagittal image planes without repositioning[17].

During follow-up examinations, imaging of the coronal plane only is often considered sufficient in order to minimize radiation dose. Thus, it is not only important to have the possibility to acquire bi-planar orthogonal images without repositioning, but to decide to only operate one plane.

In the context of the above, it is important to mention scoliosis, an abnormal lateral curvature of the spine (skolios = curved/crooked)[18]. Often young patients are affected, who require regular radiographic follow-up (therefore ALADA plays an even more important role to keep the live time exposure as low as possible), in which comparability, but also weight-bearing imaging, plays a significant role[19].

To illustrate the clinical value-add of True2scale, a scoliosis case will be discussed in more detail.

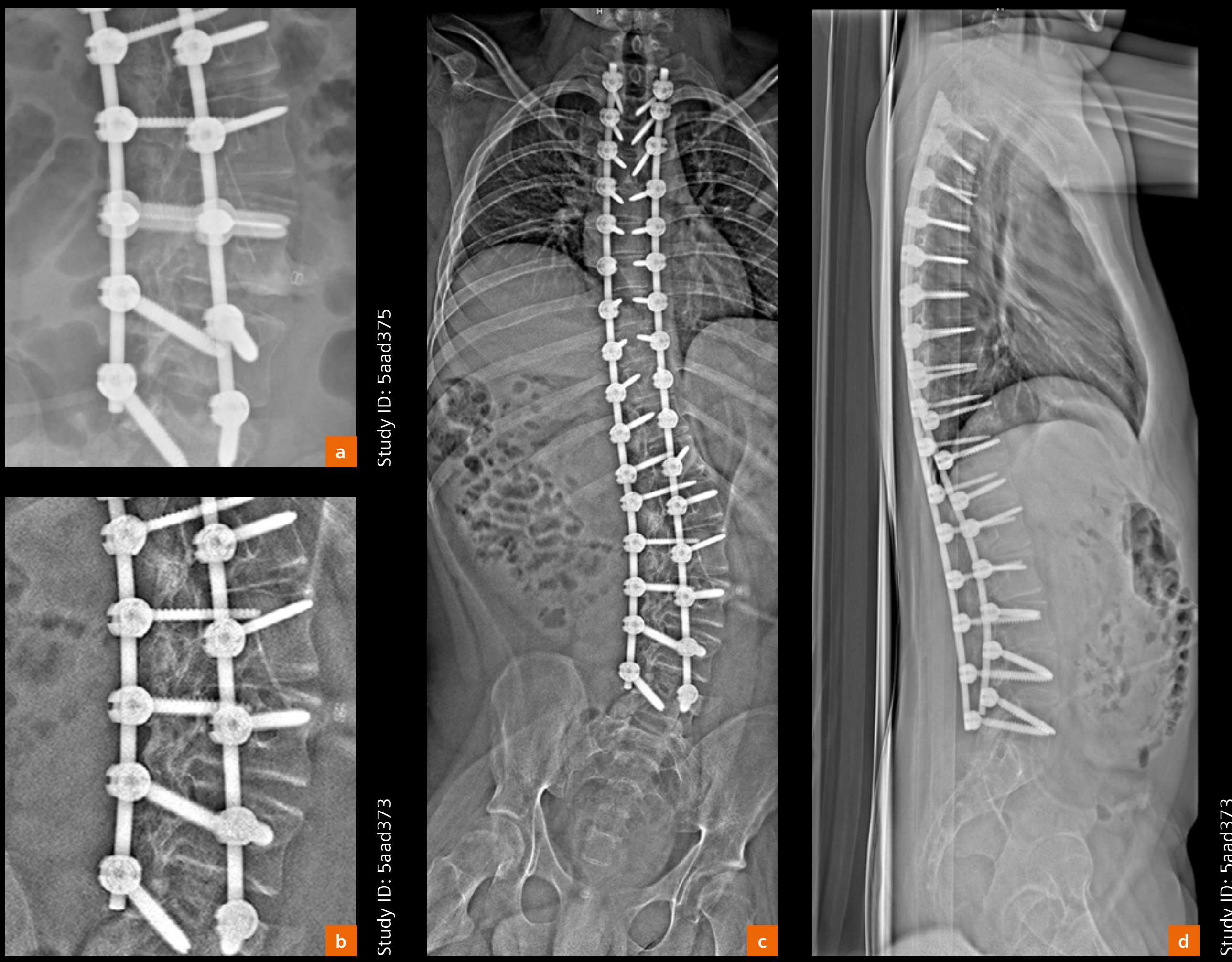

Figure 5: Images of a patient one year after internal spinal fusion with the radiological indication of loosening or dislocation. Comparable images in the source tilt & stitching (image (a)), and in the True2scale technique (image (b – d)), a.p. (image (c)) and lateral (image (d)) are shown. (Courtesy of Pediatric Radiology, Children's and Youth Hospital "Auf der Bult" Hannover, Germany)

Case 1:

Figure 5 shows the a.p. and lateral images of an adolescent patient (age 15-20 years), who had received an internal spinal fusion one year earlier due to progredient scoliosis, based on a progressive neurological disease (neuronal ceroid lipofuscinosis CLN 6 mutation) with advancing cognitive and motor impairment. The objective in this case was a routine check to exclude implant loosening or dislocation. On image (a) a typical "stitching artifact" can be seen as it might occur with the source-tilting technique, making it difficult to reveal loosening of the implanted material. These artifacts must be identified and manually processed by the technician, which was not done in this particular case. This takes additional time and is error prone. The same area, taken with True2scale (image (b)), reveals good diagnostic quality. Moreover, both, the a.p. (image (c)) and lateral (image (d)) view of the True2scale Body Scan are shown in Figure 5.

In this case, True2scale plays out its advantage of bi-planar imaging without repositioning and distortion-free imaging.

Imaging of the lower limbs

In long-leg images of the lower extremity, an anatomical and a mechanical axis can be described (Figure 6). The mechanical axis in particular plays an important role in planning a successful knee arthroplasty treatment. A clinically and functionally good outcome is found to be based on a good mechanical alignment of the knee and the entire limb[20]. For this purpose, the long-leg scan has proven to be an effective and high quality instrument with a low dose.[21] The determination of the anatomical and mechanical axis as well as joint orientation angles can be seen in Figure 7. Case 2 illustrates such a long-leg allocation.

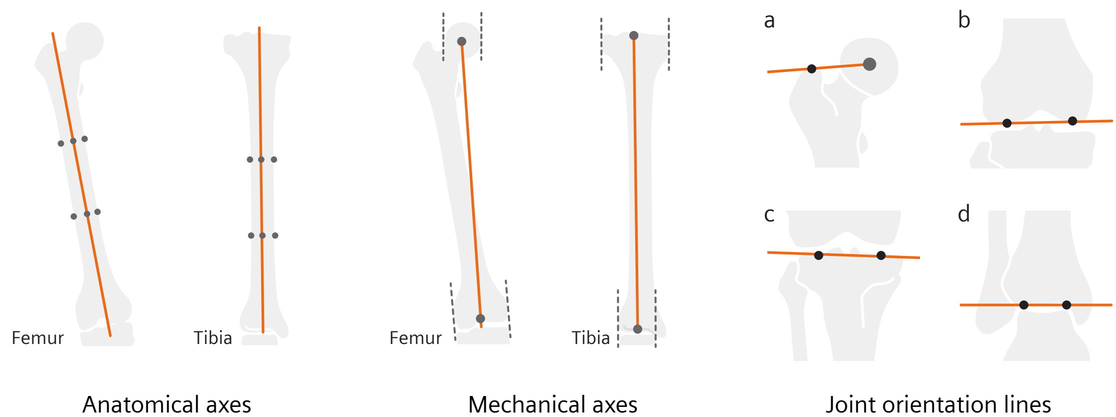

Figure 6: Differentiation between anatomical and mechanical axis of the lower extremity as well as joint orientation angle.
a) hip joint orientation line; b) distal femoral knee joint orientation line; c) proximal tibial knee joint orientation line;
d) ankle joint orientation line

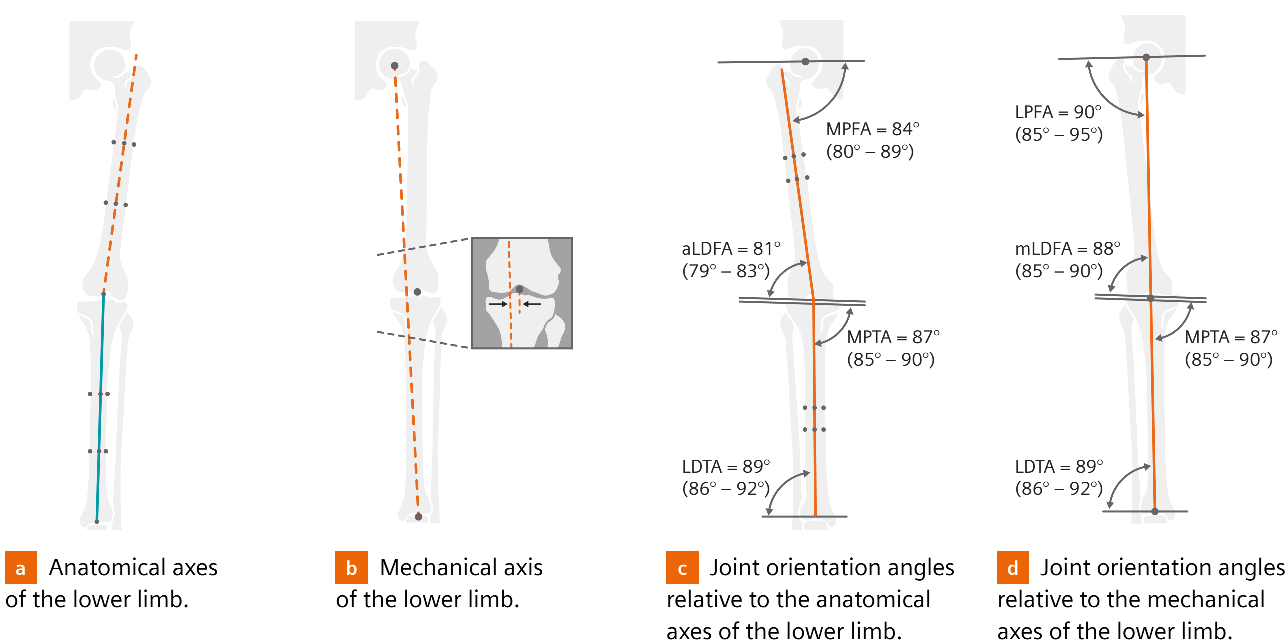

Figure 7: Planning of total knee replacement based on the mechanical axis and alignment

Case 2:
This case is a 70 - 80-year-old patient with a condition after hip replacement and a known gonarthrosis on the right side with increasing pain especially under weight-bearing. In preparation for knee arthroplasty, a long-leg True2scale Body Scan was taken under weight bearing conditions.

In Figure 8, the native image of the scan and the measurements, using mediCAD® planning software[22] for long-leg application measurements, can be seen.

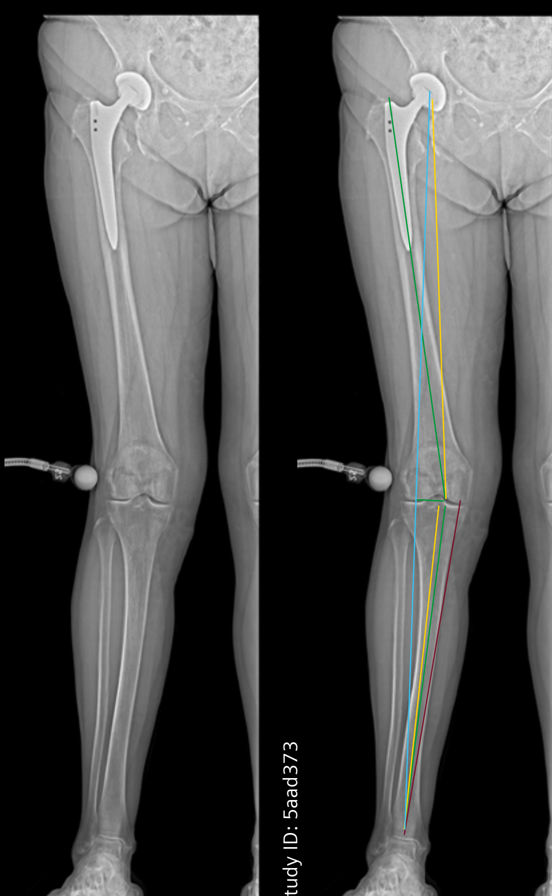

Figure 8: True2scale long-leg imaging of a 70- 80-year-old patient with gonarthrosis of the right knee for pre-operative planning; left – native image; right – measurements on the True2scale examination using mediCAD® planning software (green = anatomical axis lower limb; blue = mechanical axis lower limb; yellow = mechanical axis femur/ tibia) (Courtesy of Department of diagnostic and interventional radiology, Krankenhaus der Augustinerinnen, Cologne, Germany)

Imaging in natural weight-bearing and in lying patient position

Since True2scale of both body regions can be acquired with the patient in supine or standing position, the latter case allows imaging under natural weight-bearing conditions. Advantages in clinical decision-making and treatment planning have been described in the literature for weight-bearing imaging of the spine and lower extremity.

Several studies investigated **spinal** curvature (main KPI Cobb angle) and the rotational component of scoliosis [23,24,25,26]. Significant differences could be found between weight-bearing and supine positions. These discrepancies were found for 2D (radiography), 3D imaging (computed tomography (CT), and magnetic resonance imaging (MRI)). The variations in the studies ranged from 1° to 21° for scoliosis measurements. This shows the importance of this type of examination.

The findings for the lower extremity are similar. A.p. natural weight-bearing **hip** imaging is described as standard, since better assessability of joint space narrowing (JSN) in osteoarthrosis or the extent of hip dysplasia are described[27,28,29].

Advantages of weight-bearing have also been described in the initial assessment of the **knee** (a.p., lateral, and skyline views) for assessing the JSN and measuring the knee axes[30]. For example, Adelani et al. described that in patients > 40 years of age with a JSN greater than 50% on weight-bearing radiographs, MRI is not useful, as it has no impact on treatment decisions in 95% of cases[31].

Finally, weight-bearing is also a decisive factor in imaging the **foot**. Both in the evaluation of foot geometry and osteoarthritis, weight-bearing images should be preferred[32,33].

Figure 9: Patient (12 – 15-year-old) with idiopathic lumbar scoliosis. Routine control after fitting with a day and night orthosis. Image a (left) taken under weight-bearing conditions, image b (right) in supine. (Courtesy of Institute and Polyclinic for Diagnostic and Interventional Radiology, University Hospital Carl Gustav Carus, Technical University Dresden, Germany)

Case 3:

In this case, a young patient (12 – 15 years) with idiopathic lumbar scoliosis was fitted with a day and a night orthosis due to progressive scoliosis. The indication for the present X-ray imaging was a routine check, performed in the supine and standing position (Figure 9). The above-described findings of a more prominent cobb angle under weight-bearing can be validated with measurements – weight-bearing 35.2° vs. supine position 19.9°. However, therapy was evaluated as sufficient and kept until progression of clinical symptoms or radiographic findings.

Figure 10: True2scale Body Scan whole body image for positional diagnostics. (Courtesy of Institute and Polyclinic for Diagnostic and Interventional Radiology, University Hospital Carl Gustav Carus, Technical University Dresden, Germany)

Imaging of the whole body

Another use case is full-body radiography, which allows the system's range of motion of 190 cm supine and 170 cm standing. From a clinical perspective, the need for such images is not an everyday routine, yet it can add value for specific issues. Advanced Trauma Life Support, foreign body detection, pediatric imaging and control of ventriculoperitoneal shunts have been reported as fields for full body X-ray[34,35,36,37,38]. However, True2scale is only intended to be used for positional diagnostics of the body axes.

True2scale Body Scan and beyond with Multitom Rax

Multitom Rax is designed not only for length extended images, but has a variety of applications, that add value like True2scale in musculoskeletal (MSK) imaging.

Thanks to its modular design, Multitom Rax can be quickly configured to suit patients' needs. Starting with precision radiography, it also allows Real3D imaging for the extremities and lumbar spine, as well as fluoroscopic imaging for functional assessment. This way, Multitom Rax enables comprehensive diagnosis and can provide the basis for treatment planning – all in a single room on a single system.

True2scale Body Scan

Conclusion

Siemens Healthineers True2scale Body Scan employs a slot-scanning based acquisition and reconstruction technique as an option of the Twin-Robotic X-ray system Multitom Rax. In addition to the diagnostic use in standard radiography, fluoroscopy and 3D imaging, the True2scale functionality of Multitom Rax offers uni- or biplanar, fast and geometrically accurate information. It allows low-dose imaging of the whole spine for assessment of spinal deformities and associated malposition, as well as long-leg or whole-body imaging for the diagnosis of malalignment. Having the option of performing the image acquisition with the patient in natural weight-bearing or lying position, this acquisition can be done without the need for calibration or stitching of images, or the need of repositioning the patient.

Abbreviations

µ	Micro
a.p.	Anterior – posterior
ALADA	As low as diagnostically acceptable
BMI	Body-Mass-Index
cm	Centimeter
CT	Computed tomography
Cu	Copper
DAP	Dose area product
e.g.	Exempli gratia
Gy	Gray
JSN	Joint space narrowing
k	Kilo
kVp	Kilo volt peak
lp	Line pairs
m^2	Square meter
MRI	Magnetic resonance imaging
ms	Milliseconds
MSK	Musculoskeletal
MTF	Modulation transfer function
s	Seconds
SID	Source-image distance
SNR	Signal to noise ratio
T2S	True2scale Body Scan
TOD	Table-object-distance
V	Volt

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True2scale Body Scan can be run without restrictions up to a BMI of 30 kg/m². From software version VF11H (expected to be available from December 2022) up to a BMI of 40 kg/m². Exceeding the BMI limit requires manual and separate anterior-posterior and lateral scans. For patients with a BMI >40 kg/m², a lateral long axis image is limited to max. 130 cm.

Siemens Healthineers Headquarters
Siemens Healthcare GmbH
Henkestr. 127
91052 Erlangen, Germany
Phone: +49 9131 84-0
siemens-healthineers.com

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