Minimizing Dose in Digital Mammography

Tungsten x-ray tubes with rhodium and silver filters optimize image quality

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Introduction

Mammography is a very technically demanding radiographic procedure because it simultaneously requires high spatial resolution and good dose performance. High resolution is needed because some objects that must be depicted are very small microcalcifications, which can be visualized when they are as small as 200 microns[1]. Dose performance is also a requirement, because mammography is a screening modality and patient x-ray dose must be kept as low as reasonably acceptable.

During the era of screen-film mammography (prior to digital mammography), years of engineering development and clinical experience showed that molybdenum (Mo) was the optimal x-ray tube anode material for breast imaging. However, with the advent of digital mammography, the optimal methods of imaging need to be revisited. The superior dynamic range of digital image receptors (and amorphous Selenium detectors in particular) warrants the reevaluation of alternative anode and filter materials.

Clinical trials and scientific investigations have found that a tungsten x-ray tube with rhodium (Rh) and silver (Ag) filters is optimal for use in digital mammography for all breast thicknesses and will allow for important dose reductions on the order of 30%, while maintaining the excellent image quality already achieved with the Selenia digital mammography system.

The use of a tungsten (W) anode in the x-ray tube also offers superior performance for some of the advanced applications under development, such as digital breast tomosynthesis (DBT), iodinated contrast, and dual energy breast imaging.

The Impact of X-ray Tube on System Imaging Performance

Background

Analog mammography has a very limited dynamic range determined by the screen-film combination, and gives optimal imaging with spectra from a molybdenum x-ray tube. The tungsten anode emits a "harder" spectrum with more high energy x-rays than the spectrum from the molybdenum anode, and is less suitable for screen-film imaging. However, the wider dynamic range of digital x-ray detectors can properly exploit the harder spectra and enables the use of a tungsten x-ray tube and optimized filtration in digital mammography.

Detective Quantum Efficiency

The dose performance of a Hologic Selenia digital mammography system equipped with a tungsten x-ray tube was compared to a Selenia equipped with a molybdenum x-ray tube using the Detective Quantum Efficiency (DQE) at conditions simulating the same patient radiation dose of 1.0 mGy to the ACR phantom (standard breast). The DQE curves shown in Figure 1 show that a Selenia system equipped with a tungsten x-ray tube can produce superior imaging to a system with a molybdenum tube.

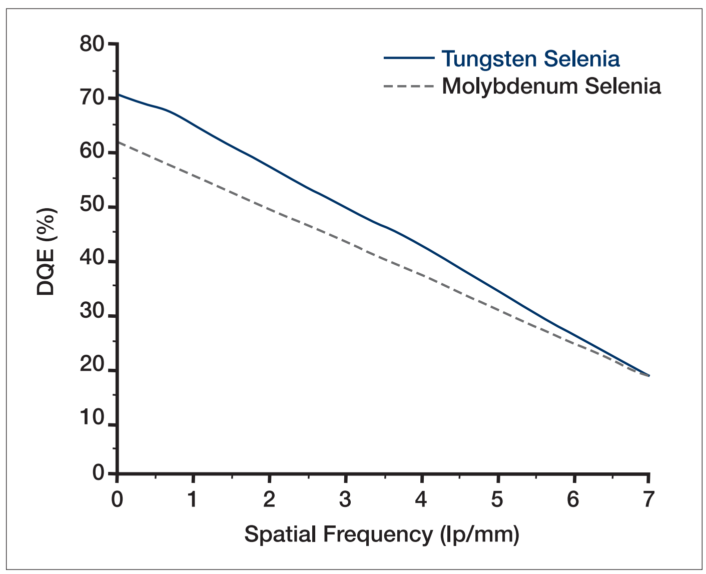

Figure 1. DQE curves for systems using tungsten and molybdenum x-ray tubes at dose levels typical for a 4.5 cm breast. The DQE for tungsten is superior to that for molybdenum.

Resolution

Using the Modulation Transfer Function (MTF), the resolutions of a Selenia system equipped with a tungsten x-ray tube and a Selenia equipped with a molybdenum x-ray tube are compared in Figure 2. The two MTF curves are identical, which shows that a Selenia system equipped with a tungsten x-ray tube offers the same high imaging resolution as a Selenia system equipped with a molybdenum x-ray tube. This conclusion is expected since both x-ray tubes have the same focal spot size, and both Selenia digital mammography systems use the same selenium image receptor with its high dose efficiency (DQE),

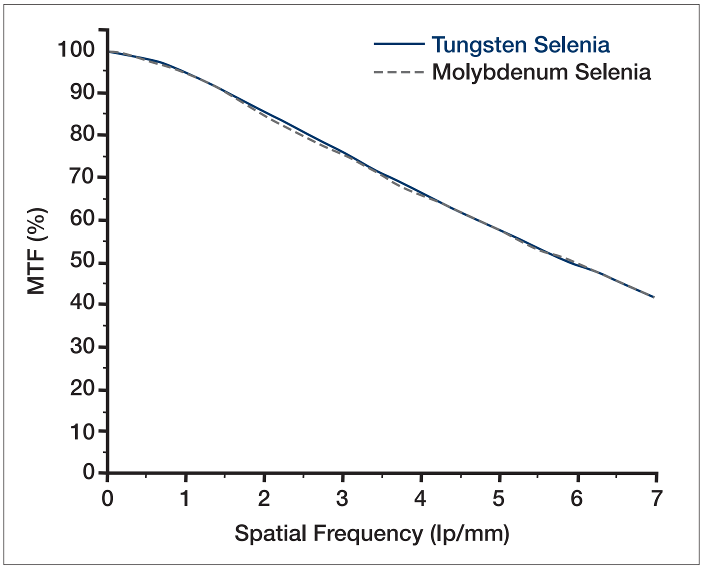

Figure 2. MTF curves for tungsten and molybdenum x-ray systems. The resolution performance for both tungsten and molybdenum equipped systems are equivalently high.

and both use the same high-transmission cellular (HTC) anti-scatter grid.

Phantom Imaging Performance

The superior image quality of a tungsten x-ray tube compared to a molybdenum x-ray tube is shown in Figure 3. The Figure shows the 3rd and 4th speck group from the same ACR accreditation phantom imaged using molybdenum (left) and tungsten (right) x-ray tubes. The dose to the ACR phantom is 1.0 mGy in both images.

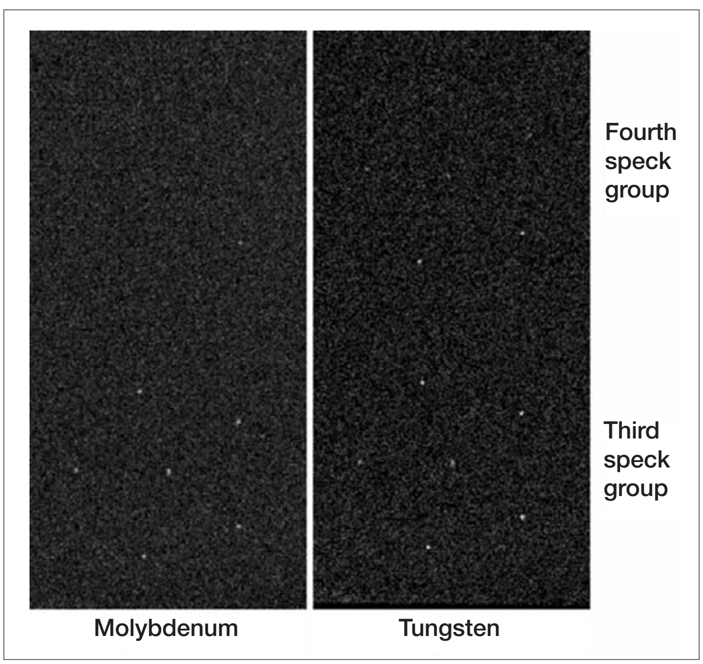

Figure 3. Images of the 3rd and 4th speck groups from the ACR phantom, taken at 1.0 mGy dose. (Molybdenum image on the left, tungsten image on right.) The system using the tungsten x-ray tube has superior visibility of the fourth speck group.

The 3rd group is the bottom set of 6 specks; the 4th group is the top set of 6 specks. Details of the small 4th speck group are much clearer with the tungsten image. In terms of system imaging performance, the MTF of the tungsten x-ray tube equipped system is equivalent to the MTF for the molybdenum x-ray tube equipped system, and the DQE of the tungsten system is superior to the DQE of the molybdenum system. The superior DQE translates into superior image quality, as demonstrated by phantom images. This is all consistent with conclusions shown in the literature[2], that the tungsten x-ray tube configured Selenia offers superior digital mammography imaging compared to the molybdenum x-ray tube configured Selenia.

The Impact of X-ray Tube and Filter on Dose Performance

The tube/filter combination used has a significant impact on dose performance. Our research has shown that a tungsten x-ray tube equipped Selenia system using both rhodium and silver filters has superior performance compared with traditional systems using molybdenum x-ray tubes and molybdenum filters. The silver filter is used for larger breasts and not only results in superior imaging performance at lower dose but also significantly reduces the x-ray exposure time to eliminate potential patient motion problems. Digital mammography systems using a tungsten anode but lacking the silver filter offer compromised clinical performance when imaging the largest and densest breasts.

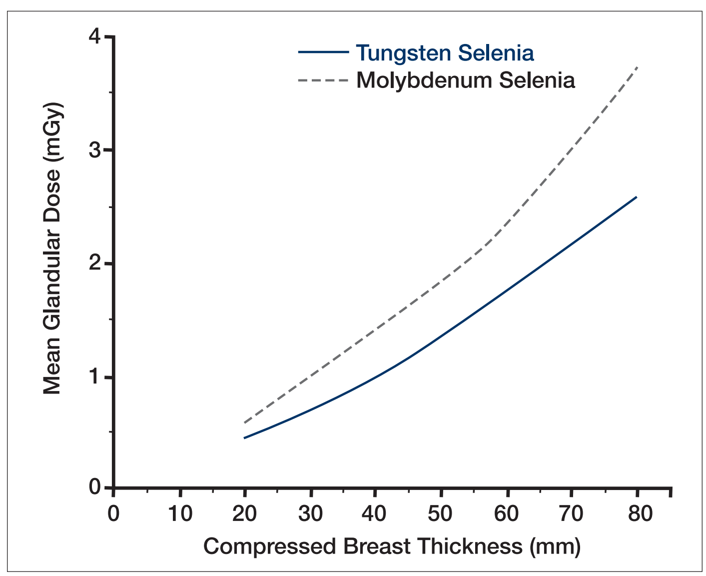

Figure 4. Typical mean glandular dose as a function of breast thickness for tungsten and molybdenum Selenia systems. Tungsten x-ray tube systems have lower dose than molybdenum x-ray systems. In addition to the dose levels shown here, other lower dose modes are available.

Clinical Benefits of Tungsten Digital Mammography

- Reduced patient dose
- Improved image quality
- Advanced applications such as tomosynthesis, dual energy, and contrast mammography

Figure 4 shows the measured glandular dose as a function of breast thickness, for standard 50/50 breasts, for a Selenia system with a molybdenum tube versus a Selenia with a tungsten tube. The system was configured to deliver dose of 1.6 mGy to the ACR phantom from the molybdenum tube, and 1.0 mGy from the tungsten tube. Other lower system dose modes are also available. Independent of the dose mode chosen, the use of tungsten tubes offers a significant dose savings compared to molybdenum tubes for all breast sizes.

Dual versus Single Track Anode X-ray Tubes

In the golden age of screen-film mammography, x-ray tubes with dual track configurations were used on some analog mammography x-ray systems to enable dose optimization for large breasts. Common dual track combinations are molybdenum/rhodium anodes and molybdenum/tungsten anodes. The rhodium and tungsten tracks are primarily used in imaging large breasts; the molybdenum track is used to image small to average thickness breasts.

While it might appear that a dual track tube is advantageous because it offers more choices of anode material, there are significant technical downsides to the use of dual track tubes. Single track x-ray tubes are more reliable and less expensive. In addition, the maximum anode heat loading of dual track tubes are considerably inferior to the anode loads for single track tubes. A system equipped with a single track tube can deliver the high current exposure needed for the largest breasts at an acceptable exposure time (reducing motion artifacts). Without this, images of large breasts are underpenetrated, suffer from long exposure motion blur, and have poor image quality. The single track tungsten tube supports over two to three times the maximum anode load compared to any dual track x-ray tube.

More importantly from a digital mammography imaging performance perspective, the use of a tungsten x-ray tube in combination with a rhodium filter has been proven to provide equivalent or better imaging performance than the use of molybdenum x-ray tube in combination with a molybdenum filter. This has been confirmed through DQE measurement, phantom study, and clinical imaging. The results indicate that the dual track x-ray tube is a poor choice for digital mammography systems. It is more important for the digital mammography equipment manufacturer to provide the optimal x-ray filters to be used with the tungsten tube than continuing the use of a dual track x-ray tube with no clinical benefit.

Clinical Experience

The majority of manufacturers of digital mammography systems now offer tungsten x-ray tubes because of the performance advantages. In particular, Hologic has evaluated the performance of tungsten imaging using the Selenia digital mammography system. Under an Ethics Board approved research protocol with informed patient consent, subjects presenting for screening and diagnostic mammography were imaged using both molybdenum and tungsten systems. Tungsten x-ray tube images, taken at about 65% of the dose compared to molybdenum x-ray tube images for an average breast, were evaluated by experienced mammographic radiologists and considered to be clinically equivalent.

One of the radiologists participating in the evaluation, Alan Semine, MD, Chief of Breast Imaging, Newton-Wellesley Women's Imaging Center, Newton, MA USA uses the tungsten system and has stated, "Tungsten imaging with the Selenia system allows performance of equivalent high quality digital mammography at reduced patient radiation dose compared to a traditionally configured Selenia with molybdenum."

Advanced Applications

Tungsten x-ray tube imaging is also particularly well suited to some of the advanced imaging applications in development. The high radiation output of tungsten anodes allows for superior tomosynthesis imaging, where it is desired to create a number of short x-ray pulses during the acquisition, so as to minimize focal spot blur[3]. Researchers are investigating contrast mammography, which involves the imaging of iodinated contrast agents[4]. Optimal imaging in this application calls for high kVp with significant energy components above the k-edge of iodine (33 keV). Another application is the use of dual energy imaging so as to improve the visibility of microcalcifications, which requires high kVp exposures[5].

Discussion

Molybdenum x-ray tube digital mammography systems already have demonstrated a 30% reduction in dose compared to screen-film mammography[6]. The introduction of tungsten x-ray tubes with digital mammography allows even greater reduction in radiation exposure, without adversely affecting image quality. This is certainly in accordance with the ALARA principle (As Low As Reasonably Achievable), the key concept in radiation protection. While the radiation exposures in mammography are very low relative to the patient benefit in terms of early detection of breast cancer, tungsten x-ray tube systems with rhodium and silver filters allow maintaining high image quality while reducing patient radiation exposure.

Although low dose is preferred, there is a trade-off between image quality and dose. X-ray dose may be reduced to the point where image quality is degraded and the resulting image lacks the necessary spatial resolution. Most would agree that image quality is optimized when when there is sufficient resolution in a mammography image to detect subtle microcalcifications which can be as small as 200 microns.

Conclusions

The use of a digital mammography system with tungsten x-ray tubes offers superior imaging performance relative to x-ray tubes equipped with molybdenum or rhodium anodes. The use of a tungsten x-ray tube with a rhodium filter offers superior performance to a molybdenum x-ray tube and a molybdenum filter. The use of a silver filter is superior to molybdenum or rhodium filters for the largest breasts. Single track x-ray tubes are superior to dual track x-ray tubes as their high anode heat loading allow for shorter exposure times. The unique combination of a tungsten x-ray tube with rhodium and silver filters offers optimal dose and image quality performance for digital mammography over a wide range of breast thicknesses. Furthermore, the use of a tungsten x-ray tube is optimal for advanced applications, such as breast tomosynthesis and for high kV iodinated contrast mammography.

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Glossary

Ag silver, a filter material
ALARA ‘as low as reasonably achievable’
DBT digital breast tomosynthesis
DQE detective quantum efficiency, a measure of dose efficiency
keV kilovolt electron volt, a measure of x-ray energy
kVp kilovolt peak, a measure of maximum x-ray energy
lp/mm line pairs per millimeter, a measure of image spatial resolution or sharpness
mGy abbreviation of milligray, a unit of absorbed radiation
Mo molybdenum, an anode and filter material
MTF modulation transfer function, a measure of image resolution
Rh rhodium, a filter material
Se selenium, a material used in direct conversion detectors
W tungsten, an anode material

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