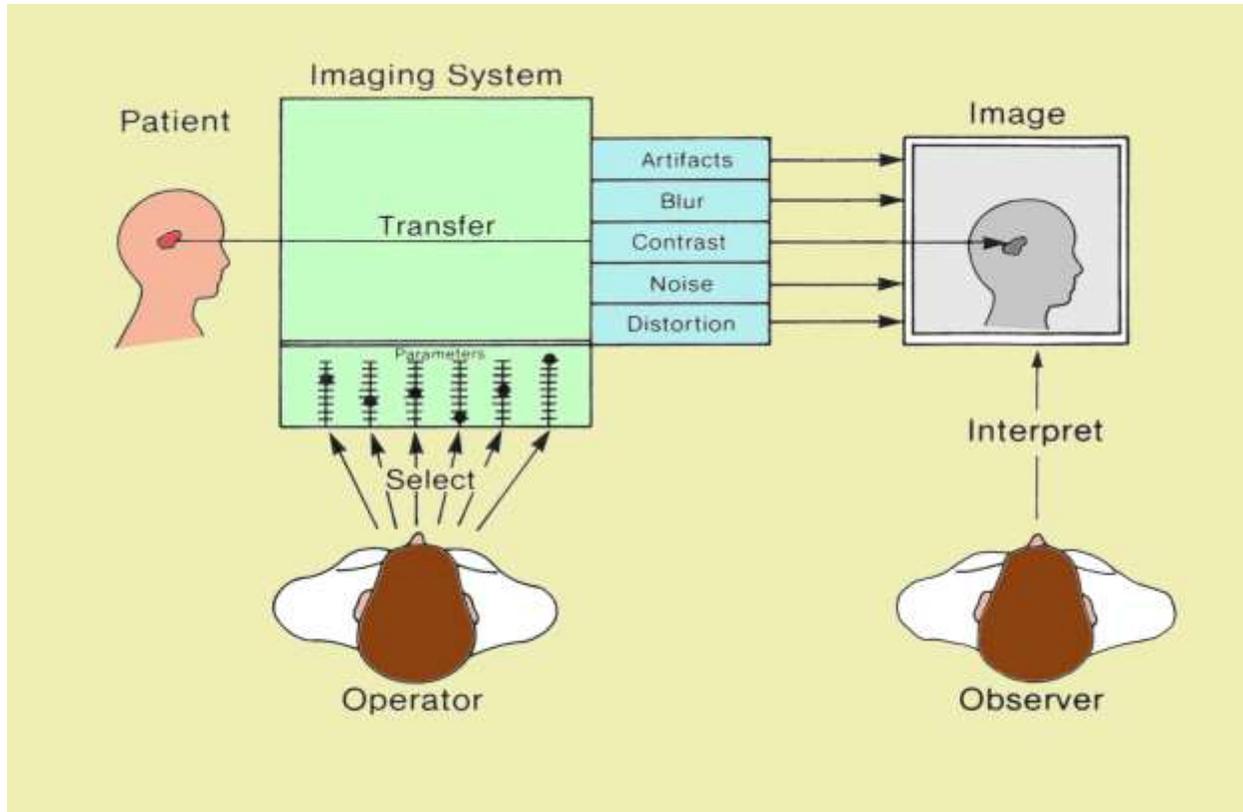


INTRODUCTION AND OVERVIEW

To the human observer, the internal structures and functions of the human body are not generally visible. However, by various technologies, images can be created through which the medical professional can look into the body to diagnose abnormal conditions and guide therapeutic procedures. The medical image is a window to the body. No image window reveals everything. Different medical imaging methods reveal different characteristics of the human body. With each method, the range of image quality and structure visibility can be considerable, depending on characteristics of the imaging equipment, skill of the operator, and compromises with factors such as patient radiation exposure and imaging time.

The figure below is an overview of the medical imaging process. The five major components are the patient, the imaging system, the system operator, the image itself, and the observer. The objective is to make an object or condition within the patient's body visible to the observer. The visibility of specific anatomical features depends on the characteristics of the imaging system and the manner in which it is operated. Most medical imaging systems have a considerable number of variables that must be selected by the operator. They can be changeable system components, such as intensifying screens in radiography, transducers in sonography, or coils in magnetic resonance imaging (MRI). However, most variables are adjustable physical quantities associated with the imaging process, such as *kilovoltage* in radiography, *gain* in sonography, and *echo time (TE)* in MRI. The values selected will determine the quality of the image and the visibility of specific body features.



Components Associated with the Medical Imaging Process

The ability of an observer to detect signs of a pathologic process depends on a combination of three major factors: (1) image quality, (2) viewing conditions, and (3) observer performance characteristics.

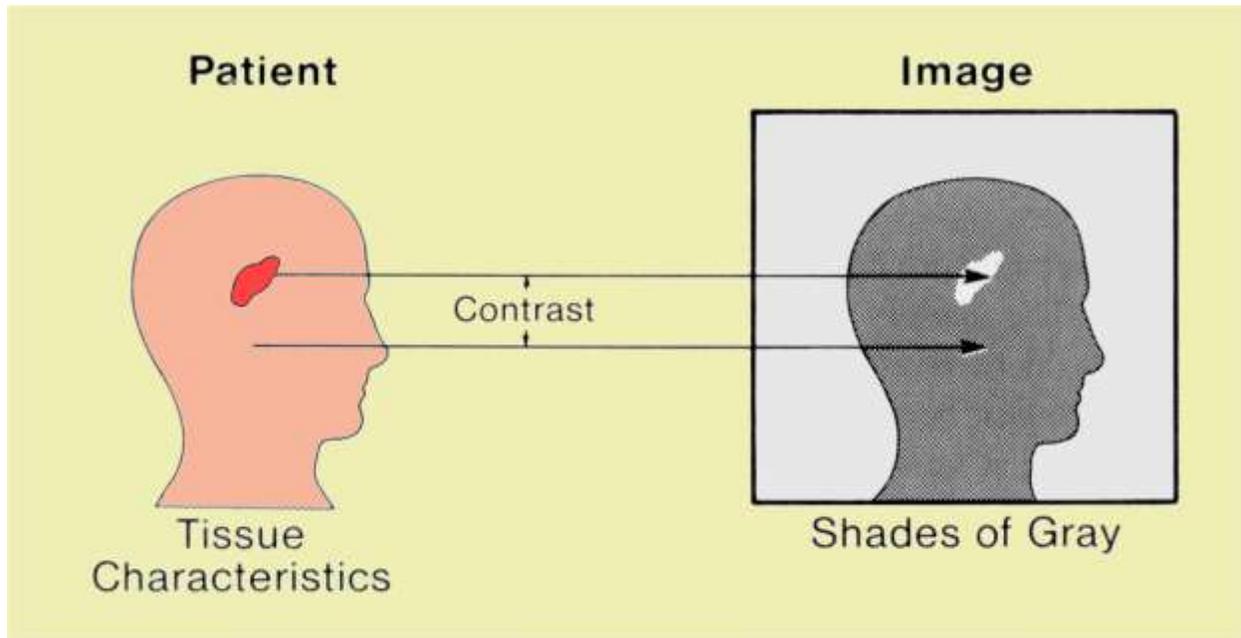
IMAGE QUALITY

The quality of a medical image is determined by the imaging method, the characteristics of the equipment, and the imaging variables selected by the operator. Image quality is not a single factor but is a composite of at least five factors: contrast, blur, noise, artifacts, and distortion, as shown above. The relationships between image quality factors and imaging system variables are discussed in detail in later chapters.

The human body contains many structures and objects that are simultaneously imaged by most imaging methods. We often consider a single object in relation to its immediate background. In fact, with most imaging procedures the visibility of an object is determined by this relationship rather than by the overall characteristics of the total image.

Consider the figure below. The task of every imaging system is to translate a specific tissue characteristic into image shades of gray or color. If contrast is adequate, the

object will be visible. The degree of contrast in the image depends on characteristics of both the object and the imaging system.



Medical Imaging is the Process of Converting Tissue Characteristics into a Visual Image

Image Contrast

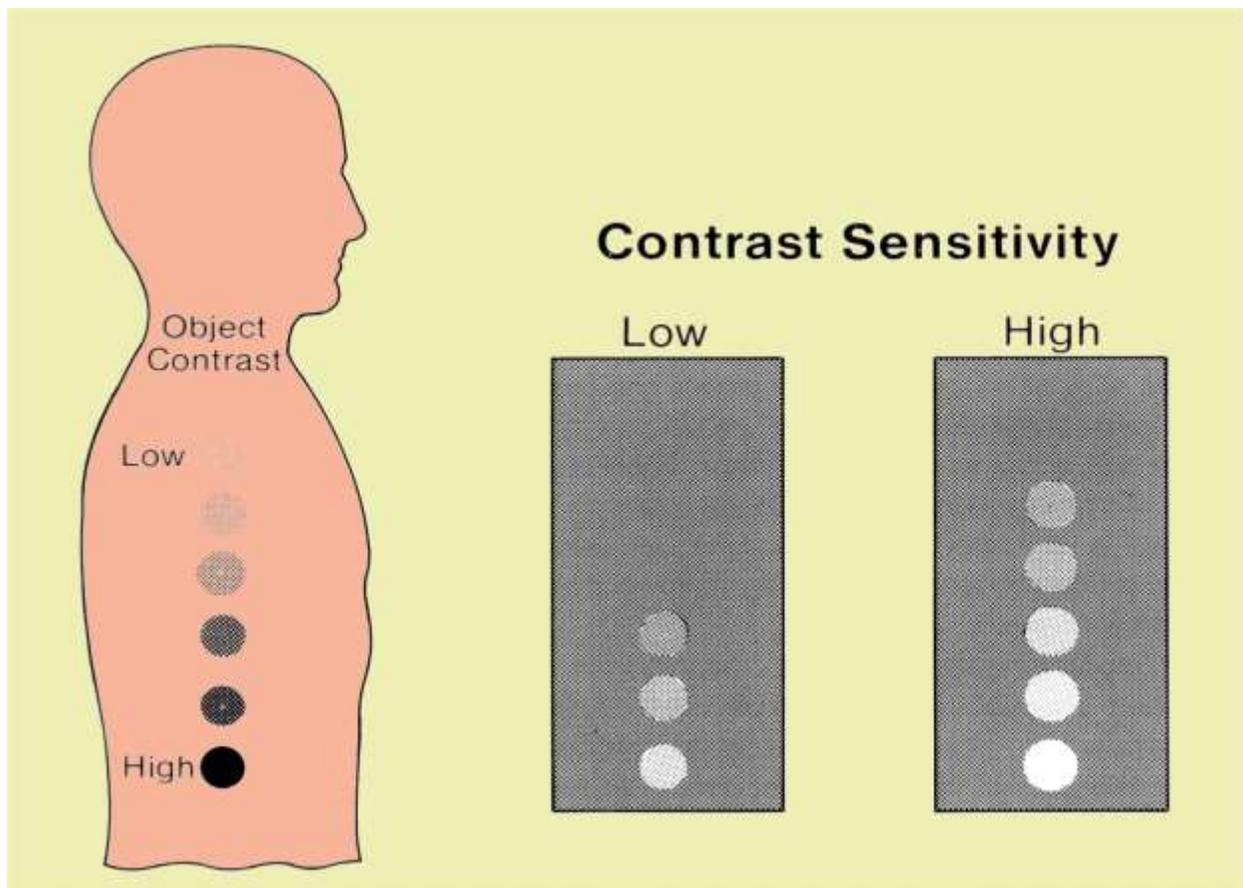
Contrast means difference. In an image, contrast can be in the form of different shades of gray, light intensities, or colors. Contrast is the most fundamental characteristic of an image. An object within the body will be visible in an image only if it has sufficient physical contrast relative to surrounding tissue. However, image contrast much beyond that required for good object visibility generally serves no useful purpose and in many cases is undesirable.

The physical contrast of an object must represent a difference in one or more tissue characteristics. For example, in radiography, objects can be imaged relative to their surrounding tissue if there is an adequate difference in either density or atomic number and if the object is sufficiently thick.

When a value is assigned to contrast, it refers to the difference between two specific points or areas in an image. In most cases we are interested in the contrast between a specific structure or object in the image and the area around it or its background.

Contrast Sensitivity

The degree of physical object contrast required for an object to be visible in an image depends on the imaging method and the characteristics of the imaging system. The primary characteristic of an imaging system that establishes the relationship between image contrast and object contrast is its contrast sensitivity. Consider the situation shown below. The circular objects are the same size but are filled with different concentrations of iodine contrast medium. That is, they have different levels of object contrast. When the imaging system has a relatively low contrast sensitivity, only objects with a high concentration of iodine (ie, high object contrast) will be visible in the image. If the imaging system has a high contrast sensitivity, the lower-contrast objects will also be visible.



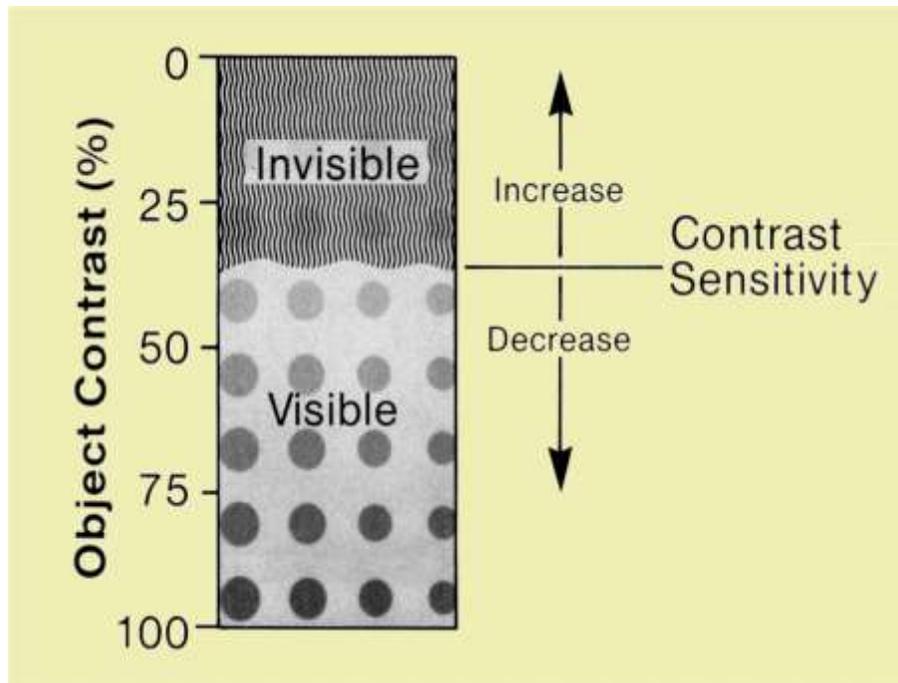
Increasing Contrast Sensitivity Increases Image Contrast and the Visibility of Objects in the Body

We emphasize that contrast sensitivity is a characteristic of the imaging method and the variables of the particular imaging system. It is the characteristic that relates to the

system's ability to translate physical object contrast into image contrast. The contrast transfer characteristic of an imaging system can be considered from two perspectives. From the perspective of adequate image contrast for object visibility, an increase in system contrast sensitivity causes lower-contrast objects to become visible. However, if we consider an object with a fixed degree of physical contrast (i.e., a fixed concentration of contrast medium), then increasing contrast sensitivity will increase image contrast.

It is difficult to compare the contrast sensitivity of various imaging methods because many are based on different tissue characteristics. However, certain methods do have higher contrast sensitivity than others. For example, computed tomography (CT) generally has a higher contrast sensitivity than conventional radiography. This is demonstrated by the ability of CT to image soft tissue objects (masses) that cannot be imaged with radiography. The specific factors that determine the contrast sensitivity of each imaging method are considered in later chapters.

Consider the image below. Here is a series of objects with different degrees of physical contrast. They could be vessels filled with different concentrations of contrast medium. The highest concentration (and contrast) is at the bottom. Now imagine a curtain coming down from the top and covering some of the objects so that they are no longer visible. Contrast sensitivity is the characteristic of the imaging system that raises and lowers the curtain. Increasing sensitivity raises the curtain and allows us to see more objects in the body. A system with low contrast sensitivity allows us to visualize only objects with relatively high inherent physical contrast.

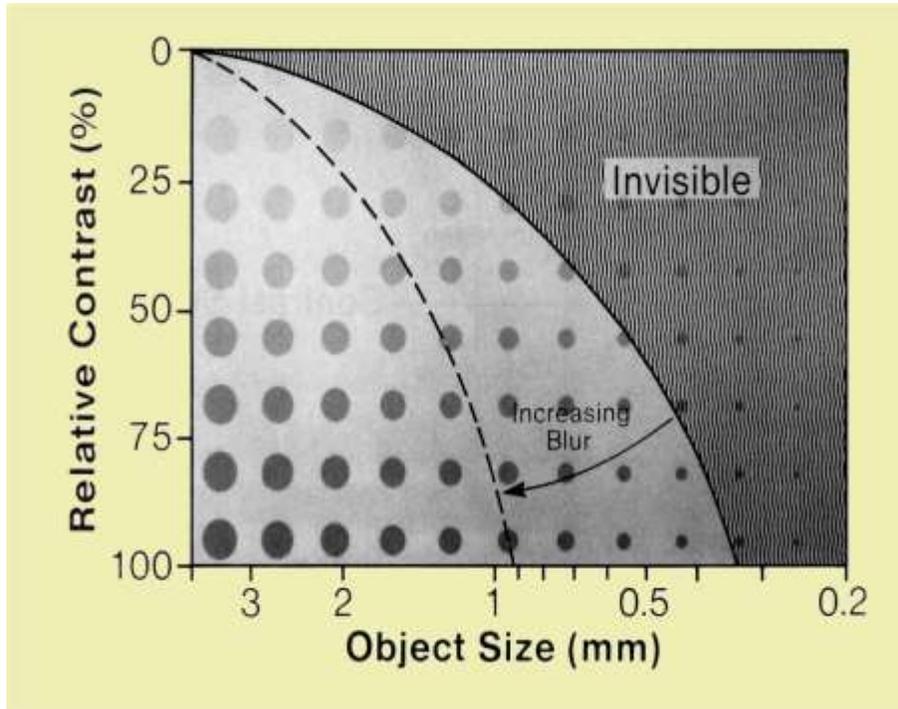


Effect of Contrast Sensitivity on Object Visibility

Blur and Visibility of Detail

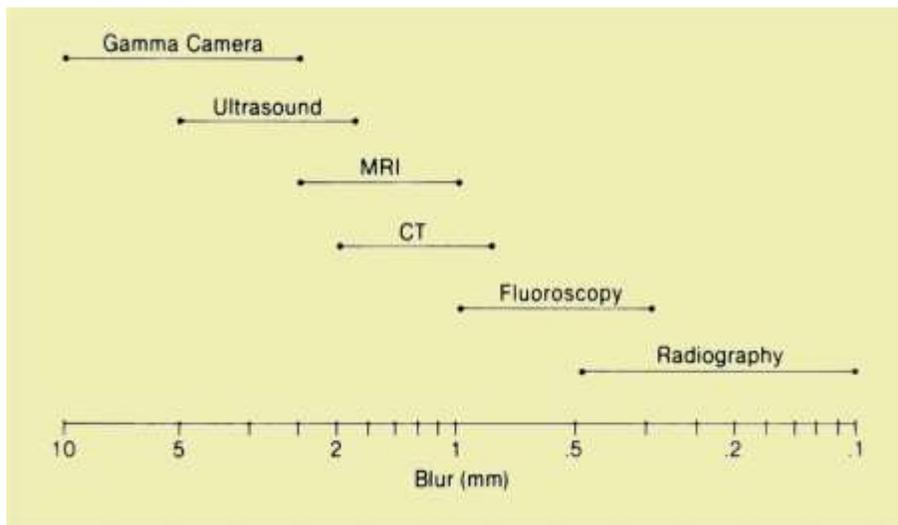
Structures and objects in the body vary not only in physical contrast but also in size. Objects range from large organs and bones to small structural features such as trabecula patterns and small calcifications. It is the small anatomical features that add detail to a medical image. Each imaging method has a limit as to the smallest object that can be imaged and thus on visibility of detail. Visibility of detail is limited because all imaging methods introduce blurring into the process. The primary effect of image blur is to reduce the contrast and visibility of small objects or detail.

Consider the image below, which represents the various objects in the body in terms of both physical contrast and size. As we said, the boundary between visible and invisible objects is determined by the contrast sensitivity of the imaging system. We now extend the idea of our curtain to include the effect of blur. It has little effect on the visibility of large objects but it reduces the contrast and visibility of small objects. When blur is present, and it always is, our curtain of invisibility covers small objects and image detail. Blur and visibility of detail are discussed in more depth in a later chapter.



Effect of Blur on Visibility of Image Detail

The amount of blur in an image can be quantified in units of length. This value represents the width of the blurred image of a small object. The image below compares the approximate blur values for medical imaging methods. As a general rule, the smallest object or detail that can be imaged has approximately the same dimensions as those of the image blur.

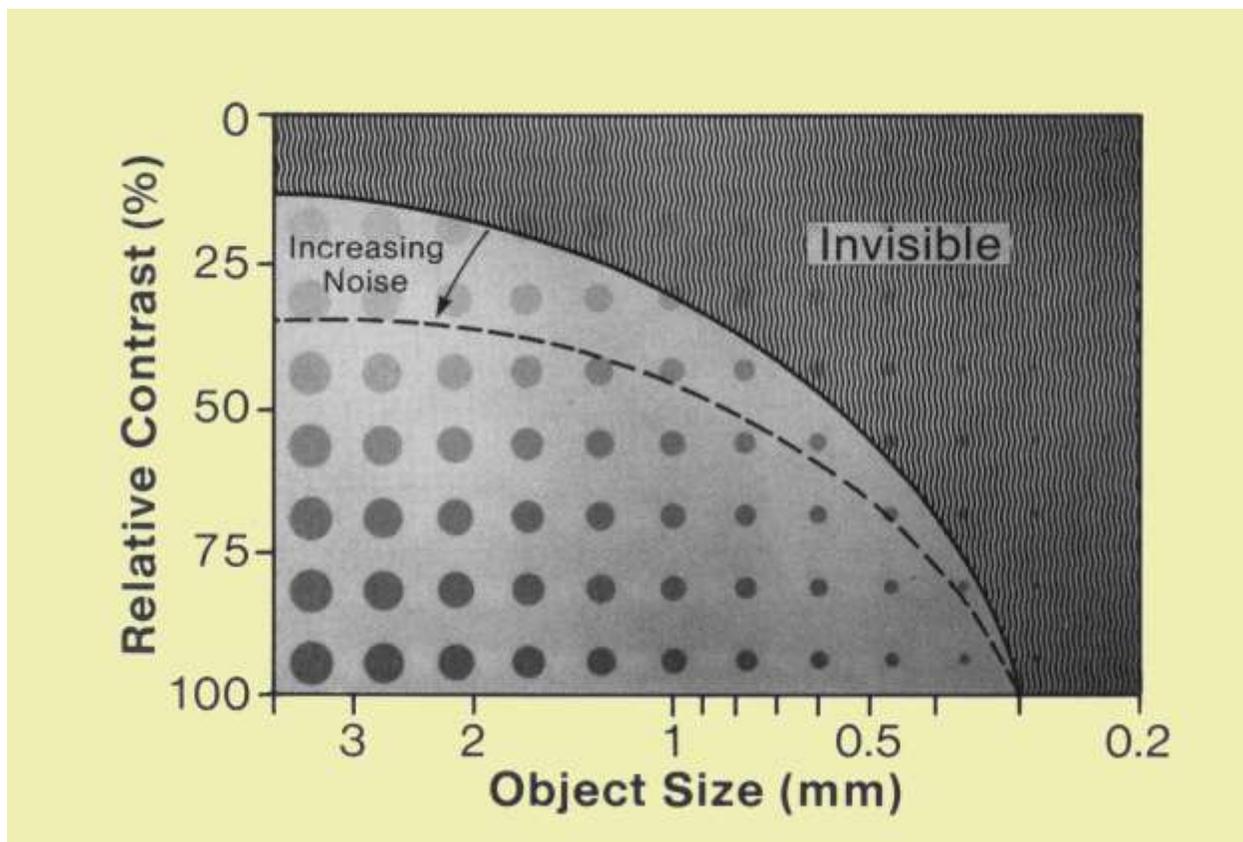


Range of Blur Values and Visibility of Detail Obtained with Various Imaging Methods

Noise

Another characteristic of all medical images is image noise. Image noise, sometimes referred to as image mottle, gives an image a textured or grainy appearance. The source and amount of image noise depend on the imaging method and are discussed in more detail in a later chapter. We now briefly consider the effect of image noise on visibility.

In the image below we find our familiar array of body objects arranged according to physical contrast and size. We now add a third factor, noise, which will affect the boundary between visible and invisible objects. The general effect of increasing image noise is to lower the curtain and reduce object visibility. In most medical imaging situations the effect of noise is most significant on the low-contrast objects that are already close to the visibility threshold.



Effect of Noise on Object Visibility

Artifacts

We have seen that several characteristics of an imaging method (contrast sensitivity, blur, and noise) cause certain body objects to be invisible. Another problem is that most imaging methods can create image features that do not represent a body structure or object. These are image artifacts. In many situations an artifact does not significantly affect object visibility and diagnostic accuracy. But artifacts can obscure a part of an image or may be interpreted as an anatomical feature. A variety of factors associated with each imaging method can cause image artifacts.

Distortion

A medical image should not only make internal body objects visible, but should give an accurate impression of their size, shape, and relative positions. An imaging procedure can, however, introduce distortion of these three factors.

Compromises

It would be logical to raise the question as to why we do not adjust each imaging procedure to yield maximum visibility. The reason is that in many cases the variables that affect image quality also affect factors such as radiation exposure to the patient and imaging time. In general, an imaging procedure should be set up to produce adequate image quality and visibility without excessive patient exposure or imaging time.

In many situations, if a variable is changed to improve one characteristic of image quality, such as noise, it often adversely affects another characteristic, such as blur and visibility of detail. Therefore an imaging procedure must be selected according to the specific requirements of the clinical examination.