Lunar Technology Advantages

DXA stands for **D**ual-Energy **X**-ray **A**bsorptiometry. It is a measurement method that uses the differences in the absorption of high energy and low energy X-ray photons by different elements in a body to quantify the amount of bone and soft tissue in the body. For example, certain elements in bone minerals (e.g. calcium) will absorb more low-energy X-rays than the elements in soft tissue, enabling a precise and accurate estimate of bone mineral density (BMD). By using relevant algorithms, we can also use the same measured data to determine body composition due to the different density and composition of fat and lean tissue. Based on DXA technology, the Lunar bone densitometry product portfolio (Lunar iDXA,™ Prodigy,™ and Aria™*) empowers physicians and clinicians to diagnose osteoporosis and fracture risk.** Lunar iDXA and Prodigy may also perform body composition analysis (fat and lean tissue mass). After a DXA scan, the measured values are compared to a reference population at the sole discretion of the physician to achieve desired clinical results.

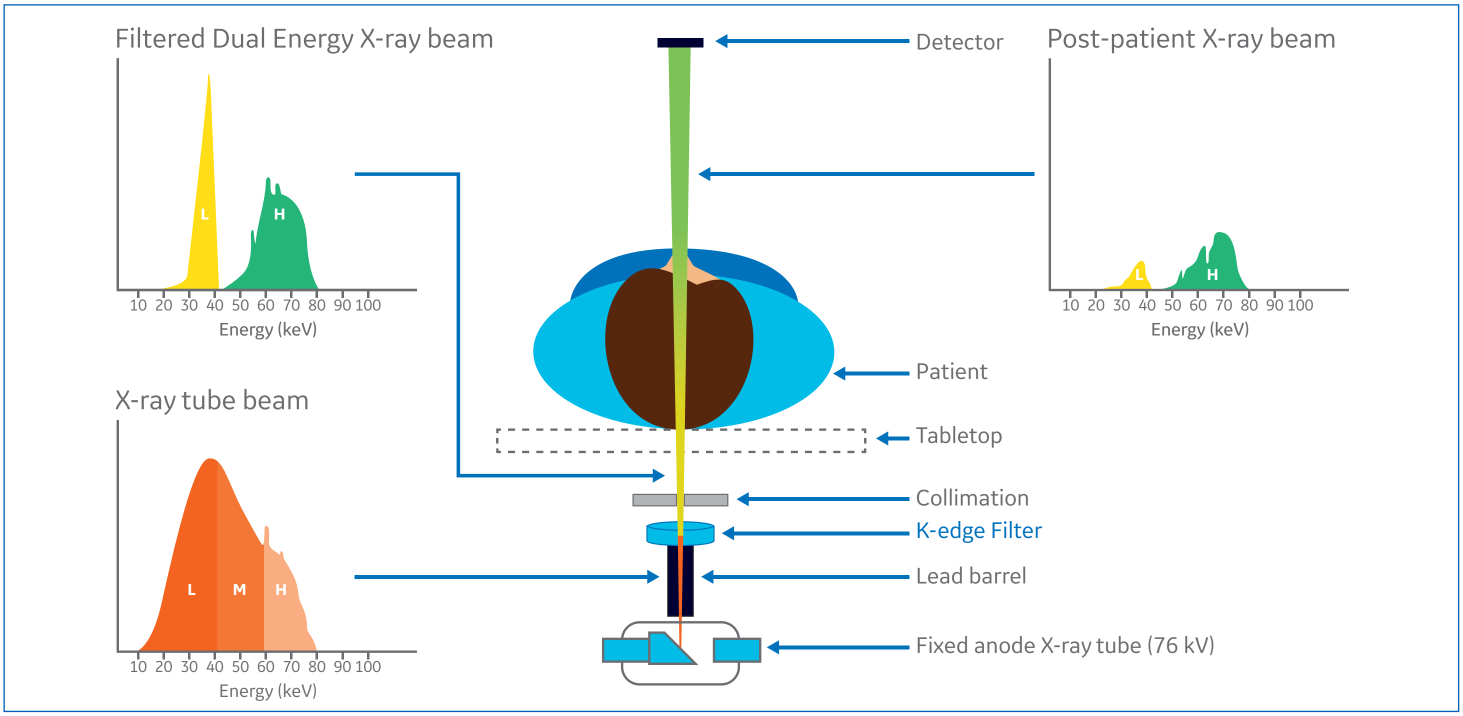
DXA X-ray Beam Generation Methods

There are two fundamental approaches to create the X-ray beams needed for a DXA scan: K-edge Filter technique and Energy Switching technique.

K-edge Filter Technique

Lunar uses a "K-edge filter" that absorbs the X-rays in the middle energy range, but allows most high energy and low energy X-rays to pass through to the patient (Figure 1).

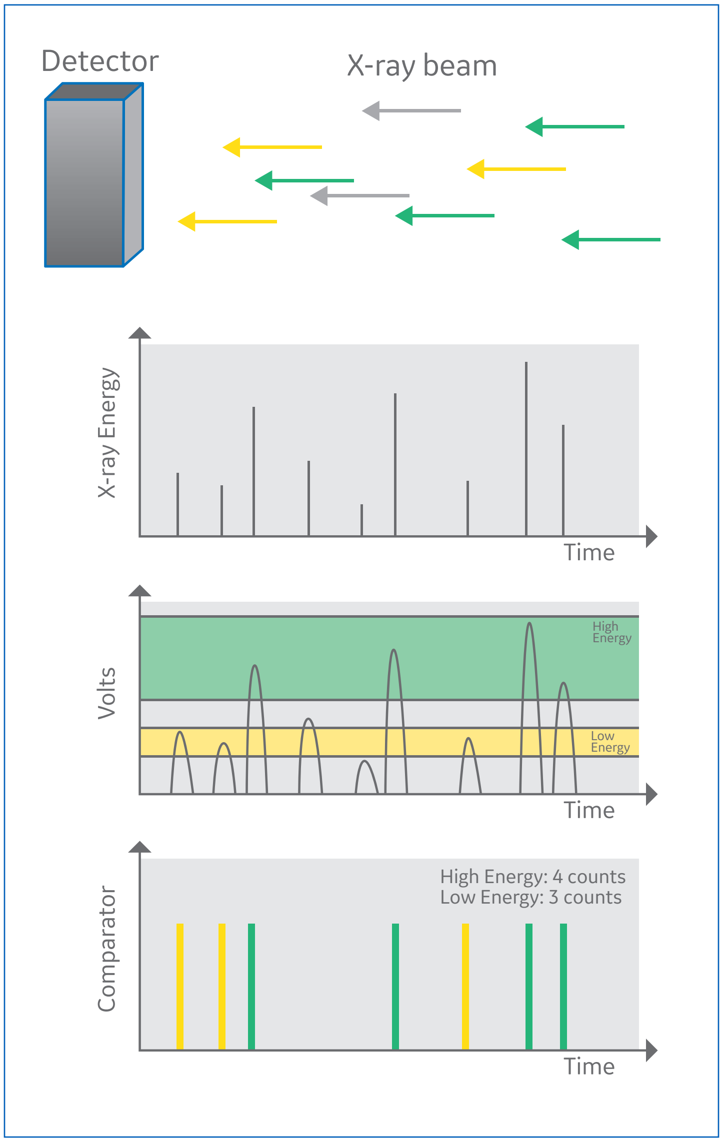
Figure 1: DXA X-ray system using K-edge filter.



*Available in select markets
** For full description of intended use, refer to the appropriate product user manual.

The initial beam (red/orange) is created using an ultra-stable X-ray generator with a fixed anode X-ray tube. The K-edge filter creates distinct low energy and high energy portions of the X-ray beam (yellow-green) before transmission through the patient. The patient absorbs more of the low-energy X-rays (yellow) than the high-energy X-rays (green). An energy-sensitive detector absorbs the transmitted X-rays and counts each X-ray photon as either low or high energy as highlighted in Figure 2

Figure 2: Lunar Photon Counting Method. X-rays with various energies are incident on a photon-counting detector. Amplifiers create voltage pulses proportional to X-ray energy and comparators sort them into low and high energy bins.



Lunar's "photon counting" method is a very dose-efficient DXA technique since low and high energy X-rays are simultaneously and individually counted. Furthermore, by blocking X-rays in the middle of the energy range before the patient, the K-edge filter lowers patient dose while improving performance, since it removes X-rays which would not efficiently distinguish between bone and soft tissue. For Prodigy and Aria, the X-ray generator runs at 76 kV and the effective energy of the low- and high-energy portions of the beam are ~35 keV and ~61 keV. Lunar iDXA uses a 100 kV generator and K-edge filtering results in ~39 keV and ~71 keV X-ray effective energies. These energies are optimized for bone and tissue separation. Figure 3 shows the difference in attenuation of cortical bone and soft tissue as a function of incident X-ray energy for Prodigy and Aria. The arrows highlight how the bone and soft tissue attenuation differ between low- and high-energy X-rays.

Figure 3: Linear attenuation coefficient of cortical bone and soft tissue (left axis) and the Prodigy and Aria X-ray beam intensity (right axis) vs. X-ray energy.

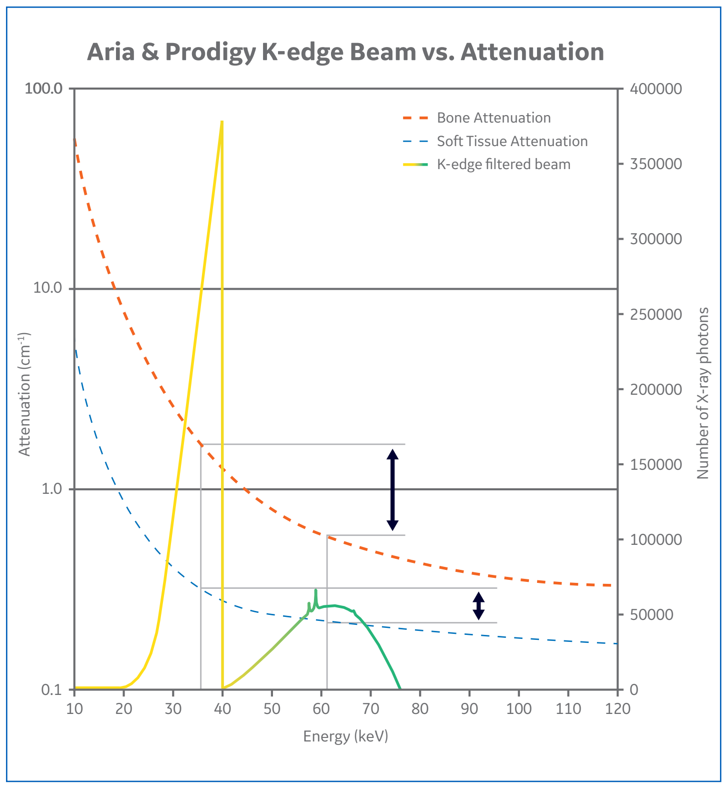
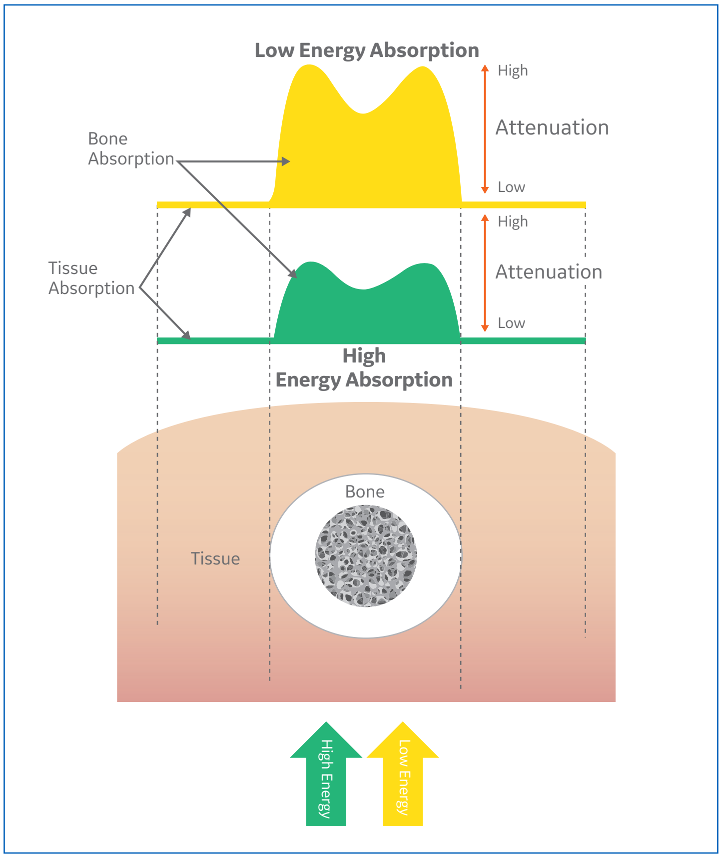


Figure 4 is a simplified illustration of how bone mass is calculated. Low and high energy X-rays attenuate differently through a region of tissue containing bone. Attenuation through the material is largely determined by its thickness and density. In regions without bone, the tissue provides a baseline attenuation. Bone mass is calculated by subtracting this baseline from the combined attenuation of tissue and bone.

Figure 4: Attenuation differences between low and high energy X-rays through tissue and bone enable bone mineral mass measurements.



Energy Switching Technique

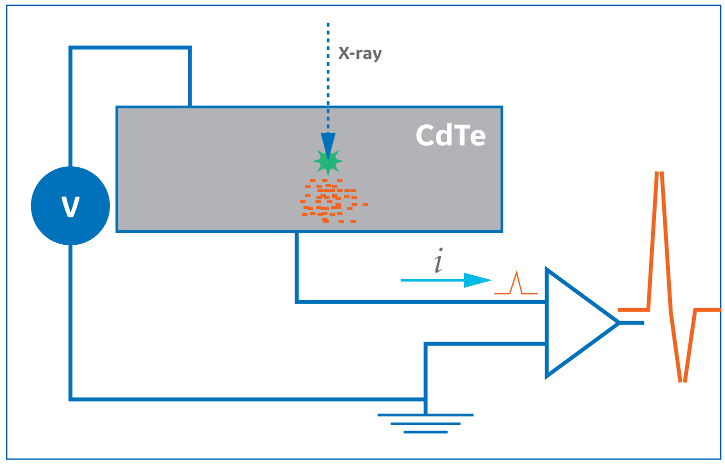
Another approach for X-ray generation uses an "energy-switching" X-ray generator to rapidly cycle between low and high voltage. A Lunar competitor uses a generator switching between 100 kV and 140 kV, synchronized to the 50-60 Hz power line frequency. Because the X-ray energy is unstable during data acquisition, it is necessary to correct each pixel measurement using a complex "spinning drum" composed of air, soft tissue, and bone equivalents. Each pixel needs six sequential measurements (2 energies through 3 chambers) leading to greater dose to the patient.

X-ray Detector Technology

The detectors in Lunar products perform a crucial task – count each individual X-ray photon and classify it as either "low-energy" or "high-energy."

Lunar iDXA detectors use solid-state crystals (Cadmium Telluride or CdTe) to generate a signal. The X-ray energy is absorbed by the crystal and results in the immediate release of electrons from their atoms (i.e. *direct conversion*). An applied voltage pushes the electrons out of the crystal, effectively creating a current pulse whose magnitude is proportional to the X-ray energy. Sensitive, low-noise amplifiers boost the signal so that counting electronics can perform the final identification as low or high energy. See Figure 5.

Figure 5: Lunar iDXA X-ray detector signal generation



Recently Lunar embraced a state-of-the-art technology from the field of Nuclear Medicine known as solid-state photomultipliers* (SSPM) to maintain high performance and provide value. Both Aria and recent Prodigy detectors are now composed of ultra-fast and bright LYSO scintillators (Lutetium-Yttrium Oxyorthosilicate, $Lu_{2(1-x)}Y_{2x}SiO_5$) coupled to solid-state photomultipliers. LYSO crystal has the advantages of high light output and density, fast decay time and excellent energy resolution. In comparison, a Lunar competitor uses conventional CT-style Gadox scintillators which are slow, energy-integrating detectors that CT researchers and manufacturers now recognize are intrinsically less dose efficient than photon counting detectors.[1,2]

*Also known as silicon photomultiplier (SiPM)

X-rays are absorbed in the scintillator which rapidly and efficiently converts X-ray energy into light (i.e., *indirect conversion*). Light is channeled to a solid-state photomultiplier which produces a highly amplified signal that is ready for the counting electronics (Figure 6). SSPM's combine the function of the conventional photomultiplier with the compactness, simple operation and low voltage of photodiodes.

Figure 6: Prodigy10 X-ray detector signal generation

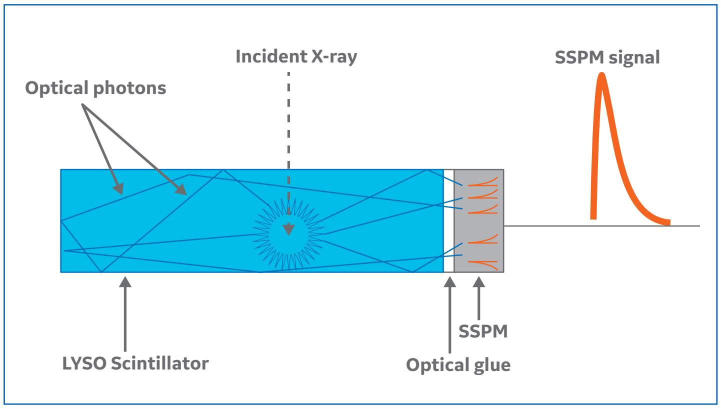
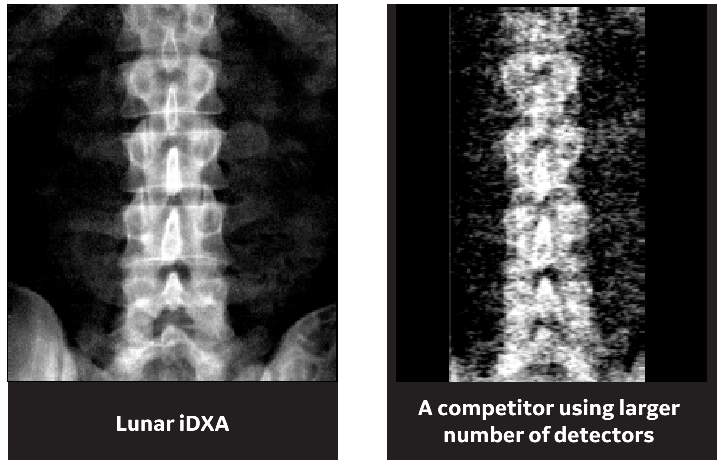


Image Quality

Image quality and BMD precision fundamentally depend on the number of low- and high-energy X-rays detected per image pixel. An image pixel is the geometric projection of the detector area to the image plane. As may be expected, image quality improves with higher density of image pixels and higher X-ray flux per pixel. The difference in image quality within Lunar's DXA portfolio reflects this. For example, the *pixel density* of Lunar iDXA images is higher than Prodigy images and Lunar iDXA's 100 kV source emits more X-rays than Prodigy and Aria's 76 kV source. By balancing smaller image pixels with higher X-ray flux, Lunar iDXA maintains good BMD precision (1%) and produces Lunar's highest quality images.

It is important to note that increasing the number of detectors does not necessarily improve image quality unless it is accompanied by a *higher density* of image pixels.* Furthermore, scanning too quickly or with insufficient X-ray source current for a patient's thickness will degrade image quality by starving each image pixel of X-rays. Figure 7 compares a lumbar spine image of a heavy patient (BMI = 46.5) captured from a Lunar iDXA scan vs. that captured by our competitor's DXA equipment that uses a higher number of detectors. The sharper image of the Lunar iDXA scan is a result of higher X-ray flux per image pixel.

Figure 7: Higher Image Resolution of Lunar's Narrow Fan Beam Technology on heavier patients



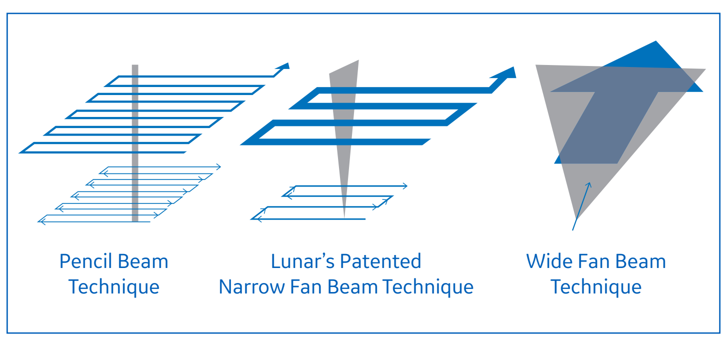
Lumbar Spine Scan, Male Subject – Weight: 229 lb/103.9 kg – Height: 5.1 ft/ 154.4 cm – Bone Mineral Density: 1.28 g/cm^2

Pencil vs. Narrow Fan vs. Wide Fan Beam Technology

The earliest DXA scanners used a pencil beam that performed "raster scans" back-and-forth across the patient. Pencil beams have the advantages of low patient dose and no magnification effects. They perform well and today are a reasonable choice for value product lines or for low-volume customer sites. However, their beam size necessarily requires many sweeps and long scan times.

Fan beam systems shorten scan times significantly and two approaches have been commercialized. One of our competitors uses a wide fan beam which makes a single sweep along the patient axis. Whereas, Lunar developed and patented the use of a narrow fan beam technology which combines the best features of pencil beams (no magnification, low dose) with the short scan time of fan beams. Figure 8 shows the three common beam shapes.

Figure 8: Pencil, Narrow Fan, and Wide Fan beam scanning techniques

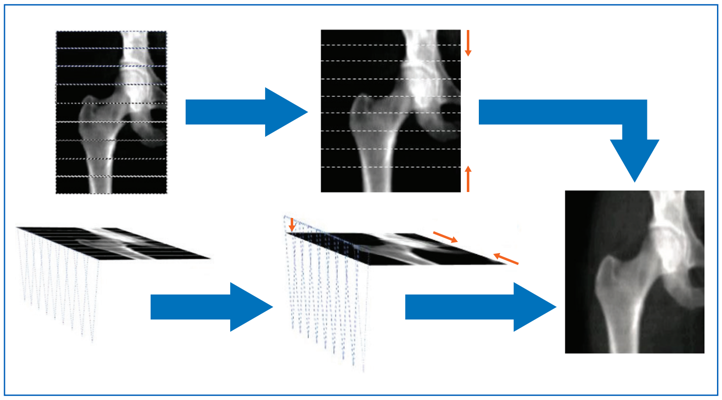


*By analogy, recent improvements in picture quality on smartphones only occurred when the number of pixels increased while the screen size remained the same.

Multi-View Image Reconstruction (MVIR) Technique

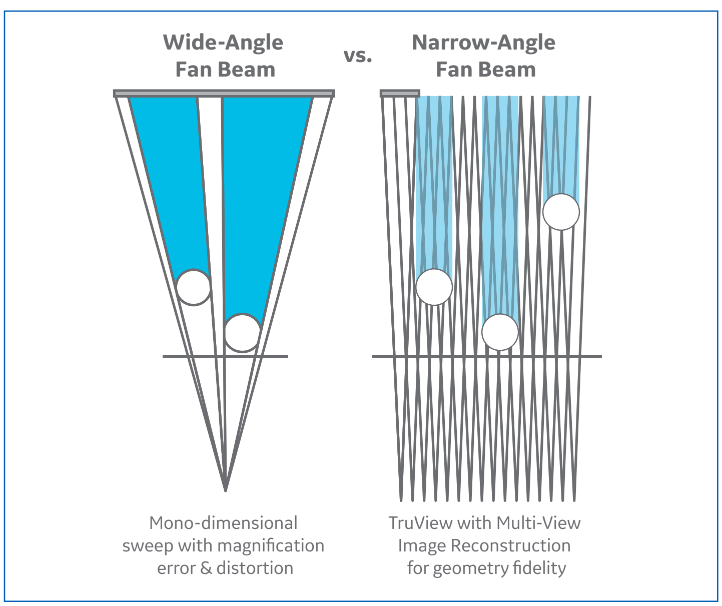
Lunar's narrow fan beam technique makes multiple transverse sweeps across the site of interest. Sweeps are spaced so that the adjacent fans overlap at the bone above the tabletop, providing multiple views of the bones (Figure 9).

Figure 9: Multi-view image reconstruction combines bone images from each sweep to construct images at the correct bone height above the table-top. The final image has no distortion and accurate distance and areas.



Lunar's multi-view image reconstruction (MVIR) technique takes advantage of these overlaps, by "sliding" adjacent sweeps over each other until the bone images in their overlapping regions match. The amount of "sliding" is related to the bone height above the tabletop by simple geometry. The resulting image is distortion-free in both dimensions.[3,4] This leads to highly accurate BMC, area and distance measurements for every individual patient. Recall that Lunar's intrinsically efficient photon-counting technique means every sweep has low exposure. Thus overlapping sweeps still result in a low overall patient dose and provide all the added benefits of zero magnification and distortion-free images. In contrast, a single wide fan beam imaging may produce magnification errors (figure 10).

Figure 10: Narrow fan beam imaging eliminates magnification errors that occur with single sweep wide fan beams.



Magnification Errors introduced by Single Sweep Wide Fan Beam Techniques

The single sweep fan beam technique cannot correctly estimate the object plane (the bone height above the tabletop), resulting in magnification errors that can introduce several problems:

1. Off-center site positioning within the single sweep of a wide fan beam can create geometric distortions. Scoliosis can be severe enough to make centering of the entire spine difficult. To avoid this, the clinician may have to perform "scout scans" that necessarily imply additional dose.

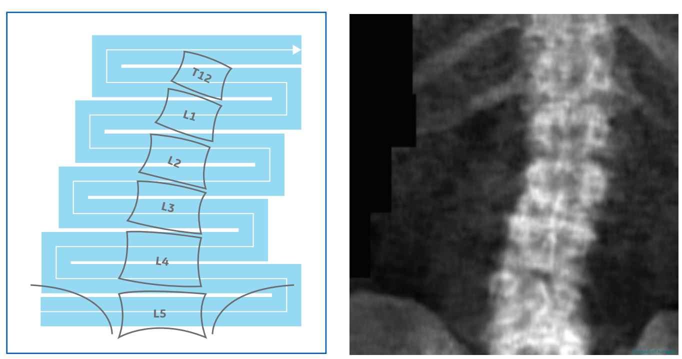
2. Geometrical measurements of bones (e.g. cortical widths, femoral neck length) may be inaccurate and are necessary for advanced bone strength analyses.

3. Accurate BMC and bone area measurements are important for pediatric patients and total body composition applications[5] and magnification results in height-dependent inaccuracies up to 25%.[6]

SmartScan™

SmartScan is an exclusive feature of Lunar DXA bone densitometers which is enabled by transverse scanning with a narrow fan beam (or pencil beam). Bone regions are identified after each transverse sweep and used to estimate where to begin exposing the patient to X-rays on the subsequent sweep. SmartScan simultaneously reduces the scan time and dose to patient. Since SmartScan follows the bone, it can track and capture a scoliotic spine without requiring a scout scan. Wide-angle longitudinal scans cannot target irregular scan sites as efficiently as SmartScan. Figure 11 shows the concept and how it is implemented in a spine scan.

Figure 11: SmartScan follows the bone to reduce patient dose and scan time.



Scatter Radiation

Scattered radiation can contaminate the measurement of low and high energy X-rays. Scatter occurs when X-rays deflect off material rather than get absorbed. X-rays that scatter lose part of the energy and change direction, somewhat like a billiard ball after a collision. If they scatter into the detector, they will be measured at the wrong energy and will be assumed to have come straight through the patient like the rest of the beam. The inaccurate counting and wrong energy measurements result in BMD inaccuracy. As fan beams get wider they are more prone to scatter contamination, but scatter effects can be minimized by collimating the beam onto a small detector. Since the body is so complex it is very difficult to model and correct for scatter. Systems that use 2-D beams (e.g., cone beams) have scatter radiation contributions that require significant corrections.[7]

Table 1 summarizes the relative performance of the three main beam types on important features of DXA scanning.

Table 1: Relative intrinsic performance comparison of DXA beam types.

	Pencil Beam	Narrow Fan	Wide Fan
Scan time	Long	Short	Short
Bone height measured	No	Yes	No
Magnification effects	No	No	Yes
Off-center distortions	No	No	Yes
SmartScan	Yes	Yes	No
Scattered radiation	Lowest	Low	High

Conclusion

Bone Densitometry products from GE Healthcare (Lunar iDXA, Prodigy, Aria) enable a precise and accurate estimate of BMD using highly dose efficient principles. K-edge filtering separates the X-ray beam into low and high-energy portions and reduces unnecessary exposure to the patient. Lunar's solid-state CdTe and LYSO scintillator detectors are highly energy-sensitive, meaning they simultaneously and efficiently count photons and identify them as low- or high-energy. Narrow fan beam techniques and particularly Lunar's multi-view image reconstruction allows accurate, distortion-free images of each patient. MVIR minimizes magnification errors that cause image distortions and BMC inaccuracies which are intrinsic to wide fan beam, single sweep systems. Furthermore, SmartScan uses transverse sweeps of narrow fan beams to reduce patient dose and scan time. SmartScan tracks bone geometries to eliminate errors from off-center positioning and irregular patient physiology.

From X-ray beam generation and detection to scanning method and analysis, Lunar bone densitometers enable short scan times and low dose while maintaining excellent clinical performance.

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