EDUCATIONAL RESOURCES

VISUAL DEMONSTRATIONS OF MEDICAL PHYSICS CONCEPTS FOR DIAGNOSTIC RADIOLOGY RESIDENT EDUCATION

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Abstract— **Diagnostic radiologists need to have a good understanding of radiologic physics to practice in a safe and effective manner. However, many physical phenomena relevant to medical imaging are challenging to teach in a method amenable for physicians. The need to avoid extensive use of mathematical formulas and other more traditional explanations of these concepts, like those commonly used in the education of physics and engineering students, presents a challenge for the communication of complex concepts. However, many of these medical physics concepts can be demonstrated visually using typical equipment found in a modern classroom. Therefore, a series of demonstrations using a projector and screen and several printed transparencies and other simple objects, representing a source of x-rays, an imaging detector and the patient or other imaged objects, respectively, has been developed and used during lectures for diagnostic radiology residents. More than a dozen different physical phenomena common in diagnostic imaging can be demonstrated in this way. These demonstrations have been well received by the residents, have resulted in more interactive didactic sessions, and, have enhanced their comprehension and recollection of these topics.**

Keywords— **Education, medical physics, radiology, residency, transmission imaging.**

I. INTRODUCTION

Radiologists need to have a good understanding of several aspects of medical physics and imaging technology [1-6]. Typically this education takes place during their residency, and, ideally, a large portion of it is provided via interaction with a medical physicist. However, the teaching of medical physics concepts by a physicist to diagnostic radiology residents can sometimes be challenging. The use of extensive mathematical derivations and formulas is in general not a successful approach, although many topics are easier to explain in this manner. In an attempt to convey information in a more graphical manner, it is tempting to also depend solely on the use of electronic slides. However, this can result in a monotonous lecture.

With the use of standard classroom equipment and a few simple objects, it is possible to provide visual demonstrations of many physical phenomena relevant to diagnostic imaging, especially in the realm of transmission imaging. By experiencing these phenomena, rather than just being told about them, the residents' grasp of the concepts is enhanced, resulting in a better understanding and recollection of them. In addition, these demonstrations provide for more interaction between the residents and the lecturer, resulting in a more interesting experience for both.

II. MATERIALS AND METHODS

A. Methods

Although the concepts presented here are in general used to perform demonstrations of transmission imaging phenomena, some of them cover basic aspects of image quality relevant to all imaging modalities. In a few cases the underlying physical phenomena during the demonstration are different than those in the imaging situation (e.g. x-ray scatter vs. light refraction), however the concepts are still better understood with these demonstrations.

To perform most of these demonstrations, a typical classroom projector connected to a computer with presentation software (e.g. PowerPoint, Microsoft Corp, Redmond, Washington, USA) is used to represent an x-ray tube. The characteristics of the "x-ray beam" emitted by this "source" are defined using appropriate PowerPoint slides. The screen projected to by the projector is used to represent both the "x-ray detector" and/or the "monitor" where images are displayed, depending on the demonstration. Finally, transparencies and some acrylic objects are used to represent the patient or other imaged objects. These are simply held up in the path of the "x rays" by the lecturer. The position where these need to be held varies depending on the demonstration.

The concepts covered by these demonstrations currently are, in no particular order:

- Straight-line travel of electromagnetic radiation
- Object, subject, image and display contrast
- Point spread functions
- Linear systems
- Frequency domain
- Contrast and modulation transfer functions
- Quantum and image noise
- Noise frequency and noise power spectrum
- Anatomical noise
- Magnification
- Geometric unsharpness
- Inverse square distance relationship
- Sampling and aliasing
- X-ray scatter

The following are descriptions of how some of these concepts are demonstrated.

Point Spread Functions: To demonstrate the concept of a point spread function, a simple transparency with a single small black circle printed on it is held up in front of the projection of a blank white electronic slide. This is sufficient to demonstrate how the manner in which a single point object is imaged by the system characterizes the system response. By varying the distance between the transparency and the projector, the size and sharpness of the projected "point" is varied. A larger blurrier point reflects the image obtained with a system of poor spatial resolution, while a sharper point reflects improved spatial resolution.

System Linearity: The introduction onto the x-ray beam of a second transparency with another equal small black circle is used to demonstrate the concept of linearity. It is apparent to the residents that although another object is introduced into the field of view, the system response to the first object does not change. This therefore provides a demonstration of why, due to system linearity, the point spread function is a useful metric. This is perhaps the best example of how some concepts are simplified by these methods; this demonstration is almost obvious, while explaining the concept of system linearity using traditional methods is typically very counterintuitive to the residents.

Object, subject, image and display contrast: To explain these four concepts, a homogeneous "x-ray field" is used by displaying a blank PowerPoint slide. Three or four disks of varying darkness are printed on a transparency, cut out, and placed in between two slabs of polymethyl methacrylate (PMMA) (Fig. 1(left)). In this case the PMMA slabs are semi-circular representing a breast undergoing mammography, but they can be of any shape. This "breast" is held up in the "x-ray beam," and the "lesions" are shown to have different object contrast, which modify the "x-ray beam" after the breast, resulting in subject contrast. The fact that how this subject contrast is captured by the "detector", i.e. the system response, can vary is demonstrated by having a volunteer hold a black paper in front of the screen, representing a different detector (Fig. 1(right)). The resulting image contrast is shown to be different if the detector is a white screen or a black screen.

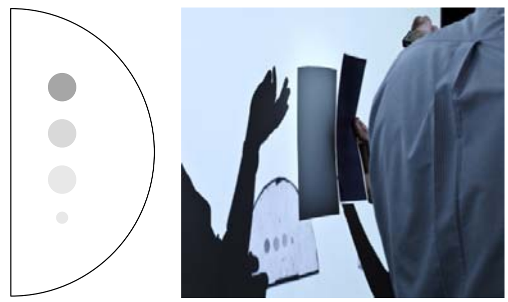


Fig. 1 (left) Semi-circular PMMA phantom with a number of disks of different graylevel representing a breast with lesions with different object contrasts. (right) The phantom is held up in front of two different "detectors" to show the difference in resulting image contrast.

Frequency domain, contrast and modulation transfer function: Without the use of formulas, explaining the concept of the frequency domain (or k-space) is very challenging. A transparency with printed line pairs or sine waves of varying spatial frequency (Fig. 2(left)) can be used to explain this concept and how it is relevant to spatial resolution. Depending on the position of the sine wave transparency, the higher frequency waves are blurred by the "imaging system", resulting in loss of contrast. It is explained that the ratio between the darker and brighter areas of the sine waves vs. their spatial frequency are plotted, creating the modulation transfer function (MTF) (Fig. 2(right)). By varying the distance between the transparency and the projector, the spatial resolution of the "imaging system" is varied, and the contrast loss at different frequencies varies, yielding a different MTF. With this demonstration, both the concept of the MTF and the relationship between spatial resolution and signal transfer properties are understood. A second transparency with line pairs instead of sine waves is briefly shown, explaining the difference between the contrast transfer function and the MTF.

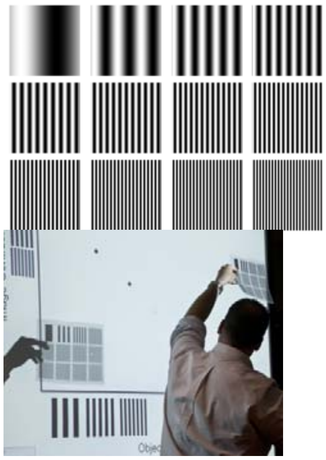
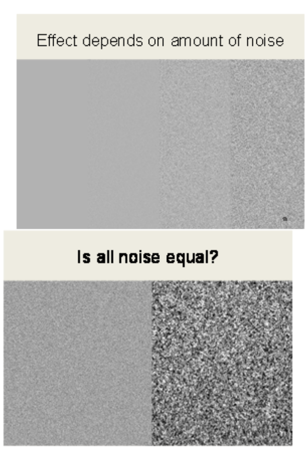


Fig. 2 (left) Transparency with sine waves used to demonstrate the concept of frequency domain and (right) the construction of the MTF.

Quantum and image noise, noise frequency and noise power spectrum: Using image processing software, images of white and colored noise of varying levels are created and included in PowerPoint slides (Fig. 3(top)). When displayed using the projector, placing a transparency with disks of varying graylevel in the path of the different areas of the noisy "x-ray beam" shows how image noise affects detectability of lesions (Fig. 3(bottom)). Then showing the disks in the "x-ray beam" with white vs. colored noise shows how noise frequency also affects detectability. This demonstration, along with the previous explanation of the frequency domain described above, also helps introduce the concept of noise power spectrum.



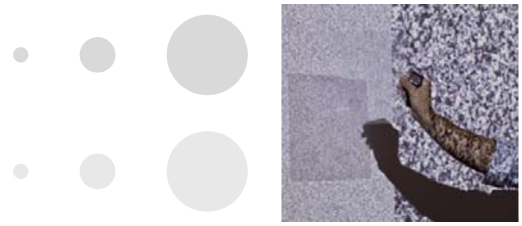


Fig. 3 (top) Electronic slides containing image noise of varying levels and frequency characteristics. (bottom) A transparency with disks of varying gray level is held in front of the different noisy "x-ray fields" to demonstrate the change in detectability of "lesions" with noise of different characteristics.

To explain the issue of anatomical noise (or tissue superposition), the electronic slide consisting of noise is replaced with one that includes a region of interest of normal mammographic background, and the transparency with "lesions" is again held up in the beam of "x rays." Again, the impact of the anatomic noise on the detectability of the lesions becomes apparent.

Magnification: Two transparencies with squares are printed; one with a single square and another one with four adjacent squares each of the same size as that of the other transparency, arranged so as to form one larger square. After comparing the two transparencies to show that the smaller square is exactly four times smaller than the larger one, a resident volunteer holds up the transparency with the larger square against the screen. The transparency with the smaller square is held up half-way between the screen and the projector (purposefully, this distance is measured during the demonstration). The perfect alignment of the small square with the larger square is shown (Fig. 4). In addition, this setup, plus the previously discussed concept that x-rays travel in straight lines between interactions, is used to explain the inverse square distance relationship. This concept is made apparent since it is explained that the same number of x-rays that went through the first small square go through the four squares in the second transparency. Therefore, the x-ray fluence is decreased by a factor of four, or the square of the increase in distance traveled.

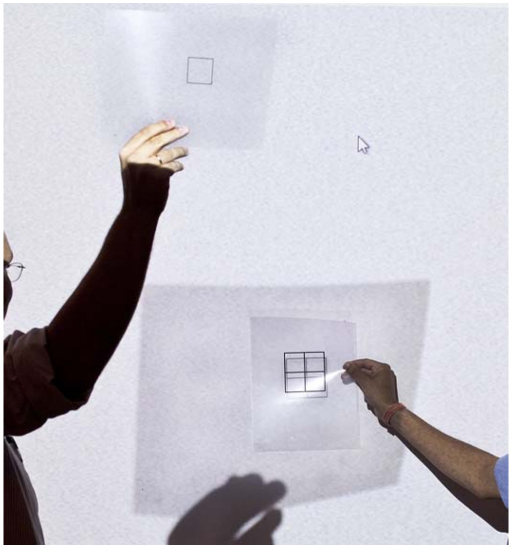


Fig. 4 Two transparencies with printed squares of different sizes are used to demonstrate magnification and the inverse square distance relationship.

Sampling and aliasing: To introduce the concept of sampling, a chest radiograph is printed on a transparency and shown in front of a projected grid representing the array of pixels of a detector (Fig. 5 (top)). It is discussed that the entire signal incident on a whole pixel is averaged to represent the signal at that pixel, and the resulting image is shown in a projected slide (Fig. 5(bottom)).

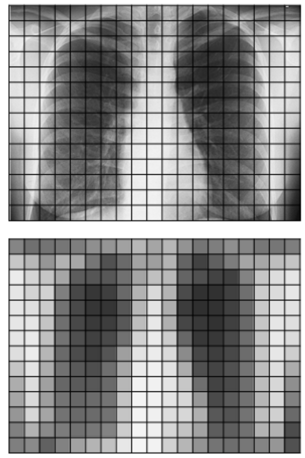
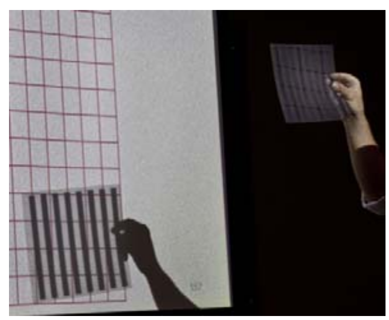


Fig. 5 (top) A chest radiograph on a transparency is shown in front of a projected grid pattern representing the pixels of a digital detector. (bottom) The continuous "x-ray beam" containing the information of the chest x-ray is then projected using a transparency with the array of "pixels" overlaid, followed by the result of the coarsely sampled image.

This demonstration serves as an introduction to the concept of aliasing, since the same setup is used but this time with a transparency with a single sine wave pattern (Fig. 6(top)). The spatial frequency aliasing that takes place when this sine wave is sampled by the "detector" is shown with two electronic slides (Fig. 6(bottom)).



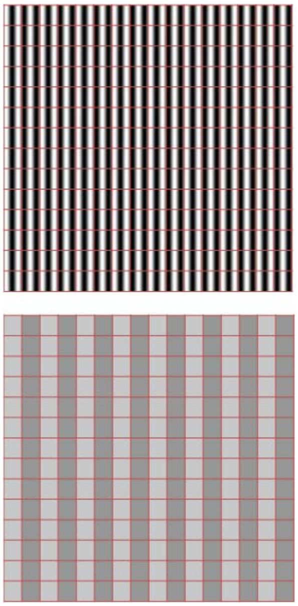


Fig. 6 (top) A sine wave pattern on a transparency is shown in front of a projected grid pattern representing the pixels of a digital detector. (bottom) Two separate electronic slides show how the high frequency sine wave pattern is aliased by the course sampling into a lower frequency pattern.

This is another example of how this type of demonstration aids immensely in the understanding of a complex topic. Using a simple transparency and the projection of a grid of “pixels,” the concept of frequency aliasing can be visualized by the residents, with no need for mathematical formulas.

X-ray scatter: A blank white electronic slide is displayed representing a noise-free “x-ray beam.” A 10 cm pediatric head CT phantom is held up in the path of the light beam with its long axis close to horizontal (Fig. 7). By adjusting the position of the phantom, it is possible to show how the shadow of the phantom is impacted by light refraction. The change in visibility of the 1 cm diameter holes in the phantom due to the refracted light falling on the projections of these holes is used as an example of how contrast is reduced by the presence of x-ray scatter. This is an example of a demonstration that does not rely on the same physical phenomenon that is being demonstrated, but it still useful to explain a key concept in radiographic imaging.

Fig. 7 A CT phantom is used to demonstrate the phenomenon of x-ray scatter and its impact on image contrast.

Other demonstrations, not all of which involve the use of the projector and screen, are used to explain other imaging concepts. For example, to demonstrate the benefit of a rotating anode in the x-ray tube, a resident volunteer is asked to direct the beam of a presenter’s laser pointer at a point close to the outer edge of a Frisbee or plastic plate. The Frisbee has an axis through its center that allows for its easy rotation. When the Frisbee is rotated while the laser is held in place, the residents can easily see how the heat deposited by the “electron beam” is distributed along a circle, therefore increasing the heat capacity of the focal spot.

B. Evaluation

At the end of each lecture, the residents are asked to complete a survey form, in which one of the questions asks specifically about the usefulness of these demonstrations, to be graded with a score from 1 to 5, with 5 being the highest score. In addition, the survey includes separate questions for free-form comments on the strengths and weaknesses of the instructor’s teaching. The residents’ responses to these surveys over the three years that these visual demonstrations were used were analyzed.

III. Results

The feedback from the residents attending these sessions has reflected a very positive opinion of these demonstrations. From a total of 51 completed survey forms, the average score on the usefulness of the visual demonstrations was 4.76 (std. dev. = 0.47), with a range of 3 to 5 (although a single score of 3 was received, all others being 4s and 5s). Of the 51 surveys, only 32 included any comment on the instructor’s teaching strengths. Of these 32 positive comments, 18 mentioned the visual demonstrations as a strength. The demonstrations were not mentioned in any of the surveys as a weakness.

Very positive feedback has also been received both directly during informal one-to-one conversations with residents that attended these lectures and indirectly through comments to other faculty.

IV. Discussion

This innovative method of communicating medical physics concepts relevant to transmission imaging has been very well received by the residents. It appears to have also substantially improved the residents' understanding of the concepts and their impact on image quality and patient dose, their ability to explain and recollect them. In addition, these types of demonstrations help promote interaction with the medical physicist during class and throughout their residency.

V. Conclusions

The use of demonstrations that show physical phenomena relevant to diagnostic imaging, rather than just describing them using electronic slides and/or blackboard diagrams, let alone mathematical formulas, can enhance the learning experience for diagnostic radiology residents. In addition, the didactic sessions become more interactive and promote a two-way discussion of concepts that is challenging to obtain during traditional didactic lectures.

Although the list of demonstrations is already extensive, additional concepts that can be shown using this methodology are always being sought. Finally, although the electronic slides needed to project and to print the transparencies are easy to prepare, these are available by request via e-mail to the author.

Acknowledgment

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References

1. American College of Radiology (ACR). ACR-SPR Practice Guideline for General Radiography (Resolution 30) at http://www.acr.org/~/media/95AB63131AD64CC6BB54BFE008DBA30C.pdf.
2. American Board of Radiology. Core and Certifying Exams Overview at http://theabr.org/core-and-cert-exam-overview.
3. Accreditation Council for Graduate Medical Education. ACGME Program Requirements for Graduate Medical Education in Diagnostic Radiology at http://www.acgme.org/acgmeweb/Portals/0/PFAssets/2013-PR-FAQ-PIF/420_diagnostic_radiology_07012013.pdf.
4. Image Wisely. Imaging Physicians at http://www.imagewisely.org/Imaging-Professionals/Imaging-Physicians.
5. Image Gently. Image Gently - Radiologists at http://spr.affiniscape.com/associations/5364/ig/index.cfm?page=389.
6. American Association of Physicists in Medicine. Diagnostic Radiology Residents Physics Curriculum at http://aapm.org/education/documents/Curriculum.pdf.

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