EDUCATIONAL RESOURCES

PHYSICS EDUCATION FOR THE OPTIMIZATION OF MRI CLINICAL PROCEDURES: VISUALIZING THE INVISIBLE AND COLLABORATIVE TEACHING

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Abstract— **Magnetic Resonance Imaging (MRI) is capable of producing high-quality images permitting visualization of a variety of tissue characteristics and fluid movement that reveal signs of pathology along with evaluations of normal conditions and functions. It is a procedure in which image characteristics and quality are controlled through a complex combination of adjustable protocol factors that must be set for each patient examination. The selection of factor values that provide an optimized protocol requires a knowledge of the physics principles by the radiologists and other members of the clinical imaging team. Medical physicists contribute to image quality and effective diagnostic procedures by providing educational opportunities within their institutions. Their role and contribution is enhanced through the process of collaborative teaching and the use of MRI educational resources available online with open access.**

Keywords— **MRI, Image Quality, Physics Education, Collaborative Teaching, Open Access.**

I. INTRODUCTION AND OVERVIEW

Magnetic resonance imaging (MRI) is a highly effective clinical diagnostic method because it produces images that provide visualization of a variety of tissue characteristics and fluid movement that relate to physiological function and show signs of disease. This extensive capability as a diagnostic method comes from the ability to adjust the image characteristics for maximum visibility of many different conditions within the patient body. However, this is not without a major challenge: the complexity of the imaging procedure because of the many variable factors that must be set and adjusted for each patient examination. Each procedure is controlled by a protocol consisting of many factors that have been set for that particular patient. MRI systems are programmed with many pre-set protocols that can be selected by the operator based on anatomical site and clinical objective such as possible diseases and this provides a starting point for each procedure.

A higher level of performance and image quality is the goal of *optimizing* the protocols by the intelligent interaction of the clinical staff, generally radiologists in collaboration with the technologists who operate the equipment. This requires a comprehensive knowledge of the physics and physical principles of the MR process. It is this knowledge and understanding of physics concepts that can be provided by clinical physicists associated with the MRI facility and medical physics educators.

The variation and potential problems with MR image quality in all countries of the world is usually associated with how the equipment is operated. A significant contribution to MR image quality control and assurance is an educated clinical team, radiologists and technologists, who understand and can apply the physics.

In this article we review the types of physics knowledge that are needed in clinical MRI and the learning experiences and types of teaching that can contribute to the development of that knowledge. We then consider the quality characteristics of MR images-- their general relationship to procedure protocols and the concept of protocol optimization-- and then identify the important physics concepts that apply. The significance of visualization in the learning process is emphasized.

Highly effective physics education to support clinical MRI can be achieved in all institutions through the process of collaborative teaching and shared educational resources .This is supported by comprehensive resources (text and visuals) with open access at: http://www.sprawls.org/mripmt/ A special emphasis is to provide resources for physicists who are not generally working in MRI to enable them to be more involved and contribute physics knowledge to support clinical activities.

II. PHYSICS LEARNING EXPERIENCES AND CLINICAL IMAGING OUTCOMES

A major objective of physics education for radiologists and other members of the medical imaging team, is to enable them to analyze, evaluate, and develop creative solutions to guide the imaging process and derive maximum clinical information from images. This requires higher levels of knowledge well above just memorized facts and other forms of verbal information. The development of this level of knowledge depends on the type of learning experience that is available to them as illustrated in Figure 1.
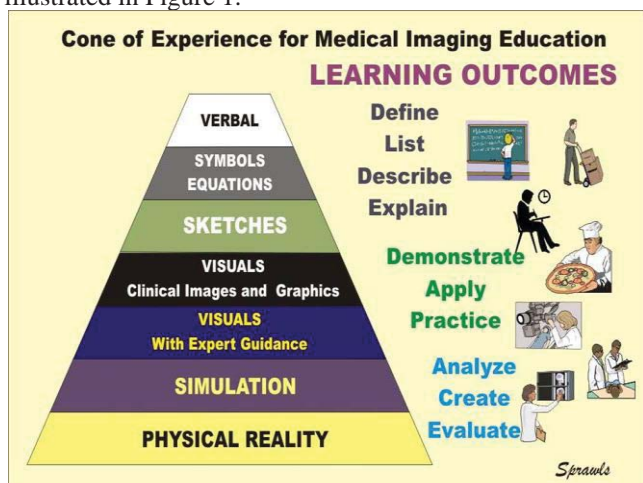

Figure 1. The general relationship between learning outcomes and the types of learning experiences and teaching methods represented by the "Cone of Experience" on the left.

Edgar Dale (1900 – 1985) was the pioneer who developed the *Cone of Experience* to describe the different types of learning activities and teaching methods that are arranged in the form of a cone. This has been published in many forms that can be found by doing a web search on his name. The great value in this organization of learning and teaching activities is this.

A.   Efficient Teaching

The learning experiences and teaching methods near the top of the cone are generally quite *efficient*. Compared to the lower ones, they require much less effort and expense to conduct. Standing up and giving a verbal lecture and maybe writing equations on the board is much less demanding that conducting an interactive physics learning activity directly in the clinic.

B.   Effective Teaching

The learning experiences at the bottom of the cone are more *effective* in producing outcomes and knowledge that can be applied in the process of medical imaging.

. C. The Challenge

A major challenge in education, especially for clinical

medical physics, is providing learning activities that are *effective* and also enable radiologists to interact with the imaging process, understand image characteristics, and optimize procedures to obtain the required clinical information.

A problem we are facing in medical physics education around the world is the separation between the classroom (in which learning occurs) and the clinical environment (in which the knowledge needs to be applied). It is just not practical or efficient with respect to the cost of human effort and facilities to conduct most physics teaching directly in the clinic.

D .Visualizing the Invisible

The higher levels of knowledge that contribute to creative thinking, analysis, problem solving, etc. are greatly enhanced by the ability to visualize the physical phenomena or physical reality that is being worked with. An advantage with learning in the clinic is the ability to observe images, the patient and the imaging process that produces the images, and to interact with the imaging procedure. This contributes to effective learning but there is a limit to what can be viewed. All medical imaging methods, including MRI, are based on much that is invisible. This includes radiation, magnetic fields, and the interactions within the patient body that produces the images.

The invisible can be made visible for learning and teaching with the use of visuals that are created to show not only the invisible physical universe but also relationships and how it is all combined to form complex imaging procedures. It is not practical, or even possible, for every teacher to draw on the board, or produce in other forms, all of the required visuals for the effective teaching of MRI physics. The solution is *collaborative teaching*.

II. COLLABORATIVE TEACHING

An appropriate concept and definition of teaching is that it is helping someone learn. It is not a transfer of knowledge from one brain to another. Rather it is providing an environment and conditions where the learner can experience the part of the physical universe that is being studied with guidance in observing, analyzing, and interacting with the physics. Collaborative teaching is when two or more medical physicists combine their contributions to the learning process as illustrated in figure 2.
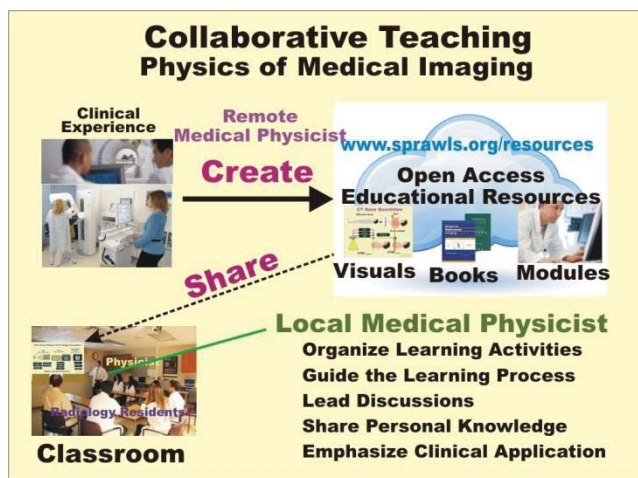
Figure 2. The two phases of collaborative teaching-- first, the creation and distribution of visuals and related resources; followed by guiding the learning process in the classroom.

A .Creating and Sharing Visuals and Related Resources

Visuals provide a "window" through which the physical universe can be observed and studied from the classroom or during any other learning activity. The creation of effective visuals is a major effort requiring extensive knowledge and experience in the subject, such as the physics of clinical MRI, along with the ability and resources to transform the knowledge into visual formats. When this is done and shared with open access it then makes it possible for teachers in all institutions to devote their efforts to organizing and guiding highly effective learning activities. It enhances both the *effectiveness* and the *efficiency* of the total teaching process.

B. Conducting Effective Classroom Learning Activities

Medical physicists in various institutions around the world can provide a major contribution to effective and safe medical imaging procedures by providing educational activities for radiologists and other medical imaging professionals. Even when their experience does not include clinical MRI applications their knowledge of general medical physics combined with the appropriate visuals and related resources provided here enables them to conduct high-quality class or small-group discussions and learning activities.

III. MR IMAGE QUALITY CHARACTERISTICS

The starting and point of focus for MR physics education for medical personnel is the *image*, not the spinning protons! That comes later. The image is what the radiologists see, interact with, and use to connect to the human body. It is the information contained in the image that is important. One of the first goals of physics education is to help understand the image characteristics

that can affect information and then how it can be controlled.

The one comprehensive characteristic that determines image quality and displayed information is *visibility*. More specifically, can the radiologist see the anatomical structures, tissue characteristics, fluid activity, and signs of pathology to make an accurate diagnosis. While visibility is an image characteristic it varies with objects and structures within each image generally depending on their biological or molecular composition and their size. The general image quality and visibility of specific structures and objects is determined by the combination of five (5) more specific image characteristics shown in Figure 3.
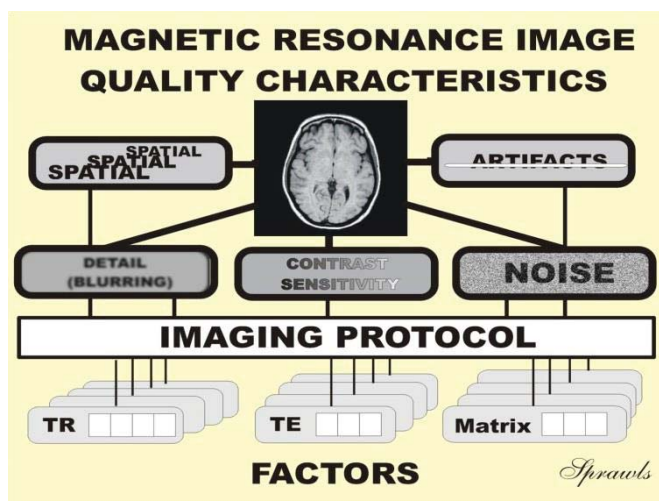

Figure 3. The five characteristics of an MR image that determine its general quality and visibility of specific anatomical structures and objects.

The critical issue in MR imaging is that each of these image quality characteristics can be, and should be, adjusted for optimum visualization in each clinical procedure. This adjustment is through a complex relationship with the many protocol factors. To understand the image characteristics, the relationship to the protocol factors, and the process of optimization, requires an extensive knowledge of physics.

A. Contrast Sensitivity

Contrast sensitivity is the most significant adjustable characteristic associated with the MR imaging process that determines visibility of specific tissue differences based on their magnetic characteristics. The three (3) magnetic characteristics-- proton density (hydrogen concentration), and the two relation times, T1 and T2, are the sources of physical contrast within the body. The first step in producing and enhancing visibility of tissue differences based on each of these characteristics is to select an appropriate imaging method (often referred to as the pulse sequence) and then to set–the optimum values

for protocol factors such as TR and TE. While all facilities have a good selection of pre-set protocols, knowledge of physics is essential for understanding why specific values are used and if protocols are optimized, especially with respect to image acquisition time.

B .Detail

Size is a characteristic of some anatomic structures or objects that might limit their visibility because of the blurring that occurs during the imaging process. This determines the visibility of detail within the image. While visibility of detail is the important characteristic for clinical imaging and diagnosis it is the characteristic that physicists often know as spatial resolution. Both visibility of anatomical detail and spatial resolution as measured with test objects are determined and limited by the same thing, blurring.

Blurring is present in all medical imaging procedures and for the most part related to design characteristics of the imaging equipment and certain parameters of the imaging process such as focal spot size and receptor design in radiography. In MRI the source of blurring is primarily the size of the tissue voxel formed during the imaging process as illustrated in Figure 4.
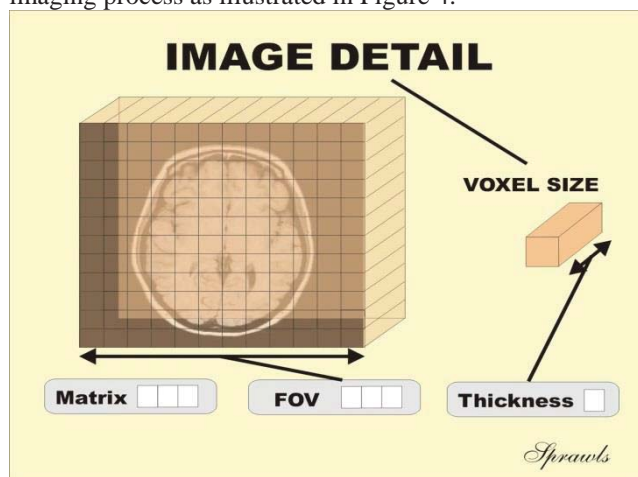

Figure 4. The protocol factors that control voxel size which determines blurring and visibility of detail in MR images.

A tissue voxel is actually a three-dimensional blur with all structures within it "blurred together" and represented by one pixel in the image. We cannot see any detail within a voxel, just an image showing a matrix of voxels. Image detail can be increased by reducing voxel size through the adjustment of the three protocol factors.

This now brings us to an interesting question….if we can reduce blurring and improve visibility of detail by setting factors to produce smaller voxels why don't we just do it? That opens up the very crucial issue of *protocol optimization!* In MR imaging many of the adjustable protocol factors have an effect on more than one image quality characteristic and other things like image acquisition time. Very often, these are opposing

factors which must be balanced in the process of optimization.

In the MR imaging process, specifically in the image reconstruction phase, the patient body is divided into a matrix of discreet samples of tissue, the voxels. As will be reviewed later, the image is composed from a collection of radio-frequency (RF) signals from each of these voxels or tissue samples. This is why voxel size is a major factor that determines image noise.

C. Noise

Visual noise is a generally undesirable characteristic that is present to some extent in all medical images, including MRI. The effect of noise is to reduce the visibility of structures and objects that have relatively low contrast. This is often the small differences among tissues that convey important clinical information.

In an MR image the predominant source of noise is random RF emissions from the total mass of tissue within the sensitive receiving area of the RF coils. While this can be controlled to some extent by selection of coil types (body, head, surface, etc.) and adjusting receiving bandwidth, an effective approach to controlling image noise is by adjusting the strength of the RF signals from the individual tissue voxels. The amount of noise that actually appears in an image is determined by the signal-to-noise (S/N) ratio. It is the desirable signals from the voxels competing with the undesirable noise emissions from the larger mass of tissue as illustrated in Figure 5.
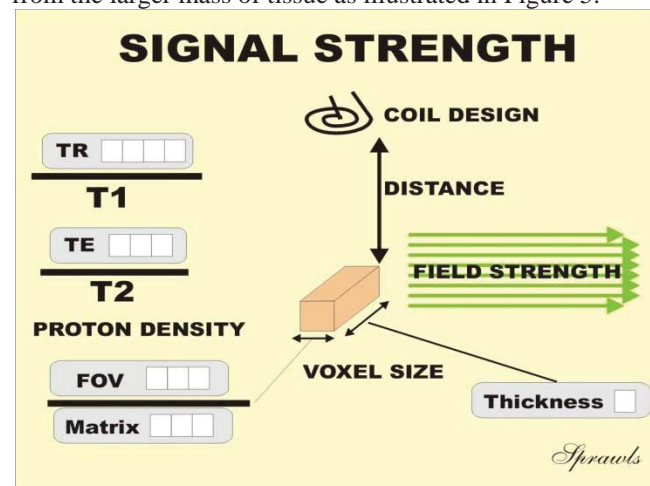

Figure 5. Protocol factors that determine RF signal strength (signal-to-noise) which determines the level of noise in MR images. Here we are emphasizing the significance of voxel size. .

In setting up a protocol for a procedure the noise can be reduced by *increasing* voxel size. Here is the challenge! Increasing voxel size to improve image quality by reducing noise also has the effect of deteriorating image quality by increasing the blurring and reducing visibility of detail.

Assuming the appropriate imaging method (pulse sequence) and associated factors to obtain the required contrast sensitivity have been selected, <u>voxel size</u> is the predominant factor that must be considered in the optimization of a protocol for a specific clinical procedure. It is a complex issue that requires knowledge of the associated physics principles.

V. OPTIMIZING VOXEL SIZE

Effective physics education to support clinical MRI procedure optimization must include a good conceptual understanding of voxels. Voxels should be visualized by the radiologists and technologists as how the body is being sampled and the image formed. The illustrations included here and others in the online resource are useful for that purpose.

The selection of an appropriate voxel size not only involves the conflict between image detail and noise. There is another major factor that must be considered: the *image acquisition time.*

The diagram in Figure 6 is helpful for understanding and communicating this somewhat complex relationship.
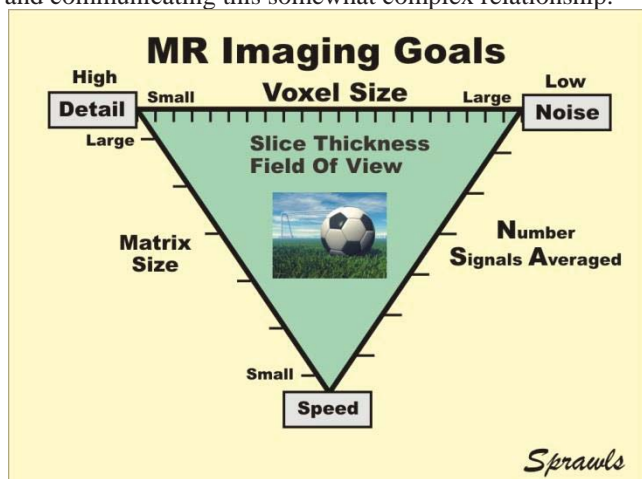

Figure 6. The relationship of image detail, noise, and acquisition time, and the protocol factors that can be adjusted to optimize a procedure.

In an MRI facility the starting point for most procedures is the pre-set protocol for the specific clinical objective. When a specific protocol is selected the major protocol factor values are displayed. With an appropriate knowledge of physics the clinical staff can understand the significance of each of the factors with respect to the image quality characteristics and if the protocol is appropriate for the procedure that is being setup.

And as a next step, with the understanding of the physics principles, the protocol factors can be adjusted to optimize the procedure for the specific patient and clinical requirements.

For each imaging procedure there are specific imaging goals, three of which are identified in the illustration. To understand the complexity and the challenge of optimizing an MR procedure let's compare it to a game of soccer (football). There is a major difference. In soccer our team always has just one goal to get the ball to. In MR imaging we have several different goals and the challenge is that they are in different and opposing directions. We can think of each imaging protocol as being represented by a ball position somewhere on the field. But here is the problem: when we make changes to move closer to one of the desirable goals, for example high detail, we are moving away from some of the other desirable goals including low noise and increased acquisition speed. The optimum "field position" for a specific procedure requires knowledge of the clinical requirements and what needs to be visualized combined with knowledge of the physics and the process of controlling the image characteristics.

VI. CONCLUSIONS

MR imaging is a process in which the image characteristics affecting visibility and general quality are determined by a complex combination of adjustable protocol factors. The optimizing of a protocol for a specific patient procedure is enhanced by understanding the physics as it relates to the imaging process.

Medical physicists make major contributions to MR image quality and clinical effectiveness by helping radiologists and the other imaging professionals develop the appropriate knowledge and understanding of the physics concepts. Through the process of collaborative teaching, physicists in all institutions can use resources that are provided with open access on the web to develop and conduct classes and other learning activities that benefit from their individual scope of knowledge and experiences.

VII. REFERENCES

Magnetic Resonance Imaging: Principles, Methods, and Techniques. P. Sprawls.

Available with open access at:
http://www.sprawls.org/mripmt/