EDUCATIONAL TOPICS

OPTIMIZING CLINICAL IMAGE QUALITY: AN EXPANDING ROLE FOR MEDICAL PHYSICISTS

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Abstract— **All modern medical imaging methods produce images in a digital format. This divides the patient body into small samples, or voxels, with corresponding pixels in the image. The size of the samples (voxels and pixels) has a major effect on image quality. The challenge is that the size generally has opposing effects on two image quality characteristics, detail and noise, and potential effects on radiation exposure to patients. For many methods the size can be adjusted with a combination of procedure protocol factors. An optimized procedure with an appropriate balance among the image quality characteristics and radiation exposure to patients requires a significant knowledge of physics. Medical physicists now have the opportunity to make additional contributions to image quality and radiation risk management through clinical consultations and educational programs including the topic of procedure optimization.**

Keywords— **Image Quality, Optimization, Radiation Exposure, Medical Physicists.**

I. INTRODUCTION

Medical physicists are the professionals who provide the knowledge and experience to insure adequate image quality for diagnostic imaging procedures and contribute to risk management relating to ionizing radiation. The quality of an image for a specific examination is determined by a combination of factors as illustrated in Figure 1.

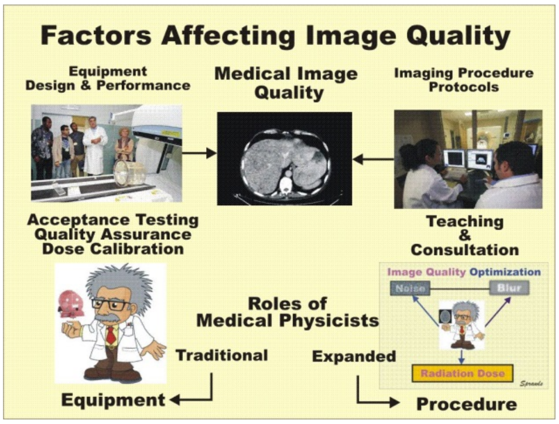

Fig. 1 Roles of Medical Physicists Related to Medical Image Quality

A starting point for image quality is the physical characteristics and design of the technology. This is unique to each imaging modality and the status of innovations and development. This generally determines both the overall capability and limits for producing images with specific quality characteristics. With respect to this, medical physicists can participate in the acquisition and installation process by reviewing specifications, consulting in the selection, and conducting acceptance testing to ensure the equipment can function as expected. The second issue is the continuing performance and maintenance of equipment that physicists verify through quality control and assurance testing and evaluations. These activities generally focus on the *equipment* and the *individual image quality characteristics*: contrast, detail/resolution, noise, and artifacts, along with radiation dose and risks issues.

II. OPTIMIZED IMAGE QUALITY: THE DIGITAL DILEMMA

Another major factor, and the one that has the greatest effect on image quality, especially for advanced modalities including CT, MRI, and digital radiography, is how the equipment is operated. Image quality for each clinical procedure is determined by a complex combination of adjustable technical parameters that collectively form the procedure protocol.

Virtually all imaging methods now produce images in a digital format. There are many advantages and values of digital images as illustrated in Figure 2.

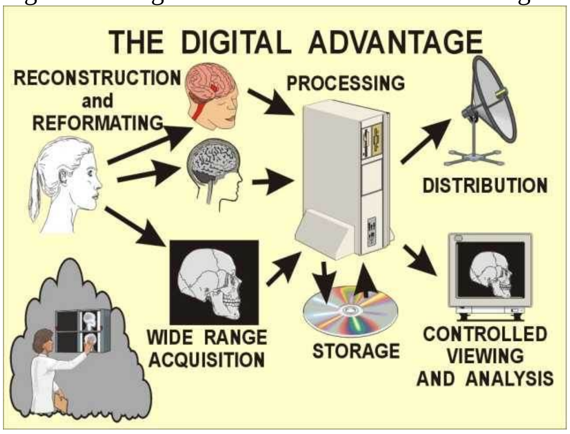

Fig. 2 An overview of the major advantages of digital medical images.

Digital imaging and technology is the foundation of our modern imaging methods and the ability to distribute and process images to improve healthcare around the world.

However, there is a characteristic of the digitizing process that has a major effect on image quality that must be taken into consideration. The digitizing process is a sampling process in which the human body is divided into discrete samples (voxels and corresponding image pixels) as illustrated in Figure 3

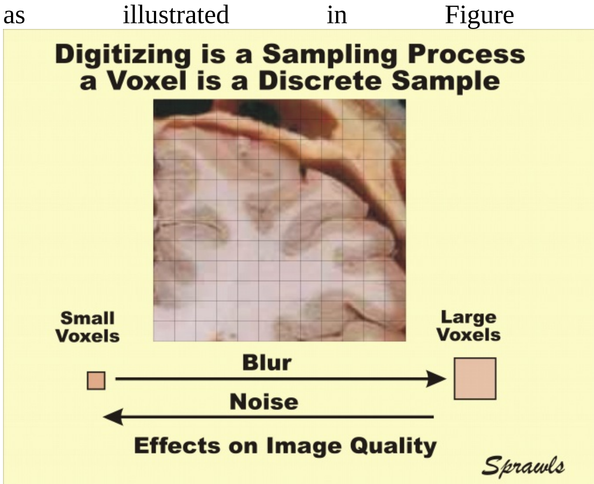

Fig. 3 The formation of digital images divides the human body into discrete samples, voxels, and corresponding pixels in the image.

The size of the sample (voxel/pixel) is usually adjustable when setting up an imaging procedure and also has a major and complex effect on image quality. And here is the dilemma: what is the best, or optimum, sample size for a specific imaging procedure? Digitizing is a blurring process. The challenge in selecting an appropriate size is that it affects two image quality characteristics, detail/resolution which is limited by blurring and noise, but in conflicting or opposing directions. It also is a determining factor in radiation exposure to the patient for x-ray, including CT, procedures and acquisition time for MRI and some nuclear imaging methods.

The sample, typically the voxel, size is adjustable through the three protocol factors shown in Figure 4, using computed tomography as an example.

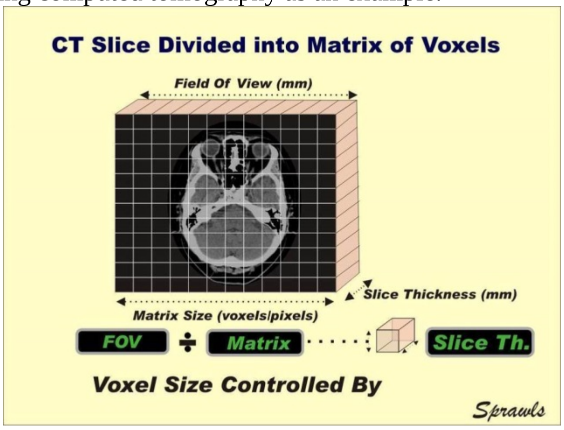

Fig. 4 The imaging protocol factors used to adjust voxel size.

For radiography and other non-tomographic imaging methods it is the image pixel that represents the sample and the size is the ratio of the field of view (FOV) to the dimension of the image matrix in pixels.

III. IMAGE BLURRING AND VISIBILITY OF ANATOMICAL DETAIL

The formation or conversion of an image in a digital format, for any modality, is a *blurring process*. Each voxel and corresponding pixel is actually a blur that adds to all of the other sources of blur in the imaging chain as illustrated in Figure 5.

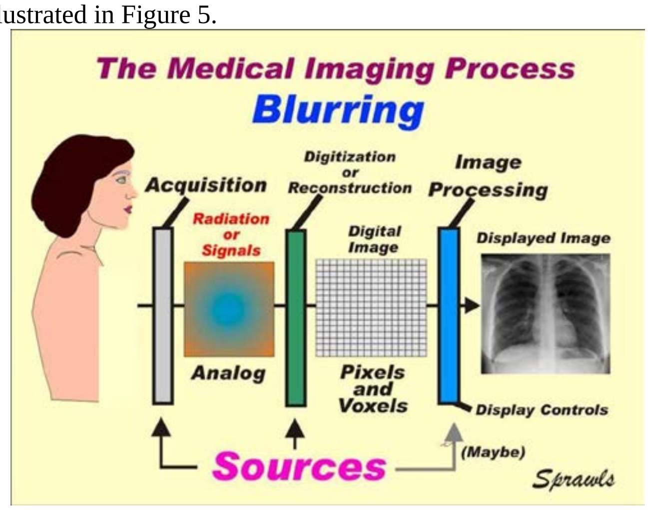

Fig. 5 The general sources of blurring for all imaging modalities.

Since voxel/pixel size and the blurring it produces is usually adjustable, a first thought might be to adjust it to the smallest possible value for each imaging procedure. That is not the appropriate action for three different reasons! The voxel/pixel size should be selected taking these factors into consideration.

Composite Blur: The blurring from digitizing an image adds to the blur from other sources within the system resulting in the total or composite blur in the image. For radiography, including mammography, these sources are illustrated in Figure 6.

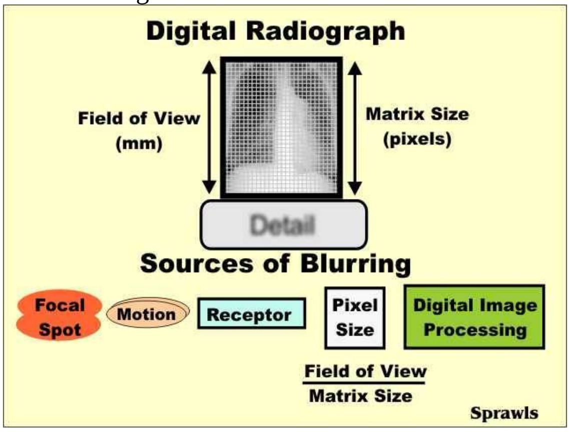

Fig. 6 Pixel size is one of the several sources of blurring in digital radiography. The sources combine to form the total or composite blur that will appear in the image.

A conventional model for determining the value or size of the composite blur is illustrated in Figure 7.

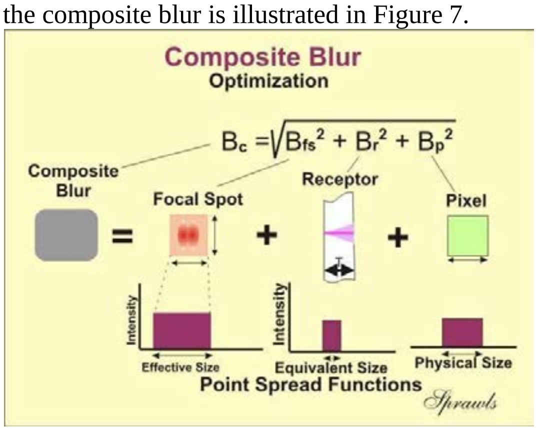

Fig. 7 A general relationship for determining the composite blur value in digital radiography.

The illustration here is for digital radiography, including mammography, but the mathematical relationship applies to all modalities. What must be considered are the factors limiting how much other sources of blurring can be reduced.

The selection of focal spot size is a compromise between image detail and heat capacity within the x-ray tube that limits the exposure, especially within a short time to minimize motion blurring, to form an image. The blurring produced within the receptor is generally a design characteristic relating to the thickness of the attenuation and conversion layer. If these sources of blur are already fixed for a specific radiography/mammography procedure the question then becomes, what is an appropriate pixel size? Should the pixel be made very small to reduce its blurring? There is actually a combination of two factors for not always using the smallest possible pixel size.

In general, adjusting the pixel blur size so that it is significantly smaller than the blur from other sources will have little effect on reducing the overall composite blur and increasing visibility of detail. The other and generally most significant factor is that reducing pixel or voxel size *increases* image noise. This is for all imaging methods with the possible exception of ultrasound.

The Digital Dilemma: It is the conflicting effects of voxel/pixel size on image detail and image noise that is the "digital dilemma" and requires a comprehensive knowledge of physics and activities of experienced medical physicists to provide optimized imaging protocols that can provide adequate image quality for a specific clinical objective and with the lowest radiation exposure as appropriate.

We will now consider the specific effects of voxel/pixel size on image noise and then the overall process of image quality optimization and effects on radiation exposure.

IV. IMAGE NOISE AND VISIBILITY OF LOW CONTRAST OBJECTS

Noise is an undesirable image quality characteristic that specifically limits visibility of low contrast objects in the body. Many small objects, breast cancer calcifications for example, also have low contrast and their visibility is limited by noise in addition to blurring. In most imaging procedures the amount of noise in an image can be adjusted, either by equipment design or the adjustment of imaging protocol factors. That raises the question, if the noise can be adjusted and controlled why not set it to a very low level and have very high image quality? There are two reasons: changes in a procedure to reduce noise often result in increased blurring and loss of detail and also increased radiation exposure to the patient. Optimizing an imaging procedure is the process of using knowledge of physics to balance these opposing factors.

The sources of Image Noise: There is noise in images produced with all modalities. Even though the sources are different there are common characteristics, especially in relation to the digital structure of images. As illustrated in Figure 8 the digitizing process is not the source of the noise but it *controls* the amount of noise that appears in an image.

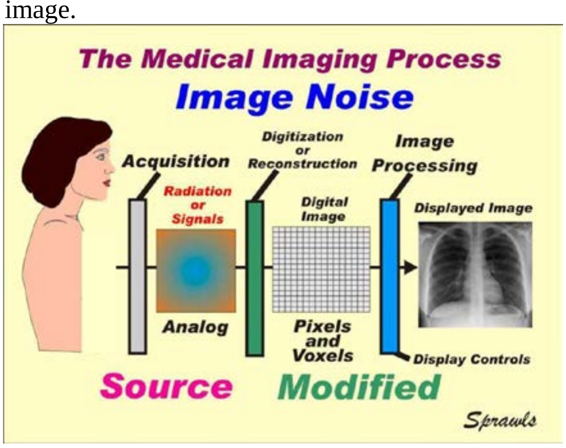

Fig. 8 The digital structure (voxel/pixel size) affects the value of the noise that comes from other sources and appears in an image.

For imaging methods using ionizing radiation--x-radiation and nuclear--the predominant source of noise is the statistical random nature of photons. This is especially true if the procedure is being conducted in the "quantum limited" mode to limit radiation exposure or acquisition time. With MRI the noise is from random RF emissions from within the body that are competing with the strength of the image RF signals that is controlled by voxel size. In all cases sample size is a controlling or modifying factor for the noise that appears in an image.

X-ray Image Noise: An important concept relating to x-ray image noise is illustrated in Figure 9.

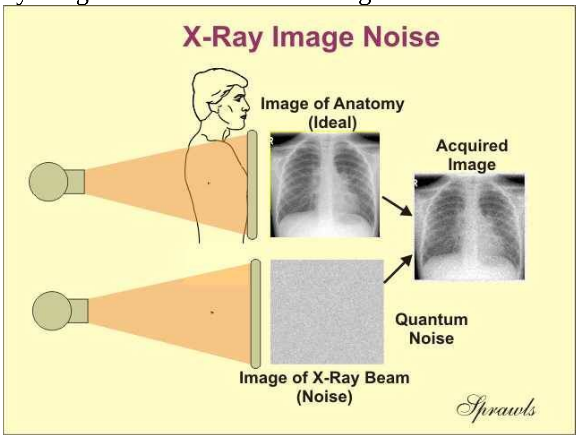

Fig. 9 The noise that appears in x-ray images is an image of the x-ray beam.

The noise is an image of the x-ray beam that is superimposed or added to the image of the anatomy. In the digitizing process of an x-ray image it is the number of photons in each sample (pixel) that determines the statistical variation which is the noise as illustrated in Figure 10.

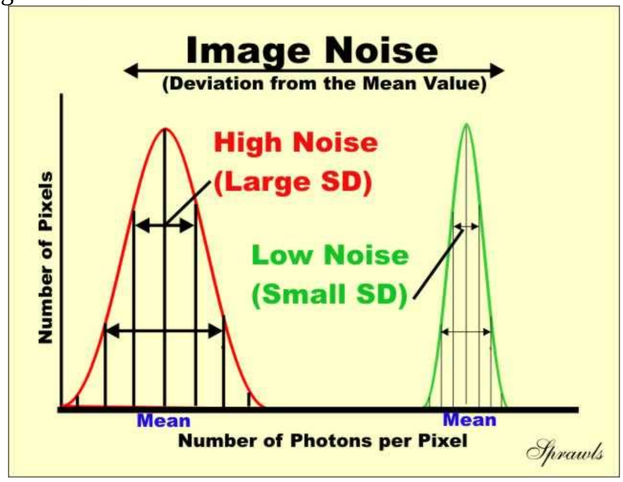

Fig. 10 The statistical distribution of photons among pixels and the relation to exposure.

There are two ways to increase the number of photons per pixel and reduce image noise. Both have adverse effects. One is to increase pixel size which increases blurring of the image. The other is to increase the exposure to the image receptor which also increases exposure to the patient.

Computed Tomography Image Noise: CT is an x-ray imaging method so the same principles regarding the source of noise apply as illustrated in Figure 11.

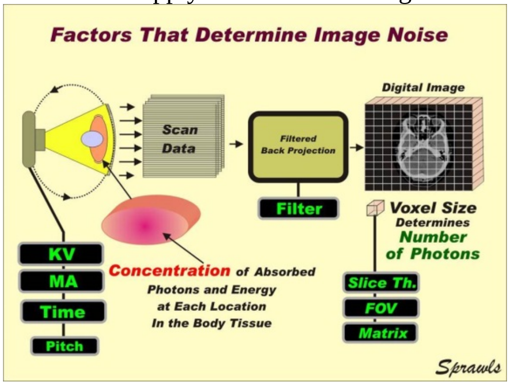

Fig. 11 The adjustable protocol factors that determine noise in CT images.

In addition to radiation dose and voxel size there is a third factor with a significant effect on CT image noise. It is the digital imaging processing algorithm or filter that is included in the "filtered" back projection image reconstruction process, sometimes referred to as the kernel. When setting up a protocol for a specific clinical procedure there is the opportunity to select from several different filters or kernels that affect image quality. The characteristics of these various filters vary among the different equipment manufacturers, who can provide information in their applications documents. However, there is a common issue that applies to all as illustrated in Figure 12.

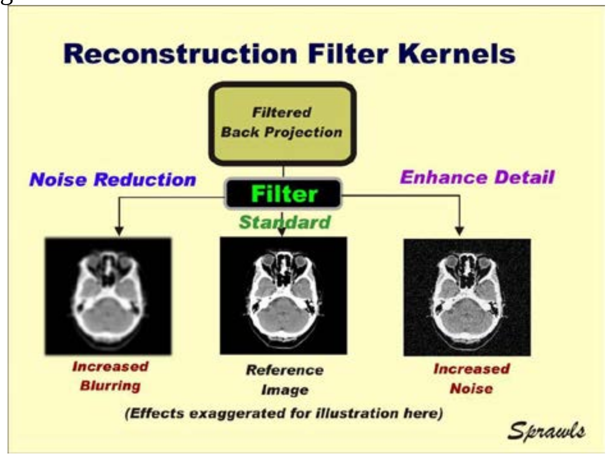

Fig. 12 Conflicting effects of CT reconstruction filters on image quality.

Digital processing an image to reduce noise is often done by mathematically blurring the image, such as by averaging adjacent pixels. Processing an image to enhance detail will typically increase the visibility of the noise. This is because noise is actually a high detail pixel-to-pixel variation in brightness. This is just another example of the opposing effects of image blurring and noise. Making changes in the imaging process to decrease one will increase the other.

V. Radiation exposure to patients and image acquisition time

In medical imaging there is always a cost, or "price to pay" for image quality. In the x-ray methods, including CT, it is the radiation exposure to the patient. In MRI it is the image acquisition time. In radionuclide or nuclear medicine procedures it can be a combination of radiation exposure and acquisition time. This is the third factor that enters into the optimization compromise or balance that needs to be achieved. Both radiation exposure and acquisition time (in MRI) are generally adjustable protocol factors that have direct effects on image quality.

As described above, the concentration of x-ray photons, or exposure, is the determining factor in image noise. As illustrated in Figure 10 noise is decreased by increasing the photons captured in each voxel or pixel.

The accepted approach in x-ray imaging is that the radiation exposure should be limited to a value that will produce the clinically necessary image quality. However, there is the realization that increasing exposure produces "better looking" images, even when the resulting quality is not required and might result in unnecessary exposure to patients.

With three competing factors, detail, noise, and radiation exposure, to be balanced, where do we start? An appropriate first step is to adjust the blurring to provide the clinically required visibility of detail. This involves selecting a voxel/pixel size that is generally equivalent to the other blur sources (focal spot, detectors. etc.) in the imaging system and is appropriate for the specific clinical procedure. This will range from approximately 0.2 mm for mammography to several mm in CT and MRI.

The selected voxel/pixel size becomes a factor for the noise. With the size now fixed because of image detail requirements it becomes necessary to increase radiation exposure or acquisition time to reduce the noise to an acceptable level.

One of the challenges in x-ray imaging, including CT, is determining what is an acceptable noise level for a specific clinical procedure which then establishes the lowest, but necessary, radiation exposure and dose. The judgment of the radiologist viewing the images is a key factor. Monitoring the radiation dose for the various procedures and comparing to reference values is the usual approach to optimizing the overall procedure. It is assumed that the reference values being used are related to image quality requirements and not more general regulatory limits.

V. The role of the medical physicist in image quality optimization

It is the conflicting effects of the three factors--image detail, image noise, and radiation exposure--that increase the complexity of modern imaging procedures and require knowledgeable medical physicists to achieve the appropriate image quality and radiation exposure for each clinical procedure as illustrated in Figure 13.

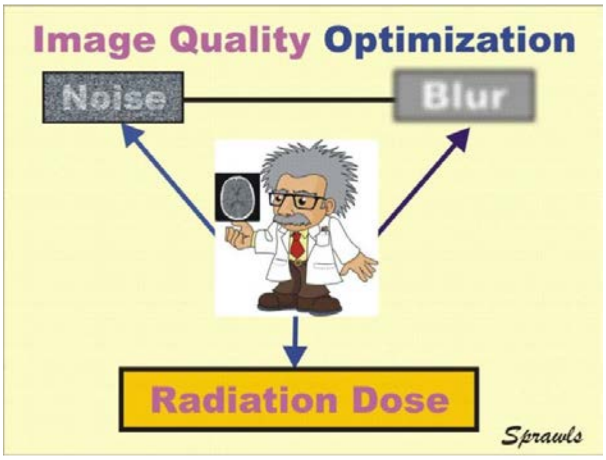

Fig. 13 Opposing factors that must be balanced to optimize an imaging procedure.

As medical physicists we are not usually capable in determining the image quality characteristics required for a specific clinical procedure, especially for the modalities of CT and MRI with the many variables, and we are not the ones who set up the protocols and actually control image quality. However, we are the professionals with knowledge of image quality characteristics, how they are related and controlled by protocol factors, and the overall issue of the process of optimization. The radiologists and imaging technologists are our connections to the actual imaging process and control of image quality.

A traditional role for medical physicists is monitoring and providing guidance on radiation exposure and dose to patients. This is a major contribution to the overall optimization process.

The very valuable role of medical physicists is that of educators and consultants. An effective educator and teacher require the combination of two things, personal experience and educational resources, especially visuals that can be used in classes, conferences, and other discussions.

Clinical Experience for Medical Physicists: For maximum effectiveness as educators, medical physicists need good knowledge of the imaging procedures as they are performed in the clinical environment. This can be achieved by observing clinical procedures giving attention to image characteristics and the selection of imaging protocol factors for a variety of examinations. The objective is not to know the details for every procedure but to have an understanding of the overall imaging process and how it is performed. This knowledge will enhance communications with radiologists and technologists both in class and conference discussions and in consultations within the clinic.

VI. Educational activities to enhance image quality optimization

A major factor in obtaining optimum image quality with the various methods and procedures is a clinical staff, radiologists and technologists, with knowledge of the physics principles relating to image quality, the control of image quality, and the concept of optimization as provided by the medical physicist. This requires both an expanded scope and content for traditional medical physics educational programs, especially for radiologists and residents, and an expanded role of medical physicists as educators/teachers.

A diagram, or mind map, for the image quality optimization program is shown in Figure 14.

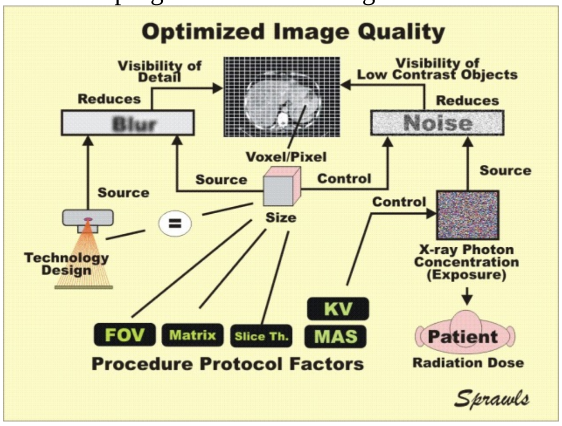

Fig. 14 A mind map giving an overview of the knowledge required to optimize image quality for digitized images.

The topic of image quality optimization can be an addition to an existing medical physics educational program or can be provided as a stand-alone course. An understanding of the concept and process of optimization requires foundation knowledge of image quality characteristics and the factors that affect and control those characteristics for each of the imaging modalities as illustrated in Figure 14. While the factors that determine image quality are specific for each modality the overall principle of optimization is the same as it relates to the digital structure and image characteristics.

A course to develop an understanding and capability for medical imaging procedure optimization for medical physicists, radiology residents, and other imaging professionals, will include these topics.

- Introduction and Overview of Medical Image Quality Characteristics
- Structure of Digital Images (pixels) and Imaged Body Segments (voxels)
- Image Contrast and Procedure Contrast Sensitivity
- Image Blurring, Visibility of Detail, and Effect of Digital Structure
- Spectral and Statistical Characteristics of X-radiation
- Image Noise, Effect on Visibility, Sources, Relation to Digital Structure
- Digital Radiography and Mammography, Factors That Affect Image Characteristics
- Computed Tomography, Factors That Affect Image Characteristics
- MRI, Factors That Affect Image Characteristics
- Radiation Quantities and Units, Emphasis on Dose to Patients
- Concept and Application of Medical Imaging Procedure Optimization

Resources to support these and related educational activities are available through the websites: www.sprawls.org/resources and www.sprawls.org/PhysicsWindows .

VII. CONCLUSION

The formation of medical images in a digital format is a sampling process in which the body is divided into voxels and the image into pixels. The size of the samples, voxels and pixels, has a conflicting effect on image quality and potential radiation exposure to patients. The voxel/pixel size is adjustable through a combination of imaging procedure protocol factors. A comprehensive knowledge of physics is required to optimize imaging procedures producing the necessary image quality and without unnecessary exposure to radiation or image acquisition times. The medical physicist is the imaging professional that provides this knowledge through consultations and educational activities.