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RADIOLOGIC TECHNOLOGY

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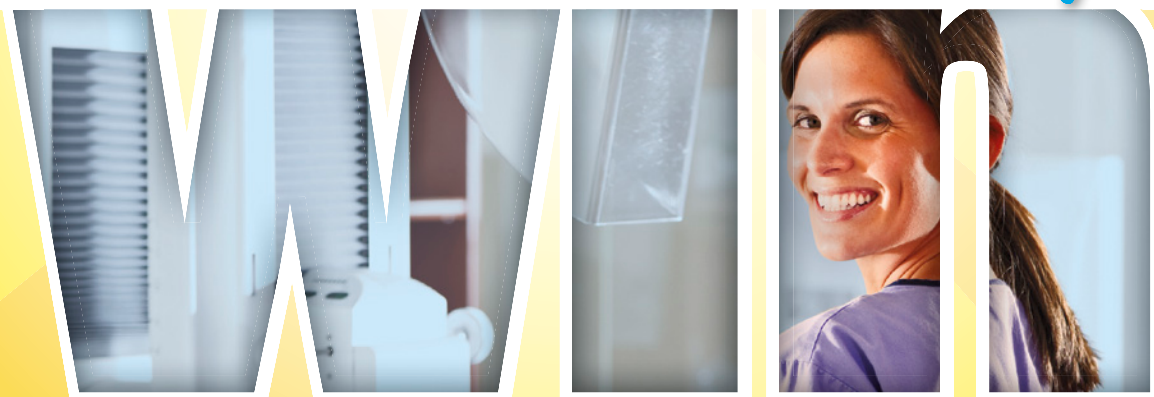

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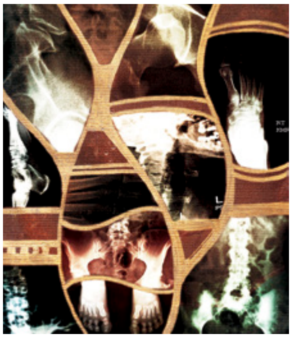

ON THE COVER

"Skeletal B" is the fourth piece by Kristie Hayes-Beaulieu of Syracuse, New York. It was one of the earliest in her x-ray art series. "I enjoy the randomness of the images because they are each elegant alone and the compilation has a playful, energetic feel."

Computed Tomography Angiography for Transcatheter Aortic Valve Replacement

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Background Transcatheter aortic valve replacement (TAVR) is an established alternative to surgery for patients with severe, symptomatic aortic stenosis who are not suitable candidates for surgical replacement of the aortic valve. The computed tomography (CT) technologist has a critical role in the care of patients undergoing TAVR. Because image acquisition and postprocessing for TAVR planning are highly complex, it is important for CT technologists involved in the planning to understand clinical detail, protocols, potential pitfalls, and factors that may influence workflow.

Purpose To describe, from the CT technologist's point of view, the details of CT angiography acquisition and postprocessing at 1 institution for patients being screened for TAVR.

Discussion For TAVR patients, CT image acquisition and postprocessing is essential for a successful intervention. It is clinically essential to maintain and execute a detailed, standardized imaging approach.

Conclusion TAVR planning is among the most complex procedures in radiology. For these patients, meticulous image acquisition and image postprocessing protocols are paramount, and successful patient outcomes depend on attention to clinical detail, protocols, potential pitfalls, and factors that may influence workflow.

Aortic stenosis is a common valvular degenerative disease that affects almost 5% of individuals older than 75 years of age.[1] After symptoms appear, approximately 50% of patients die in the first 2 years if their aortic stenosis is left untreated. Surgical replacement of the aortic valve is the suggested treatment for symptomatic patients with severe aortic stenosis, and approximately 60 000 patients undergo aortic valve replacement every year.[2]

At least 30% of patients with severe, symptomatic aortic stenosis do not undergo surgery for replacement of the aortic valve because of advanced age, left ventricular dysfunction, or the presence of multiple existing conditions.[3-6] For these higher risk patients, transcatheter aortic valve replacement (TAVR) is an established alternative to surgery. Given the initial success of the procedure, the number of patients who undergo TAVR is likely to grow rapidly, emphasizing the need for computed tomography (CT) technologists to become familiar with imaging and postprocessing protocols for this patient population.

Image acquisition and postprocessing for TAVR planning are among the most complex procedures in radiology. The CT technologist has a large and potentially increasing role in the care of patients undergoing TAVR; consequently, CT technologists who play a role in TAVR planning must be knowledgeable about clinical detail, protocols, potential pitfalls, and factors that may influence workflow.

With meticulous attention to detail, CT technologists can provide angiographic images that give excellent 3-D visualization and accurate measurements of the aorta, iliac, and common femoral arteries for TAVR planning. The purpose of this article is to describe — from the CT technologist's perspective — CT angiography data acquisition and postprocessing procedures for patients being screened for TAVR at Brigham and Women's Hospital in Boston, Massachusetts.

Transcatheter Aortic Valve Implantation

The TAVR procedure requires the interventionalist to introduce a very large catheter and sheath system into a femoral artery and pass it through the iliac system and the entire aorta. This is followed by the intervention itself at the level of the aortic valve. CT has come to play a key role in planning because, unlike an open repair in which the surgeon enters the thorax, TAVR requires a thorough, volumetric understanding of the entire aorta, with extension to the femoral arteries. In this respect, TAVR CT imaging is similar to imaging of the aorta for either dissection or intramural hematoma of the aorta.[7] However, there are key differences, as noted throughout this article.

Imaging of the aortic annulus is essential, and for safe introduction of the catheter system, meticulous measurements and angulations of the distal aorta, iliac arteries, and femoral arteries are necessary. Because it is rapid, reproducible, and accurate, CT angiography has emerged as the best imaging modality to evaluate the entire aorta and branches to the point of catheter insertion in the femoral arteries. At Brigham and Women's Hospital, this is accomplished using a wide-area detector (320-slice) and a first-generation dual-source CT (64-slice) system. The volumetric nature of the acquisition enables precise measurements derived from image postprocessing from the root to the iliofemoral arteries. Vessel tortuosity, noncalcified plaque, and calcification are detailed, reported, and used for screening.

Review of the Literature

The authors searched PubMed to identify and assess the peer-reviewed literature regarding TAVR and the relevant imaging strategies — CT, echocardiography, and magnetic resonance (MR) — to evaluate candidates before the intervention. A literature search also was performed in MeSH, the National Library of Medicine's controlled vocabulary thesaurus, and included the terms *TAVR*, *minimally invasive*, and *aortic stenosis*.

Some elderly patients with severe aortic stenosis are poor surgical candidates because of a high prevalence of comorbidities.[5] In addition, medical treatment of this group of patients with severe aortic stenosis has had relatively poor outcomes.[8] In these patients with severe aortic stenosis who cannot undergo the traditional surgical approach, the catheter-based technique (TAVR) most commonly is performed through the femoral artery. Thus, the CT images must include the entire femoral artery and should extend inferiorly as far as the lesser trochanter of the femur. Less commonly, the catheter is inserted through the apex of the heart or via the axillary artery; however, discussion of these patients is beyond the scope of this article.[9-13] Results from experienced centers have shown high implantation success rates, significant clinical improvements, and improved survival rates.[11,13-17] In addition, landmark publications by Leon et al and Smith et al demonstrated that TAVR significantly reduces all-cause mortality rates for critically ill patients with severe aortic stenosis who cannot undergo traditional open surgery.[18,19]

The best TAVR program includes a multidisciplinary team.[20] To the authors' knowledge, there is no literature from the perspective of the CT technologist regarding this intervention. The technologist or radiologist who performs the image postprocessing procedure should be considered a key member of this team, particularly because CT images are critical for screening the entire aorta, iliac arteries, and femoral arteries to establish the subset of potential candidates with aortic stenosis who are best suited for TAVR.

Regarding the annulus, transesophageal echocardiography (TEE) is currently the main reference tool used to size the prosthetic valve.[21,22] There have been efforts to interpret electrocardiography (ECG)-gated CT in conjunction with TEE because CT produces high-resolution volumetric cine images of the aortic root, including the valve leaflets and coronary ostia. When ECG gating is used, any plane can be postprocessed, including but not limited to those from TEE.[23,24] For this reason, many studies have focused on CT imaging of the aortic root.[20,23-25] CT can supplement echocardiography entirely for patients with poor acoustic windows. The decision to use primarily echocardiography or CT as the reference modality is beyond the scope of this article. Instead, the authors focus on the remainder of the arterial system, from the aortic arch to the femoral arteries, the latter being the most common percutaneous access site for

TAVR. It is critical to evaluate the iliac and femoral arteries to ensure that these vessels will allow the delivery of large sheaths, ranging from 18 F (French catheter scale) to 25 F. Many patients with aortic stenosis are excluded from the transfemoral approach because their vessels have a small luminal diameter, are too tortuous, are severely calcified, or demonstrate a combination of these. These clinical decisions are based on CT images.

To the authors' knowledge, there is relatively sparse data regarding common or best practices for CT angiography image acquisition and image postprocessing of the iliac and femoral arteries for TAVR planning. In the research phase of these procedures, patient volume has been limited to larger academic centers that have individualized protocols reflecting the CT scanners available at those institutions and the preferences of individual radiologists. For example, Schoenhagen et al and Kurra et al have detailed those image protocols prescribed by the radiologist and carefully evaluated the radiation dose using filtered back-projection techniques.[26,27] They have compared these standard protocols with iterative reconstruction methods that can lower patient radiation exposure, improve image signal-to-noise ratio, or both. However, although iterative methods are available for most scanners recently manufactured, these algorithms are generally not available for older CT units. There are recommendations for iodinated contrast doses with respect to patient size; 1 of the advantages of new scanners is the ability to lower the iodine load, in keeping with imaging protocols for the coronary arteries.[28-30]

As imaging moves from large academic, research-based centers to smaller hospitals and outpatient centers, the CT technologist's role in image acquisition and postprocessing is expected to become increasingly important. Moreover, images can undergo Web-based postprocessing strategies so that image acquisition and postprocessing are separated. This further emphasizes the need for a detailed, standardized approach to the complex patients who require CT imaging and postprocessing of a larger fraction of the arterial system prior to TAVR.

Image Acquisition and Postprocessing

For TAVR patients, the imaging task is a comprehensive angiogram that includes the entire aorta, the iliac, and common femoral arteries. The protocol is similar to imaging for aortic dissection because the entire aorta is imaged. However, for TAVR imaging, the craniocaudal field of view should extend more inferiorly. Moreover, if there is no contraindication, iodinated contrast should be given for first-pass imaging, similar to CT for aortic dissection, because 1 objective is to describe noncalcified plaque and measure the lumen in places where there is atherosclerotic narrowing. However, when contrast is given to TAVR candidates, noncontrast imaging is not needed because, unlike patients with suspected aortic dissection, the risk of intramural hematoma is small. It is possible to evaluate vessel size without iodinated contrast, but image postprocessing is far more complex, and information regarding noncalcified atheroma is not available.

Imaging Platforms

Both axial and helical protocols can be used. At our institution, axial imaging is performed using a 320-detector row (Aquilion One, Toshiba Medical Systems Corporation, Tochigi-ken, Japan) scanner that provides 16 cm of craniocaudal coverage in each volume. From the perspective of the technologist, there are several protocol considerations. The first decision is whether to use ECG gating for the most superior volume (ie, the volume that includes the aortic valve). As noted previously, the current reference standard for size of the aortic annulus is TEE. Because ECG gating dramatically reduces motion artifact, if it is not used, CT may not provide reliable data for planning the size or deployment of the device.

For the protocol itself, 320-detector CT enables ECG gating for the superior volume only. However, the potential drawback is poor timing of the contrast bolus for the inferior volumes (see **Figure 1**). When ECG gating is chosen, the technologist and the imaging team should be prepared to perform a second study, with a separate injection, if the enhancement of the iliac and femoral arteries is not adequate.

In a typical case, the scan range extends from the lung apices to the lesser trochanter of the femur with wide-volume (axial step-and-shoot) mode. Once set, the scanner automatically adjusts to the number of volumes required to cover the craniocaudal field of view (see **Figure 2**). It is important for the technologist to center the patient in the x-y plane because, as described

later, a small axial field-of-view reconstruction is used to enhance relative spatial resolution.

Helical imaging at Brigham and Women's Hospital uses a first-generation dual-source CT scanner (Somatom Definition, Siemens Medical Systems, Erlangen, Germany). If high-pitch spiral mode is available, ECG gating usually is not required to achieve adequate images of the annulus, and the entire craniocaudal field of view can be enhanced in a single contrast injection. If high-pitch spiral mode is not available and CT images of the annulus are needed, the authors recommend that the scan be performed with ECG gating for the arch to the midheart, followed by a continuous non–ECG-gated acquisition for the remainder of the craniocaudal field of view. Like the protocol using wide-area detector CT, this may require a second injection to achieve good distal enhancement. If ECG gating is performed, the CT pitch can be raised to roughly 1.5, and imaging can be performed rapidly to increase the probability that enhancement is adequate.

For both imaging platforms, if ECG gating of the

Figure 1. *A curved multiplanar reformatted image of the entire aorta and iliofemoral system in a transcatheter aortic valve implantation patient showing poor contrast enhancement distally. The evaluation of noncalcified plaque within the iliac and femoral arteries is not possible, and thus, the lumen cannot be sized with confidence.*

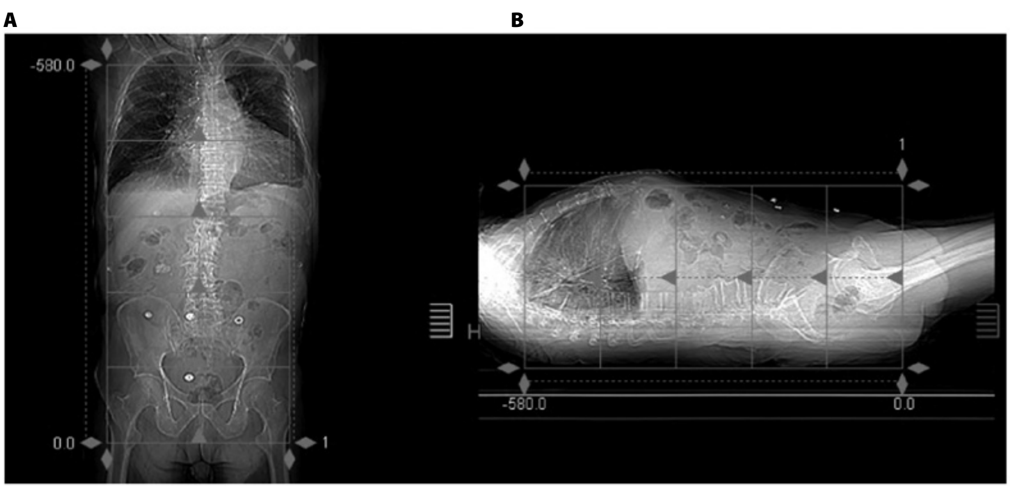

Figure 2. *Anteroposterior (A) and lateral (B) topograms from the wide-area detector computed tomography system demonstrating the 16-cm volumes used for step-and-shoot axial imaging.*

chest is used to decrease motion artifact between the left ventricular outflow tract and the ascending aorta, it can be performed either prospectively or retrospectively.[31-33] For both, image acquisition is synchronized to the ECG. Retrospective gating acquires the data throughout the cardiac cycle so that the entire valve motion can be viewed as a cine loop, as in echocardiography. Prospective gating limits the acquisition to a small fraction of the cardiac cycle; motion artifact is reduced but the cine loop is not available. The relative disadvantage of using retrospective gating is the higher radiation dose. However, in the authors' experience, TAVR candidates are elderly with substantial comorbidities. For this reason, TAVR is preferred over traditional, open surgery to replace the aortic valve. In these patients, life expectancy is short, and the risks of a fatal radiation-induced malignancy are negligible.[34] Thus, at Brigham and Women's Hospital, ECG gating usually is performed retrospectively to maximize the information from the CT scan.

For the CT acquisition, the rotation time can be minimized to lower the total scan time. Moreover, for both platforms, we scan from the caudal to the cranial direction. Finally, the breath-hold instruction is given as the scan commences, without additional delay. The time of the breath hold can be long, particularly with older-generation scanners, and as noted previously, patients may be ill. The technologist should practice and time the breathing with the patient, keeping in mind that it may be necessary to image the chest and the abdomen/pelvis separately if patients are short of breath.

High-quality images are routinely generated from both imaging platforms used at our institution. For wide-area detector CT, the typical patient is imaged in 5 to 6 subvolumes; scanner software automatically stitches these subvolumes into a final complete data set.

The time between subvolumes is roughly 1000 ms; arterial contrast-enhancement differences have been observed but typically are not problematic for image postprocessing or interpretation. Except for the high-pitch spiral mode, helical acquisition is less rapid. As described later, for our 32 × 2 detector row scanner, the collimation was set to 1.2 mm so that imaging of the entire volume could be achieved in times approximating a breath hold. For second-generation dual-source systems, this tradeoff of thicker slices can be largely avoided because of the increased craniocaudal coverage per unit of time. Finally, although high-quality images can be achieved with 64- through 320-slice scanners, images from 16-slice scanners may be limited by breathing artifact or poor contrast enhancement, and it may be appropriate to either perform these studies on a 64-slice scanner or alternatively image the chest and the abdomen/pelvis separately.

Imaging Parameters

The imaging protocol is designed to obtain high-quality images; thus, the authors recommend relatively high tube currents and voltages, despite potentially increased individual patient radiation exposure (see **Table 1**). As noted earlier, for the purposes of minimizing both the scan time and the delay between bolus triggering and acquisition, the authors recommend high pitch and low rotation times as well as scanning in the caudal to cranial direction.

At Brigham and Women's Hospital, image reconstruction has produced isotropic or near-isotropic voxels amenable to the extensive postprocessing. This includes patients for whom noncontrast imaging was requested by the referring clinician. As with other body parts, the imaging parameters input by the technologist influence image quality, primarily by determining the signal-to-noise ratio and the subsequent patient radiation exposure. Using our protocol and visual inspection of the images with more than 60 patients, no images were severely degraded by high noise. Moreover, the automated arterial segmentation is readily recognized as distinct anatomical structures, and thus, image postprocessing is not dramatically lengthened by poor image quality.

Injection Protocol

Iodinated contrast (iopamidol 370 mg iodine/mL; Bracco Diagnostics, Princeton, New Jersey) is intravenously injected with a dual-syringe power injector (EmpowerCTA Contrast Injection System, Bracco Diagnostics Inc, Princeton, New Jersey). The contrast volume and concentration determine the iodine load and are chosen according to the individual patient's estimated glomerular filtration rate (eGFR; see **Table 2**). If the eGFR is more than 60 mL/min/1.73 m^2, then 100 mL of contrast is used; if the eGFR is between

Table 1

Summarized Parameters for CT Acquisition for Dual-Source 32 × 2 Detector and Wide-Area Detector Imaging Systems

Acquisition	Dual-Source 32 × 2 Detector Row CT	Wide-Area Detector CT
Scout/scanogram	Anteroposterior	50 mA AP/100 mA lateral[a]
Patient position	Supine, feet first	Supine, feet first
Scan range	Femoral head to aortic arch	Femoral head to aortic arch
Field of view (mm)	240	260
Scan direction	Caudal–cranial	Caudal–cranial
Tube voltage (kV)	120	120
Approximate tube load[b] (mAs)	120-140 use CARE dose 4-D[c] (dependent on patient habitus)	125-150 use SURExposure[d]
Gantry rotation time(s)	0.33	0.35-0.45
Pitch	1.5	Axial imaging
Detector width (mm)	0.6	0.5
Collimation (mm)	32 × 0.6	320 × 0.5
Table feed (mm/rotation)	14.4 or 17.28 (dependent on mAs)	Axial imaging

Abbreviations: CT, computed tomography; mA, milliampere; AP, anterior-posterior; kV, kilovolt; mAs, milliampere-seconds.
[a] *Note that actual values should be patient dependent. Wide-area detector scanner uses 2 topograms.*
[b] *Dose modulation used for both CT hardware platforms and readings are patient-dependent.*
[c] *Siemens Medical Solutions USA, Inc, Malvern, PA.*
[d] *Toshiba America Medical Systems, Tustin, CA.*

Table 2

Contrast Injection Protocols Stratified by Patient Renal Function

100 mL total contrast injection protocol for patients with normal estimated glomerular filtration rate.

Phase	Medium	mL/sec	mL
1	Contrast	4.0	60
2	Contrast	2.5	40
3	Saline	2.5	30

75 mL total contrast injection protocol for patients with decreased estimated glomerular filtration rate.

Phase	Medium	mL/sec	mL
1	Contrast	4.0	50
2	Contrast	2.5	25
3	Saline	2.5	30

30 and 60 mL/min/1.73 m^2, then 75 mL of contrast is used. For patients with severe renal impairment (eGFR < 30 mL/min/1.73 m^2), noncontrast imaging can be performed.

When contrast is administered, manual triggering is used to maximize enhancement in the iliac and femoral arteries. Because the scan direction is caudal to cranial, a reference slice is chosen just above the femoral heads.

In the authors' experience, this requires a boost in the triggering scan mAs compared with other protocols, such as stent graft planning, where peak enhancement occurs in the distal aorta. Moreover, the small caliber and tortuosity of the target vessels make the region of interest placement within the patient unreliable. For this reason, we place the region of interest outside of the patient and manually initiate the scan when the contrast is visually considered to be adequately dense. The researchers' rationale for not using a test bolus is that this increases the total iodine load to the patient; moreover, the test bolus increases the total examination time.

The challenges of full vascular contrast enhancement are met with a dual-syringe power injection. The iodine load is adjusted according to eGFR using 1 of 2 contrast protocols. A more detailed correlation between iodine load and eGFR can be attempted, but it is unlikely that more than 100 mL of contrast at 370 mg of iodine/mL will be needed if the contrast bolus is properly timed.

The caudal-to-cranial injection method is chosen for these patients at Brigham and Women's Hospital so that if contrast enhancement diminishes at the end of the acquisition, it does not negatively affect the interpretation of the iliac and femoral arteries, where measurements with specific cutoffs (eg, 7 mm for catheterization) are paramount. Manual triggering is used for both injection protocols, and we have not had suboptimal timing of the contrast delivery. To the authors' knowledge, there has not been a case of contrast-induced nephropathy among the TAVR patients at our institution.

Image Reconstruction

For the wide-area detector platform, 3 smooth kernel reconstitutions are performed, including 2 thin-slice volumetric datasets (0.5-mm thick × 0.5-mm interval) and 1 thicker slice dataset (3.0-mm thick × 3.0-mm interval). One thin-slice dataset is reconstructed using a full-scan reconstruction for less image noise to evaluate the iliac and femoral arteries. The other thin-slice dataset is reconstructed using a half-scan reconstruction for superior temporal resolution (ie, less motion artifact) to evaluate the aortic annulus. The 3.0-mm dataset is used to evaluate the chest, abdomen, and pelvis for incidental findings. For the first-generation dual-source CT in helical mode, half-scan reconstruction is not an option. Thus, the annulus has motion artifact because of the poorer temporal resolution.

The principle for choosing the x-y field of view is that it should be the smallest area possible to include the entire aorta and the iliofemoral system. We use both frontal and lateral topograms to ensure adequate coverage (see **Figure 2**). For wide-area detector CT, 280 mm is typically sufficient, even for larger patients. For smaller patients, we may choose 240 mm to improve the apparent in-plane spatial resolution. For helical imaging on the first-generation dual-source scanner, if the high-pitch mode is available (it is a software upgrade for first-generation scanners) and is used, the maximum x-y field of view is 240 mm. Thus, larger patients cannot be imaged with this protocol. When this is the case, we use the standard helical mode, and thus, the x-y field of view can be expanded to accommodate all the required vasculature. It is also important to note that, at the time of this writing, if a first-generation scanner is upgraded to include high pitch, ECG gating is no longer an option because it is for a second-generation dual-source CT unit.

Image Postprocessing

At Brigham and Women's Hospital, all DICOM (Digital Imaging and Communications in Medicine) images are transferred to a dedicated image postprocessing workstation (Vital Images Inc, Minnetonka, Minnesota). Analyses are performed using the Vitrea fX 6.0 software package. Because of the large arterial coverage needed for planning, the postprocessing tasks are divided into 4 parts: the annulus, the remainder of the aorta, the right iliac artery and its branches, and the left iliac artery and its branches. Using the methods described in the next sections, each postprocessing task is performed separately.

The analyses begin with a postprocessing software subpackage designed for aortic stent graft planning that provides an initial arterial segmentation, including a plot of the centerline that displays at least 1 cross-sectional view and a curved multiplanar view of each vessel.

The total time ranges from 1 hour to approximately 3 hours, depending on the degree of disease and tortuosity of vessels. Noncontrast images require longer postprocessing time. In the authors' experience, high-quality images were generated and used to plan the intervention in all cases.

Aortic Annulus Segmentation

For the annulus, the images with the minimum motion artifact are used. For wide-area detector CT, this is either the ECG-gated images, if available, or the half-scan reconstructed images that do not have gating. For first-generation dual-source CT, high-pitch-mode images are used, if available. In the absence of ECG gating, excessive motion typically prohibits adequate annulus segmentation. If gating is available, these images then are postprocessed.

Once the best volume for the annulus segmentation is selected, using a curved multiplanar reformation (MPR), the volume is cropped to the thoracic aorta. Because of atherosclerotic disease, motion, and differing contrast enhancement, the machine-derived centerline requires manual editing to avoid measurement errors. Centerline correction is performed by visually inspecting curved MRP views on a slice-by-slice basis, particularly at the annulus. Because the geometry of the valve leaflets is critical (see **Figure 3**), the centerline is adjusted so that the annulus is viewed orthogonal to the best projection at the anchor points.[35]

After the centerline is finalized, the lumen boundaries of the aortic annulus are manually edited on a slice-by-slice basis. Meticulous postprocessing and verifying each of the images ensures that the final 3-D volumes accurately represent the annulus diameter that potentially can be used for planning the intervention. From a straightened MRP centered on the annulus, the 16-mm segment expected to span the extent of the Sapien valve is approximated.

Segmentation of the Remainder of the Aorta

Images of the entire aorta demonstrate size, tortuosity, and calcium burden. This helps to guide the intervention because the large catheter potentially must be navigated in an enlarged or ectatic aorta, and the compliance of the aorta can be roughly estimated by the degree of calcification.

For wide-area detector CT, we use the full-scan reconstructed images or, if 2 injections are required,

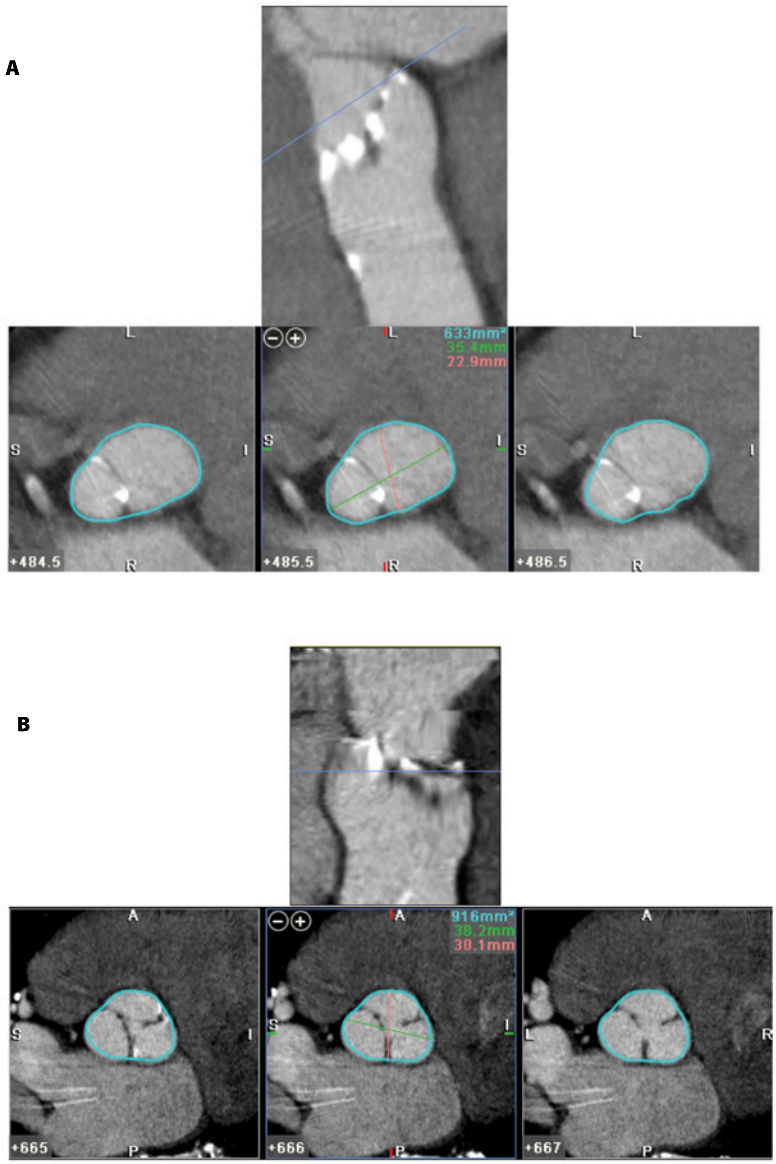

Figure 3. *Aortic valve leaflets. A. Off-axis views (top) demonstrating asymmetric planes through the valves (bottom). These are the result of an inaccurate centerline. B. After correction of the centerline, each sinus of Valsalva has a roughly equal area and can be better evaluated before intervention.*

that injection tailored to the descending aorta. For first-generation dual-source CT, high-pitch-mode images are used, if available. Otherwise, non–ECG-gated images are used.

The previously described aortic stent graft planning software package provides segmentation as well as a volumetric display. Unlike the annulus, a manual slice-by-slice correction of the centerline typically is not required. Using the segmented images provided by the software, we create a stack of left anterior oblique images in the parasagittal ("candy-cane") projection. Finally, 3-D volume-rendered images are generated in a rotating frame, typically 60 equally spaced projections of 6° each.

Iliac and Femoral Artery Segmentation

The same acquisition for the descending aorta is further processed; the left and right iliac and femoral arterial systems are evaluated separately. For patients with pathology related to the internal iliac arteries, (eg, internal iliac aneurysm), separate postprocessed images are created to highlight the abnormality. For the segmentation, the volume is initially cropped from just superior to the bifurcation through the level of the femoral head because this is roughly the point at which the catheter is introduced.

Because of tortuosity from atherosclerotic disease and the changing caliber of the arteries, the machine-derived centerline may require manual editing. This is performed on the curved MPR mode and transverse cross-sectional views. The automated lumen boundaries are inspected manually and, where necessary, corrected. As opposed to performing the correction of the lumen on a slice-by-slice basis, interpolation of the contrast-enhanced lumen borders can be used along short arterial segments to decrease the total image postprocessing time.

Noncontrast Imaging

For patients who cannot receive iodinated contrast media, a modified postprocessing algorithm is used. The entire aorta and branch vessels are segmented manually by drawing regions of interest at multiple slice levels with interpolation to aid in the speed of segmentation. This allows the 3-D volume to be created. Because the aorta and iliac arteries are segmented as a separate object, the color look-up table is adjusted to simulate a contrast-filled vessel. This requires window-level manipulations to identify properties of the lumen and arterial wall, but eventually allows vessel calcification and tortuosity to be analyzed (see **Figure 4**).

After the aorta and iliofemoral system have been segmented as separate objects, a manual centerline is created to identify arterial segments less than 7 mm in diameter. The manual centerline enables true short-axis views and double-oblique projections for accurate lumen measurements. The entire volume then is displayed as a rotating 3-D volume; this is valuable to determine the extent of calcium deposition. Multiplanar images then are rendered in the left anterior oblique, or candy-cane, view.

Image Archival

Each segmentation data set typically is stored in the postprocessed state, a so-called "snapshot" view, so that it can be restored using the postprocessing software. Each projection and volume is saved in multiple formats, including batch MPRs and 3-D volumes stored with semitransparent bone (see **Table 3**). These are permanently archived in the picture archiving and communication system (PACS). Additional axial 3-×-3-mm images are reconstructed in soft-tissue windows, and for the thorax lung windows, for image interpretation. Finally, all source submillimeter reconstructed images are archived in PACS. At Brigham and Women's Hospital, raw CT data are not saved.

The software used in the authors' laboratory is also available in a Web-based format (Vitrea Enterprise Suite, Vital Images, Minnetonka, Minnesota). The snapshot state, even as it exists in PACS, enables further postprocessing from any device that can operate on this enterprise.

Image interpretation is beyond the scope of this article. However, at Brigham and Women's Hospital, all images are interpreted, coded, and reported by the attending radiologist who has all of the reformations, as well as the axial 3-mm reconstructions and the submillimeter source images, available from the PACS.

Discussion

Because many TAVR patients have compromised renal function, there is a tradeoff between the acquisition time and the iodine load. In theory, all else being equal, faster scanning can translate into lower contrast loads. Thus, increasing the pitch (for helical imaging) and the width of the detector rows adds value by lowering the scan times.

The decision regarding tube current and voltage is based on experience with both CT systems and advice from the manufacturers. Patient radiation dose is linearly proportional to the tube current and nonlinearly related to the voltage. Specifically, small increments in kV can increase radiation exposure dramatically.

Because of overall concern with radiation exposure in CT imaging, imaging follows the ALARA (as low as reasonably achievable) principle to minimize unnecessary radiation doses. Although these efforts are important for the population in general, as noted previously, the TAVR patient population generally is older, has severe cardiovascular disease, and thus, has a relatively short life expectancy compared with the general population. Therefore, although limiting radiation dose is important in every case, it is paramount to acquire high-quality, relatively low-noise images. Image quality for these patients should never be compromised for the purpose of dose reduction.

As noted earlier, the CT acquisition for TAVR planning resembles a long-segment aortic dissection protocol.

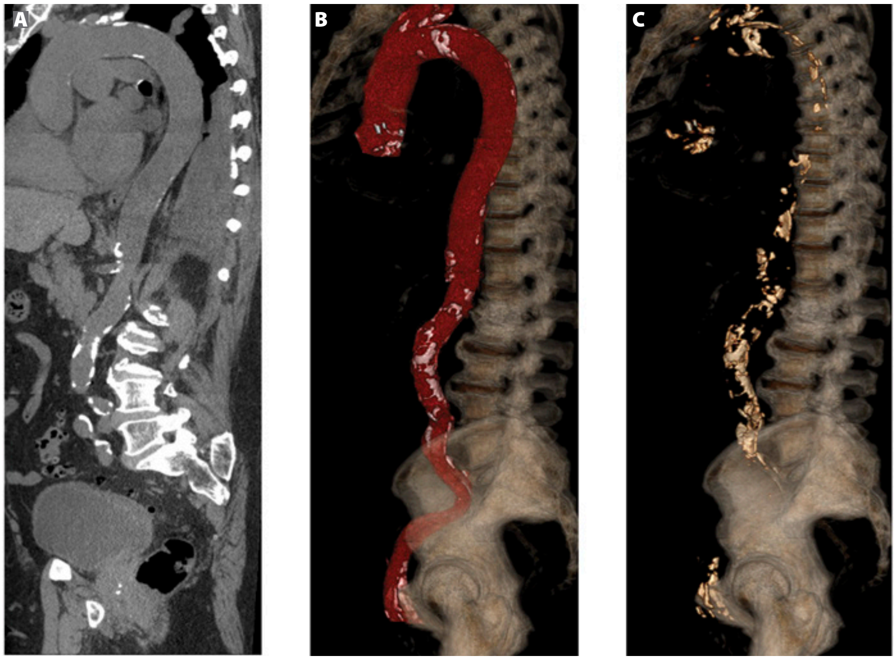

Figure 4. *Noncontrast imaging is used for patients with either severe allergy to iodine or severe renal dysfunction. A. Left anterior oblique 30° projection through the aortic arch shows the thoracic and part of the midabdominal aorta. B. 3-D volume rendering using a thick maximum intensity projection. The aorta is displayed in red via window and leveling within the postprocessing software. The centerline was manually drawn. C. Subtracted image from B, demonstrating only the calcification.*

Table 3

CT Image Postprocessing, Stratified by Anatomy of the Aorta

Anatomy	Image Post-Processing and Saved Images[a]
Aortic annulus	Combined 3-D LAO 30° projection of the aorta; annulus manual segmentation; curved MPR of the annulus with 16-mm measurement (see **Figure 5**)[b]
Overview of entire aortoiliac system	3-D VR rotating batch (60 frames each separated by 6°) with semitransparent bone (see **Figure 6**)[c]
Distal aorta and both iliofemoral arteries	Curved multiplanar reformation with short-axis segmentation at level with minimum diameter (see **Figure 7**)

Abbreviations: LAO, left anterior oblique; MPR, multiplanar reformatted images; VR, volume rendering.
[a] *Saved images can be restored in the postprocessed state for additional analyses.*
[b] *16-mm length corresponds to the expected craniocaudal dimension of the valve after intervention.*
[c] *Available as cine.*

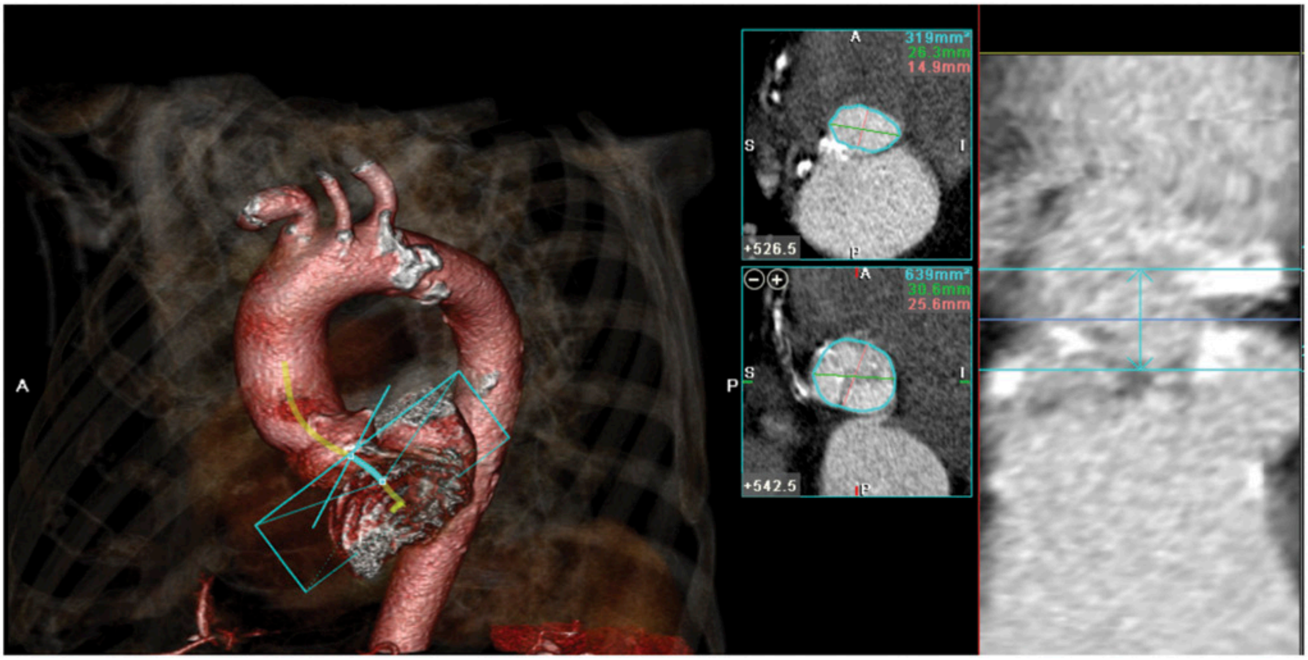

Figure 5. *Three-dimensional (left) aortic arch with focus on the annulus (inset). Curved multiplanar reformatted view through the aortic valve plane (right) with the expected 16-mm span of the valve dimension overlayed.*

However, because TAVR patients all have severe aortic valve disease, the enhancement along the course of the aorta is atypical. Based on the authors' experience to date, 1 key message for the technologist is that the iodine bolus is delayed compared with patients who have a normal aortic valve. Because the delay time can be prolonged and variable among TAVR patients, the authors recommend manual contrast bolus triggering. This strategy should serve to increase, not decrease, the confidence of the technologist.

Although differences in contrast enhancement are observed in normal vessels as well as in those with disease, in the setting of large vascular volumes, inadequate enhancement is most likely related to suboptimal timing.[36-38] This emphasizes the importance of excellent timing so that the entire length of the aorta, iliac arteries, and femoral arteries are imaged with adequate enhancement. In the absence of rapid scanning, 2 separate injections may be required. This ensures adequate contrast enhancement for all arterial stations for all patients at the expense of a potentially higher dose of iodine. We do not have experience in minimizing the contrast bolus for patients imaged with 2 injections. In theory, imaging of the annulus and aortic arch could be performed with approximately 50 mL of contrast media. However, there are challenges in timing because of the severe aortic disease. Although the authors do not have experience with such protocols for TAVR patients, it is likely that bolus tracking yields adequate image quality with limited iodine loads for each arterial station. This probably will become important for the CT technologist because the use of the TAVR procedure expands beyond large academic centers.

The postprocessing required for TAVR is complex and time-consuming. Editing the centerline and individual lumen contours is tedious; nevertheless, this part of the imaging process is essential to determine the vessels' sizes and tortuosity and the presence of atherosclerotic disease that can negatively affect the procedure. As noted previously, it has been suggested that CT images be used for illustrating the annulus and providing detailed size measurements of the entire aortic root.

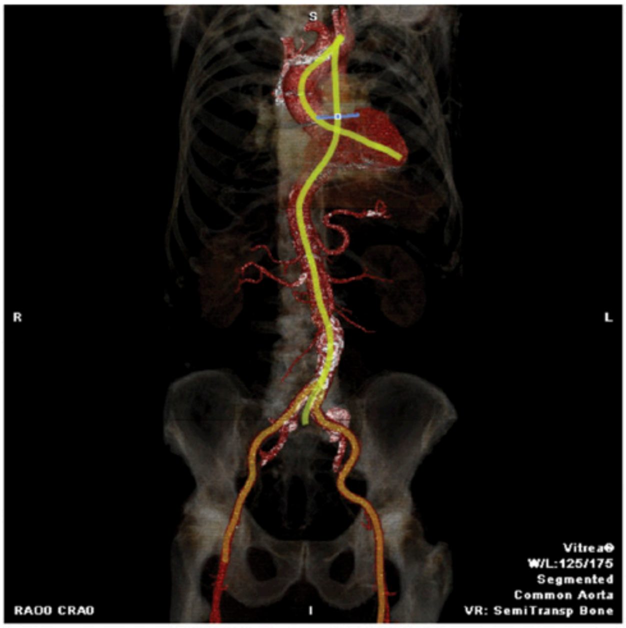

Figure 6. *Single frame from the rotating batch that depicts the entire anatomy required for transcatheter aortic valve implantation planning.*

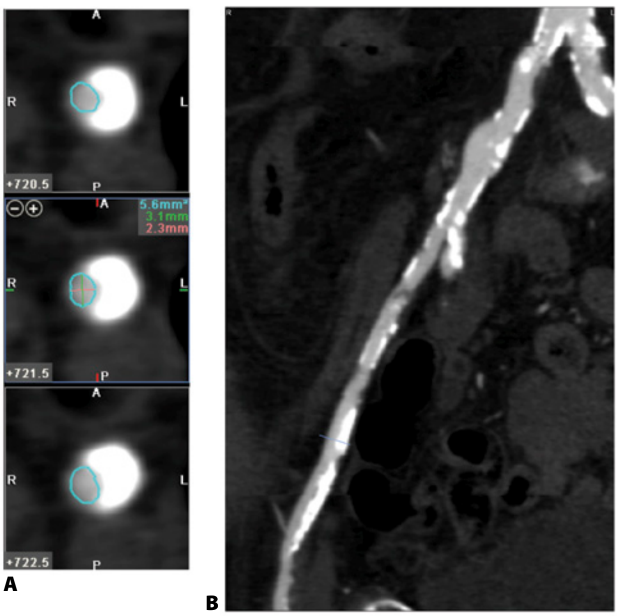

Figure 7. *A. Short-axis views through the center line of the right external iliac artery, where there is minimum lumen diameter (blue tracings). B. Extended curved planar reformatted image shows the full extent of the artery. In this patient, lumenal stenosis is a contraindication for catheter insertion.*

Regarding the prosthesis, an incorrectly sized device may migrate or the patient may have paravalvular aortic regurgitation or blood leakage at the location of the procedure. At present, TEE is considered the reference standard and can be used during the procedure, and most studies to date have correlated CT angiography measurements with those obtained from TEE.

It is possible that cine CT could supplement ultrasonography methods for sizing and visualization of the aortic root. CT measurements of the annulus can be routinely generated if the arch images are acquired with ECG gating. For CT image acquisition, 1 theoretical disadvantage of ECG gating is the greater patient radiation exposure, although this is less of a concern in the current TAVR patient population than in the general public.

It is also important that the sizes of the iliac and femoral arteries are accurate to ensure that the TAVR catheter can traverse through the femoral system to the annulus. The most common size sheath for TAVI is 18 F to 25 F, which correlates with a minimum vessel diameter of 7 mm. Consequently, at the authors' institution, 7 mm is considered the minimum diameter necessary for safe access via the common femoral arteries. In each vessel, the most important landmarks corresponding to the femoral head and both bifurcations are carefully reformatted, measured, and reported.

In addition to this size requirement, many higher risk patients with severe aortic stenosis referred for transcatheter aortic valve replacement may not be candidates for the femoral approach. The main reasons are the presence of large, noncalcified, or complex plaques, tortuous vessels that would limit the ability to safely pass the catheters for the procedure, or a combination of these issues. For these reasons, meticulous characterization of vessel abnormalities and course is essential.

With respect to clinical indications, we expect that the TAVR program will follow the lead of stent graft placement in patients with abdominal aortic aneurysm. Initial clinical trial rules imposed limits, in particular, the requirement that for TAVR patients, all branches of the aorta are a minimum of at least 7 mm in diameter. However, as experience grows and the procedure moves from research to the clinical domain, patients are likely to undergo percutaneous interventions for increasingly challenging cases. Thus, it remains critical that accurate, reproducible measurements are generated for each case.

Although both CT and MR angiography provide a noninvasive assessment of the arteries, CT is becoming the reference standard for patients who require arterial assessment of the lower extremities.[39] It has become the reference standard to visualize these vessels and assess whether a patient is a candidate for TAVR via the femoral approach.

Finally, it is essential to implement a meticulous postprocessing algorithm for all TAVR candidates because comprehensive arterial segmentation is cumbersome. In the authors' experience, for patients with good enhancement, relatively straight arteries, and little atherosclerosis, automated segmentation is quite accurate, requiring only small changes to the centerline and lumen contours. On the contrary, complex patients (characterized by poorer enhancement, tortuous iliac and femoral arteries, and complex plaque) require extensive postprocessing. Individual cases typically require 1 to 2 hours to postprocess, whereas complex cases might take longer. Increased postprocessing time allows for better visualization of vessels and more accurate sizing of vessels in complex cases; however, it does not necessarily exclude patients from TAVR. The authors believe that methods for rapid, accurate segmentation will prove critical so that future studies do not overwhelm a 3-D lab or postprocessing center.

Conclusion

Based on the initial success of TAVR and the overall enthusiasm for minimally invasive procedures, the number of TAVR procedures is expected to increase. CT image acquisition and postprocessing for TAVR candidates is an important component of the intervention. The CT technologist has a critical role in the care of these patients, emphasizing the clinical importance of a detailed, standardized imaging approach.

TAVR is among the most complex procedures in radiology, and thus it is important that CT technologists involved in the image acquisition and image postprocessing procedures are as knowledgeable as possible regarding clinical detail, protocols, potential pitfalls, and factors that may influence workflow.

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Ultrasonographic Kidney Sizes Among Children in Benin, Nigeria: Correlation With Age and BMI

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Purpose To determine kidney sizes among Nigerian children using ultrasonography to provide local reference data that could be compared with renal growth charts when assessing kidneys of Nigerian children for growth or pathology.

Methods The study design was cross-sectional and a convenience sampling technique was used to select a sample. Consent was obtained from participants and ethical approval was obtained from the local ethics committee. A DP-1100 sector scanner with a 3.5 MHz probe was used for the study. Sonographers measured kidney length, width, and thickness and calculated renal volume. Renal sizes were correlated with somatometric parameters. Regression equations were derived for each pair of variables.

Results No statistically significant difference was found in kidney sizes between male and female participants or between length, width, or volume of right and left kidneys. A strong correlation was found between kidney length and volume and the participant's age and body mass index.

Conclusion This study has provided values of kidney sizes in a normal Nigerian pediatric population. Regression equations also were derived for easy computation of kidney sizes.

Ultrasonography has virtually replaced conventional radiography for evaluating kidney diseases. Ultrasonographic measurement of kidney sizes, particularly in children, is essential in the evaluation and follow-up of treatment outcomes. It is also essential in evaluating kidney growth. Accurate sonographic kidney size measurements can prevent other more costly examinations and invasive investigations such as biopsies. Because many renal disorders affect kidney size, it is important to have a set of sonographic measurements available that clinicians can refer to when patients are examined.[1,2]

Sonography is known to be highly sensitive (about 70%) in renal disorder diagnosis, particularly among children. In the pediatric population, sonography is very specific in discriminating renal pyramids from the renal cortex, and use of sonography to measure kidney size can minimize the use of equally sensitive, but costlier modalities.[3,4] Because extremely small kidney size points to chronic and irreversible renal failure, knowing parameters of normal kidney sizes in a given population assists clinicians in detecting renal disorders in their early acute stages and aids in decisions regarding surgical intervention.[5]

Data is available regarding normal kidney sizes for Western and Asian populations.[6-9] The literature has reported that racial differences exist in kidney size and that reliance on universal patterns should be discouraged.[10] Therefore, the authors used sonography to measure renal dimensions (ie, length, width, and thickness) and calculated renal volume in a population of healthy Nigerian children.

Literature Review

Sonography can be used to produce simple growth charts for evaluation of kidney size in children.[1] Sonographic methods have been used to measure kidney sizes among populations of neonates and adults in Nigeria, and sonography now is the imaging modality of choice for kidney evaluation because the modality is less expensive, easier to perform, and more readily available than other imaging modalities.[11,12] In addition, sonography does not involve ionizing radiation and is a real-time study. Sonographic renal size measurements are not affected by radiographic magnification.[13] This enlargement of images is associated with plain film radiography because of the large subject/film distance. This renders renal size measurements from either a plain film or the nephrogram film of the intravenous urogram series inaccurate.[13] The ability to discriminate the renal pyramid from the cortex in children has been identified as 1 of the major reasons sonography is so specific in detecting renal diseases.[3,4]

Measurement of kidney size is important because most renal diseases affect kidney size.[2] An extremely small kidney size can indicate chronic and irreversible renal failure, thus knowledge of normal kidney sizes obtained from local population studies can assist clinicians in early detection of kidney diseases at an acute stage and assist in determining management, particularly whether surgical intervention is required.[4] Sonographic kidney size measurement must therefore include measurement of kidney length, width, thickness, and volume.[14] Several studies have assessed renal sizes in children and have correlated kidney length and volume with somatometric parameters such as age and body mass index (BMI).[15-17]

Kidney size is known to be affected by several factors, including race.[10] Other factors that affect sonographic renal size measurement include the state of the ultrasound machine used, the training and experience of the examiner, observer measurement errors, and the subject's nutritional status.[17-20] Sonography has been used widely to measure kidney sizes among American, Western, and Asian pediatric populations.[6-8] In India, for example, Otiv et al reported on use of sonography to measure kidney sizes among 1000 children.[9] It is imperative to measure kidney sizes accurately to establish data suitable for different local environments instead of relying solely on American, Asian, or Western data as universal patterns.[10]

Methods

This cross-sectional study was conducted between April and July 2010. An age group stratified convenience sample of 518 Nigerian children with no history of renal disorder was drawn from among students of the University of Benin Teaching Hospital (UBTH) staff schools, Benin City, Nigeria. All volunteers returned consent forms signed by their parents and the head teacher of the staff school before they were accepted for screening. The study was approved by the UBTH ethics committee.

Before the examination, volunteers were screened by a pediatrician to ensure that only subjects who had no history of acute or chronic disorder were included in the study. Each subject's age, weight, and height were recorded at the time of scanning. Subjects were weighed on a beam balance and their weights were recorded to the nearest kilogram. Height was measured on a stadiometer to the nearest meter. BMI was calculated from weight and height of each subject. Two subjects were excluded from the study because of extreme obesity.

Participating children were not asked to fast overnight or skip their breakfast. However, all participants were asked to empty their bladder immediately before the examination. All ultrasound examinations were conducted using a real-time mechanical sector scanner DP – 1100, manufactured by Shenzhen Mindray Bio-Medical Electronics Co Ltd (Shenzhen, China), with a 3.5 MHz convex array probe having a wide contact face. Subjects were placed in a prone position while the examinations were conducted by a sonographer with wide experience in renal sonography and about 2 years of hands-on experience on the sonography unit.

The sonographer measured maximal length of each participant's kidney in the section visually appearing to represent the longest longitudinal dimension of the kidney on a longitudinal scan image. Width, however, was measured from the longitudinal image at the renal hilum, and thickness was measured from a transverse image obtained with the probe placed close to the renal hilum and almost perpendicular to the longitudinal axis of the kidneys.[8] Renal volume was calculated according to the following formula [9]:

$$\textit{Renal volume} = \textit{Length} \times \textit{width} \times \textit{thickness} \times \pi/6$$

BMI was calculated with the formula:

$$\textit{Body mass index (BMI)} = \textit{weight (kg)/height squared } (m^2)$$

Mean length, width, thickness, and volume of the right and left kidneys were calculated separately for participant age groups aged 1 year to 17 years. Dimensions of kidney size (ie, length, width, thickness, and volume) were dependent variables and were correlated with independent somatometric variables (age and BMI). Regression equations and correlation coefficients (***r***) were derived for each pair of dependent and independent variables. Statistical significance of differences among the groups was computed with the t test statistic. Pearson product moment correlation was used to derive the correlation coefficients. All statistical analyses were performed with the computer software SPSS version 17.0 (IBM, Armonk, New York).

Results

The research included 518 children (273 boys and 245 girls) stratified into 17 groups. The smallest group had 18 subjects and the largest group included 41 subjects (see **Table 1**). There were no statistically significant differences between the right and left kidney sizes for length, width, and volume; however a significant difference was found between the right and left renal thickness measurements (see **Table 2**). Mean kidney length ± SD rose from 6.32 ± 0.8 cm at 1 year to 10.9 ± 0.35 cm at 17 years of age. Mean kidney volume ± SD also rose steadily from 37.66 ± 6 mL at 1 year of age to 119.89 ± 15 mL at age 17 years (see **Table 3**).

Renal sizes correlated well with age and BMI. Renal length correlated most with age (***r*** = 0.8) and thickness correlated the least (***r*** = 0.6) with age. Kidney volume had the strongest correlation with BMI (***r*** = 0.8), whereas kidney length had the weakest correlation with BMI (***r*** = 0.6). The **Figure** shows scatter diagrams of kidney sizes relating to age and BMI. Linear regression equations for predicting kidney sizes from age or BMI are shown in **Table 4**.

Discussion

In the study, renal sizes correlated well with somatometric variables (age and BMI). There was no statistically significant difference between renal sizes of male and female subjects despite appreciable differences in body size and growth rate between the 2 sexes and between right and left kidney length, width, and volume. Statistical difference was significant, however, between right and left kidney thickness (*P* = .008). This result is similar to the findings of other studies that suggested that many sonographers find it difficult to measure renal thickness acurately.[9,15] Furthermore, a number of earlier studies that assessed kidney sizes among children and correlated sizes with somatic parameters also reported findings similar to this study.[16,17]

On comparison, sonographically measured kidney length was higher by 21% and volume by 24% among a population of Nigerian children than the same measurements among a population of Indian children. A similar study

Table 1
Age Group Distribution of Children

Age (year)	n (%)
1	23 (4.4)
2	28 (5.4)
3	34 (6.6)
4	33 (6.4)
5	36 (6.9)
6	27 (5.2)
7	37 (7.1)
8	41 (7.9)
9	30 (5.8)
10	32 (6.2)
11	33 (6.4)
12	37 (7.1)
13	25 (4.8)
14	32 (6.2)
15	27 (5.2)
16	25 (4.8)
17	18 (3.5)
Total (N) =	518 (100)

Table 2
Mean Kidney Sizes in Overall Studied Population

	Right kidney (mean ± SD)	Left kidney (mean ± SD)	*P* value
Length (cm)	8. 81 ± 1.20	8. 86 ± 1.19	0. 269
Width (cm)	3. 62 ± 0.46	3. 68 ± 0.44	0. 254
Thickness (cm)	4. 61 ± 0.56	4. 54 ± 0.55	0. 008
Volume (mL)	79.76 ± 28.76	80. 85 ± 20.90	0. 299

Table 3

Mean Kidney Sizes of Different Age Groups in the Studied Population

Age (Year)	Kidney length (cm)	Kidney Width (cm)	Kidney thickness (cm)	Kidney volume (mL)	Weight (kg)	Height (m)	BMI (kg/m^2)
	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD
1	6.32 ± 0.8	2.77 ± 0.3	3.66 ± 0.4	37.66 ± 6.0	9.03 ± 0.50	0.83 ± 0.20	13.09 ± 04
2	6.61 ± 0.7	2.81 ± 0.6	3.68 ± 0.4	43.90 ± 8.0	14.50 ± 0.80	0.95 ± 0.40	16.07 ± 0.3
3	7.40 ± 0.8	3.01 ± 0.2	3.82 ± 0.3	44. 59 ± 9.2	15.30 ± 0.40	1.07 ± 0.30	13.42 ± 0.5
4	7.53 ± 0.7	3.07 ± 0.4	3.83 ± 0.2	45.60 ± 8.0	16.00 ± 0.40	1.12 ± 0.20	12.80 ± 0.30
5	7.62 ± 0.8	3.18 ± 0.3	4.10 ± 0.3	51.90 ± 6.0	20.1 ± 0.50	1.14 ± 0.30	15.46 ± 0.50
6	7.70 ± 0.7	3.31 ± 0.2	4.18 ± 0.3	55.33 ± 7.1	21.0 ± 0.70	1.23 ± 0.20	14.02 ± 0.80
7	8.04 ± 0.7	3.48 ± 0.3	4.35 ± 0.4	64.15 ± 6.3	22.0 ± 0.30	1.25 ± 0.50	13.75 ± 0.20
8	8.69 ± 0.6	3.54 ± 0.2	4.43 ± 0.5	72.78 ± 8.4	28.3 ± 1.50	1.41 ± 0.60	14.08 ± 0.21
9	9.15 ± 0.8	3.80 ± 0.5	4.76 ± 0.4	87.54 ± 9.6	30.20 ± 1.04	1.43 ± 0.30	15.10 ± 0.40
10	9.86 ± 0.6	4.04 ± 0.4	4.82 ± 0.5	106.49 ± 13.6	32.0 ± 1.02	1.45 ± 0.40	15.24 ± 0.33
11	10.02 ± 0.9	4.04 ± 0.5	4.84 ± 0.6	109.86 ± 20.1	33.5 ± 0.60	1.47 ± 0.14	15.22 ± 0.50
12	10.70 ± 0.6	4.25 ± 0.3	4.85 ± 0.2	116.18 ± 20.7	35.0 ± 0.40	1.49 ± 0.20	15.77 ± 0.30
13	10.79 ± 0.8	4.26 ± 0.4	4.87 ± 0.7	118.03 ± 16.4	38.10 ± 0.20	1.54 ± 0.30	15. 88 ± 0.40
14	10.86 ± 0.5	4.30 ± 0.3	4.90 ± 0.3	119.01 ± 17.4	42.20 ± 0.30	1.59 ± 0.10	16.68 ± 0.30
15	10.89 ± 0.7	4.31 ± 0.6	4.92 ± 0.8	119.80 ± 20.4	46.80 + 0.20	1.61 ± 0.20	18.08 ± 0.40
16	10.95 ± 0.6	4.34 ± 0.2	4.96 ± 0.4	119.89 ± 24.3	48.30 ± .10	1.61 ± 0.10	18.58 ± 0.20
17	10.99 ± 0.5	4.36 ± 0.3	4.97 ± 0.7	119.96 ± 15.7	51.10 v ± 0.40	1.63 ± 0.80	18.93 ± 0.40

Table 4

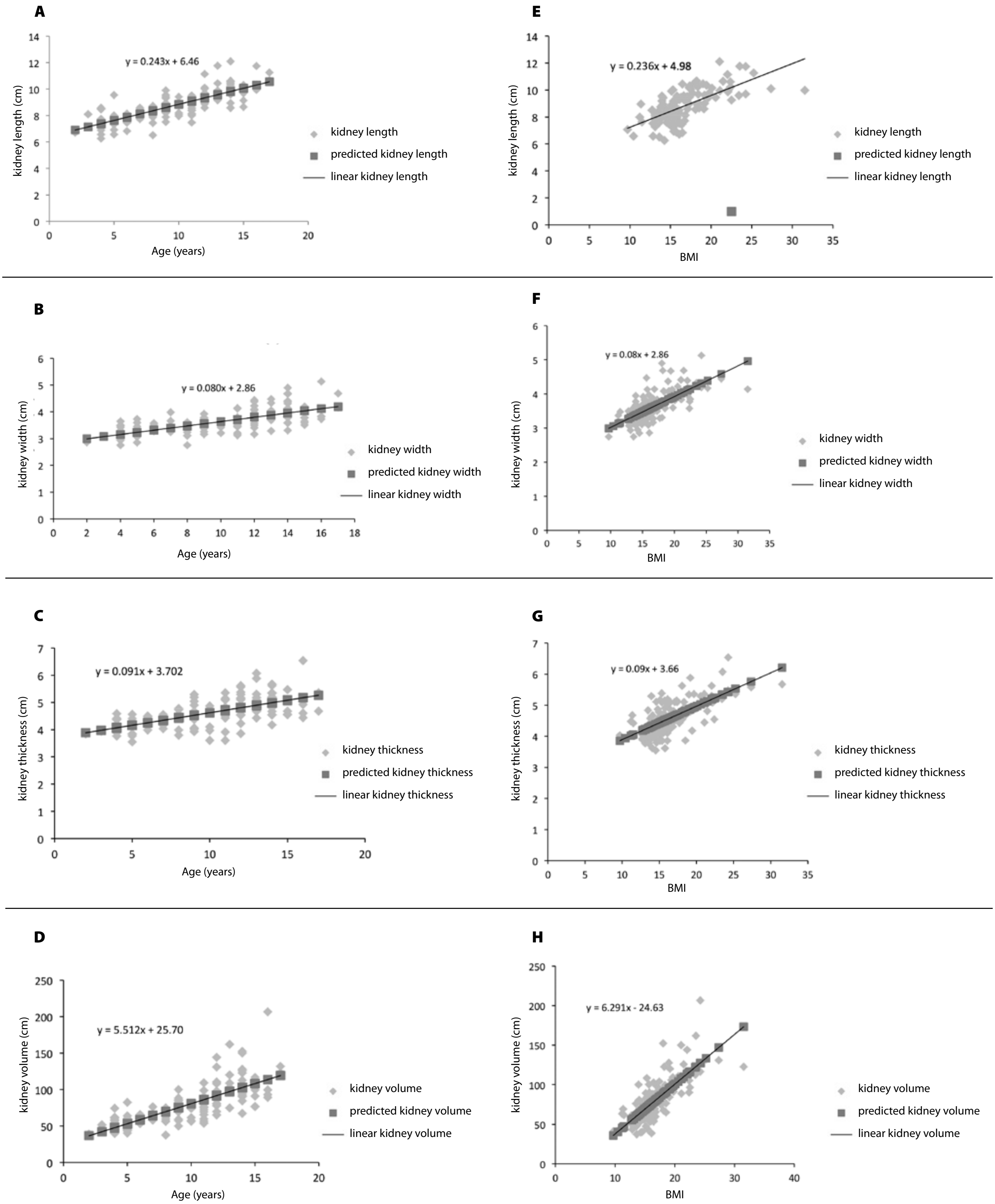
Linear Regression Equations for Predicting Kidney Sizes

	With Age	With BMI
Length (cm)	0.24 (age) + 6.46	0.24 (BMI) + 4.98
Width (cm)	0.08 (age) + 2.86	0.09 (BMI) + 2.16
Thickness (cm)	0.09 (age) + 3.66	0.11 (BMI) + 2.79
Volume (mL)	0.54 (age) + 25.70	6.30 (BMI) + 24.63

reported that kidney length and volume among Indian children, on the other hand, was higher than the same sizes measured among a population of American children by between 11% and 20%.[9] These differences are statistically significant ($P < .05$). The variations could be because of racial differences in kidney size.[10]

The use of sonography in the assessment of the kidney for pathology and follow-up of treatment outcomes and kidney growth rate has several advantages. Sonography is less expensive than other imaging modalities, readily available, and easy to perform. In addition, the imaging method does not involve the use of ionizing radiation. Furthermore, sonography is a real-time study not affected by organ functions and sonographic measurements are

Figure


A
y = 0.243x + 6.46
kidney length (cm)
Age (years)
kidney length
predicted kidney length
linear kidney length
E
y = 0.236x + 4.98
kidney length (cm)
BMI
kidney length
predicted kidney length
linear kidney length
B
y = 0.080x + 2.86
kidney width (cm)
Age (years)
kidney width
predicted kidney width
linear kidney width
F
y = 0.08x + 2.86
kidney width (cm)
BMI
kidney width
predicted kidney width
linear kidney width
C
y = 0.091x + 3.702
kidney thickness (cm)
Age (years)
kidney thickness
predicted kidney thickness
linear kidney thickness
G
y = 0.09x + 3.66
kidney thickness (cm)
BMI
kidney thickness
predicted kidney thickness
linear kidney thickness
D
y = 5.512x + 25.70
kidney volume (cm)
Age (years)
kidney volume
predicted kidney volume
linear kidney volume
H
y = 6.291x - 24.63
kidney volume (cm)
BMI
kidney volume
predicted kidney volume
linear kidney volume

not associated with the use of radiographic contrast agents. Intravenous contrast agents excreted by the kidneys during intravenous urogram results in osmotic diuresis, which causes the kidneys to swell. This swelling is believed to be 1 of the causes of geometric magnification of urographic films.[17] Therefore, the use of sonography in evaluating and measuring kidney sizes, especially in children, is justified.

Although strong correlations exist between kidney sizes with both age and BMI, the calculation of BMI is a bit cumbersome. Renal volume, on the other hand, involves multiple measurements, thus creating room for higher levels of observer error.[19,20] It is, therefore, simpler and more clinically practical to compare kidney growth rate with age (growth is usually directly proportional to age during development).

Using sonographically measured kidney length to determine size and growth is similar to an earlier study that suggested that height (a positive indicator of growth) can be used to predict kidney sizes clinically because height is an easily measured somatometric parameter.[9] Measurement of kidney thickness is less feasible because of poor definition of the border between renal parenchyma and the central echogenic area. However, measurements of kidney thickness might be necessary in assessing certain renal diseases, such as acute or chronic pyelonephritis. Further, sonography is very useful in the assessment of ectopic location (not in the usual location) and agenesis of the kidneys.[8]

Limitations

The sample of Nigerian children used in this study is rather small for a country as densely populated as Nigeria. The sample could have been increased to more effectively represent the population. In a study such as this, the nutritional status of the participants should be established because it affects a child's kidney size.[21] Most children recruited for the study, however, came from middle- and upper-class families, so their nutritional well-being was assumed.

The comparison of our findings with the cited works might have been limited by the availability of state-of-the-art equipment in our environment. The beam balance used in this study to measure the children's weight, for instance, is quite old, and this obsolete equipment could have affected the weights recorded. Moreover, quality assurance tests were not carried out on the ultrasound scanner because of a shortage of medical physicists and basic quality assurance kits in the hospital where the work was conducted. Observer errors in sonographic measurements also could have contributed to differences in measurements.[18,19]

Conclusion

Sonography is a reliable imaging modality for the measurement of kidney sizes. Sonographically measured kidney sizes among a Nigerian pediatric population were significantly different from those of Indian and American children.

Both kidney length and volume correlated most strongly with somatometric parameters of age and BMI; therefore, measurement of both dimensions can be relied on in cases of follow-up of renal growth among children. In particular, measurement of renal length appears to be the most practical clinically, with the subject in the prone position. Moreover, when the age or height is known, the regression equations derived in this study could be used to calculate kidney sizes easily. The clinical benefit derived from using the regression equations, especially in rural Nigerian settings where sonography is absent, however, requires further investigation.

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What Imaging Teaches Us About Pain

Elizabeth J Church, JD

Pain diminishes the quality of life for many people, although it also may be a vital teacher or a warning message to be heeded. How humans process pain is a complicated, individualized process affected by genetics, personality, life experiences, and straightforward physiological processes. Imaging provides investigators with insight into this complicated phenomenon, and it promises to continue to help experts understand not only how pain is processed, but also why chronic pain develops in some people but not others, how we might better manage pain, and how pain may have played a key role in human evolution.

This article is a Directed Reading. Your access to Directed Reading quizzes for continuing education credit is determined by your membership status and CE preference.

After completing this Directed Reading, the reader should be able to:

- Explain the various purposes pain serves.
- Specify imaging's contributions toward understanding how the human brain processes pain.
- Identify several chronic pain syndromes and the effect of chronic pain on the brain and body.
- Describe how stress, genetics, sex, and age affect the pain experience.
- Discuss self-inflicted pain, including what purpose it may serve.
- Understand current treatment options, including inexpensive, effective, and readily available alternative interventions such as meditation and yoga.

The human wish for a pain-free world is ubiquitous. Julius Caesar is credited with saying that it "is easier to find men who will volunteer to die, than to find those who are willing to endure pain with patience."[1] Some poets imagine a world in which there is no pain, no fear, no suffering. Many religions define the afterlife as a place with complete freedom from pain. We try our best to prevent or end the pain of our children, spouses, friends, and parents. Often, people choose a health care career motivated by the desire to alleviate pain and suffering.

At the same time, there are those who seek pain, who use it to prove strength of character or fortitude, who through pain try to achieve a certain mental state and access a spiritual world or vision. "Mortification of the flesh," for example, refers to the practice of quelling lustful thoughts by self-inflicting bodily pain — often flagellation — both as penance for a sin and as a route to spiritual purity.[2,3] Although prohibitions have since been rescinded, at the close of the 19th century both Canada and the United States outlawed the sun dance, a ceremony meant to ensure regeneration of the earth and practiced by the Great Plains Indians. Among the reasons for the ban was the fact that some tribes included ritual piercing as part of the ceremony.[4,5]

The painful truth is that we need pain. Pain matters. Pain teaches us. If it did not, how many times might we press our palms against the burner on the stove? How many times would we single-handedly try to lift a living room sofa? Pain forces us to rest, allowing the body sufficient healing time.[6] It also is "an alarm system that protects individual organisms from potential or actual physical threats."[7] From a Darwinian slant, survival depends upon protecting one's self from dangerous and threatening situations and, by doing so, avoiding premature death.[7] The more sophisticated and effective a system is in terms of detection of and reaction to physical danger, the more successful that organism will be — and pain is precisely what permits such success.

Dr Paul Brand, an English orthopedic surgeon, worked with lepers for the majority of his medical career, starting in the late 1940s.[8] He noted that lepers seemed to have preternatural strength in their hands — just a handshake felt to him as though his fingers were in a vise. However, he made a discovery that led him to understand why lepers lost fingers and toes. The reason was not the disease itself. One day, Dr Brand had trouble turning a key in a rusty lock. A 12-year-old boy who passed by easily turned the key, but when Dr Brand examined the boy's thumb and forefinger afterward, he saw that the key had cut the child's flesh to the bone. Whereas a healthy person whose nerve endings had not been desensitized by leprosy would have stopped turning the key because of the pain, the boy felt no pain and so had continued to turn it. Dr Brand realized that lepers did not have unusually strong hands — they simply did not feel the pressure that would have told them when to stop. Lepers lost fingers and toes during the night because they could not feel rats eating their flesh. They lost parts of their body because they felt no pressure, injury, or pain.

Pain Defined, Pain's Toll

Complexities of Pain

Pain is variously defined. Some define it as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage."[9] From this viewpoint, pain provides an organism with information concerning the physical and temporal aspects of an injury.[10] Pain perception also is seen as the body's way of causing us to act in response to a noxious stimulus.[11] Pain tells us something is wrong — whether it is an unseen tumor in a vertebra or a similarly unseen stomach ulcer. Some areas of the brain that are activated by painful stimuli are associated with motor responses — the brain receives a pain signal and directs the body to react, to pull the hand off of the stove burner, to run away, or to "initiat[e], propagat[e], and execut[e] defensive motor responses."[11]

Pain is a complex, highly subjective response that combines sensory processing with cognitive and emotional components.[12] Cognitive neuroscientists view pain as a subjective experience "triggered by the activation of a mental representation of actual or potential tissue damage."[13] *Nociception*, a term often used by pain experts, involves the activation of nerve endings that respond differently to noxious or tissue-damaging stimuli. Activation of these nerve endings may or may not be perceived as pain.[14] Nociceptive pain signals tissue damage.[15] Examples of nociceptive pain include surgical pain, arthritis, and angina. This type of pain usually responds well to more traditional approaches to pain management, including analgesics and nonpharmacological interventions.[13,15]

Neuropathic pain, on the other hand, is mild to severe and can be characterized as "maladaptive" in nature.[13] It arises from a pathophysiological process involving the nervous system and includes such pain syndromes as diabetic neuropathy, pain following a stroke, and phantom limb pain subsequent to amputation.[15] This type of pain does not respond as predictably or consistently to analgesic interventions but is instead addressed through unconventional pharmacological approaches such as antidepressants or anticonvulsants.[15]

Pain may be defined by context, and it may be either extolled or condemned, depending upon the stage in which it appears. As 1 pain expert stated, "Pain may be the warning signal that saves the lives of some people, but it destroys the lives of countless others."[6] For the past 2 decades, modern imaging techniques have contributed significantly to our understanding of how the brain processes pain, pain modulation, and the efficacy of standard, innovative, and alternative treatments for pain.[16] Imaging illuminates how our brains react with empathy to another's pain and what anatomical changes result from chronic pain. The rapid pace of technology offers ever-increasing opportunities for refined visualization of brain signals and spatial and temporal resolution. For example, the first modern functional magnetic resonance (fMR) imaging experiments in humans were conducted using 1.5-tesla (T) scanners; the industry has progressed through 3-T machines and is now on its way to adopting 7-T machines for anatomical and functional imaging.[16]

By means of imaging techniques such as fMR and positron emission tomography (PET), researchers are able to conduct noninvasive investigations into the pain process and avoid the traditional pitfalls associated with subjective, highly variable, and individualized pain reporting.[17] Neuroimaging potentially provides objective, diagnostic information connected with each individual patient's subjective pain experience.[18] PET and fMR measure brain activity by recording changes in blood flow, blood oxygenation, and metabolic changes associated with activations of neuronal networks.[16] Because fMR results in better temporal and spatial resolution than PET, and because it is less expensive, fMR is the imaging method researchers most often use when studying the brain's reactions to pain.[16]

With respect to pain research, the most commonly used fMR method is that of the blood oxygenation level-dependent (BOLD) technique.[16] However, the BOLD technique is not optimal for the study of chronic pain because it requires a rapidly changing signal — something that is not always present in chronic pain patients. Instead, arterial spin labeling fMR often is used, because it directly measures blood flow (thus, revealing activation of specific brain regions). Arterial spin labeling is more sensitive than BOLD imaging when it comes to detecting signals associated with stimuli lasting longer than 2 minutes; it has been used to study muscular pain and has revealed blood flow patterns to brain regions during a painful stimulus lasting 15 minutes. Arterial spin labeling assists researchers in gaining an understanding of the temporal relationship between activations of different brain regions during pain perception and processing.[16]

The majority of pain processing research uses test subjects and controls who are willing to submit to laboratory-induced pain. That form of pain can include:

- Thermal pain (probes heated to certain temperatures) and applied to various body parts (usually forearms and calves).
- Mild electric shocks.
- Squeezing or pressure.

The pain is necessarily short-lived, and so ongoing pain processing cannot be observed. Finding a way to assess and reproduce pain that is independent of patient self-reporting, that includes tissue damage (something typical experiments cannot include), and that is thus more objective in terms of research results and reproducibility is a longstanding research need.

A recent British experiment solved these problems by following healthy male patients before and after tooth extraction — a setting that avoided ethical implications of inducing pain and that permitted study of tissue damage and postsurgical pain processes.[17] Women were excluded because of variability in menstrual cycles, which would affect the reproducibility of a response to postsurgical pain. Investigators used a relatively new perfusion MR imaging technique, pulsed-continuous arterial spin labeling, to observe and measure changes in regional cerebral blood flow following surgery — changes that would indicate what areas of the brain were activated and when activation occurred. Study authors characterized arterial spin labeling as "an ideal methodology for central investigation of ongoing, non-paroxysmal pain" with "superior noise-power characteristics" compared with fMR imaging.[17] They observed a bilateral pattern of blood flow changes throughout the brain, and concluded that pain-related changes were reproducible and consistent among study participants, with no blood flow differences identified across scans either within session or between postsurgical pain sessions (see **Figure 1**).

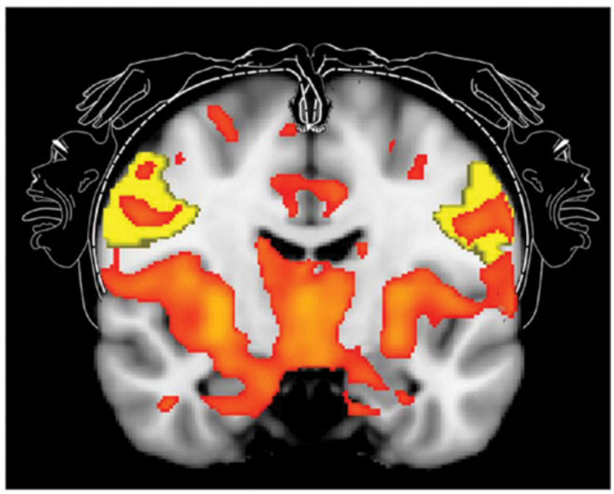

Figure 1. *Image showing cerebral blood flow changes — the processing of pain — following tooth extraction. Changes are shown as they relate to the classical representation of the jaw. Reprinted with permission from Howard M, Krause K, Khawaja N. Beyond patient reported pain: perfusion magnetic resonance imaging demonstrates reproducible cerebral representation of ongoing post-surgical pain.* PLoS One. *2011;6(2):e17096. doi:10.1371/journal.pone.0017096.g002.*

Cost of Pain

Pain is expensive. In 2011, the Institute of Medicine reported that at least 100 million Americans endured chronic pain conditions; the figure does not include the number of people suffering from acute pain, nor does it include pain suffered by children.[19] Pain poses a substantial public health problem, costing each American approximately $2000 per year, for an annual national expenditure of $560 billion to $635 billion.[19] That figure includes costs associated with lost productivity; lost wages, employment, and health insurance; longer or repeat hospital stays; outpatient office visits; and rehabilitation. Pain affects more Americans than diabetes, heart disease, and cancer combined (see **Box 1**).[20]

In addition, although we possess the therapies that would alleviate most pain, 50% to 75% of cancer patients die in moderate to severe pain. Despite a plethora of effective pain medications, more than half of all hospitalized patients have pain in the final days of their lives.[21] The world picture is different from that of the United States in that low- and middle-income countries lack the resources that would permit patients what the World Health Organization characterizes as "the dignity of access to pain relief and palliative care."[22] Although oral morphine is a cost-effective pain medication for the treatment of pain associated with cancer and human immunodeficiency virus/acquired immunodeficiency syndrome, opioid analgesics are not available in adequate amounts in developing countries.[22] The lack of availability stems from ignorance concerning the medical uses of opioids, excessively restrictive regulations that limit supply and use, and lack of funding.[22]

Pain Perception and Processing

Manifestations of Pain

Pain can be classified as acute or chronic. Temporary, acute pain includes that which is experienced following surgery or when a knee is scraped.[23] Additional distinctions between types of pain can include mechanical pain, a common form of pain encountered every day when one stumbles, falls, bumps against a wall or furniture, or is pricked by a thorny rose.[24] Mechanical pain is self-induced. Passive pain, however, is externally induced pain, such as thermal pain or pain caused by a malignancy.[24]

Acute pain can mutate into chronic pain. Chronic pain is long acting, localized or widespread, and is present beyond expected healing time.[25] When pain lasts for longer than 3 months, it is considered to be chronic.[18] In the United States, chronic pain reportedly is the cause of 21% of emergency department visits, with more than 90 million Americans displaying symptoms of chronic pain.[26]

Box 1

America's Painful Facts[19,20,22]

- Pain interrupts the sleep of 20% of adults at least a few nights each week.
- Lower back pain is the most common pain complaint and the leading cause of disability in those younger than 45 years of age. Frequent back pain is experienced by more than 25 million of those aged 20 to 64 years.
- Other frequently reported pain conditions include headache or migraine, and neck, knee, shoulder, finger, and hip pain.
- People with lower back pain are 3 times more likely to be in fair or poor health; they are 4 times more likely to have serious psychological distress than are those without lower back pain.
- Chronic pain sufferers often have difficulty performing household chores, attending social events, driving, walking, or participating in sexual activity.
- In 1 survey of chronic pain sufferers, only 58% of patients reported that their prescription medication was even "fairly effective" in reducing pain.
- Adults aged older than 65 years are the least likely to report pain; those aged 45 to 64 years are the most likely to report pain that lasts more than 24 hours.
- Chronic pain can lead to depression, a loss of enjoyment of life, trouble with concentration, lowered energy levels, and sleep disturbances.
- Seven out of every 10 U.S. citizens believe that pain research and management should be 1 of the medical profession's top priorities.
- None of these factors considers the emotional toll chronic pain exacts on patients and their families and friends.

On a day-to-day functioning level, chronic pain does more than simply reduce sufferers' productivity. Recent studies demonstrate that chronic pain or discomfort can affect social behavior, even increasing the risk of aggression and violence.[27] Unexpected pain can cause infants to display angry facial expressions, and human aggression increases in situations involving pain. More than 70% of chronic pain patients questioned in 1996 expressed angry sentiments.[28] Some experts theorize that humans and other animals are actually programmed to react aggressively when faced with physical or psychological pain as a means of increasing the odds of survival.[29] This propensity toward violence in the presence of pain is supported by statistics: In 1992, patients receiving health care services committed 45% of a reported 22 400 nonfatal workplace assaults — placing health care workers in a surprisingly risky stratum of the workforce.[27]

There are numerous theories as to what happens within the brain to cause the perception of pain to transmute from acute to chronic. One hypothesis is that persistent nociceptive input to the brain eventually causes a hyperexcitability in the neural network, leading to the development of chronic pain.[30] It also may be that a deficiency of dopamine, an important neurotransmitter in the brain, creates a vulnerability to the development of chronic pain.[30,31] Whatever the underlying physiological processes may be, chronic pain is blamed for up to $100 billion in annual health care costs, rendering it "the most financially challenging condition to date."[26]

Perceiving Pain

Beginning in the 1990s, whole-brain fMR first established that several brain areas are involved in pain processing.[16] Since that time, researchers have discovered that neurotransmitters in the forebrain are involved in pain modulation, which is the reduction in intensity of the pain experience.[16] Focused investigation has led to a fairly comprehensive understanding of acute pain.[6] Conversely, more puzzling chronic pain syndromes often present with severe pain that is not clearly associated with any discernible injury or disease process. Furthermore, the relationship between chronic pain and the psychological or physical stressors commonly associated with chronic pain remains unclear. Current research employing imaging technology focuses more on these chronic pain syndromes, such as fibromyalgia, and demonstrates that there are functional and anatomical changes in the brain associated with long-lasting pain. Cutting-edge brain imaging techniques assist experts in gaining a better understanding of the functional connectivity of pain pathways, including biochemical changes associated with chronic pain.

How we perceive pain is affected by our interpretation of the experience, which, in turn, is colored by factors including our beliefs about pain, our expectations, and our mood. Some people view themselves as more sensitive to pain, while others assert that they are impervious to pain or have a "high pain threshold." Numerous factors can amplify or reduce the intensity of the pain experience, and somatic sensory input is only a portion of the pain experience (see **Figure 2**).[6,18,32] Even our memories influence how we experience pain: Recollections of pain and suffering help warn us to avoid dangerous situations.[6]

Because so many factors can alter our pain experience, our perception of the degree or intensity of pain may not "match" the actual stimulus or nociceptive input. What is considered by a given culture or particular environmental milieu to be an "appropriate" behavioral response to pain may even modify the perception of pain. Sometimes, people feel pain in the complete absence of any nociceptive input.[18] When emotional and behavioral health factors generate a pain sensation, increase the intensity of the pain experience, or even prolong the pain experience, the pain is classified as psychogenic pain.[33] The pain is nevertheless real, and such patients and their pain complaints should not be dismissed. Indeed, neuro-

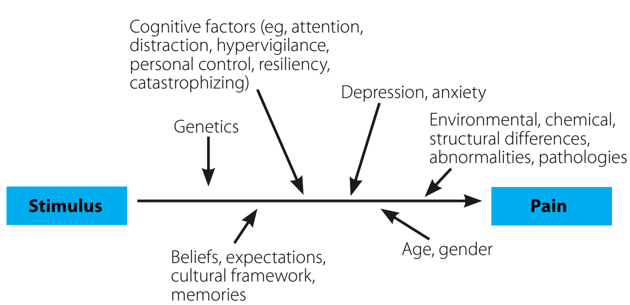

Figure 2. *Factors that can alter the perception of pain.*

imaging studies have shown that there is extensive neural activation in the brains of such individuals, despite the lack of any known or verifiable painful stimulus.[18] One author remarked that such imaging studies "illustrate how powerful the mind can be in terms of activating specific networks within the brain to subsequently produce a realistic and vivid experience."[18] Another author observed that medical diagnosis is imperfect, and all organic causes of pain cannot be identified: "All too often, the diagnosis of neurosis as the cause of pain hides our ignorance of many aspects of pain medicine."[34]

Increasing evidence points to genetic factors as playing a decided role in how each individual experiences pain. Chronic pain syndromes tend to run in families, which implies that the risk for developing a pathological pain condition is substantially influenced by one's genetic inheritance.[35] Both pain and analgesic (pain-relieving) responses appear to have weighty hereditary components, and current psychiatric genetic research is exploring the genetic tendency toward anxiety disorders and depression, as well as any connections between that genetic picture and pain states such as migraine and fibromyalgia.[35] Still, while a genetic predisposition to experience pain in a certain way may provide a foundation for the pain experience, that foundation is certainly modified by life experiences.[6] Individual differences also are on display when it comes to the duration of the pain experience. Common experience teaches us that painful sensations continue even after the stimulus has been extinguished. How long the pain response continues appears to depend largely upon the character of the stimulus and the individual person's receptive state.[36]

Clearly, pain is "a multidimensional experience produced by multiple influences."[6] It is both a sensory experience (the intensity of the pain felt), and an emotional, affective experience (the unpleasantness or suffering felt).[37] This complicated picture renders pain a difficult matter to assess, diagnose, and treat. Imaging's noninvasive look into the pain process is particularly helpful to scientists who seek to distinguish pathological from emotional and cognitive influences. When these contributing factors are better understood across the board and on an individualized basis, physicians will have greater insight when it comes to recommending whether patients should undergo physical therapy, pharmacological, behavioral, or surgical treatments.

The Pain Matrix

PET and fMR studies reveal a large, distributed brain network that is activated during nociceptive processing.[18] That network is referred to as the "pain matrix" or the "neuromatrix," although it is not a precisely defined entity.[6] Depending on the individual's pain experience and the interplay of factors, different portions of the central nervous system (CNS) may play greater or lesser roles in pain processing. Because so many factors play a role in how pain is processed and experienced, it should come as no surprise that widespread areas of the brain are active or that images of individuals' brains processing a similar or identical stimulus sometimes differ. These highly individualized patterns have led some experts to assert that "cerebral signature for pain" may be a more useful descriptor than a pain matrix.[18] Pain experts theorize that the repeated, cyclical processing of impulses through the neuromatrix results in the development of the pattern that can be called an individual's "neurosignature."[6] What has been identified as the pain matrix may more accurately be described as a brain network that detects the importance of incoming information and evaluates the potential threat of the incoming sensory information.[38]

Although individualized, commonalities exist within the brain's pain-processing network. PET and fMR imaging studies have revealed that the most common regions active during acute pain processing are the sensory-discriminatory areas of the CNS (the parietal lobe of the cerebral cortex, including the primary somatosensory, secondary somatosensory, thalamus, and posterior portions of the insula) and the areas of the brain associated with cognition and affect (eg, the anterior portions of the insula, the anterior cingulated cortex, and the prefrontal cortex [PFC]).[18] This makes logical sense: The primary somatosensory area of the brain is where the receptive area for the sense of touch resides, and touch plays an important role in how pain is felt. The thalamus sits at the top of the brainstem, and 1 of its many functions is relaying sensory and motor signals to the cerebral cortex. The insula, which is located in a fold of the cerebral cortex, is linked to regulation of emotion and homeostasis.[39] Homeostasis is the body's way of tending toward and achieving stability of normal body states. The insula also is responsible for such diverse functions as perception, motor control, self-awareness, and cognitive functioning. Pain medications primarily affect this network of the CNS, providing further evidence of the identified regions' influences in how pain is perceived.[18]

The suffering component of pain is reflected in several fMR studies that show a robust connection between subjective reports of pain and activation of the anterior cingulate cortex, a portion of the brain implicated in regulation of blood pressure and heart rate and such cognitive activities as decision-making, emotion, empathy, and reward anticipation.[36]

The brainstem also is involved in pain processing. Functional MR studies provide evidence indicating that the brainstem and its structures play a role in the modulation of pain perception.[18] Experts have used diffusion tractography, an imaging process that demonstrates the degree of connectivity or neural tracts between different regions of the brain, to confirm the connections between the brainstem and portions of the cortex.[16,18] Scientists believe that the brainstem plays a vital part in the process by which a placebo reduces or eliminates pain. They theorize that the PFC, or frontal lobe, triggers the release of opioids within the brainstem, leading to a modulation of pain perception.[18]

The PFC is active in decision-making and planning complex cognitive behavior, and it is largely responsible for moderating social behavior and personality expression. Interestingly, the PFC's activity is not limited to generation of the placebo effect; it is activated consistently in all clinical pain conditions.[18] Again, that the PFC would be activated consistently in pain processing makes sense: Those factors described in Figure 2 that affect pain perception, such as emotional, cognitive, and personality factors, all reside in the PFC. Individual beliefs about the personal ability to control pain or the degree to which one believes he or she has an internal locus of control over pain would all implicate the PFC.[18] Furthermore, imaging studies point to neurodegeneration in the brains of chronic pain sufferers, and the major site for such potential cell death is the PFC.[40]

The spinal cord's role in pain processing remains more obscure. The cord is difficult to image because of its small size and significant motion-related artifacts caused by the heartbeat, respiration, and the movement of cerebrospinal fluid.[16,18] Technological advances promise more opportunities for noninvasive studies of this portion of the CNS's pain processing mechanisms.[41,42]

The Role of Stress in Pain Perception

An injury does more than produce pain — it also disrupts the brain's system of homeostatic regulation.[6] That dysregulation produces stress and sets in motion a number of complex processes designed to regain homeostasis. Importantly, stress is more than the psychological state commonly recognized in today's culture of pressurized time management and sense of overburdening. The term encompasses physical injury, infection, and pathology; stress is the biological system's response to any threat to homeostasis, whether the threat is physical or psychological in nature.[6]

When an injury disrupts homeostasis, and depending upon the extent and severity of the injury, genetically predetermined neural, hormonal, and behavioral programs kick into action.[6] The body responds as follows:

- The injury triggers a process by which sensory information is relayed rapidly to the brain, which initiates the complex sequence of events to reinstate homeostasis.
- The body releases cortisol, a hormone produced by the adrenal glands, in an effort to re-establish homeostasis. Cortisol produces and maintains high levels of glucose for quick response following an injury, threat, or other form of emergency (such as the fight or flight response).[6,43]

Although cortisol is essential for survival, it also is potentially destructive. To generate a high level of glucose, cortisol breaks down muscle protein and stymies the replacement of bone calcium. Sustained production of cortisol can result in muscular weakness, fatigue, and bone decalcification; it also suppresses the immune system. In the natural aging process, the hippocampus, which is a portion of the brain responsible for memory formation, organization, and storage, undergoes neural degeneration. Cortisol may increase the speed of that degenerative process.

And so, other than stress being a natural response to a painful stimulus, what is the connection between longstanding, chronic stress and pain? It may be that chronic stress exposure leads to structural brain changes that reduce patients' capacities to cope with pain.[44] One pain expert theorized that some forms of chronic pain are actually the result of the cumulative destructive effects of cortisol on muscle, bone, and neural tissue. Ronald Melzack, a professor in the department of psychology at McGill University in Quebec, Canada, and 1 of the world's leading experts on pain, noted that fibers in the hippocampus help to produce a natural "brake" on the release of cortisol.[6] As we age, the loss of fibers in the hippocampus results in a reduced ability to restrain cortisol release, and so cortisol is released in larger volumes, exacerbating the already deleterious effect of chronic high levels of cortisol. Melzack said that this intricate domino effect could explain the higher incidence of chronic pain problems in the elderly. He further hypothesized that dysregulation of homeostasis patterns may produce chronic pain conditions that are resistant to treatments designed to manage pain triggered by simpler sensory input mechanisms.[6] In other words, treatments fail because they are designed to address an entirely different pain processing phenomenon. Several other experts also attribute such conditions as fibromyalgia, rheumatoid arthritis, chronic fatigue syndrome, muscular weakness, fatigue, bone decalcification, and accelerated neural degeneration to prolonged exposure to stress and dysregulation of the cortisol system.[45,46]

Modifications of the Pain Experience

Imaging plays a particularly important role in assisting investigators to ferret out the neural basis for the psychological and cognitive modulation of the pain experience.[16] Experts use brain imaging to explore what happens in the brain when distraction, attention, and focus alter the pain experience, when emotional states alter pain perception, and what happens when we anticipate or expect pain.[16] Thanks to imaging technology, investigators are able to distinguish those brain circuits that modify the pain experience through differences in attention states from circuits that modulate pain by emotional states.

As indicated earlier in this article, the mere anticipation or expectation of pain can activate areas of the brain associated with pain processing.[16] Neuroimaging also has demonstrated that anticipation of a reduction in pain is part of the placebo effect.[16] Imaging reveals that the amygdala — an almond-shaped portion of the brain associated with emotions, fear, and stress — is less responsive if experimental pain is less intense than anticipated.[39,44]

Emotional states have a dramatic effect on the pain experience.[11] Because of insights gained through the use of imaging, we now know that a negative mood state can lead to a greater susceptibility to pain, and that a depressed mood (induced by having subjects read a sad statement and listen to sad music) can increase pain-evoked activity in certain areas of the brain.[16] Loneliness, particularly in seniors, can render people more vulnerable to pain.[47] While an active lifestyle with mood-enhancing exercise and social interaction can counteract pain, seniors often feel isolated, and they may tend to focus on their pain, in addition to pondering what they can no longer accomplish physically. This emotional state can generate a more precipitous decline, leading some seniors to feel that "they're sort of done with life."[47]

Once again, however, the pain picture is not as simple or comprehensible as we might wish it were. In 1 study, for example, pain reduced test subjects' acute fear of spiders — it distracted them from their phobia.[48] Other emotional states and mental disorders also have a complicated relationship with pain. People with post-traumatic stress disorder and borderline personality disorders experience pain differently than do people who are free of these disorders.[44] Self-injurious behaviors, often tied to emotionally painful states, represent a little-understood phenomenon and another complicated modification of our relationship to pain (see **Box 2**).

Personality — separate and apart from any mental disorder — also comes into play, including whether one sees the world as an optimist or as a pessimist.[53] Using fMR imaging, Oxford researchers exposed test subjects to thermal pain, adjusting pain exposure to individual tolerances and taking precautions to avoid skin damage. While undergoing scanning, subjects received a 6-second warning that pain was on its way, paired with a subsequent painful heat application lasting 5 seconds. In half of the trials, the warning was followed by a painful event; in the other half of trials, the warning was followed by a safety cue, without pain. After the second cue, subjects rated their relief at the lack of a painful event. Subjects were questioned as to their ratings of pain intensity and dread of pain, and they underwent behavioral testing designed to rate their personalities along a continuum of optimism to pessimism.

Functional MR results revealed firings in the brain centers associated with reward processing (when pain was not delivered but when pain was expected or dreaded). How intensely the brain was activated with respect

Box 2

Self-inflicted Pain[24,48-52]

Historical Perspective. Victorian society viewed self-mutilation as an indication of insanity, and the most commonly reported behaviors included flesh picking, biting, hair plucking, punching or knocking against objects, cutting, swallowing or inserting foreign objects in the body (eg, needles), and eating trash. More extreme forms included self-castration, amputation, and removal of eyes. Self-inflicted pain often was associated with religious sentiments, including obedience to scripture. Toward the end of the 19th century, behavior such as fasting, flagellation, and other types of religious penance increasingly were viewed as overenthusiastic, if not pathological.

Self-injurious Behavior. Cornell University reports that those who injure themselves generally use multiple methods, and that most often injury is done to the hands, wrists, stomach, and thighs. The behavior can begin as early as age 7 or even earlier, last for years, and may be cyclical. It is seen as a maladaptive coping mechanism that can help to alleviate anxiety, distract from problems, and relieve stress or pressure. The behavior engages the endogenous opioid system, which regulates pain perception and levels of endogenous endorphins — substances that act as an analgesic in the brain. Repeated self-injury and activation of the endogenous opioid system can result in a tolerance so that over time, self-injurers may need to increase the frequency or level of pain-inducing injury. Self-injurious behavior is linked to childhood abuse/trauma, eating disorders, post-traumatic stress disorder, borderline personality disorder, depression, and other anxiety disorders.

Borderline Personality Disorder. Functional MR imaging reveals that patients with borderline personality disorder have altered pain perception and different brain connectivity compared with healthy control subjects. People with the disorder are less sensitive to painful sensory stimulation, and when they are in a state of high emotional tension, their sensitivity to pain is reduced further. For these patients, self-injurious behavior appears to:

- Distract attention from emotional thoughts – pain is used to avoid processing negative emotions.
- Reduce inner turmoil and tension – self-injurious behavior is a maladaptive strategy adopted to manage negative emotions. Short-term, the strategy permits the individual to focus on mental tasks instead of emotional turmoil; however, long term, it can cause substantial physical damage.

Self-induced Pain vs Externally Generated Pain. Chinese investigators used fMR to study how voluntary motor movement influences the brain's perception of pain. Subjects were scanned while they either squeezed their own hands to cause pain/pressure (active pain) or had their hands squeezed by an experimenter (passive pain). Subjects rated self-induced pain as lower than passive pain both in intensity and unpleasantness. When pain was externally induced, the brain activated a large network; self-induced pain resulted in a deactivation of certain brain areas. The experts concluded that self-generated movement created an analgesic effect on sensory and emotional dimensions of pain processing. They further theorized that this phenomenon of pain suppression proves necessary when an individual must engage in flight or fight responses, despite injury and pain.

to relief/reward processing varied according to the subject's outlook as either a pessimist or optimist. Pessimists experienced greater feelings of both dread and relief than did optimists. Optimists, on the other hand, had diminished BOLD signals in brain regions signaling prediction error, as well as an attenuated sense of relief, in comparison with pessimists. Pessimists experienced an increased positive mood as a result of their pleasant surprise when a better outcome occurred.[53]

In discussing the meaning of their findings, study authors referred to earlier investigations that found that for some people who tend toward pessimism, waiting for pain is worse than actually experiencing the pain.[53] The Oxford investigators concluded that "habitually expecting the worst enhances aversion of punishment cues, and consequently increases relief."[53] In other words, although optimists are seen as having more pleasure in life, if one expects the worst and then the worst does not happen, there not only will be less disappointment, but also a positive feeling of relief.[53]

"Pain inhibits pain" is a long-recognized phenomenon. If your foot is aching, a whack to the knuckles with a ruler can make you forget about the foot pain — at least temporarily. Experiencing another pain somehow decreases the pain perceived elsewhere in the body, a phenomenon known to experts as "diffuse noxious inhibitory control" or "counterirritation."[16] Interestingly, scientists have discovered that counterirritation occurs in anesthetized animals, a fact that seems to indicate that counterirritation is a separate phenomenon from distraction or other cognitive processes that require consciousness.[16] It could be that in humans, cognitive operations might contribute to the analgesic effects of counterirritation, making it a more powerful pain modulator in humans as opposed to other animals. That is, our thoughts alter our perception of pain, so counterirritation results in a greater reduction of the perception of pain than it does in other, more "nonthinking" animals.

Current research indicates that the counterirritation system is impaired in chronic pain patients.[16] Chronic pain alters brain structure, a fact that was first demonstrated in chronic back pain patients but now is recognized in several chronic pain conditions.[30,54] The most consistent finding concerning pain's power to alter brain structure over time is a reduction in gray matter, although it is also clear that unique brain changes are associated with specific pain conditions. Several studies demonstrate that pain-induced structural changes occur in areas of the brain devoted to pain perception and modulation. In other words, chronic pain states alter brain structure so that those portions of the brain that might otherwise help to modulate pain are rendered less effective or completely ineffective. Chronic pain states do not limit their damaging effects to brain regions responsible for pain processing; chronic pain appears to cause structural changes in areas of the brain having to do with behavior, perhaps signaling a reduced ability on the part of the brain to cope with persistent pain.[54]

Does chronic pain lead to altered brain structure, or does an existing, altered brain structure predispose a person to develop a chronic pain condition?[30] Different chronic pain conditions tend to be associated with different patterns of abnormal brain structure, but experts have yet to determine the starting point of these structural anomalies. Another question yet to be answered is whether structural changes in the brains of chronic pain patients are responsible for behavioral and cognitive deficits generally seen in these patients.[30] Imaging has led to insights concerning the neural foundations of pain and the pain-cognition interaction, but further investigation is needed to determine the relationship between chronic pain and depression, anxiety, and chronic fatigue, as well as chronic pain's interference with cognition and memory.[30] Perhaps the most promising imaging technique to investigate the correlations between brain structure and cognitive performance is voxel-based morphometry, a technique that permits comparisons of differences in brain anatomy to standardized templates.[30]

Painful Aberration

Pain Without Reason

Pain can be felt despite the absence of any identifiable stimulus. For example, phantom pain is experienced despite the loss of pain signals from a body part or amputation of a body part.[18] Almost 82% of upper limb amputees feel phantom pain, and 54% of lower limb amputees feel pain from a limb that no longer exists.[55] Generally, phantom pain subsides with time, although some amputees continue to experience pain despite the passage of time. The pain can be shooting, burning, cramping, or crushing, and it may occur several times a day or every week or so.[18]

The existence of the phantom pain phenomenon provides significant clues to pain processing. The lack of any painful input paired with the sensation of pain leads to the conclusion that pain processing resides within the neural networks of the brain. When stimuli exist, they may trigger pain patterns in the brain, but they do not produce the patterns.[6] In other words, the stimulus can be a trigger, but it does not generate the neurosignature.

Further proof of the lack of a need for any stimulus to generate a pain experience is the fact that the mere expectation of pain can elicit brain activation patterns that mirror those of a real pain experience.[11] Simply imagining pain — in the complete absence of any physical injury or other form of painful stimulus — engages the pain-related neural network.[11,53] Moreover, the degree of anticipatory brain activity appears to correlate with the degree of pain expected.[13] Apparently, memories of earlier pain experiences can affect pain anticipation and cause the activation of the same brain areas as are activated in "actual" pain processing.[11]

In an experiment using subjects with and without lower back pain, researchers theorized that visualization of a painful experience would trigger unpleasant emotions that might play a role in the maintenance of chronic pain syndromes, such as low back pain.[11] The experiment, which employed fMR imaging, required subjects to view images of simulated back pain (depiction of a man carrying heavy luggage in a half-crouching position) and neutral images (a man standing in front of luggage). In the group with lower back pain, the images of simulated back pain elicited unpleasant feelings, and areas of the brain commonly recognized as part of the pain matrix were active during the virtual pain experience. In the control group, viewing the images of simulated pain did not activate regions of the classic pain matrix. The researchers concluded that previous painful experiences of lower back pain might sensitize individuals to pain anticipation, and that certain brain activation patterns might be associated with preparation of protective motor responses to be taken against anticipated pain. Chronic lower back pain sufferers might be hypervigilant and might pay more attention to pain-related visual stimuli to prepare for pain sensations.[11]

Some areas outside of the typical pain matrix also were active in the lower back pain test subjects. The hippocampus, an area of the brain associated with memory consolidation and fear-initiated pain-avoidance behaviors, was active when these subjects viewed the images of simulated back pain. The study's authors proposed that the hippocampus might help maintain a chronic pain condition by memorizing the painful stimulation and preparing the body's pain-avoidance responses.[11]

Pain and Empathy

In 1992, former President Bill Clinton famously emphasized his empathetic abilities in response to an AIDS activist.[56] But do we truly feel others' pain, and if so, how? What happens in our brains when we see another person in pain? Does it matter whether we know or care for the person? Does our sex matter? What functions might empathy serve?

The Usual Empathetic Response

Functional neuroimaging studies indicate that our brains light up in the same way when we see another person in pain as they do when we experience the pain ourselves; empathy for another's pain literally activates similar neural networks as does the actual, personal experience of pain.[57] Nearly the entire pain matrix is activated in an empathetic response to another's pain. This is particularly true of the areas of the brain responsible for processing the affective-motivational aspects of pain.[57] Interestingly, scientists demonstrated that the same brain network activated in empathetic responses to physical pain in another also is involved when we process compassion for another's social pain (eg, embarrassment or social rejection).[58,59] Through neuroimaging studies, experts have concluded that watching, hearing, or even imagining another in pain activates the same neural brain network known to be involved in the emotional aspect of personal pain processing.[60]

When pain in another person signals a possible threat to the observer, empathy may be an automatic response that helps to ensure survival — a response that involves motor control areas of the brain and that starts the flight response.[13] Empathy apparently serves as an important survival mechanism in addition to the simple flight response. It is also important to our survival that we learn to read signals in varying social contexts, that we are able to infer another person's emotional state by evaluating his or her facial expressions and "understanding" (or empathizing) with the other's plight. Humans are social animals that rely upon the human group — fitting in, gaining the group's acceptance and protection — for survival.[61] An ability to empathize also is believed to be important to appropriate moral development, and deficits in empathy have been found across the board in psychopaths.[62]

Empathetic responses and the degree to which empathy is experienced may be affected by whether direct eye contact is established and whether the observer is the target of the other's emotion. More communication occurs in this type of situation, and areas of the brain associated with theory of mind, or the ability to sense what might be in another's mind, are implicated.[61] Electromyography experiments have demonstrated that muscles used to create facial expressions also respond when one is merely observing others' faces while they express emotions.[63] This mirroring ability may well play a role in ensuring survival.

We are not, however, either wholly empathetic or completely lacking in empathy; the experience of empathy is weakened or exaggerated by numerous factors, including personality traits, cognitive processing of the event, and the situation in which social interaction takes place.[57]

Some people are more empathetic than others, and, even in those highly empathetic individuals, the degree of empathy felt often varies with context. Although a portion of our empathetic response appears to be automatic, other factors also influence the degree of empathy, including the observer's assessment of the other's situation. A number of neuroimaging studies support the conclusion that the empathetic experience recruits both somatosensory and affective, or emotional, areas of the brain.[64] The empathetic response to others' observed emotional states may include cognitive components (eg, taking another person's perspective, self-other distinction, or knowing the difference or boundaries between one's self and another person), and emotional components (eg, resonance with the emotions of others).[63]

The complexity and variability of empathetic brain activation patterns revealed by imaging is only initially confusing if one considers the multitude of factors that come into play on seeing another person in pain. Experts theorize that how an individual interprets an event determines the event's emotional consequences and its connected experiences.[57] Emotional responses such as empathy depend on a person's history, the ability to appraise a situation and develop coping mechanisms, and the way in which the individual processes emotions.[57] Empathy is a highly emotional experience — in addition to being an experience likely tied to survival. As with the experience of personal pain, numerous areas of the brain appear to be implicated in the empathetic experience — from areas devoted to motor responses, to portions of the brain associated with judgment, evaluation, motivational processing, and executive control.[57]

Functional MR assists the exploration of the motor and cognitive aspects of empathy. In 1 experiment, subjects viewed 2 sets of photographs: 1 set portrayed painful needle injections into a hand, while the other set showed a capped syringe merely placed near a hand.[57] Subjects were asked to consider either the sensory or the affective result of the photographs. In a paired experiment, subjects were told the injections were performed on an anesthetized hand — and so injections that only appeared to be painful — contrasted with depictions of injection of a local anesthetic. While undergoing fMR, test subjects received different types of instructions designed to activate either somatosensory or emotion-processing neural networks.

Researchers then compared the resulting fMR images. They discovered that activation of the sensory portion of the pain matrix as opposed to the emotional portion depended, to a large degree, on the context in which the pain occurred and the focus of the observer. When test subjects focused on assessments of pain intensity (eg, an anesthetized hand vs 1 that had not been numbed), images revealed increased signal in the areas of the brain associated with sensorimotor (sensory and motor) consequences of pain.[57] The areas of the brain that fired were those typically related to action anticipation and the interpretation of painful sensory input.

Experts concluded that the activation pattern observed in the MR images indicated that when an individual focuses on pain intensity, there is a greater personal involvement in the empathetic process. This may be, in part, a matter of survival: We need to understand a potential threat, to evaluate that threat, and to take protective action in response to the threat. Our brains must initiate motor action to withdraw from a possibly dangerous situation. Pain intensity may be the most important aspect of empathy in terms of ensuring survival. As the investigators summarized, in the context of physical survival, "it is more important to evaluate the actual injury inflicted than its affective correlates or 'side effects.'"[57]

Other investigators used fMR to study the brain's response when the person in pain is someone we love, as opposed to a stranger.[65] Two groups of test subjects were categorized according to their cognitive styles and how they processed emotions (outward-oriented vs inwardly oriented dispositions).[65] Participants were shown photographs depicting a loved one displaying both neutral and painful expressions. The faces of strangers, also depicting neutral and painful expressions, were used as controls.

Study authors first noted that imaging has shown that the insula, an area of the brain responsible for processing feelings and emotions, plays a key role during the processing of personal pain and during vicarious or empathetic pain experiences. The insula apparently assists us in connecting an emotional experience with our sensitivity to stimuli that originate outside of our bodies. The investigators noted, too, longstanding neuroimaging evidence establishing the involvement of the insular cortex in the brain's pain matrix. The investigators sought to discover whether individual differences in emotional-cognitive styles might be associated with the insula's level of reactivity during empathetic responses to the perceived feelings of others.[65]

Results showed that cognitive styles play a role in explaining differences in insula reactivity to images of loved one's painful facial expressions. The portion of the insula associated with regulating bodily states showed greater activation in subjects who were more inwardly focused and thus more aware of bodily changes during emotional experiences. The test subjects whose cognitive style was more outwardly focused engaged those portions of their brains responsible for information-gathering and other external information while viewing images of their loved ones portraying painful expressions.[65] Just as in pain processing, the neurosignature for empathetic responses to pain is highly variable and individual.

Is it possible to increase one's empathetic abilities, and can such increases be seen in brain activation patterns? The answer to both questions is yes. Functional MR has helped to show the effect on the brain of meditative practices that seek to cultivate compassion and the desire to relieve others' suffering.[66] Authors of 1 study used emotional and neutral sounds to trigger reactions in practiced meditators and nonpracticing controls. Sounds were played while meditators were instructed to maintain their practice. When emotional sounds were played, investigators saw greater activation of brain regions associated with emotion sharing and perspective taking in those who practiced meditation compared with control subjects. The authors concluded that cultivation of positive emotion actually alters the activation of brain circuitries linked to empathy and perspective taking.[66]

Battle of the Sexes

Sex, too, plays a role in empathetic responses to another's pain. Women have a documented advantage when it comes to reading nonverbal emotional cues; they reportedly display a higher degree of complexity of analysis and differentiation in their articulation of emotional experiences, and they tend to score higher than do their male counterparts on self-reporting measures of empathetic abilities/responses.[63] Imaging reveals that men and women activate similar brain areas during the processing of personal pain and while viewing others' pain. However, if men perceive the "other" to have acted unfairly, their brains do not light up empathetically.

Women's brain activation patterns tend to support the theory that women possess a better ability to suspend the boundary between self and other temporarily.[63] Women tend to rate their own emotions as more intense in response to facial stimuli depicting angry or fearful faces than do men.[63] This emotional responsiveness to others is strongly associated with empathetic behavior, and the awareness of others' feelings is, in women, accompanied by more intense emotional resonance. Women also show more enhanced emotional arousal in areas of the brain implicated in such states, and they rate the intensity of their own experienced emotion in reaction to the observation of others' pain as being more heightened than do men.[63]

Ongoing research using fMR imaging to investigate these sex differences supports the theory that women engage in a more elaborate processing pattern when experiencing compassion; they also report a more heightened emotional sensitivity to images portraying suffering.[67] In the context of empathy or compassion, women tend to engage areas of the brain having to do with the experience of love, sexual selection, and reward systems (the thalamus and putamen, outermost portion of the basal ganglia).[67] Women also show a more pronounced activation of the cerebellum, a brain structure that controls fine motor activities (and may play a role in the decision to exhibit motor activities designed to be helpful).[67]

Men, on the other hand, appear to possess a brain circuitry that permits them to retain a more distant approach, a more cognitively driven reaction to the emotional states of others.[63] Imaging studies have shown that the mental circuitry that permits us to separate our own feelings from those seen in others is more strongly activated in men than in women — meaning that men may have a stronger ability to disconnect from the emotional states of others.[63] Furthermore, fMR studies have demonstrated that automatic mirror reactions in response to pain are better suppressed by men when empathy might be inappropriate because of the unfair behavior of the observed other.[63]

In 1 experiment, fMR was used to measure brain activity while subjects either received mild electric shocks or witnessed another receiving a similar shock.[62] Investigators manipulated subjects' like or dislike of their fellow subjects so that some were seen to have played a game unfairly while others were portrayed as having played according to the rules. Both sexes showed bilateral activation of pain-related areas of the brain when they received a shock or watched a "fair" fellow subject receive a shock. However, when an unfair player was shocked, men's brains lit up differently — their brains showed activation in reward-related areas of the brain. Women's brains did not react differently when they saw an unfair subject receiving a shock — they continued to react in an "empathetic" manner. Perhaps not surprisingly, additional research to date suggests that women may show more empathy for the perceived pain of the enemy or competitor than do men.[62]

Electroencephalography is capable of measuring electrophysiological brain responses to events, or event-related brain potentials (ERP).[68] ERP findings support some experts' theory that the brain's empathetic response to pain has an early, automatic phase and a late, controlled reaction. The early phase has been described as an "emotional sharing" phase, and the later phase as a "cognitive evaluation." Experiments using electroencephalographic measurements of ERP to study sex differences in empathy have shown no difference between men and women when it comes to the initial, automatic empathetic response. Differences do arise, however. Women appear to stay in the "emotional sharing" phase longer than do men, a finding interpreted as indicating that women likely undertake a more intensive evaluation of the painful stimuli. Investigators theorize that this longer initial phase seen in women might be connected with the traditional female role of caring for offspring, a task which in turn might require a higher sensitivity to threats and danger signals. Other experts also have connected sex differences in empathetic abilities to evolutionary survival, noting that women who were both cognizant of and responsive to their offspring's needs "likely out-reproduced those who remained indifferent."[69]

Perhaps women evolved differently, with selection favoring traits of maternal preverbal communication and responses to helpless offspring.[67] Maybe the different brain activation patterns imaging reveals are due in part or whole to cultural experiences.[67] Perhaps the differences between men and women are yet another example of the "nature-nurture" conundrum. Whatever the genesis of these sex differences, the empathetic response to another's pain is a complex, multidimensional phenomenon. Different types of empathy appear to involve different regions of the brain, and it may be that men and women differ not so much in their overall empathetic capacity as in the settings in which empathy may be generated.[62]

Pain Sensitivity and Empathy

Healthy small-caliber nerve fibers transmit nociceptive information along sensory nerves.[60] Some people experience a rare, congenital insensitivity to pain (CIPA).[60,70] In people with CIPA, small-caliber nerve fibers do not function normally, and pain perception is impaired from birth.[60] Because pain information is not relayed correctly, these patients are highly susceptible to injury; in those with often-accompanying mental retardation, self-mutilation of the hands and feet also is common (see **Figure 3**).[71]

If empathy for someone else's pain requires that we perceive and judge the other's pain, that we evaluate

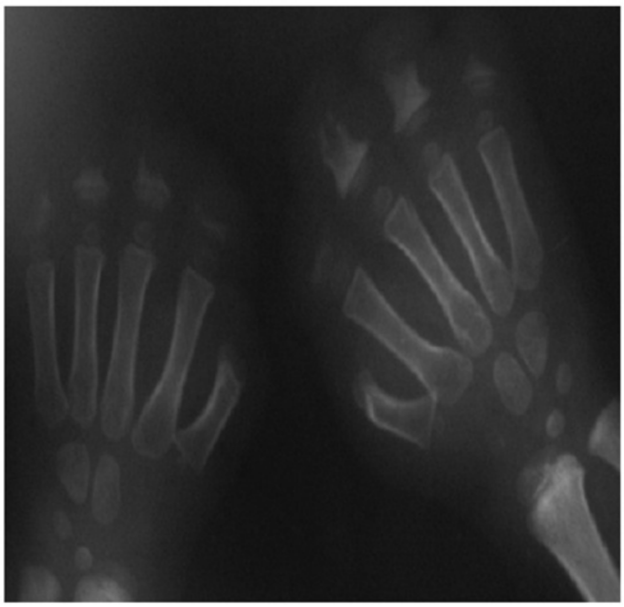

Figure 3. *Without the ability to feel pain, injury and destruction of tissue results. This radiograph shows destruction of fingers in a child suffering from congenital insensitivity to pain. Reprinted with permission from Labib S, Berdai M, Abourazzak S, Hida M, Harandou M. Congenital insensitivity to pain with anhydrosis: report of a family case.* Pan African Medical J. *2011;9:33.*

the pain in the context of our own pain experiences, and that our experiences resonate with others' experiences, do people with CIPA feel empathy?[13] What does imaging teach us about the empathetic brain activation patterns of people who are insensitive to pain vs those patterns displayed by individuals who can feel pain? If our brains compose a map of our pain experiences over time, is there any possibility that a person with CIPA can relate to another's pain?

In an experiment conducted in 2006, investigators presented CIPA patients and control subjects with situations in which they were asked to rate the pain experiences of others based on verbally presented imaginary painful situations.[60] The semantic knowledge of CIPA patients concerning the pain experiences of others did not differ from the knowledge expressed by control subjects. CIPA patients and control subjects also had similar abilities to infer pain from depictions of painful facial expressions. When CIPA patients watched video clips without visible or audible pain-related behavioral information, however, their responses varied from those of control subjects; CIPA patients gave significantly lower pain ratings, and their aversive emotional responses were reduced in comparison with those of controls.[60] The investigators concluded that a normal, personal experience of pain is not essential for the perception of pain in others or to feel empathy for another's pain. The perception of the level of another's pain, however, might be underestimated significantly when there is a lack of emotional cues.

In another experiment that compared empathetic pain responses of CIPA patients to those of control subjects, fMR images showed normal activation responses to observed pain in 2 key brain areas identified with empathetic, "shared circuits" for self and other pain.[70] Test subjects were scanned under 2 scenarios. In the first, they observed body parts in a painful situation, and in the second, they observed facial expressions depicting pain and were asked to imagine how the person felt. Salient results were as follows:

- CIPA patients rated the degree of pain intensity represented in pictures of body parts depicted in painful situations much lower than did control subjects.
- The inclination to infer pain from facial expressions did not differ between the 2 groups of test subjects.
- When the groups observed body parts in painful situations, similar brain activations occurred in both groups. No brain area was differently activated between the 2 groups.
- Although the same areas of the brain were activated, areas showed less activation in the CIPA group. Brain activation responses were weaker, in comparison with controls.[70]

What is the significance of these results? The results challenge traditional assumptions that activities in certain brain regions during observed pain signify automatic engagement of the observer's own pain experiences. Instead, engagement of these areas of the brain may represent the processing of the emotional meaning of aversive stimuli in general, as opposed to such stimuli as memories or personal experience.[70] Despite their lack of painful experiences, CIPA patients might understand what it means to feel pain through their own, albeit altered, experiences of psychological distress or pain.[70]

Selected Pain Syndromes

Experts recognize numerous pain syndromes — far too many for this article to encompass, although the more common ones are discussed. More women than men suffer from chronic pain syndromes, and stress may provide a clue as to why this disparity exists: Estrogen increases the release of certain substances that produce increased cortisol. Women may thus be hormonally inclined toward the development of chronic pain.[6]

Dysfunctional pain regulation is seen in such chronic pain syndromes as fibromyalgia, osteoarthritis, tension headache, and migraine, and functional neuroimaging reveals that people who suffer from chronic pain syndromes actually process acute pain differently than do nonsufferers.[16,35] In several experiments, test subjects who experienced chronic back pain, fibromyalgia, and irritable bowel syndrome showed enhanced pain-evoked neural responses when subjected to experimental painful stimuli.[16] Healthy subjects did not perceive the stimuli as painful, but the same stimuli was perceived as painful by the pain patients, and their brains showed activation of pain-related areas, while those of control subjects did not.[16]

Chronic pain syndromes often run in families, implicating genetic heredity as at least a partial explanation for why some people develop chronic pain while others do not.[35] Psychiatric genetic research, a promising area of pain research, has found specific genes in several anxiety disorders and depression, along with their associated pain states of migraine and fibromyalgia.[35] The same genetic tendencies also may predispose a person to develop chronic postsurgical pain, a possibility that leads some experts to propose genotyping as a preemptive, presurgical approach to pain control.[35]

Imaging provides insights to experts who seek to decode the underlying processes that result in development of these pain syndromes and to learn what harmful changes might result from such chronic pain syndromes. Chronic pain alters the brain's structure in various ways, and different pain conditions are associated with varying patterns of brain changes.[30,54] Unremitting pain is accompanied by changes on molecular, neuronal, and structural levels.[54] It also is associated with distorted information flow in the brain's reward and motivation system.[54] Structural neuroimaging supports a correlation between gray matter changes and the duration of pain.[54]

For a time, experts were uncertain as to whether brain changes are brought about by the pain experience or whether brain anomalies are instead responsible for pain amplification or development of chronic pain.[30] Now, however, experts tend to agree that brain atrophy typically seen in chronic pain patients is a result of damage, not a reason for the development of chronic pain.[72] Further supporting the perspective that structural changes are a consequence of constant pain is the fact that there are gray matter changes associated with both phantom pain and spinal cord injury.[72]

Fortunately, it seems that some pain-related brain changes are reversible. Using voxel-based morphometry, researchers observed gray matter changes in patients with hip osteoarthritis — both before hip replacement surgery and after.[72] Study results revealed that pain-related brain changes at least partially receded when the patient was pain free, after joint replacement surgery. Of great importance is the authors' cautionary observation that other behavioral changes following hip-replacement surgery also might be responsible for the brain's resilience: After surgery, patients were able to participate in exercise and increase their physical conditioning and well-being. These factors also might be responsible for increased volumetric changes. Authors also noted that other studies had shown that in patients with chronic fatigue syndrome, increases in gray matter volume were observed following cognitive behavioral therapy — a finding that again seems to support the observation that pain-induced brain structure changes are not necessarily permanent but can be, at a minimum, reduced.[72]

How unique might brain changes be to each underlying chronic pain condition? A recent study used structural MR imaging to view pain-related changes in patients with different chronic pain conditions to answer that question. Viewing only the resulting MR images, investigators were able to classify individual brains as to their pain conditions with a high degree of accuracy.[54] Study authors compared changes in gray matter properties in patients with chronic back pain, osteoarthritis of the knee, and complex regional pain syndrome, an uncommon form of chronic pain that is out of proportion to the severity of the initial injury (or surgery, stroke, or heart attack) and that typically affects an arm or leg.[54,73] Study authors found that different chronic pain sufferers exhibited anatomical "brain signatures" unique to their pain condition.[54]

Orofacial Pain Disorders

Orofacial pain disorders represent approximately 40% of chronic pain disorders and include headaches (tension and migraine), temporomandibular joint disorders (TMJ), cervical musculoskeletal pain, and sleep disorders related to orofacial pain, among others.[9,74] In orofacial pain disorders, pain may be linked to a clearly identifiable, singular cause such as postoperative pain or pain associated with a malignancy, or pain may be the primary problem, such as is the case with TMJ pain or headaches.[74] Headache disorders are 1 of the most common disorders of the nervous system; tension headaches alone affect more than 80% of women and 66% of men in developed countries.[75] The incidence of migraine headaches is estimated to be 3000 migraine attacks each day for each million of the general population.[75]

Chronic headache pain changes the brain's structure. Diffusion tensor imaging measures the speed and flow direction of water diffusion in anatomic regions of the brain and is more sensitive to structural brain abnormalities than other imaging techniques. The technique can reveal altered anatomical connectivity patterns within the brain, including any changes to white matter connectivity.[76] On diffusion tensor imaging, white matter, which supports the network of connections between gray matter information processing centers, appears decreased in frontal and parietal areas of the brain in migraine patients with high attack frequency.[16,76] In patients with chronic tension headache, voxel-based morphometry studies reveal a decrease in gray matter in several areas of the brain's pain matrix.[44]

Back Pain

Chronic lower back pain is costly to employers and a common reason for limited activity levels in people aged younger than 45 years.[77] It also is 1 of the most common reasons people schedule appointments with their physicians. High body mass indices and the obesity epidemic are contributing factors to the growing numbers of people experiencing chronic lower back pain.[77]

Altered brain structure associated with a longstanding pain condition was first demonstrated in chronic back pain patients.[54] Interestingly, voxel-based morphometry studies in these patients have shown anatomical changes to the brain and brainstem that are not correlated with the duration of pain — leading some experts to interpret the changes as a "disorder-specific reorganization of the brain."[44] This reorganization perhaps explains why this particular pain syndrome morphs into a condition less responsive to therapy and reversal than other chronic pain conditions.[44] The difficulty of this condition may be partially responsible for the fact that many back pain patients misuse opioids, and many of those who suffer from chronic back pain also have significant concurrent medical and psychiatric conditions such as depression, anxiety, irritability, and some form of mood disorder.[26] Some experts believe that back pain patients may abuse pain medications as a means of reducing their psychiatric symptoms — as opposed to or in addition to their pain levels.

Fibromyalgia

Fibromyalgia has long been a controversial diagnosis, as identification of patients depends for the most part on subjective, patient-reported symptoms.[36] Patients with fibromyalgia experience widespread musculoskeletal pain along with stiffness and tenderness at numerous specific body points.[30,44] They exhibit lower pain thresholds and heightened subjective pain; in these patients, even gentle stimuli trigger severe pain (see **Figure 4**).[36,44] Scientists use imaging to understand the underlying causes of fibromyalgia as well as the long-term effect of the disease on those who suffer from it. However, this group of patients has proven difficult to study and comprehend. They tend to be quite variable, and the fibromyalgia picture is complicated by the fact that the disorder often is accompanied by other physical and mental disorders such as sleep disturbances, fatigue, and depression, as well as confounding psychosocial factors.[30,44] In this patient group, teasing apart the factors so as to distinguish the precise cause of a specific result is a Herculean task.

Imaging helps demonstrate the reality of this disorder by revealing aberrant brain responses characteristic of these patients.[36] As with many other chronic pain states, patients with fibromyalgia display volumetric brain changes, including a reduction in gray matter.[44] Changes appear in areas linked to emotional disturbances and to pain processing areas of the somatosensory and motor systems of the brain. Experts hypothesize that the sensitization of the pain processing areas is modified or even initiated by psychological mechanisms.[36,44] Psychological factors not only may encourage development of the syndrome, but they also may help maintain the pain condition.[44]

Functional MR imaging studies, including voxel-based morphometry technologies, suggest that brain responses to stimuli are unusually heightened in these patients and that there is abnormal neurological input, in addition to abnormalities of endocrine and immunological systems.[36,44] Furthermore, responses in the brains of fibromyalgia patients consistently outlast the application of a stimulus. In other words, these patients not only interpret a stimulus as being more painful than do controls, but their brains also "experience" the painful stimulus for a longer time than healthy controls.[36] Current fMR data indicate that the enhanced brain activation seen in fibromyalgia patients occurs in areas of the brain associated with emotional processing.[36]

Using imaging, experts have discovered volumetric changes in the amygdala and frontal cortex in disorders

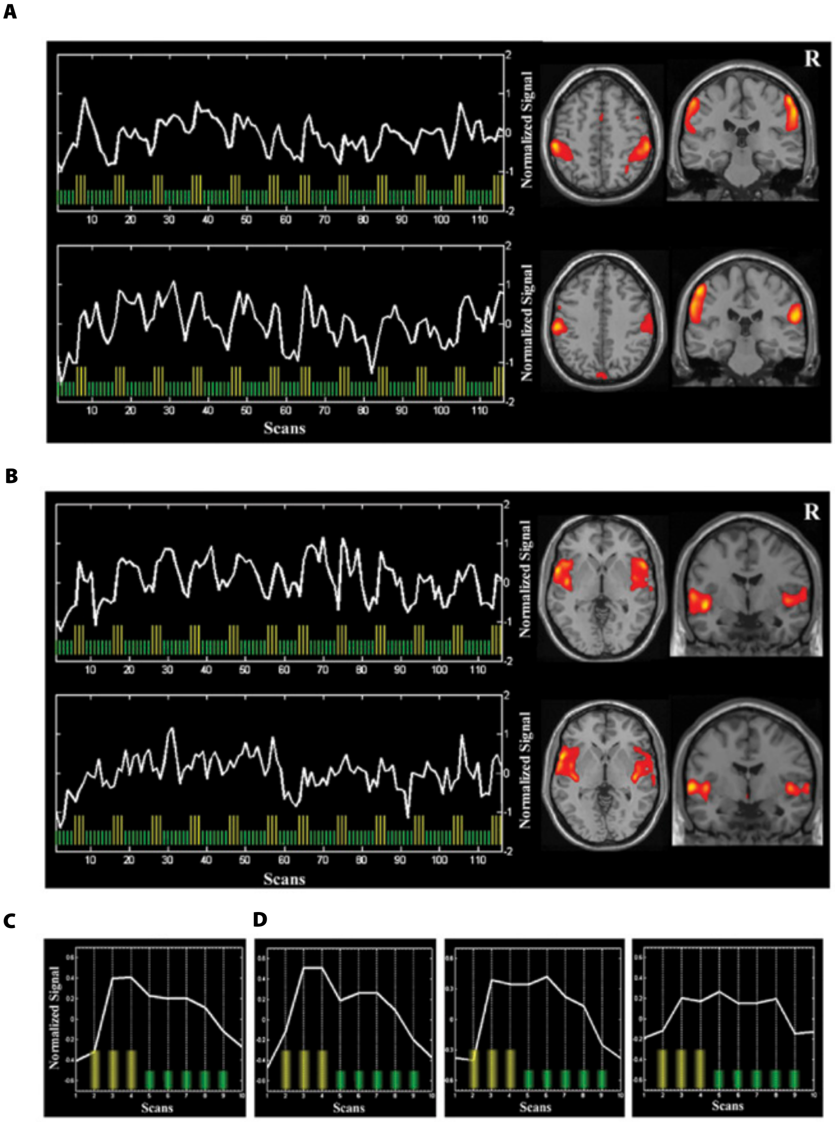

Figure 4. *Functional magnetic resonance images showing brain activation maps of fibromyalgia patients compared with healthy test subjects. Note the more pronounced responses of fibromyalgia patients to pressure of 4 kg/cm² applied to the right thumb (A) vs responses of healthy subjects (B). In addition, the response duration — how long the brain reacted to the pressure/pain sensation — varied between fibromyalgia patients (C) and healthy subjects (D). R indicates right hemisphere. Reprinted with permission from Pujol J, Lopez-Sola M, Ortiz H. Mapping brain response to pain in fibromyalgia patients using temporal analysis of fMRI.* PLoS One. *2009;4(4):e5224. doi:10.1371/journal.pone.0005224.g002.*

caused by trauma or stress, such as post-traumatic stress disorder and borderline personality disorder.[44] Emerging research indicates that people with fibromyalgia exhibit the same volume losses in the same areas of the brain, leading experts to hypothesize that fibromyalgia may be a stress-related disorder.[30,44] It seems clear that evidence of volumetric changes in these patients reflects both the preconditions for development of the syndrome as well as changes in neural pathways resulting from chronic pain input.[44] PET studies conducted on fibromyalgia patients reveal reduced dopamine activity in several brain areas in which dopamine plays an essential role in modulating pain.[18] This finding provides a persuasive explanation as to why these patients experience intense pain levels, despite the relative weakness of painful stimuli. Because stress can disrupt a healthy dopamine system, this finding may lend support to the theory that fibromyalgia is a stress-induced disorder.[18]

Many fibromyalgia patients complain of cognitive impairment, in particular with respect to working memory performance. Voxel-based morphometry data suggest that neurocognitive deficits in fibromyalgia patients correlate with changes to the frontal lobe and other areas of the brain associated with cognition and memory. These changes likely reflect the interaction between pain and cognition.[30]

Finally, functional neuroimaging shows that mood depression in these patients is associated with increased activation of brain regions that process the emotional or suffering components of pain.[36] Characterization of pain as awful, horrible, and unbearable ("catastrophizing" of pain) has been shown to relate to increased activation of numerous brain regions associated with emotional processing, attention, and sensorimotor processing.[36]

Treating Pain

Traditional Approaches

Because chronic pain is such a complex phenomenon, it logically follows that treatment of chronic pain might be a similarly complex puzzle, with some approaches proving effective for certain patients but bringing little to no relief to other patients.[78] The long-term intake of pain medications by patients with chronic pain may be responsible for some of the gray matter reduction revealed by imaging.[44,72] Controversy exists as to whether at least some of the cognitive impairments seen in fibromyalgia patients are the result of pain medication, as opposed to any disease process.[30] At the same time, some experts argue that sufficient pain control in chronic pain patients might protect against volumetric and neural changes.[30,44] The matter is further complicated by ethical concerns (withdrawing pain medication and thus leading to increased suffering), as well as the lack of solid information with respect to how long a person might need to forego medication — so that any structural or behavioral changes because of medication could be identified.[30] Addressing these issues, in addition to pinpointing which medication best serves these patients, remains a salient area of research.

Diffuse optical tomography (DOT) is a promising imaging technique in terms of assessing both pain intensity levels in a nonsubjective manner and response to analgesics.[79] Similar to fMR imaging, DOT is a noninvasive, portable technique. The subject wears a sort of helmet that contains light sources and detectors or sensors that absorb and respond to light (see **Figure 5**).[80] A computer that controls the electronics and analyzes the data is connected to the helmet device. DOT detects changes in cerebral blood flow (and thus areas of brain activity), including changes in concentrations of oxygenated hemoglobin (changes in "cerebral hemodynamics"). DOT's ability to provide information that is exact and independent of subjective patient reporting eventually may help experts more precisely target pain

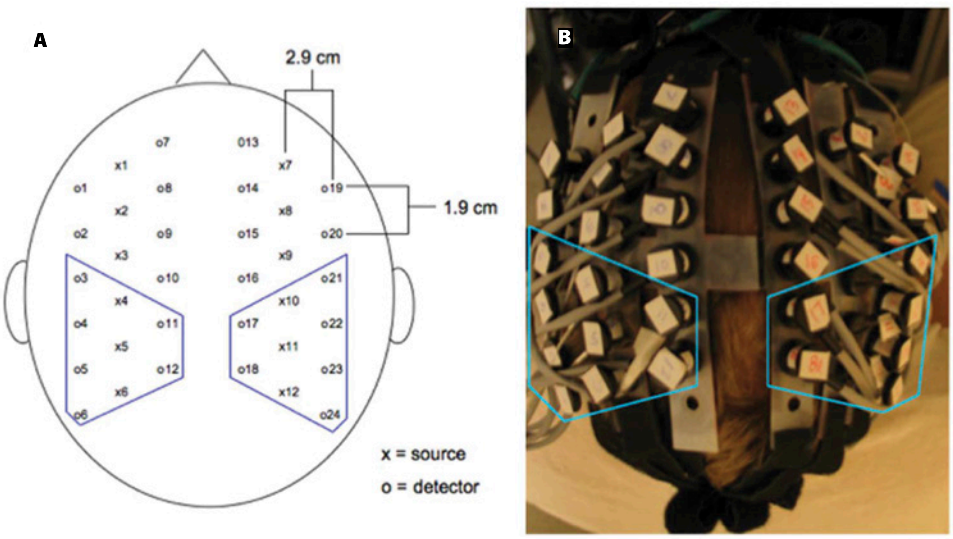

Figure 5. *The diffuse optical tomography system. A. Schematic of the source-detector arrangement as it relates to a test subject's head. B. Photograph showing the helmet in place, including sources of light and detectors. Reprinted with permission from Becerra L, Harris W, Grant M, George E, Boas D, Borsook D. Diffuse optical tomography activation in the somatosensory cortex: specific activation by painful vs nonpainful thermal stimuli.* PLoS One. *2009;4(11):e8016. doi:10.1371/journal.pone.0008016.g001.*

using patient-specific, effective analgesics administered at appropriate, effective dosages.[79]

Functional MR has been used extensively to evaluate the effectiveness of different analgesics, in particular how specific analgesics affect activation of discrete brain regions. For example, studies indicate that psychotropic medications result in no significant alterations or ameliorative effects on already-existing abnormal fMR measurements.[36] Benzodiazepines (sedatives often used to treat anxiety and insomnia) apparently diminish brain activity typically connected with the anticipation of pain, and nonsteroidal anti-inflammatory drugs (NSAID) suppress pain-induced activity in most areas of the brain implicated in pain processing.[36,81] Imaging reveals that antidepressants reduce activation of the brain's emotional processing area — the areas largely responsible for the suffering aspect of pain.[36]

Assessing Pain Levels To Treat Pain

Two patient populations present particular challenges when it comes to successful pain management: children and the elderly. Both populations may have a limited ability to convey their degree of pain, and pain in both populations may be under-rated and undertreated. Before pain can be treated, it has to be recognized. Effective pain treatment depends on the health care practitioner's ability to assess whether a particular drug or dosage is effective, or whether some other approach to pain reduction might be appropriate. The professional cannot successfully meet these challenges if he or she lacks adequate, accurate information concerning the patient's pain level.

Traditional self-reporting pain scales — "What number is your pain, between 1 and 10, with 1 being the least serious and 10 the most painful?" or "Which face most accurately reflects your pain level?" (with happy, neutral, and pained faces depicted) — can be inadequate in any population, but in particular in children and the elderly. Efforts have been made to refine patient self-reporting scales to overcome some of their historical inadequacies, and growing electronic data collection practices have reportedly improved documentation of pain levels and speed of medical intervention.[82] A recent study concluded that even in children as young as 4 years of age, electronic versions of a pain scale using faces could be successfully adopted in a hospital setting. The children's self-reported pain assessments using a personal digital assistant device that included simple line drawings of faces closely correlated with paper versions of the same pain reporting scale. Because the children preferred the digital version, they were more likely to complete the information using the device, as opposed to a paper version. Electronic reporting also contained fewer errors and omissions.[82]

Pain management in the elderly, in particular at the end of life, is exceedingly complicated. Although pain is 1 of the most prevalent symptoms of deterioration in the period preceding and accompanying death, all evidence points to a lack of sufficient pain management in this phase of life.[15]

The elderly represent the fastest-growing segment of the world's population. In 2008, 506 million people exceeded age 65 years; by 2040, that number will increase to 1.3 billion.[83] Pain and the constancy of pain increases with age. Although we have the ability to alleviate suffering, pain often is not treated appropriately. Between 25% and 40% of older cancer patients in 1 study had daily pain. More than a quarter of those patients aged 75 to 84 years received no pain medication at all, and 30% of patients older than 84 years of age received no pain medication. In another study of geriatric nursing home residents, 66% had chronic pain, but 34% of that pain was not detected by the treating physician.[83]

The U.S. Federal Drug Administration launched a Safe Use Initiative program in an effort to raise general awareness on medication safety in connection with pain management.[84] Staff from the initiative convened a panel of experts to address pain management in those older than 65 years of age, and their report noted the complexities encountered in pain management for elderly patients, along with key reasons for medication errors and failures in this population. The report stated that a high degree of skill level is needed to prescribe successfully for pain management in the elderly because:

- A 1-size-fits-all approach is inapplicable because of the high variability seen in this population.
- Liver and kidney functions decline with age, affecting how drugs are processed by the body. Drug recommendations and dosages need to be adjusted accordingly.
- The composition of body fat and water changes with age, altering how drugs are absorbed and how long drugs stay in the system.

- Cognitive function may be impaired, reducing the ability to communicate a pain level and interfering with drug regimen compliance.
- Numerous comorbidities are likely; a 2009 study reported that 24% of Medicare beneficiaries had more than 4 morbid conditions.
- A multiplicity of providers and polypharmacy can lead to medication errors, overdosing, and drug interactions. In elderly patients taking 7 or more drugs, the risk of an adverse drug interaction is 82%.
- A majority of physicians studied were unaware of potential cardiovascular and gastrointestinal complications associated with the use of NSAIDs in the elderly.
- Even when a patient can communicate, that communication often goes undocumented; physicians studied failed to record more than 50% of the medical histories described by their patients.
- Physicians often do not ask about or record over-the-counter drug use, including herbal remedies; these drugs can intensify or mask side effects associated with commonly prescribed NSAIDs and may increase the likelihood and severity of gastrointestinal bleeding or peptic ulcer.[84]

One of the most complicating factors is the lack of solid research in this patient population. Few well-designed, specific research studies are available, and consequently there are few evidence-based practices with respect to pain management in the elderly.[15] Some authors characterize the published information available concerning the use of opioids in the elderly as "scarce."[15] Older people with complex medical pictures are not sufficiently represented in clinical trials of pain medications, and so possible side effects specific to this population, along with a high degree of variability in terms of how a drug is metabolized, have not been sufficiently studied.[15]

Some studies have revealed that aging affects pain thresholds and evidence suggests that our pain tolerance increases as we age.[83] How does this changing pain threshold affect pain management, expression of pain, and pain symptoms? And how does that combine with dementia and an inability to communicate the existence or level of pain? What about a loss of language because of stroke or some other pathological change — how does that affect pain level assessments? Again, insufficient studies have been conducted and published, and caregivers are faced with attempting to interpret sometimes-vague forms of communication (eg, crying, groaning, or withdrawn and agitated behavior) in an effort to provide adequate relief of suffering. The explosive demographic associated with this population — the aging of the baby boomers — argues persuasively in favor of focusing research efforts on this health care need.

Rethinking Treatment Options for Pain

There is good reason for the medical profession's increasing concern over traditional, drug-based therapeutic approaches to pain control — or at the very least for modification of those approaches. Growing concern over the misuse of opioid analgesics has led to more concerted efforts at finding effective, alternative ways to treat and manage pain (see **Box 3**). Children in particular present a challenge to traditional pain control methods, although fortunately the myth that children do not feel pain seems to have subsided.[85] Awareness is increasing in terms of techniques for effective pain management for all groups of children, and most health care professionals no longer believe that children's pain cannot be prevented or safely treated because of concerns about the risks of drug side effects and addiction.[91]

Hypnosis is a promising alternative to pain management in both children and adults.[92] Investigators have explored the efficacy of hypnosis in treating chronic pain related to fibromyalgia, irritable bowel syndrome, headache, cancer, and other pain disorders.[78] Results indicate that hypnosis reduces pain in a variety of chronic pain syndromes; reduces the perception of the intensity level of pain; reduces duration, frequency, and use of analgesic medications; and is equally as effective as progressive muscle relaxation and biofeedback.[78] The numerous approaches to hypnosis have not to date been consistently studied, but thus far hypnosis in general appears to be an effective option for managing chronic pain because it is inexpensive and comes without addictive side effects. Patients also give hypnosis high satisfaction ratings — even when hypnosis fails to reduce their pain.[78]

Yoga may prove to be another less toxic approach to pain management. Studies have shown that yogic practices stimulate pleasure centers of the forebrain while at the same time inhibiting reflex mechanisms associated

Box 3

Pain Treatment by the Numbers[25,85-90]

Access to medication is a huge impediment to pain treatment for the vast majority of the world. Six developed countries accounted for 79% of worldwide morphine consumption in 2003. Fear of abuse and addiction account for some of the limited access. The World Health Organization has initiated a program designed to improve access to controlled substances, as well as training and development of treatment guidelines.

At the same time, in 2010 in the United States, enough prescription painkillers were prescribed to medicate each adult in the country 24 hours a day, for a month. The Centers for Disease Control and Prevention reports that:

- 100 people die daily from drug overdoses in the United States.
- Overdose death rates are more than 3 times what they were in 1990.
- About 3 of every 4 prescription drug overdoses are caused by opioid pain relievers.
- In 2008, prescription painkillers were implicated in more overdose deaths than cocaine and heroin combined.
- Depression and suicide are associated with chronic pain, with, by 1 estimate, the risk of successful suicide doubling for chronic pain patients.
- Misuse of pain relievers accounted for nearly half a million emergency department visits in 2009.
- Death rates are the highest in the Southwest and Appalachian regions, with the highest death rates in 2008 being in New Mexico and West Virginia; the lowest rate was in Nebraska.

Health care costs for patients who abuse opioids are nearly 9 times higher than for nonabusers. Inadequate pain relief may motivate some patients to engage in drug-seeking behaviors that they would otherwise avoid. A large population of young adults with a history of misuse of prescription drugs is regularly denied adequate pain relief; they often resort to self-medicating their pain with heroin or illegally obtained prescription opioids. Still unclear is whether a low pain threshold increases the risk for addiction, or whether addiction lowers pain thresholds.

Intense research efforts are under way to discover novel formulations of drugs that will make them less desirable to abusers, including:

- Extended-release formulations (preventing a drug high).
- Pharmacological barriers that divest the opioid of its power to intoxicate.
- Physical barriers, such as hard gelatin capsules designed to resist tampering.

Other efforts to combat opioid abuse include off-label approval of drugs that can be used to treat dependence in an office-based setting.

with stress; this results in lower anxiety, heart and respiration rates, and blood pressure.[93] It can reduce aches and pains and serve as a preventive measure by helping build or maintain muscle mass and strength, thus serving to prevent back and arthritis pain. Primarily, yoga helps to reduce stress, which, as discussed earlier in this article, plays a major role in the development and exacerbation of pain.[93]

The real winner in the alternative approach contest of pain reduction is meditation. Exciting, persuasive evidence proves the value of meditation in several regards, including mindful alteration of pain perception, raising of pain thresholds, and management of pain. The evidence is not new, although the visualization of the actual brain changes is novel because of advances in imaging technologies. More than 30 years ago, a medical professor at the University of Massachusetts Medical School began recording meditation-related health improvements in patients whose pain was intractable.[94] Professor Jon Kabat-Zinn's stress-reduction techniques are now widely used in both hospitals and clinics.[94]

Meditation is said to result in a brain pattern reflecting a sense of "feeling safe in the world…less vigilant and afraid"; it appears to create left-brain hemisphere dominance over the right hemisphere, which is associated more with vigilance and fearful reactions.[94] Numerous studies show that meditation can improve attention, relieve anxiety and depression, and reduce anger and cortisol levels; it can strengthen immune responses and gray matter density — it literally can change the brain's structure and functional capabilities.[37] A Tibetan lama described the effects of meditation practice by comparing his mind before training to a stag with great antlers, attempting to make his way through a thick forest. His antlers repeatedly caught in branches. After training and years of practice, he could move instead as if a monkey in a jungle, "swinging freely from vine to vine."[95]

Canadian researchers recruited highly trained Zen meditators and control matches for a study in which they applied thermal stimuli to subjects' calves to elicit pain.[37] Results of the study included the following dramatic revelations:

- Meditators had lower pain sensitivity than control subjects. The moderate pain level was significantly different between the 2 groups — meditators required higher temperatures before they even felt pain. Two meditators reached the highest temperature allowed by study parameters.
- Meditation decreased the intensity of pain felt. Zen practitioners reduced the intensity of pain felt by an average of 18%, with practitioners of greater experience reducing their pain by even more.
- The degree of meditation experience predicted the degree to which the individual could modify his or her pain experience.
- Clinically significant analgesic effects (reduction of pain intensity) were achieved only in the meditators who had more than 2000 hours of experience.
- Meditators breathed at a slower rate than controls, and pain modulation correlated with changes in respiratory rate across all test subjects.[37]

Why does meditation have these myriad positive effects? Several theories exist, including meditation's regulation of attention (distraction can help to alleviate pain); its reduction of stress and stress-related chemicals such as cortisol; its ability to increase activation of the PFC, where endorphins are released; and the slower respiration rates that accompany meditation.[37,96]

Mindfulness meditation likely causes reorganization of frontal hemispheric activity usually associated with emotional reactivity and outlook — and this, too, may contribute to altered pain perception.[96] Some experts have referred to meditation training as "eliciting a cascade of neuroprotective events."[96]

The positive effects of meditation on pain experiences do not appear to be limited to those who have practiced meditation for decades. In 2010 at an annual meeting of the American Academy of Neurology, experts reported on a study in which a Buddhist monk led subjects who suffered from painful conditions in a weekly, 90-minute class that incorporated mindfulness meditation.[97] Although the class lasted only 2 months, patients reported significant improvement in bodily pain, fatigue, and quality of life.

Conclusion

Experts' imaginative use of imaging technologies has resulted in huge insights when it comes to assessing, diagnosing, treating, and understanding the ways in which humans experience pain. As experts continue to refine their understanding of pain processing, innovative imaging technologies lend hope that those who suffer from intractable pain will find reprieve and solace.

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Read the preceding Directed Reading and choose the answer that is ***most correct*** based on the article.

1. ________pain is triggered by activation of nerve endings, signals tissue damage, and includes surgical pain, arthritis, and angina.
   a. Psychogenic
   b. Phantom
   c. Nociceptive
   d. Empathetic

2. Which kind of pain is maladaptive and arises from a pathophysiological process involving the nervous system?
   a. nociceptive
   b. neuropathic
   c. psychogenic
   d. phantom

3. Which of the following measure brain activity by recording changes in blood flow, blood oxygenation, and metabolic changes associated with activations of neuronal networks?
   1. functional magnetic resonance (fMR) imaging
   2. positron emission tomography (PET)
   3. electroencephalography

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

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4. Functional MR is the imaging method most often employed by those studying the brain's reactions to pain because fMR:
    1. results in better temporal resolution than PET.
    2. results in better spatial resolution than PET.
    3. is less expensive than PET.

    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

5. Arterial spin labeling is a type of _______ procedure that helps researchers understand the temporal relationship between activations of different brain regions during pain perception and processing.
    a. PET
    b. computed tomography (CT)
    c. fMR
    d. voxel-based morphometry

6. Approximately how much does pain cost each American per year?
    a. $560
    b. $2000
    c. $75 000
    d. $100 000

7. Opioid analgesics are not available in adequate amounts in developing countries because of:
    1. ignorance concerning the medical uses of opioids.
    2. excessively restrictive regulations that limit supply and use.
    3. medical practitioners' refusal to prescribe them.

    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

8. When pain lasts longer than _______ , it is considered to be chronic.
    a. 2 hours
    b. 7 weeks
    c. 3 months
    d. 1 year

9. Pain modulation refers to:
    a. exacerbation of the pain experience.
    b. reduction in the intensity of the pain experience.
    c. anatomic changes to the brain resulting from chronic pain.
    d. abnormal pain processing resulting from genetic tendencies.

10. Numerous factors can influence how we perceive pain, including:
    1. genetics.
    2. age and sex.
    3. beliefs and expectations.

    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

11. Pain is classified as _______ when emotional and behavioral health factors generate a pain sensation, increase the intensity of the pain experience, or prolong the pain experience.
    a. phantom
    b. motor
    c. acute
    d. psychogenic

12. Chronic pain syndromes tend to run in families, and pain and analgesic responses also appear to be genetically influenced.
    a. true
    b. false

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13. _______ refers to the large, distributed brain network activated during nociceptive processing.
    a. Pain matrix
    b. Central nervous system
    c. Neurosignature
    d. Prefrontal cortex

14. The _______ is located in a fold of the cerebral cortex and is linked to regulation of emotion and homeostasis.
    a. amygdala
    b. hippocampus
    c. insula
    d. pain matrix

15. The _______ triggers the release of opioids within the brainstem, leading to a modulation of pain perception.
    a. amygdala
    b. prefrontal cortex
    c. hippocampus
    b. medulla

16. The spinal cord is difficult to image because of:
    1. its small size.
    2. motion-related artifacts.
    3. difficulties with proper positioning in the scanner.

    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

17. _______ is a responsive biological system activated by any threat to biological homeostasis, including psychological threats.
    a. Pain
    b. The central nervous system
    c. The amygdala
    d. Stress

18. _______ is a hormone produced during the body's response to stress that maintains high levels of glucose for quick response.
    a. Bilirubin
    b. Testosterone
    c. Cortisol
    d. Estrogen

19. _______ may lead to structural brain changes that reduce patients' capacities to cope with pain.
    a. Benzodiazepines
    b. Chronic stress exposure
    c. Acute stress
    d. Muscular fatigue

20. Which of the following conditions have experts attributed to prolonged exposure to stress and dysregulation of the cortisol system?
    1. fibromyalgia
    2. chronic fatigue syndrome
    3. bone decalcification

    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

21. People who suffer from _______ are ***less*** sensitive to painful sensory stimulation.
    a. chronic fatigue syndrome
    b. post-traumatic stress disorder
    c. fibromyalgia
    d. borderline personality disorder

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22. Experiencing another pain somehow decreases the pain perceived elsewhere in the body, a phenomenon known to experts as:
    a. fibromyalgia.
    b. counterirritation.
    c. empathetic response.
    d. self-injurious behavior.

23. Almost _______ % of upper limb amputees feel phantom pain.
    a. 62
    b. 72
    c. 82
    d. 92

24. Simply imagining pain — in the complete absence of any physical injury or other form of painful stimulus — engages the pain-related neural network.
    a. true
    b. false

25. Nearly the entire pain matrix is activated in a(n) _______ to another's pain.
    a. empathetic response
    b. counterirritation response
    c. diffuse noxious response
    d. critical response

26. In an experiment discussed in this Directed Reading, subjects viewed photographs portraying needle injections into an anesthetized hand vs 1 that had not been numbed. Functional MR revealed that activation of the _______ portion of the pain matrix as opposed to the _______ portion depended on the context in which the pain occurred and the focus of the observer.
    a. phantom; sensory
    b. emotional; phantom
    c. sensory; emotional
    d. emotional; sensory

27. According to ongoing fMR imaging research, men engage in a more elaborate processing pattern when experiencing compassion.
    a. true
    b. false

28. Experiments using event-related brain potentials to study sex differences in empathy have shown _______ when it comes to the initial, automatic empathetic response.
    a. no difference between men and women
    b. that men are much more sensitive than women
    c. that women are slightly more sensitive than men
    d. that boys are more sensitive than girls, but women are more sensitive than men

29. In people with _______ , small-caliber nerve fibers do not function normally, and so pain perception is impaired from birth.
    a. borderline personality disorder
    b. self-injurious behavior
    c. fibromyalgia
    d. congenital insensitivity to pain

30. Which 1 of the following hormones is ***most likely*** to explain why more women than men suffer from chronic pain syndromes?
    a. adrenaline
    b. testosterone
    c. estrogen
    d. insulin

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31. Orofacial pain disorders represent _______% of chronic pain disorders, including headaches, temporomandibular joint disorders, and sleep disorders related to pain, among others.
    a. 12
    b. 24
    c. 38
    d. 40

32 Patients with fibromyalgia suffer from which of the following?
    1. widespread musculoskeletal pain
    2. stiffness and tenderness at numerous specific body points
    3. sleep disturbances and fatigue

    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

33. Evidence from some studies shows that our pain tolerance _______ as we age.
    a. decreases
    b. increases
    c. varies
    d. remains unaffected

34. Study results reported in this Directed Reading indicate that hypnosis:
    1. is less effective than biofeedback in the relief of chronic pain.
    2. reduces the use of pain medications in patients with chronic pain.
    3. reduces pain in a variety of pain syndromes.
    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

35. Meditation helps in the treatment of chronic pain by doing all of following ***except***:
    a. altering pain perception.
    b. raising pain thresholds.
    c. increasing cortisol levels.
    d. managing pain.

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Directed Reading Evaluation
What Imaging Teaches Us About Pain

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○ Yes ○ Partially ○ No

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○ Yes ○ No

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○ Very valuable ○ Valuable ○ Somewhat valuable ○ Not very valuable

If you have comments or questions about this Directed Reading, please write them below or send them separately to Ellen Lipman, Director of Professional Development, ASRT, 15000 Central Ave SE, Albuquerque, NM 87123-3909 or elipman@asrt.org.

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What Imaging Teaches Us About Pain

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3	③	③	③	③	③	③	③	③	③
4	④	④	④	④	④	④	④	④	④
5	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤
6	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥
7	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦	⑦
8	⑧	⑧	⑧	⑧	⑧	⑧	⑧	⑧	⑧
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Managerial Strategies for Creating an Effective Work Environment

Kimberly A Luse, EdD, R.T.(R)

To create a highly functioning medical imaging team, radiology managers must be able to analyze their departments and identify areas for improvement. This type of analysis means assessing front-line personnel who already work in the department, along with identifying staffing needs and recruiting talented new employees. In addition, managers must develop effective retention tools such as career ladders and mentorship programs to improve the overall working environment. This article discusses a variety of different strategies to help managers develop a more effective department.

This article is a Directed Reading. Your access to Directed Reading quizzes for continuing education credit is determined by your membership status and CE preference.

After completing this Directed Reading, the reader should be able to:

- Describe the department's ability to attract talent.
- Implement meaningful employee evaluation processes.
- Discuss how to implement a 360° review process for management.
- Discuss professional development strategies for employee retention and promotion that includes career ladders.
- Articulate a plan for addressing problematic employee behavior.
- Formulate a plan to implement a mentorship/sponsorship program.

Each radiology department has unique characteristics and dynamics that reflect the diverse group of people who make up the medical imaging team. Radiology managers must shape that assortment of individuals into a viable work unit and point staff in the same direction to reach a common goal. To accomplish this task, each manager must create an effective and motivating work environment.

Several challenges work against the manager. Often, there is the ingrained perception that the status quo must be maintained, and it is difficult to make changes going forward. A misconception persists that it is easier to ignore many issues that arise in the workplace than to address those issues directly. The price for this approach is the loss of imaging departments' best personnel as staff members seek more healthy working situations. In addition, potential employees almost certainly sense the negative environment when they interview for an open position. Managers must learn to reduce or eliminate negative behaviors that affect morale — and ultimately productivity — to manage effectively. In general, radiology department managers face a complex issue of how to care for the caregivers in imaging departments.[1]

Assessing Employee Performance and Satisfaction

Although the general concept of burnout often is used casually in describing employee dissatisfaction, there is empirical research regarding burnout in the radiologic technology profession. Akroyd et al investigated patterns of burnout among U.S. radiographers and found that these professionals exhibited much higher levels of emotional exhaustion compared with other health care workers.[1] Therefore, it is critical for managers to take the time necessary to discover what could be driving poor performance among their staff.

Poor performance can be multidimensional. For example, technologists might perform poorly purely in technical tasks. A technologist who produces high-quality images might have poor interpersonal skills, which requires a different interventional strategy from the manager. Intervening in problematic behavior can be a difficult and overwhelming responsibility, but inaction leads to dysfunction on a larger scale. In the absence of leadership, negative behavior flourishes.[1,2]

Addressing negative employee performance and behavior might require eliminating the source of the problem or even employee termination. The cost of termination can be high, however. The literature reports a conservative estimate of 6 months for a newly hired employee to begin producing at a level that is sufficient to justify the salary that he or she receives.[2] The high cost does not justify retaining an employee who clearly causes problems for the department or is ineffective. As stated previously, avoidance by department leadership can lead to further dysfunction or decreased departmental performance.[3]

Competent managers examine the workplace they lead before developing strategies for improvement. The following questions adapted from Porter-O'Grady and Malloch can assist a manager in beginning a workplace assessment:

- Why would anyone want to work at your organization?
- Do employees find location, pay scale, benefits, reputation for quality care, research commitment, affiliation with an educational institute, or something else most attractive?
- In what type of culture does the work occur?
- How is the work recognized and valued?[4]

Effectively analyzing the imaging department takes a manager's time and energy. Leaders within the medical imaging community are well aware of the integral role their department plays in relation to the entire health care facility or system, and research is conducted to assess how the medical imaging department interacts with other departments, but communication and workplace effectiveness assessments often are skipped at the departmental level. It is unwise to eliminate department-level evaluations in consideration of the bottom line because failing to identify problems can add to a dysfunctional workplace for medical imaging employees. According to some statistics, nearly 1 in 3 health care employees are considered high risk (ie, they are actively planning to leave their current position) at any given time. In addition, 4 of 10 employees report they would leave if they could, but feel constrained by life circumstances to remain at their place of employment. Only 1 in 4 truly are satisfied with their work environment, have chosen to stay, and are happy with their choice.[5]

Research from the American Society of Radiologic Technologists' (ASRT) Environmental Scan of the Radiographer's Workplace concluded that technologists rank their job, organization, coworkers, and quality of patient care as their top priorities when choosing an employer. Interestingly, managers participating in the survey reported that they believed salary and time off from work were most important to their employees. This type of disconnect leads to suboptimal plans for employee satisfaction and retention and emphasizes the importance of local assessment and fact gathering.[6]

Health care managers often are faced with the challenges of recruiting and retaining qualified workers, and radiology is no exception. Maintaining a supportive and effective workplace is key to retention.[6,7]

Employee Evaluations

The information obtained from employee evaluations helps provide a comprehensive review of an imaging department and helps to satisfy a critical requirement of The Joint Commission regarding consistent performance appraisals for all personnel.[7] If not planned and executed properly, this process easily can develop into a meaningless annual activity, fraught with anxiety on the part of supervisors and staff members. Managers should consider the purpose of assessing employee performance when planning for evaluations. Once the process is embedded into a department's culture as a tool to provide support, continuous improvement, and professional development, attitudes toward performance evaluations tend to be more positive. Attitudes of openness, transparency, and a shared goal of working toward individual and team improvement lead to more successful evaluation processes and results.[8]

Framing the performance evaluation experience as a structured opportunity for managers and staff to sit down and communicate in a neutral and nonthreatening environment supports more openness and more successful evaluations. Ideally, staff members are allowed valuable one-on-one time to speak openly with managers about issues that affect their work performance. Managers gain employees' trust by demonstrating respect and holding confidences shared during the exchange. When a department develops or changes annual evaluation processes, it is important to educate staff at all levels regarding expectations.[9]

Managers can use a number of tools for employee performance appraisals. The comparative method, absolute standards, and management by objectives are commonly used types. The comparative method compares employees against one another, resulting in a ranking system. There are several ways that managers can structure feedback from the comparative method, depending on their department makeup and what works best for their team.[4,7]

The absolute standards method evaluates employees according to a designated list of written standards that the department values. In a typical medical imaging department, absolute standards might include patient satisfaction or complaints, number of retakes, and formal performance issues that have resulted in written reprimands. There are multiple ways that managers can capture the information so it can be used most effectively.[7,8]

Use of management by objectives has increased because this method allows managers and staff members to work together to develop a list of goals to accomplish during the period under review. Employees and their managers can review together which goals have been attained and which ones need to be adjusted, added, or deleted. This model allows the manager and employee to identify areas for improvement or projects of interest to the radiologic technologist that can benefit the department or organization. For example, a technologist might be a good candidate for the department's mentorship program. Managers should help employees align goals with the department's overall organizational structure and strategy, along with the personal and professional goals of the worker.[7,8]

360° Evaluations

A 360° evaluation provides the employee who is being evaluated with anonymous feedback from his or her manager(s), peers, and direct reports. An effective model involves no more than 12 people who can provide their feedback, preferably in an online format.[10] These types of evaluations should be structured in such a way that the questions do not reveal the role of the evaluator and instead maintain anonymity.

Strict adherence to anonymity allows participation from coworkers at as many levels as possible, such as supervisors to whom a chief technologist reports, the technologists who report to the chief technologist, along with colleagues within the imaging department and professionals outside the department (eg, clinical partners and educational affiliates) who may have insight and thoughtful feedback. Focusing on areas that reveal opportunities for improvement in departmental analyses can strengthen communication, leadership styles, and other issues.[10]

The purpose of a 360° survey is to measure behaviors and competencies. This evaluation tool is not to be mistaken for an evaluation method that measures performance objectives, such as ensuring the department is under budget for the fiscal year or reaching target staffing goals. As with any employee evaluation, poor planning and poor communication render the 360° evaluation less effective. Beginning the evaluation process without proper buy-in from senior management can make the evaluation process fail. Most importantly, failure to follow up on the results of the feedback or to hold those evaluated and their managers accountable for findings can seriously undermine morale and confidence in the facility's administration.[10]

Managers can apply a modified version of the 360° evaluation to perform a comprehensive evaluation of how an entire team is performing. This type of evaluation examines individual contributions from team members, along with the team's effectiveness as a unit.[7]

Management Self-evaluation

Managers also should participate in 360° evaluations. It is not always easy for managers to examine their personal shortcomings, but feedback from others is necessary for successful leadership. This type of feedback can help open lines of communication between management team members and those who interact with them. A well-conducted 360° evaluation can help a manager understand how he or she is perceived by peers, supervisors, and subordinates, as well as provide an excellent measure for leadership, listening, and other essential skills. Managers must lead by example and demonstrate the types of behaviors they are asking of their employees. Further, by participating in 360° evaluations, managers set the tone for the entire departmental evaluation process and examination of issues that could be undermining the team's effectiveness.[11]

Effective Leadership

Transformational Leadership

More than 30 years ago, James MacGregor Burns developed a theory describing effective leaders as transformational.[12,13] Effective leadership has been identified as a key component to the level of employee satisfaction in the allied health professions. In fact, it follows only a sense of job security in the workplace and salary in determining health care workers' job satisfaction. In the mid-1980s, Bass suggested 4 elements of transformational leadership:

- Idealized influence – capacity to be a role model.
- Inspirational motivation – having a vision.
- Intellectual stimulation – encouraging creativity and ideas.
- Individualized consideration – rating each person uniquely.[12]

Radiology managers can focus on transformational leadership by following these 4 elements. Specifically, managers can promote the sense of professionalism, quality, and culture they want their staff members to emulate by example. Other potential strategies can address specific issues identified in departmental assessments and managers' 360° evaluations. For example, if employees express frustration with a manager's communication skills, he or she can become more visible or schedule regular team discussions.[13] The transformational leadership theory continues to be explored. Although the positive effect of transformational leadership has been documented in other professions, a study performed by Legg concluded that radiography leaders' skills are lacking in this management style.[14] He suggested that attention be given to developing formal programs to help fill the gaps.[14]

Addressing Evaluation Results

Once a manager gains insight into strengths and weaknesses gathered from evaluations of others and self-assessment of his or her leadership style, the manager should develop a plan to address weaknesses and reinforce strengths. It is far worse to do nothing with information learned from assessments and evaluations than to never seek information in the first place. An outside consultant might be needed to help a manager brainstorm ideas for handling particularly challenging situations. Those at upper management levels must use evaluation information to ensure that leaders with the right tools are in the right positions to continue managing effective teams.[14,15]

The American Hospital Association has developed strategies to assist the health care leader in providing more effective support to direct reports. Strategies include ensuring that:

- Front-line employee expectations are known and respected.
- Leaders have the skills necessary to manage the needs of their direct reports.
- Leadership is a pathway to manage employees vs managing the workload or workflow.[15]

Even when managers use performance evaluations to overcome a natural tendency to avoid honest assessment, many fail to act on findings. Jim Bolton, CEO of communications consulting firm Ridge Associates in New York, said of employees with performance problems: "You not only have to manage their performance, but, as chronic offenders, they become problems in your performance." According to Bolton, executives find workarounds, avoid the employee, provide vague feedback, and often add to their own workloads when they compensate for underperformers instead of addressing issues upfront.[2]

A manager can work more easily with results from appropriately designed and conducted performance evaluations. For example, when a manager circles all of the highest values in each category for employees, there is little room for employee feedback or growth. Few employees are at the highest level in every category, and managers should work with those who perform at this level to develop ideas for professional advancement.

As mentioned previously, setting expectations for the performance evaluation process can help eliminate employee disappointment or concerns regarding imperfect results. Needing improvement in a few areas can generate discussion and the opportunity to plan radiologic technologist advancement, perhaps leading the employee to share his or her career aspirations.

Managers should perform employee evaluations on a regular schedule that is well communicated so everyone has the opportunity to prepare. Evaluations can be stressful for employees, particularly if they have too little time to prepare. The evaluations are not effective if managers fail to invest the time necessary to review each member of the team thoroughly and provide written assessments to the employees for reflection and review before the personal discussion. Managers should require employees to spend thoughtful, deliberate time processing the evaluation from their perspective; this allows workers the opportunity to outline their concerns and discuss them with their manager if necessary.[16]

Honest discussions regarding performance evaluation results, including successes and shortcomings, can lead to employees revealing problems they perceive in the workplace. It is better to address an employee's dissatisfaction — even if the manager sees the issue as invalid or unimportant — to prevent the situation from becoming worse. For example, some employees might resent what they perceive as unequal time off for vacations or holidays. Managers might make their staffing decisions based on ensuring that the most skilled or trustworthy employees are working at the most critical times, but employees' perceptions might be that decisions are punitive. Open communication can help employees and managers understand motivations and improve trust and team cooperation to provide quality patient care and lessen employee morale issues.[9]

Use of modified 360° evaluations that assess the entire team can help managers identify or improve projects in their departments, such as streamlining patient scheduling or reducing patient wait times. This type of evaluation can help the team develop and implement strategies to achieve departmental goals. It also offers opportunities for measurable assessments of team members who embrace and engage in department goals. As with individual evaluations, the manager must follow through in a timely manner to build confidence in management among employees and to gather support while employees are engaged.[7]

Professional Development

When conducting an honest self-assessment and fair, candid employee evaluations, the radiology manager helps establish an environment of trust and openness. These reviews also lay the groundwork for an important management opportunity: the professional development of radiology department staff members. Radiologic technologists come to work each day with their individual career dreams and their desire to make a meaningful contribution. Some are content to maintain the same role in an organization for the duration of their career, but most aspire to develop in their profession. According to author Herminia Ibarra, individuals' working identities usually change so gradually that they fail to notice the natural course of their professional paths. Some professionals attempt to make rapid changes — or are forced to by circumstances. Some employees need help when trying to make drastic or rapid changes in their skills or roles.[17]

Savvy managers can help create pathways within their departments for employees' personal growth and development (see **Figure 1**). Some imaging departments have perpetuated the practice of promoting exceptional technologists into management positions with little or no preparation. Radiologic technologists who stand out technically or in patient care show many skill sets that might serve them well as managers; they improvise and work around obstacles to produce high-quality results. Although it seems natural that these technologists would be equally successful as department leaders, supervising and managing roles require different and additional skills as well.[18] For example, the ability to work independently often is a desired skill in

Figure 1. *Managers who create pathways for employees' personal growth and development often have dedicated, high-performing teams.*

a radiologic technologist, but contradictory to being a good manager. A newly promoted manager might have the best intentions when he or she steps in to complete a task assigned to someone else, but delegation is an important management skill, and the employee who was assigned the task originally could feel micromanaged and begin to shut down.[19]

Assumptions and lack of training or preparation for technologists promoted to management positions too often lead to their contributing to department dysfunction and perhaps failing at their first managerial position. Departments must examine their internal structure and think carefully about what a particular employee who has been promoted would need to be successful in the transition to management. Such support systems must be put into place well before transitioning an employee to management to ensure success.[20]

Radiology managers should not assume that only human resources (HR) staff are responsible for dialogs with employees regarding professional development. Managers should consider employee desires and skills when forming comprehensive succession plans for their medical imaging department's future.[21] Succession planning occurs when senior management thoughtfully considers what likely will happen when leaders leave positions within their departments and plan for who could move into the vacant roles. The best succession plans begin by examining if the position remains relevant and, if so, whether the way it is currently structured continues to make sense when the leader departs. Once those questions are answered, a plan for those who might move up and into the roles can be devised.

Management Strategies

Before radiology managers can help their employees develop, they must clearly outline and communicate their department's mission and how they will execute the mission and goals of the organization and department. Only then can the department's employees fully grasp their place within the team and the larger picture.[4,22]

One of the defining characteristics of a great manager is the ability to delegate and trust other members of the team to accomplish the tasks assigned to them. If new managers are properly selected and prepared, more experienced managers should be confident enough to allow the new managers to work in ways that are the most comfortable to them. An experienced manager should not insist direct reports adhere to a style that he or she prefers. According to author Marcus Buckingham, managers should not only ensure all of the leaders working for them are on parallel paths, but also should appreciate the value of each manager's unique abilities and learn how best to integrate the unique skills and personalities of team members into a team model for departmental effectiveness.[18]

There are tools and methods that radiology managers can use to develop the skills of employees in the medical imaging department and successfully transition employees between roles. Baystate Health in western Massachusetts successfully implemented a career ladder program in their laboratory department between 2008 and 2010. The system's radiology department modeled a program on its success that is in progress as of this writing.

To develop the career ladder program, Baystate staff reviewed existing career ladders in other U.S. laboratory facilities and designed the model that best served their organization. The goal was to provide greater opportunities for current staff members to advance, which consequently led to improved retention and an additional recruitment tool. Staff members were expected to be responsible for exploring opportunities and pursuing their individual career pathways. Baystate Health measures progress and rewards employees for trends that demonstrate behavior change; for example, the program awards for sustained improvement, not a singular event.[23]

Employee Recruitment

Many of the strategies discussed above concern employee retention, which is important to maintaining a highly functioning imaging department. Managers also must replace radiologic technologists and other staff members who retire (as is the case with many aging baby boomers) or who otherwise depart. Radiology managers must resist the temptation to take shortcuts in vetting and hiring new employees and instead allot adequate time and attention to this important task.[21]

Cultivating a strong relationship with the HR department is a critical step that managers must take to successfully recruit and retain skilled staff, sometimes referred to as "talent." HR department staff should be key partners when a radiology manager begins a search to fill new or vacant imaging department roles.[21]

Recruitment Strategies

Once the HR department has helped screen candidates and presented them to the radiology manager, he or she must evaluate candidates' qualifications. A trend that has caught a lot of momentum among recruiters is the practice of reading résumés backward. The idea sounds counterintuitive, but it can be quite effective. With the large volume of résumés often received and the multiple avenues with which they reach recruiters and managers, it is becoming increasingly difficult to sort through them to determine the best candidates for open radiologic sciences positions. Many candidates possess the same credentials and similar work experience, and they frame that information in ways that look identical following print or electronic formats. Scanning a résumé backward might help prevent discarding a candidate who should stand out, but does not because of weary screeners or automated systems used by many large employers.[24]

It is often toward the end of the résumé that a candidate lists information that could be considered as supplemental. Examples include personal information such as completing a decathlon or starting a business. This type of information can provide a potential employer a more complete view of a candidate and point to unique skill sets that a manager might need for the role being filled within the medical imaging department. Once a manager practices this new method of evaluating résumés, it becomes easier to assess desirable qualities such as stamina, drive, and persistence. The method also can help eliminate a candidate who otherwise would appear desirable or prompt interview questions by quickly identifying a lower grade point average or unexpectedly long time to complete professional training. Scanning more deeply into this type of information might reveal a potential problem or that the candidate was balancing 2 jobs while completing schooling.[24]

Author George Anders defined this résumé review process as "sorting out jagged résumés."[24] He stated that traditionally, interviewers have attempted to place résumés in stacks with labels according to whether the candidates are being considered, not considered, or may be considered for hire. Most often, managers have an unwieldy list of qualities desired in candidates to fill the vacant position. According to Anders, excellent candidates often fall into the group of candidates who may be considered, but are overlooked until someone implements a fresh process to evaluate candidates more thoroughly. For example, exercises such as discovering a candidate's ability to rebound from failure can be indicators of future success.[24]

Figure 2. *During an interview, the manager and candidate should behave as professionals and follow a formal process often established by the Human Resources department.*

Interviewing Strategies

Once the best potential candidates have been selected, the manager must plan for interviews. Even when the manager knows the candidate, such as a radiologic technologist who already works in the department, the manager must follow a formal process that allows the candidate and manager to consider carefully the appropriateness of the candidate for the position (see **Figure 2**).[24] Managers should work within the parameters set forth by their HR department to structure the interview and to elicit the information needed while avoiding questions that are too personal or that border on discriminatory or illegal questions.[21,24] Because many laws vary by state, managers should first meet with HR and the company's legal team to understand fully the relevant laws and how they have been translated into departmental policies and procedures.

The radiology manager's time and attention is stretched with his or her daily responsibilities of running the medical imaging department, and it might be difficult to adequately address the interview process. Up to 3 in-person meetings with a prospective candidate can produce the most effective hiring results. It also is helpful to involve 3 separate managers in the interviews to more objectively and thoroughly evaluate a candidate. Fewer than 3 interviews can cause managers to miss red flags regarding the candidate, and more than 3 meetings might introduce too many opinions, potentially eliminating an excellent candidate.

The ultimate decision regarding a hire should be left to the manager who will supervise the person in the position directly. The supervisor and worker should know in advance whether they perceive that they will have a good working relationship.[21,24]

One of most difficult situations a medical imaging department manager can face is when the recruiting and interview process fails to produce the right candidate. This is less likely to happen in a slow job market, but it can occur, particularly in certain geographic regions or for specialized positions. If a manager fails to identify the right person for a job, he or she should readvertise the position and begin again, perhaps seeking the help of the HR department for a different recruiting or advertising approach if necessary.

This decision can be particularly uncomfortable when internal candidates have applied and the manager decides not to hire or promote them into the position. Managers should avoid the temptation to place the current employee in the new role for fear of losing the employee altogether; in fact, the worker likely would be lost eventually after being unsuccessful in the new position. Managers must handle the process with discretion and honesty and help the candidates who are not successful understand the reasoning behind the decision.[24]

Supervision and Personnel Matters

Addressing Problem Behaviors

Beyond assessing the medical imaging department and evaluating employee performance, managers must ensure that their teams continue operating smoothly while addressing employee problems. Employees become disenchanted with their positions and work environment for varied and unique reasons. The disenchantment of a single employee can spread, affecting otherwise satisfied and highly valued employees. Often, an employee acts out in ways that become increasingly difficult for coworkers and managers, but if managers ignore the problem, it becomes more widespread, and the manager might become entangled in a department-wide predicament complicated by legal issues.[25]

Poor employee behavior can assume many forms. Blatant insubordination includes an employee refusing to perform a task, not reporting to work on time, or showing disrespect to the radiologist or others. Such behaviors should be addressed immediately. Highly problematic behavior often is more subtle, but equally serious. Undermining fellow team members (eg, by spreading gossip or participating in exclusionary activities) and creating an unwelcome or hostile workplace also are behaviors managers should address. Formal documentation is crucial to moving successfully through the process that could end in terminating the employee. The HR department is the radiology manager's resource for addressing difficult employees. Simply meeting with an HR department representative to discuss the situation serves as a formal step in documenting an employee problem.[24,25]

Generally, the manager outlines a plan to discuss the problematic behavior with the employee. Once the employee has received the appropriate information regarding what needs to be corrected, the manager should establish a reasonable timeline in which improvements should occur. If the behavior in question is serious enough that it must be remedied immediately, then immediate improvement must be expected. The employee should receive a written document that outlines expectations, along with a summary of the meeting; the employee should be required to sign this document. The goal of the corrective meeting and document is to eliminate any possible confusion between the employee and the manager regarding the problem behavior and expectations of correction. Attention to this detail can save managers time, trouble, and potential legal action.[25]

Dealing with difficult team members is possibly the most important responsibility that managers have in retaining employees. Ignoring problems can inevitably lead to the loss of the most skilled and hardest working members of the team. High-performing employees might seek other opportunities if they cannot trust the medical imaging management team and become frustrated by a workplace made more difficult by 1 or a handful of coworkers. Excellent workers are well aware of the unfairness related to some team members consistently performing better and behaving professionally when others are not required to do the same. In the worst scenarios, ignoring the problem can escalate to bullying or violence in the workplace.[24,25]

Employees behave poorly for a variety of reasons, which reinforces the importance of involving the HR department. Sometimes, it simply is best that an employee leave the department or organization. The management team can listen to why a departing employee is dissatisfied, evaluate what part management might have played in the loss of the employee, and determine whether other employees might have similar concerns. The individual manager or employer can gather information that might be used to help avoid the same situation with a different employee. For example, the issue might be related to the employee's generation, so a manager might need to better understand how having a mix of team members from different generations affects workplace dynamics and communication.[25,26]

Delivering Feedback

When delivering difficult feedback, it is imperative that the manager frame the information correctly. The manager should make every effort to begin by reflecting on an employee's positive attributes and by expressing appropriate appreciation and feedback about what the employee is doing right.

Next, the manager should turn to negative or problematic issues that need to be addressed. Author Timothy Butler says that difficult messages should be delivered with respect, but in a direct and detailed manner. Managers should focus on behavioral terms, being specific about the types of behaviors that are causing problems instead of making the problems appear to be personal in nature. The more the manager addresses the behavior and the more descriptive the discussion, the more effective the feedback will be.[16]

Many managers miss an important step in the feedback process that Butler calls "normalizing" the relationship.[16] Even when warranted, negative feedback is difficult for people to receive. Employees might feel defensive, and they often require time to let their defenses down and absorb the information. Once the feedback is thoroughly processed, employees can see it more positively and as support to help them become a more valuable member of the team.

Managers can assist employees to accept feedback by making certain that they continue to interact with the employee in a "normal" fashion. This means that managers should not avoid the employee but should maintain the relationship as it was previously established by asking the usual questions, such as how the employee's day is going, or how issues important to the employee are developing. Acting normal helps the employee move away from the awkwardness of the negative feedback and allows the worker to again feel comfortable in the job role. This can help employees begin to address the issues about which they received feedback and move forward.[16]

Managers also must recognize the need to provide positive feedback, whether part of a formal evaluation process or simply as warranted. The fast-paced, technologically driven radiology workplace can lead to feelings of working in isolation and a disconnect from the work team. Managers should never underestimate how powerful it is to take the time to ensure that the people who work for them understand how valuable their contributions are to the department's quality of patient care.[5]

Authors Amabile and Kramer described 4 major nourishers to ignite joy and creativity in the workplace. The first is respect, which comes in many forms. At its most basic, respect takes the form of civility between employees, both up and down the lines of authority. Respectful environments must be maintained during all meetings. Actively listening to employees or coworkers and being forthright when responding to input demonstrate respect. Feeling disrespected is a catalyst for employees to begin looking elsewhere — including to another employer — for validation.[27]

The second nourisher is encouragement. Managers can encourage employees daily. They can bolster morale and productivity by structuring formal and informal ways to help the members of their team to feel empowered to be successful in their roles. Managers must remain aware of the emotional well-being of their employees to nourish emotional support, which is the third nourisher. Sometimes, managers also must support employees for personal challenges along with those that are work related. Providing an environment where team members feel they can be honest about matters affecting them and, ultimately, their performance makes it easier for managers to gather information to help them support their direct reports.

The fourth nourisher is affiliation; it is crucial for coworkers to develop an affiliation with each other and their organization. Managers can build events into the work schedule that allow employees to relax around each other. The resulting connections provide a foundation for employee satisfaction and loyalty that improve retention.[27]

In addition to nourishing employees to help them remain satisfied and engaged in the workplace, managers can regularly recognize the outstanding contributions of team members publicly and privately. Managers can acknowledge their appreciation openly and encourage others in the team to do the same. The appreciation must be genuine.[28,29]

Delivering any type of feedback to employees should happen with consistency and within legal parameters. Managers should set up a system that rewards positive performance to boost morale and increase retention. Radiology managers should learn how and when to reward employees with recognition, praise, and monetary increases.[16]

Reward systems should be distributed and communicated fairly to be effective. For example, if employees are told that overtime or bonuses are being withheld to help defray the rising costs of health care for the patients they serve, they will be upset to learn that members of upper management are not following the same example. If morale and trust are to remain high, consistency is necessary.[13]

Other creative ways to reward employees include monthly vs annual bonuses and nonmonetary rewards during difficult economic periods. Perks such as employee of the year parking spots can add to employee satisfaction and a sense of appreciation to team members. Leadership can poll team members to discover what employees consider to be a valuable reward. Perhaps it is an additional day off with pay for staff members who attain their annual goals. Time off might be seen as 1 of the most valuable gifts an employee can receive.[8,13,25]

Mentoring Programs

Once the management team is running smoothly and the right personnel are in the right positions in the department, mentorship programs can help prepare the next group of managers in line. Mentors continue to learn as they go through the process of helping to mold and guide the protégés assigned to them. In addition, establishing a formal mentoring program within the medical imaging department can provide opportunities for communication to flow in both directions.[30,31]

The most important aspect to remember when establishing a mentoring program is to pay particular attention to the relationships established. Mentorship works best when it benefits both parties involved. Given the right combination and structure, each person continues to grow professionally and personally (see **Figure 3**).[30,31]

The relationship between mentor and protégé becomes an important psychosocial one, and mentors can offer emotional support as they guide and advise their protégés. Mentors can help newcomers understand the culture and nuances of a department and its processes and ease them into a healthy and positive early experience in their jobs. This helps new staff identify with the organization early in their careers. If the process fails, protégés often feel isolated and might fail to make meaningful internal connections in the workplace that make them happier and more productive employees.[30]

Many benefits of mentoring might not be evident immediately in departmental function and improvement, but often are manifested in the productivity and retention of employees who feel supported in their jobs. Many successful mentoring relationships transcend the department and organization in which they originate and become lifelong relationships.[31]

A traditional mentoring relationship, such as a senior or chief technologist mentoring a young or newly licensed technologist, is most common, but there are alternatives. Other examples include pairing a radiologic technology professor with technologists who aspire to teach or a senior manager with technologists interested in the administrative aspect of the field. Leaders from professional groups, such as the ASRT or state affiliate societies, might be recruited to mentor those who want to contribute to the profession in a broader capacity.

A remote mentor is someone who is removed in a significant way from the protégé, allowing for a perspective that is less influenced by internal issues. Invisible mentors are chosen by the protégé and the 2 might never meet. In

Figure 3. *Mentors and protégés often develop strong bonds that last and allow each person to grow professionally and personally.*

fact, a worker might select as an invisible mentor a person who is deceased, but who can be studied and emulated. Comentoring is when 2 colleagues at fairly equal points along their career paths come together to help one another reach identified goals. No matter the arrangement, confidentiality between a mentor and protégé is essential for a successful mentoring relationship.[32]

Sponsors sometimes are confused with mentors, but the differences between their roles are significant. Sponsors are much more visible in the eye of the organization as they take an active role in promoting those they sponsor along their career pathways. Sponsors also protect employees from harmful politics and other potential issues that can derail professional progress. When appropriate, they "sponsor" their protégé for opportunities, whether they are professionally developmental in nature or nominations for promotion within the department. Sponsorship tends to be identified with more senior employees, but it is not necessarily limited in scope.[30]

Research regarding generational differences has produced some important points to consider with regard to mentorship and sponsorship (see **Figure 4**). In any mentor/protégé relationship, the protégé should actively listen and use the information received. For example, workers from generation X (1960 to the late 1970s) prefer to spend their time differently than those of previous generations. Thus, mentors or sponsors should be chosen who enable workers from this generation to demonstrate strengths that most closely align with their short- and long-term career goals. Targeting those who can help them through the transitions that most naturally occur during this stage of career development and change is crucial.[33]

Conversely, people who are part of generation Y, or millennials (born after 1980), might face challenges when looking for more senior mentors or sponsors. Because millennials' technologically driven communication methods might not be preferred by more senior leaders within the organization, millennials should be encouraged to match their style to the style preferred by their mentors or sponsors. Millennials should find at least 1 mentor who is relatively close to them in age and who has been successful.[34]

Leading Teams

A new radiology manager might begin working with a team that already is formed, or he or she might have to form a departmental or special work team. For example, the manager might oversee a team responsible for quality control or the purchase and installation of new imaging equipment. Encouraging participation on special teams might require offering monetary or other incentives for participation. Managers can remind potential team members that participation in the team's work also makes the employees look good internally or on their professional résumés.[35]

Finally, when forming teams, managers should consider what level of involvement management will have in the overall process. Management might simply charge the group with a task or participate in the team's work. If a manager participates, he or she should participate fully; everyone who is a member of a team should be equally accountable for the work that is produced (see **Figure 5**).[35]

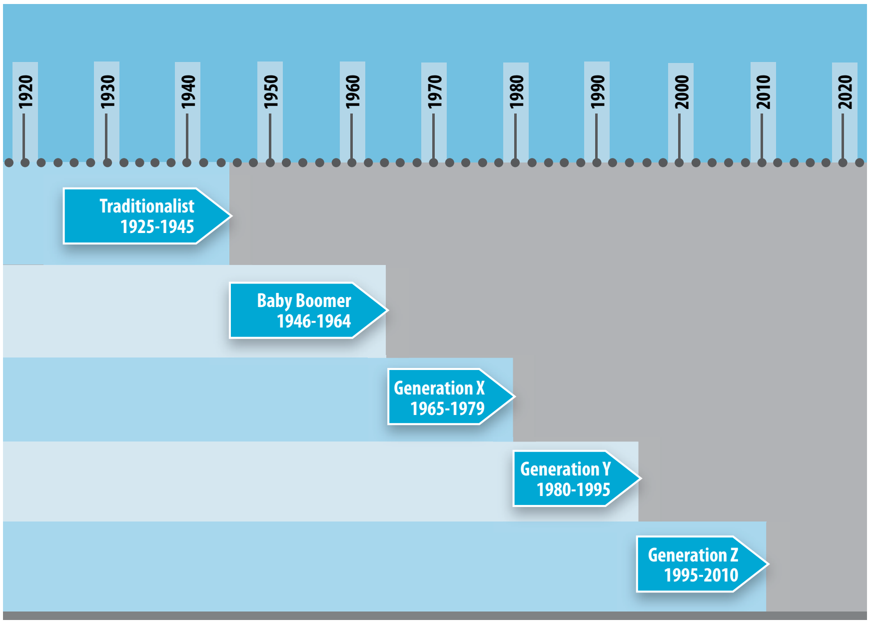

Figure 4. *Understanding the traits of specific generations can help managers and employees work together more effectively. Specific year ranges for each generation vary depending on the source, but this visual representation offers a guideline to start with.*

A manager's first meeting with a team is critical to establishing credibility and should be structured carefully. He or she should provide a succinct agenda before the meeting. It is helpful to obtain research from within professional networks to learn what has worked for colleagues, along with what approaches have failed when they have set up similar work groups.[35,36]

Regular team meetings can ensure that all medical imaging department employees are well informed. Managers should follow a few rules when establishing the tone for the meetings they conduct to ensure that meetings are an effective use of time. The meetings should be conducted in an environment that welcomes spirited debate and a healthy exchange of ideas, without being disrespectful. Managers who lead team meetings must help everyone involved feel comfortable participating by controlling input from extroverts and encouraging introverts to contribute.[35]

Managers often make 1 of 2 mistakes when setting up or conducting meetings: They present no clear reason why the meeting is being held, or they introduce so many issues and goals that it becomes virtually impossible for the group to agree or produce results effectively in a single area. Managers should instead charge the group with accomplishing particular tasks or goals to maintain productive and meaningful meetings. Innovative managers do not rely on old styles of meetings, but they instead consider how best to help the team add value to the department.[35]

The synergy that develops when a team begins to function at a high level is both exciting and energizing. Team members look to each other for accountability and help in reaching common departmental goals. By setting aside time for productive management team meetings, managers also improve communications and effectiveness as a management team. Meeting times need to have top priority and be protected from alteration or cancellation. This signals to employees that meetings are valued activities.[35]

Some team members might believe that attending meetings of any kind means staff is being asked to do work beyond that already required by daily tasks, which can cause negative reactions to meetings. It takes only 1 employee who vocalizes negative opinions about teamwork and meetings to affect the process and the attitudes of others on the team. A manager can proactively prevent or mitigate this behavior before it occurs. One technique is to involve potential detractors from the beginning in forming the team. Achieving buy-in from those who could undermine efforts instead shifts their attitude in a positive direction, and the involved employees can be instrumental in garnering support from others. Managers still are responsible for:

- Ensuring the meetings are scheduled.
- Setting a safe environment in which everyone can feel comfortable contributing to the process.
- Setting meaningful goals for the group and department.[35,36]

Figure 5. *Commitment to a team is crucial for success.*

Managing for Employee Retention

Having a synergistic team and a process for effective meetings in place can help a department run more smoothly and its workers function more effectively. However, a manager also needs to retain valued team members.[5]

Many employees depart the workplace because they feel disengaged. This can happen in 1 of 2 ways. First, the employee might never form an attachment to the job and people in the department. The second is that somewhere along the work/life continuum, the employee begins to drift away. Dissatisfaction with the employee's peer group and lack of confidence in the organization's leadership contribute greatly to the disengagement process.[5,6]

Authors Martin and Schmidt examined young top employees (called "stars" by the authors) at many different companies.[36] They noted several observations about a seeming lack of engagement, reporting a likelihood that:

- About 1 in 4 young stars intends to leave their current employer within the year.
- Another 1 in 3 admits to not putting all possible efforts into the job.
- About 1 in 5 believes that their personal aspirations differ markedly from the plans the organization has for them.
- As many as 4 of 10 have little confidence in their coworkers and even less confidence in the senior team.[36]

Although these projections can be quite unsettling to managers, the good news is that medical imaging department leadership can address them. One of the best tools for retention is making open communication integral to departmental administration.[36]

Research performed by Hicks and Britt determined that 100% of the radiologic technologists from 4 of the largest hospitals in northwest Louisiana who responded to a survey ranked communication as a critical characteristic for a manager to possess. The ability to resolve conflicts and correct problematic performers also were identified. Employees who feel connected to their department and their managers through well-structured communication lines are far less likely to be lost to another organization.[36]

Communication is 1 of the most important employee retention methods managers can use, but other strategies also exist. Implementing a program of professional development for existing employees is another excellent method for promoting employee satisfaction and increasing retention. When choosing employees for formalized internal development programs, managers should require that the employees be engaged in the department in positive ways that add value to the entire team. This can be built into the annual performance evaluation process as a goal, and the employee and supervisor can agree to the benchmarks that measure success in this area. Making the process competitive for employees to enter such a program can help to determine which workers are serious about participating.[21]

Managers also can consider differentiating salary ranges for employees who participate in professional development programs as an incentive and a retention strategy. It takes extra effort for employees to work with mentors and actively pursue a defined pathway for professional growth and development. Rewarding that effort monetarily sends a strong signal that the employee's efforts are valued by upper management and supported throughout the organization.[11,37]

One of the biggest benefits to the organization of retaining and developing top employees is that doing so leads naturally to departmental succession planning. When management evaluates departmental leadership positions, they can identify the skills needed to fulfill the roles effectively. The desired skills then can be emphasized and nourished in the personnel who may move into leadership positions.[37]

Conclusion

New and experienced imaging department managers face a number of challenges in their jobs to manage processes and projects. Managing people is 1 of the most critical and challenging tasks to ensure that teams are effective and patient care goals are achieved. Imaging department managers can help ensure that they are successful at managing people by carefully assessing their department's function, performing regular and effective employee evaluations, conducting thoughtful and effective self-evaluations, and carefully managing teams and meetings with the goal of recruiting and retaining highly skilled employees.

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Read the preceding Directed Reading and choose the answer that is ***most correct*** based on the article.

1. A survey regarding burnout among U.S. radiographers found that these professionals experienced ______ levels of emotional exhaustion than other health care workers.
   a. much higher
   b. slightly higher
   c. slightly lower
   d. much lower

2. The literature reports that a newly hired employee begins producing at a level to justify his or her salary after ______ on the job.
   a. 6 weeks
   b. 12 weeks
   c. 6 months
   d. 12 months

3. Statistics have shown that 1 in ______ employees report that they are truly satisfied with their work environments.
   a. 2
   b. 4
   c. 7
   d. 10

4. In the American Society of Radiologic Technologists' Environmental Scan of the Workplace, managers reported that they believed which of the following were most important to their employees?
   1. coworkers
   2. salary
   3. time off from work

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

5. Use of ______ for performance appraisals has increased because this method allows managers and staff members to work together to develop a list of goals to accomplish during the period under review.
   a. absolute standards
   b. the comparative methods
   c. 360° evaluations
   d. management by objectives

continued on next page

6. An effective 360° evaluation model involves no more than ______ people who can provide feedback.
   a. 1
   b. 4
   c. 6
   d. 12

7. Managers should ***not*** participate in 360° evaluations.
   a. true
   b. false

8. Top determinants of health care workers' job satisfaction include:
   1. effective leadership.
   2. chance for promotion.
   3. compensation rate.

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

9. Which of the following is ***not*** a strategy developed by the American Hospital Association to assist health care leaders in supporting those they manage?
   a. providing formal program models for implementing shared governance
   b. approaching leadership as a pathway to manage employees vs managing the workload or workflow
   c. ensuring that front-line employee expectations are known and respected
   d. ensuring that leaders have the skills necessary to manage the needs of their direct reports

10. Employee evaluations should be performed on a ______ schedule that is ______ .
    a. regular; not communicated
    b. regular; well communicated
    c. irregular; not communicated
    d. irregular; well communicated

11. The ability to work ______ often is a desired skill in a radiologic technologist, but contradictory to being a good manager.
    a. independently
    b. cooperatively
    c. rapidly
    d. accurately

12. Baystate Health in western Massachusetts successfully implemented a ______ program in their laboratory department that now is being tested in radiology to help improve employee retention and recruitment.
    a. 360° evaluation
    b. bonus
    c. career ladder
    d. transformational leadership

13. A manager can achieve a more complete review of a medical imaging department candidate by reading résumés:
    a. 3 times.
    b. once, and then again the next day.
    c. after the interview.
    d. backward.

14. Managers should work within the parameters set forth by their human resources (HR) department to structure interview questions that are not too:
    a. impersonal.
    b. long.
    c. personal.
    d. short.

continued on next page

15. The Directed Reading recommends up to ______ in-person meetings with potential candidates, along with involving ______ separate managers in interviews.
    a. 2; 2
    b. 2; 3
    c. 3; 3
    d. 3; 4

16. Which of the following employee behaviors should managers address?
    1. blatant insubordination
    2. refusal to report to work on time
    3. spreading gossip

    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

17. An employee should be required to sign a document outlining problem behavior and manager expectations regarding correction.
    a. true
    b. false

18. Many managers miss an important step in the feedback process called ______ the relationship, which helps employees again feel comfortable in their job role.
    a. assessing
    b. formalizing
    c. improving
    d. normalizing

19. ______ is ***not*** 1 of the 4 major nourishers described by Amabile and Kramer.
    a. Affiliation
    b. Autonomy
    c. Encouragement
    d. Respect

20. The ***most*** important aspect to remember when establishing a mentoring program is to pay particular attention to the:
    a. ages of the mentor and protégé.
    b. credentials and work experience of the mentor and protégé.
    c. pay the mentor receives.
    d. relationships that are established.

21. Comentoring is described as:
    a. 2 colleagues at equal points in their careers helping one another.
    b. 1 mentor and 1 protégé helping each other.
    c. 2 mentors helping 1 protégé.
    d. 2 mentors exchanging periods of time helping 2 protégés.

22. When setting up or conducting meetings, managers should ***not***:
    a. allow spirited debate.
    b. charge the group with any goals or tasks.
    c. provide an agenda for the meeting in advance.
    d. rely on old styles of meetings.

23. A manager can address the problem of a staff member who expresses negativity about team meetings by:
    a. involving the potential detractor in forming the team.
    b. involving the HR department in formal disciplinary actions against the employee.
    c. preventing the potential detractor from participating.
    d. sending the employee to teamwork training sessions.

24. Martin and Schmidt revealed that among top young employees, about ______ of 10 have little confidence in coworkers or their senior teams.
    a. 2
    b. 4
    c. 6
    d. 8

continued on next page

25. Research on radiologic technologists in Louisiana revealed that 100% of those surveyed ranked ______ as a critical characteristic for a manager to possess.
    a. clinical skills
    b. communication
    c. sensitivity
    d. a sense of humor

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A Book Report

Stewart Carlyle Bushong, ScD, FACR, FAAPM

I was walking down the B-corridor of Baylor College of Medicine sometime in the early 1970s with my academic chairman, Robert MacIntyre, MD. I had a well-functioning, grant-supported research laboratory and 2 scientists, Sharon Glaze and Ben Archer, who are still with me and are dear friends. Together we published many research papers and I developed a pretty nice curriculum vitae.

At the time, Dr MacIntyre congratulated me on a research paper we wrote that appeared in the journal *Radiographics* and on the productivity of my lab. He continued, "You know, Stewart, I cannot submit your name to the promotions committee for full professor with tenure until you have published a textbook!" Authoring a textbook was the farthest thing from my mind.

About the same time, I met an editor for the CV Mosby Company who was looking for health care authors. He particularly was looking for a textbook to challenge Selman, who authored perhaps the only physics textbook for radiography students at that time and nearly all programs, including mine, used it.[1] My intention in writing *Radiologic Science for Technologists* was not to replace any existing textbook. I simply wanted to become a tenured professor. I never expected anyone to read my book, much less buy it!

However, as we go through life and career, we are constantly presented with unexpected opportunities. I write this article in hopes that my experience might encourage others to write a textbook or a Web-based instructional tool or recognize and accept a similar challenge. I hope you are as fortunate as I was in making so many new friends because of *Radiologic Science for Technologists*. Several of my friends already have taken this path and published similar textbooks.[2-6]

Before *Radiologic Science for Technologists* was published, I was on the volunteer faculty of the radiography program at The Methodist Hospital, a principal affiliate of Baylor College of Medicine. The program director agreed to be a coauthor, and we planned a 16-chapter book. I was to write the first half about the physics of radiography and fluoroscopy; she would cover imaging technique in the remaining half. Some months later, I had finished my 8 chapters, but my coauthor had not started and then was transferred to another state. I had to complete the textbook having first to educate myself on the techniques of radiography and fluoroscopy.

Appearance and Acknowledgements

In June 2012, the 10th edition was published — 37 years after the first edition. Who would have imagined that this textbook would be translated into 4 additional languages, making it not just a leader in the United States, but throughout the world?

A lot has changed in medical imaging during this time and it is reflected in the changes in this book. Of course, 1 big change is cost. The first edition came out at $12.95; the 10th edition sells for $110.95 (see **Figure 1**). Through the first 5 editions, the book was 7.5 × 9.5 inches. It increased to 9 × 11 inches with the sixth edition and remains that size. The fifth edition was the first to use color inside the book, but only 1 — red for some titles. The sixth edition and beyond are full color.

Cover

I chose magenta and gold for the first edition cover, the official colors of the radiation symbol. For the second edition, we simply reversed the colors. Editions 3 and 4 had the same colors with a small change in design. Beginning with the fifth edition, a layout artist at Mosby prepared several layout styles and my editors and I selected from those. The covers have been different with each of the following editions (see **Figure 2**).

Editors

The editors with whom I have worked have been excellent. Several of the early editors — Dugan, Spilver, Culverwell — became good friends. For the early editions, I traveled to the Mosby headquarters in St Louis, Missouri, to discuss plans for the next edition. The **Box** lists the editors with whom I have worked and I take this opportunity to thank each for their time and effort.

It was not until the third edition that the editor was even identified on the inside publication information page. The identification of publishing personnel also changed, so in the 10th edition, Andrew Allen is a vice president and publisher followed by 6 other helpers — none of whom are identified as an editor.

Dedication

Although the content of the book is serious, I have had fun with the dedication page. I dedicated the first edition to my wife and 3 children. With the second edition, I began to include our dogs, 4 of them (with a cross when they died). My friends got wind of this and asked for their own dogs to be included on the dedication page. Through the seventh edition, if a friend wanted his or her dog on the dedication page, I would comply, but only after it died. The list grew to 25. However, my friends wanted their living dogs honored, and I relented with the eighth edition. The 10th edition lists 65 dogs, living and dead, but no cats. I am not a cat person.

The past 4 editions also have been dedicated to some special people. The seventh edition was dedicated to, "Two outstanding academic radiologists who encour-

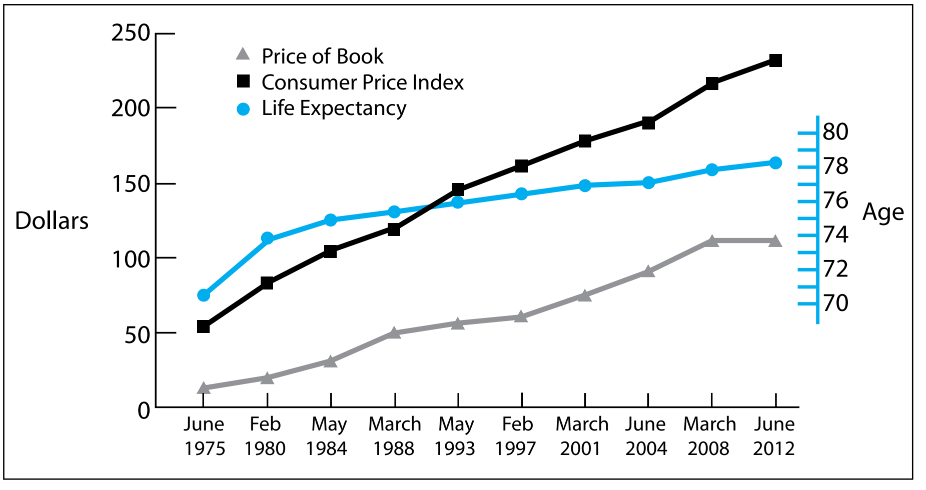

Figure 1. *Cost of the successive editions of* Radiologic Science for Technologists *with life expectancy (National Vital Statistics Reports, Vol 59, No 9, September 2011) and Consumer Price Index (U.S. Department of Labor, Bureau of Labor Statistics, CPI History Table, 2012) for comparison.*

Figure 2. *Ten editions of* Radiologic Science for Technologists. *Photograph courtesy of Kraig Emmert.*

aged me, supported me, and allowed me the freedom to do science, lecture, and write…and we became good personal friends." I have served 5 academic chairmen; Vincent P Collins (1953-1968) and James E Harrell, Sr, (1976-2000) were the best.

The Houston Community College was established in 1971, and I was volunteer faculty for 35 years in its radiography program. The eighth edition was dedicated to the 827 graduates of the Houston Community College radiography program that I had taught at that time, and many continue as good friends.

> *No medical physicist has been as fortunate as I over these past four academic decades. My success would have been so shallow if not for the support, encouragement, and friendship of these two wonderful people to whom I dedicate this 9th Edition. Thanks you two for the great ride — Benjamin Ripley Archer and Sharon Briney Glaze.*

I acknowledged another group of friends by dedicating the 10th edition to you educators with whom I have participated all these years at educational conferences and programs. That list numbers 266 but as I mentioned, "I'm late in the fourth quarter and know I've forgotten many." If you are 1 of the many, please e-mail me with a scolding.

Preface

The preface of a textbook provides an opportunity to describe the contents and extent of coverage of a subject. In addition, it provides a space for additional recognition of those who helped with the project. Kraig Emmert, medical illustrator, is a prime example of one who has contributed exceptionally to each edition I have produced.

Box

Editorial Assistance for *Radiologic Science for Technologists*

1975 first edition: Michael Dugan
1980 second edition: David Spilver
1984 third edition: Don E Ladig
1988 fourth edition: David Culverwell
1993 fifth edition: David Culverwell
1997 sixth edition: Don Ladig
2001 seventh edition: Jeanne Wilke
2005 eighth edition: Jeanne Wilke
2009 ninth edition: Andrew Allen
2013 tenth edition: Andrew Allen

Content

As you might imagine, the content of this book has changed considerably over the editions (see **Table**). No one can explain to me why the 10th edition, which appeared in June 2012, has a publication date of 2013. It is probably like my car — I bought it in June 2004, but it is a 2005 model.

Imaging Modalities

Consider the progress of medical imaging and education in radiologic technology since 1975. At that time, all programs focused on radiography and fluoroscopy. Sure, nuclear medicine and diagnostic ultrasonography were around, but in the very early stages.

The second edition of *Radiologic Science for Technologists* included separate chapters on mammography, computed tomography (CT), and diagnostic ultrasonography. The third edition included new, separate chapters on computer science, digital imaging, and magnetic resonance (MR) imaging. The chapter count increased from 26 to 30. By 1988,

Table

Content Summary for *Radiologic Science for Technologists*

Edition	Illustrations	Chapters	Pages
First	317	17	331
Second	526	26	485
Third	712	30	597
Fourth	712	34	643
Fifth	711	37	683
Sixth	693	40	586
Seventh	756	40	626
Eighth	758	40	638
Ninth	724	40	685
10th	706	38	654

when the fourth edition appeared, there were 34 chapters because of additional chapters on diagnostic ultrasonography, MR imaging, and new chapters on radiographic technique and radiation management.

With the appearance of the sixth edition, the 40 chapters were divided into 5 parts. I purposefully limited the content to 40 chapters by combining much of the early chapter material on basic physics into fewer chapters. I also removed all chapters on diagnostic ultrasonography and MR imaging and expanded that information into 2 separate books.[7,8] That made room for the 9 chapters on digital imaging.

Cartoons

One of my friends at Baylor College of Medicine was Emmert. He produced the drawings for the first edition; they were good and got him enlisted for future editions. His department had a birthday party for him with a gigantic birthday cake. As they all sang "Happy Birthday," I jumped out of the cake. That birthday party was the toast of the Baylor College of Medicine for many years.

When starting the second edition, I asked Emmert if he could make the illustrations more attractive and physics-friendly. He showed me a cartoon character with eyeglasses and a big mustache he planned to use, and I was delighted. I think the cartoons have added immensely to what I hoped would be an easy read for a physics textbook.

Penguintoons

About 10 years ago, I learned of *The Penguin Tale* from my colleague, Ben Archer, and published it on the first page of the eighth edition of *Radiologic Science for Educators*. When Emmert also learned about *The Penguin Tale*, he fashioned a mustachioed penguin with his flipper out to identify bullets in that edition.

That same year, 2004, I first produced several PowerPoint (Microsoft, Redmond, Washington) slides to describe *The Penguin Tale* to audiences such as the Atlanta Society of Radiologic Technologists Student and Educator Conference.

In the middle of my presentation, 3 students in the front row went to the aisle microphone to interrupt me and ask, "Dr Bushong, do polar bears eat penguins?" to which I replied, "Yes, polar bears are carnivorous; they eat penguins." The students replied, "No, polar bears live in the north pole and penguins in the south pole." There was uproarious laughter from the audience.

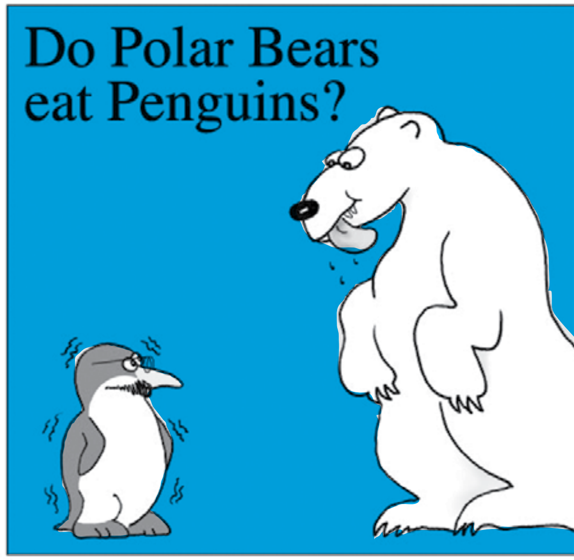

Figure 3. *The first of many Penguintoons suggested by readers and meeting attendees. Illustration courtesy of Kraig Emmert.*

The day I told Emmert about the question from Atlanta students, he e-mailed me the first of what he calls "Penguintoons" (see **Figure 3**). That started what is now 30 Penguintoons that I show regularly during presentations. All of these Penguintoons are the result of suggestions from members of various audiences following the slides I show to describe *The Penguin Tale*.

I even proposed for the past 2 editions of my textbook inserting a Penguintoon on the last page of each chapter if there is more than a half page of empty space. Although I think students would enjoy the added bonus — and it would give me the opportunity to recognize the suggester of the Penguintoon in an appendix — my editor has disagreed.

Future

Just as *Radiologic Science for Technologists* has accelerated considerably over the past 10 editions, so too has education in the radiologic sciences. I have been surprised that this book and others continue to be published. I am also impressed with today's radiography students. If you were my student in, say, 1975, you would have to know radiography and fluoroscopy. Today's students have to learn both of these topics, plus CT, digital radiography, digital fluoroscopy, MR, and sometimes diagnostic ultrasonography and nuclear medicine.

What is the future of education for radiologic technologists? I think it will mirror what I am currently doing with my resident radiologists:

- Much less face-time.
- Web-based instructional materials.
- Team-based learning, an interactive instructional program for groups.[9,10]

My editors tell me that students still want a textbook in which they can highlight and annotate. Well, one can do that now on many digital book devices. There are exceptional opportunities for educators to contribute to Web-based instructional materials, which can look great on curriculum vitae. The future is clearly in electronic publishing. Stay tuned.

Epilogue

Back to my first thoughts about *Radiologic Science for Technologists*: I wrote this book to be promoted academically but my greatest reward has been the many educators in the radiologic sciences who have become friends. No one has been as blessed as I have. Check out the dedication page in the recently published 10th edition and enjoy with me all those friends. And stay alert and willing. If I am right that the future is Web-based instructional material, *Radiologic Science for Technologists* is headed to the dinosaur dig and history.

Stewart Carlyle Bushong, ScD, FACR, FAAPM, is professor and chief of the Section of Radiologic Science for the Baylor College of Medicine Department of Radiology in Houston, Texas. He obtained his doctoral degree in medical physics from the University of Pittsburgh in Pennsylvania. During his more than 40 years at the Baylor College of Medicine, he has published 150 peer-reviewed scientific papers and 43 books. He is also a lecturer, humorist, and mentor for many instructors, radiologists, physicists, students, and fellow colleagues.

Dr Bushong has served in executive positions for the American Association of Physicists in Medicine and the American College of Medical Physics. He holds Fellowships with the ACR, AASM, ACMP, RCI, and USPHS, and he has received many professional awards, including Sigma Xi. Texas Governor Ann Richards appointed him to chair the inaugural Texas Medical Physics Licensure Board; he holds Medical Physics license number 0001.

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Imaging Physics

***Webb's Physics of Medical Imaging.* 2nd ed. Flower M, ed. 2012. 864 pgs. CRC Press. www.crcpress.com. $89.95.**

Webb's Physics of Medical Imaging is designed to help readers understand the physics behind different imaging modalities. This reference book is a compilation of articles written by staff members of research centers and hospitals in the United Kingdom.

The introduction reviews German physicist Wilhelm Roentgen's discovery of the x-ray and is followed by chapters on diagnostic imaging, computed tomography, nuclear medicine, ultrasonography, and magnetic resonance (MR) imaging. Chapters also describe imaging system computer requirements, image processing, interpretation of images, infrared and optical imaging, and electrical impedance.

I do not feel that this book is intended for technologists trying to increase their knowledge in the clinical setting. Rather, it seems to be designed for technologists in a research setting or for graduate students. The multitude of formulas in the text are not useful to working technologists. The published Radiographs are not the best quality, but it can be difficult to reproduce good radiographic images in a textbook. Most of the diagrams and charts are easy to understand, and the glossary of abbreviations at the beginning of the book is helpful.

I was hoping to better understand MR imaging after reading the chapter on the modality. It helped my basic knowledge of MR — including its history and improvements in the technology — but not to the degree that I was expecting. However, the book does explain reasons for artifacts in medical imaging so that they can be avoided as much as possible in daily practice. Although this book is not ideal as a portable reference because of its weight, it may be useful to keep this reference text in the imaging department for technical questions that may arise.

Gail M Kurpinski, R.T.(R)(CT)
Staff Technologist
Teton Radiology Advance Medical Imaging
Idaho Falls, Idaho

Distal Limb Radiographic Technique

Terry R Eastman, R.T.(R), FASRT

Approximately 18% of all radiographic studies are of the distal limbs.[1] Some clinical sites still use distal limb techniques in the 50 kVp range; however, Arthur Fuchs, in his classic text *Principles of Radiographic Exposure & Processing*, showed that these studies can be performed using an optimal kVp of 60.[2]

With the advent of digital imaging and preprogrammed automatic exposure control (AEC), some radiologic technologists came to believe that technique charts are no longer required. However, distal limb studies do not lend themselves to using AEC. Instead, a technique chart is necessary. In addition, beam collimation and the use of lead blockers help ensure good results and prevent errors.

Older radiographers might remember using a cardboard exposure holder for distal limb examinations. More recently, detail intensifying screens have been used for these studies. In either case, extremity radiography requires maximum detail sharpness to visualize hairline fractures, small bone chips, and minimal pathology.

Let us compare a cardboard technique and a detail screen technique for a posteroanterior table-top examination of a hand, 3 cm to 5 cm thick, with a 40-inch source-to-image-receptor distance using 60 kVp:

- Cardboard – 60 mAs.
- Detail screen – 5 mAs.

The detail screen technique represents a 92% reduction in exposure technique. The **Table** is an exposure chart readers can use to review their distal limb techniques. The technique described falls within the optimal sensitivity range of the computed radiography and direct digital radiography systems. To reduce the guide exposures by 34%, multiply by 0.66x. To increase the guide values by 32%, multiply by 1.32x.

To formulate these techniques, technologists should first remember that patients should not be used for test exposures.[3] Instead, a water phantom test can be used, such as a plastic juice container filled with 3 cm of water to simulate an average-sized hand. Collimate to a 2-inch × 2-inch field, and make 3 test exposures:

- 3.3 mAs (-34%).
- 5 mAs (guide mAs).
- 6.6 mAs (+32%).

Using the imaging system's sensitivity number, the technologist should determine which mAs falls within the acceptance guideline. If a change is indicated, he or she uses this formula to obtain a correction factor:

$$\frac{\text{corrected mAs}}{\text{guide mAs}} = \begin{array}{c}\text{correction}\\ \text{multiplicand}\end{array}$$

Optimal distal limb radiography plays a significant role in patient management, and a technique chart makes this possible.

Terry R Eastman, R.T.(R), FASRT, is the technical director of Radiographic Techniques, a consulting service based in Roanoke, Virginia.

Table

Distal Limb Imaging Technique Chart[a]

Hand	Anterior-oblique		Lateral	
	cm	mAs	cm	mAs
	1-2	3.3	4-6	8.3
	3-5	5	7-10	10
	6-8	6.6	11-13	13.3
Wrist	Anterior-oblique		Lateral	
	cm	mAs	cm	mAs
	1-2	3.3	3-4	8.3
	3-6	5	5-8	10
	7-10	6.6	9-11	13.3
Forearm	Posterior-lateral			
	cm	mAs		
	3-5	5		
	6-9	6.6		
	10-13	8.3		
Elbow	Posterior		Lateral	
	cm	mAs	cm	mAs
	3-5	8.3	4-6	8.3
	6-9	10	7-10	10
	10-12	13.3	11-13	13.3
Toes	cm	mAs		
	1-2	2.5		
	3-5	3.3		
Foot	Dorsal plantar-oblique		Lateral	
	cm	mAs	cm	mAs
	3-5	5	3-5	8.3
	6-9	6.6	6-9	10
	10-13	8.3	10-13	13.3
Os Calcis	Axial		Lateral	
	cm	mAs	cm	mAs
	4-6	13.3	3-5	8.3
	7-10	16.6	6-9	10
	11-14	20	10-12	13.3
Ankle	Posterior-oblique		Lateral	
	cm	mAs	cm	mAs
	4-6	13.3	3-5	8.3
	7-10	16.6	6-9	10
	11-14	20	10-13	13.3

[a] Assumptions for all examinations: 60 kVp, 48-inch source-to-image-receptor distance, table-top examination with a small focal spot.

Mr Eastman would like to thank Mark Adkins, MSEd, R.T.(R)(QM), and Kevin L Murray, MSEd, R.T.(R)(QM), for their critique and suggestions in preparing this article. Mr Adkins is the radiography program director for St Vincent Health/St Joseph Hospital in Indianapolis, Indiana. Mr Murray is the program director for Danville Regional Medical Center, Danville, Virginia.

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Basis of CT: The Radon Transform

Kevin L Wininger, BS, R.T.(R), RKT

Austrian mathematician Johann Radon is credited with the earliest work from which our knowledge of computed tomography (CT) originates. In 1917, Radon published a foundational paper that gave rise to the Radon transform — a mathematical construct that, among other applications, underpins CT theory.[1] Fourier analysis, the mathematical field that the Radon transform falls within, deals with how functions converge for periodic and nonperiodic phenomena relative to mathematical procedures known as Fourier series and Fourier transforms.

In many ways, the focus of this article (ie, the mathematics of CT) picks up where Friedland and Thurber left off in their 1996 article published in the *American Journal of Roentgenology*.[2] In that article, the authors assessed the theory of CT, as well as engineering and clinical concepts, and presented a brief synopsis of the work of the French mathematician Jean Baptiste Joseph Fourier, after whom the Fourier techniques are named. Today, almost all CT scanners use fast Fourier transform algorithms by means of filtered (convolutional) back projection. This algorithm, an efficient computational implementation of the discrete Fourier transform, enables rapid computer processing of CT images.[2]

There is an essential and elegant relationship between the Radon transform and the Fourier transform. This relationship is based largely on the fact that the latter is reserved for studying nonperiodic phenomena.[3,4] X-ray photons in the exit beam strike the CT scanner's detector plate in burst-like impulses that are nonperiodic in nature. In physics and mathematics, such phenomena can be viewed as line impulses. To grasp the Radon transform's application in medical CT, assumptions will be made that ignore certain computational issues, such as:

- The playoff between Cartesian and polar coordinate representations (ie, the 2-D *xy*-plane vs spherical/circular symmetry, respectively).
- Adjustments in modeling that account for fan-beam or cone-beam CT constructs.[5,6]

Therefore, the mathematical rendering of CT in this article (ie, inverting the Radon transform) is most conducive to parallel beam models, that is, first- and second-generation CT scanners. Because there is no rigorous tomographic-based algorithm, Radon transform inversion will be described in simple mathematical language aided by the online computational engine Wolfram Alpha (Wolfram Research, Champaign, Illinois) to plot the line equations for the x-ray photons in slope-intercept form.[7]

Application Setup

A mathematical technique known as inversion recaptures information lost to attenuated x-ray photons. The steps necessary to invert the Radon transform will be presented without discrete numerical analysis. The underlying theme is a signal processing challenge, and the set-up for the analysis is straightforward. In medical imaging, the patient represents a region of variable density from which a 2-D slice is captured. The goal in CT scanning is to reconstruct the resulting x-ray signal as an image after repeatedly passing photons through a region at different angles of initial projection using the CT gantry. Stated simply, technologists measure the resultant signal at different trajectory lines by accumulating (integrating) the signal after projecting x-rays through a patient. This approach reconstructs tissue densities based on their interaction with photons so that density values can be assigned according to the Hounsfield unit scale of CT numbers for data acquisition/image processing.[8,9] Such modeling serves as an engineering template for troubleshooting in the event of errors that may increase radiation dose to the patient (eg, equipment or computer algorithm failures).[10]

Because the approach resolves signal processing by calculating line integrals to recover the intensity of the x-ray signal (ie, capture the data lost to attenuated or scattered x-rays), a somewhat crude comparison can be made to the inverse square law, which estimates present beam intensity based on the previous beam intensity, and the present and previous source-to-object distances.[11]

The mathematics concerning medical x-ray CT are relatively easy to follow because the steps relate to imaging tasks carried out in the CT suite. We begin with a detailed inspection of representative x-ray trajectories relative to the CT gantry (ie, the family of parallel lines), and then compare the suitability of 2 proposed coordinate systems.

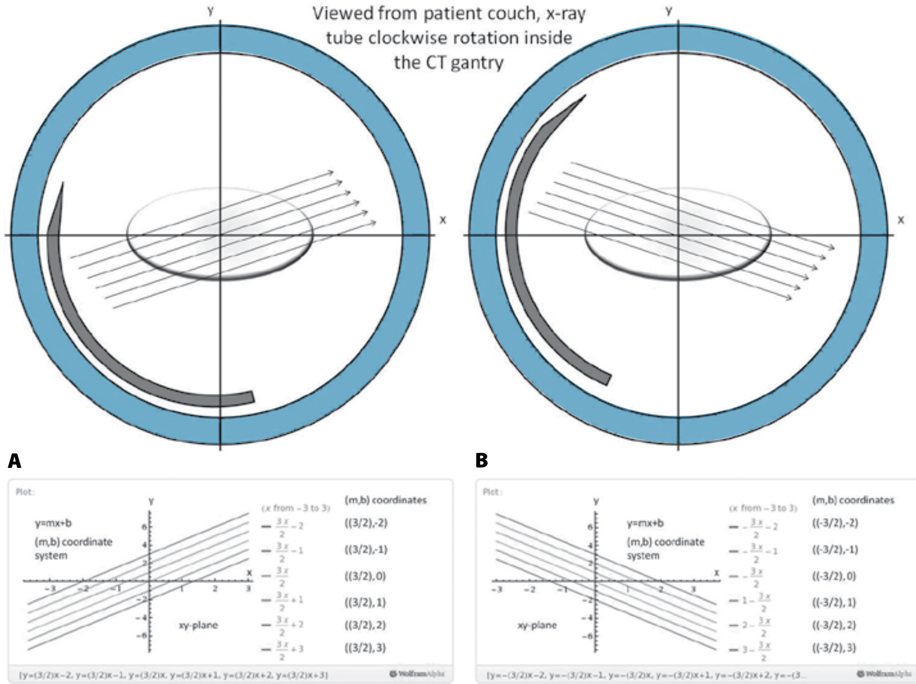

Figure 1. *A. Gantry of a computed tomography scanner showing trajectories of x-rays (long arrows) emitted as a family of parallel lines. B. Illustrated clockwise rotation of the x-ray tube inside the gantry. Representative, corresponding line equations written in the slope-intercept form* y = mx + b *in the* xy*-plane. The* (m, b) *coordinates are given by the line equations. Wolfram Alpha LLC. 2012. Wolfram|Alpha. www.wolframalpha.com (accessed November 1, 2011).*

Lines and Family of Lines

The CT gantry with a projected x-ray beam can be drawn as a family of parallel lines though a region (see **Figure 1**). Each representative x-ray trajectory (parallel line) can be written in the slope-intercept form of a line:

$$y=mx+b$$

In this form, the coordinates of the lines in the *xy*-plane are the points (m, b), where m is the slope of the line and b is the y-intercept. However, this coordinate system is not ideal in this context because the formula is not valid for vertical lines.[12] From a mathematical point-of-view, vertical slopes are undefined, and thus, representative lines of x-ray trajectories when the tube at the 6 and 12 o'clock positions inside the gantry are problematic. A more suitable coordinate system that exploits common features is required to parameterize all lines (ie, all families of parallel lines).

In **Figure 2**, note that each line has the same angle to the horizontal (x_1) axis. This angle is called the angle phi (φ). Specifically, the normal vectors of these lines have the same angle to the x_1-axis. However, to better identify locations of lines, more than just the angle to the x_1-axis is needed. To single out a line, we measure the distance, rho (ρ), from the line passing through the origin. Thus, with these parameters — distance ρ and angle φ — an unambiguous coordinate system without nonexistence issues for vertical slopes is established. A Cartesian equation of the line is now specified by a given coordinate pair (ρ, φ) in the form:

$$x \cdot n = x_1 \cos\varphi + x_2 \sin\varphi = \rho$$

where both x and n are vectors, each defined as $x = (x_1, x_2)$ and $n = (\cos\varphi, \sin\varphi)$. The line equation is derived by vector multiplication using the dot product method, where it is said that x is dotted with n.

Line Impulse

To account for the nonperiodic nature of the signal concentrated along each trajectory taken by the x-ray photons, consider the line impulse.[4] The line impulse describes the physical phenomenon of x-ray photons striking the image receptor in the CT gantry. To define the line impulse mathematically, we first need to set the Cartesian equation of the line to 0.

$$\rho = x_1 \cos\varphi + x_2 \sin\varphi$$

$$\rho - x_1 \cos\varphi + x_2 \sin\varphi = 0$$

The resulting equation then becomes a function of delta (δ).[4]

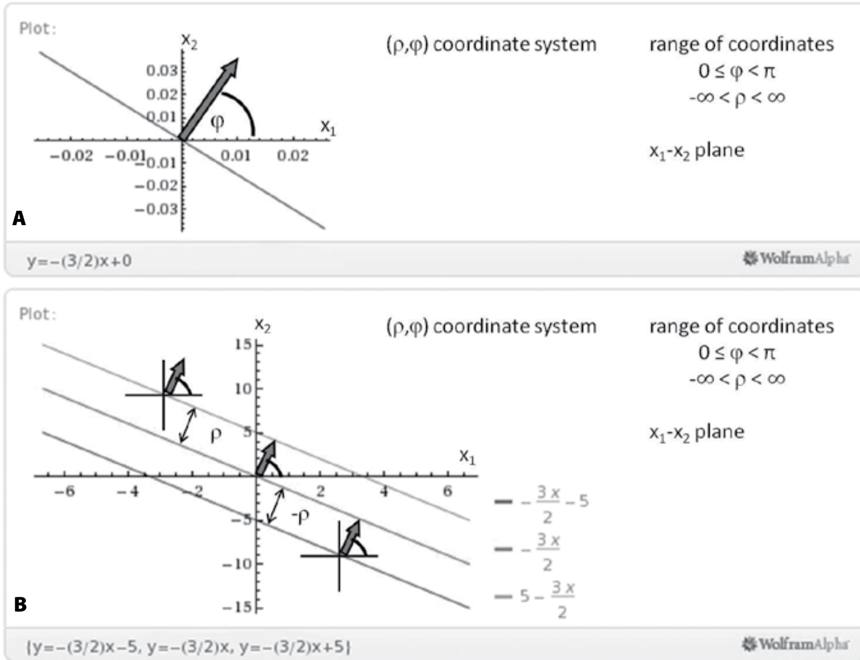

Figure 2. *A better-suited coordinate system (ρ, φ). A. Arrow demonstrating the unit normal vector associated with the line passing through the origin and oriented with an angle phi (φ) to the x_1-axis in the x_1, x_2-plane. B. A family of 3 parallel lines and their unit normal vectors (arbitrarily placed on the lines) showing signed distances rho (ρ) from the origin (double-ended arrows). By convention, distances are positive (ie, ρ) when measured in the direction of the normal vector from the line passing through the origin to associated parallel lines. Similarly, distances are negative (ie, -ρ) when measured from the line passing through the origin to parallel lines spatially existing opposite to the direction established for the normal vector. The ρ value is 0 at the line passing through the origin. Note that the unit normal vectors are not drawn to scale, and compared to Figure 1, the xy-plane has been renamed the x_1, x_2-plane. Wolfram Alpha LLC. 2012. Wolfram|Alpha. www.wolframalpha.com (accessed November 1, 2011).*

$$\rho - x_1 \cos\varphi - x_2 \sin\varphi \xrightarrow{becomes} \delta(\rho - x_1 \cos\varphi - x_2 \sin\varphi)$$

The delta function δ is the classical approach to the line impulse.[3] It has advantageous implications for dimensionality and integration of a line.

Eq. 1

$$\int_L \mu = \iint_{R^2} \mu(x_1, x_2)\, \underbrace{\delta(\rho - x_1 \cos\varphi - x_2 \sin\varphi)}_{line\ impulse}\, dx_1\, dx_2$$

On the left side of equation 1, the line integral denoted by L is a single integral that evaluates the function μ for the 1-D case of the line. On the right side, the double integral R^2 evaluates μ in the 2-D case of the plane. Note that the line impulse (the delta function δ concentrated on a line) has a domain of infinity on the line and 0 off the line.

The Radon Transform

Equipped with a suitable coordinate system and having addressed the line integral with respect to the line impulse, we are ready to introduce the central mathematical steps. It is important to first point out what varies as we work through the computations (ie, to identify the variables associated with the integrand or the terms being integrated).

Superimposition of the coordinate system onto a representative cross-sectional image (the region of interest) helps identify the variable (see **Figure 3**). Think in terms of what it means to fix φ and let ρ vary. This means the family of parallel lines is defined by the angle made with the x_1-axis, and we concern ourselves only with the distances of such lines from the line passing through the origin. In other words, the angle is held constant, allowing ρ to vary, and hence we may accumulate (integrate) data. Thus, the Radon transform $\mathfrak{R}$ can be introduced by rewriting equation 1 in relation to the x-ray signal/function μ, where μ is a function of ρ and φ.

Eq. 2

$$\mathfrak{R}\mu(\rho,\varphi) = \int_{L(\rho,\varphi)} \mu = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mu(x_1,x_2)\delta(\rho - x_1\cos\varphi - x_2\sin\varphi)\,dx_1\,dx_2$$

Note that both the line integral L and the double integral are more definitively expressed in equation 2 than equation 1. The line integral is written as a function of ρ and φ, and the limits of integration for the double integral are explicitly stated from negative infinity to positive infinity.

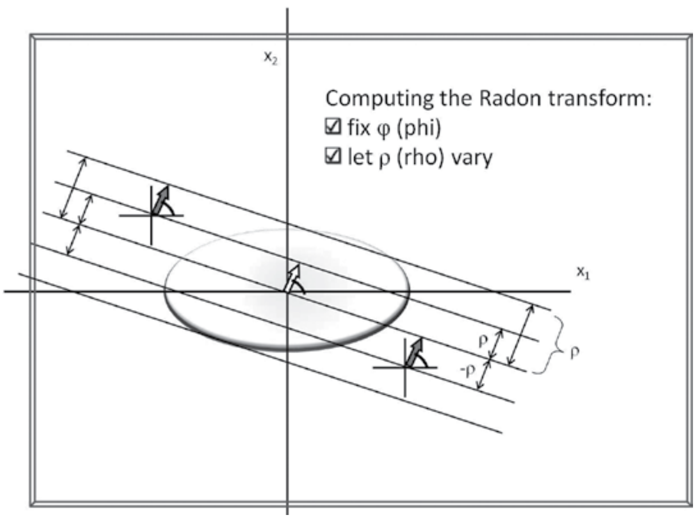

Figure 3. *In this family of parallel lines, each line has the same angle phi (φ) to the x_1-axis. To integrate the constituent integrals of the Radon transform (and those integrals contributing to the Fourier transform), it is necessary to use the distance rho (ρ) as the variable of 1-D integration.*

Because the Radon transform and the Fourier transform share an elegant relation, we can write the Fourier transform $\mathfrak{F}$ with respect to ρ (denoted by the subscript ρ) as a function of the Radon transform $\mathfrak{R}$.[4]

Eq. 3

$$\mathfrak{F}_\rho(\mathfrak{R}\mu(\rho,\varphi)) = \int_{-\infty}^{\infty} e^{-2\pi i r\rho}(\mathfrak{R}\mu(\rho,\varphi))d\rho$$

Here the letter r in the complex exponential, $e^{-2\pi i r\rho}$, accounts for the spatial domain.[3] In the context of CT, the physical interpretation considers 2 domains, spatial and frequency, and both are represented in the complex exponential.

Further evaluating equation 3, including switching the order of integration, we can address dimensionality by first dealing with the 1-D component.

$$\mathfrak{F}_\rho(\mathfrak{R}\mu(\rho,\varphi)) = \int_{-\infty}^{\infty} e^{-2\pi i r\rho}(\mathfrak{R}\mu(\rho,\varphi))d\rho$$

$$= \int_{-\infty}^{\infty} e^{-2\pi i r\rho}\left(\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mu(x_1,x_2)\delta(\rho - x_1\cos\varphi - x_2\sin\varphi)\,dx_1\,dx_2\right)d\rho$$

$$= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mu(x_1,x_1)\left(\int_{-\infty}^{\infty} e^{-2\pi i r\rho}\delta(\rho - x_1\cos\varphi - x_2\sin\varphi)\,d\rho\right)dx_1\,dx_2$$

$$= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mu(x_1,x_2)\left(\underbrace{\int_{-\infty}^{\infty} e^{-2\pi i r\rho}\delta(\rho - (x_1\cos\varphi + x_2\sin\varphi))\,d\rho}_{\text{The 1-dimensional Fourier transform}}\right)dx_1\,dx_2$$

The multiline evaluation yields:

Eq. 4

$$\mathfrak{F}_\rho(\mathfrak{R}\mu(\rho,\varphi)) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mu(x_1,x_2)e^{-2\pi i r(x_1\cos\varphi + x_2\sin\varphi)}\,dx_1\,dx_2$$

where the complex exponential, $e^{-2\pi i r(x_1 r\cos\varphi + x_2 r\sin\varphi)}$, may be rewritten after distributing r, such that we obtain $e^{-2\pi i(x_1 r\cos\varphi + x_2\sin\varphi)}$. To finish simplifying the exponential, the concept of dual variables is introduced. Hence, x_1 and x_2 are paired with ξ_1 and ξ_2, respectively, where ξ_1 and ξ_2 are each constants defined as:

$$\xi_1 = r\cos\varphi \text{ and } \xi_2 = r\sin\varphi$$

Although the above equalities suggest implementation of polar coordinates (the coordinate system used for spherical/circular symmetry), that is not the intent. The equalities merely serve as a means to express the complex exponential more simply with dual variables:

$$e^{-2\pi i(x_1\xi_1+x_2\xi_2)}$$

Now that we have evaluated the 1-D integral (the integral involving the line impulse), computational steps must be performed to recover (or reconstruct) the density values of μ by inverting the Radon transform as a function of the Fourier transform over the 2-D region.

Inverting the Radon Transform

To invert the Radon transform, we first plug the result of the 1-D integral back into the original Fourier transform set up earlier. We now have the 2-D Fourier transform of μ (ie, the double integral) set up to first evaluate along the x_1-axis (the inside integral dx_1) and then along the x_2-axis (the outside integral dx_2).

Eq. 5

$$\mathfrak{F}_\rho\big(\mathfrak{R}\mu(\rho,\varphi)\big) = \underbrace{\int_{-\infty}^{\infty} \underbrace{\int_{-\infty}^{\infty} \mu(x_1,x_2)e^{-2\pi i(x_1\xi_1+x_2\xi_2)}\,dx_1}_{\text{inside integral}}\,dx_2}_{\text{outside integral}}$$

It may be helpful to review the entire mathematical derivation up to this point. First, a suitable coordinate system (ρ, φ) was found. Second, φ was fixed to let ρ vary, where φ is the angle that each line in the family of parallel lines makes with the x_1-axis, and ρ represents the values of distances of these lines from the line passing through the origin. Third, the 1-D Fourier transform of the corresponding Radon transform was found with respect to ρ, resulting in the 2-D Fourier transform of μ.

In principle, the problem is solved. We measured the Radon transform (ie, the line integral of μ along the family of parallel lines). Because we know the expression of the 1-D transform and the values that emerge (those associated with $e^{-2\pi i(x_1\xi_1+x_2\xi_2)}$), the Fourier transform with respect to ρ can be computed.[4] By doing so, we get the 2-D Fourier transform with respect to μ. This means that we can find μ by taking the inverse of the 2-D Fourier transform of what was found:

Eq. 6

$$\mathfrak{F}\mu(\xi_1,\xi_2) = \mathbb{G}(\xi_1,\xi_2) \xrightarrow{\text{recovers } \mu} \mu = \mathfrak{F}^{-1}\mathbb{G}(\xi_1,\xi_2)$$

where $G(\xi_1, \xi_2)$ equals $e^{-2\pi i(x_1\xi_1+x_2\xi_2)}$, the known values of the 1-D Fourier transform. By taking the inverse of the signal/function μ, we recover the attenuated data for the trajectory lines of the x-ray photons passing through the region of interest.[4] With μ, the CT scanner can reconstruct the densities of the region by assigning values according to the Hounsfield unit scale for data acquisition and image processing.[9]

Conclusion

The language of mathematics permeates all scientific study, and its application allows exploration at the limits of discovery. Mathematicians such as Radon guide physicists and engineers in determining the plausibility of their theories and innovations. Radon did much to advance 20th century mathematics, and this article focused on his fundamental work that underpins medical CT (ie, the Radon transform and its inversion). This single contribution earns Radon a notable place in the history of medical imaging.

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This article is the last in a series of 3 articles by Mr Wininger on Johann Radon and the mathematics of CT

that appeared in Radiologic Technology. *The first article, "Foundations of CT: The Radon Problem" (November/December 2012), traced the lineage of the Radon problem (ie, knowing a body by knowing the line integrals passing through it). In "The Life and Work of Johann Radon" (online supplement, November/December 2012), Mr Wininger presented a brief overview of the life and esteemed career of Johann Radon.*

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Moving to an E-book Curriculum in an Allied Health Program

David Heflin, MS, R.T.(R), RDMS, RVT

As tuition and book costs increase, so too do the financial stresses of today's college students. The radiography students at West Kentucky Community and Technical College (WKCTC) are no exception. In addition, students in the WKCTC radiography program are required to travel to clinical sites several times a week during the semester. Thus, rising gas prices add to the financial stressors they face. Economic relief for radiography students is needed, but how can faculty offer cost savings without reducing the quality of the program?

Moving to an E-book Curriculum

In the fall of 2011, WKCTC radiography program faculty made an effort to reduce costs for incoming radiography students by piloting a complete e-book curriculum. The secondary goals of the e-book curriculum were to streamline book purchasing, improve learning of the radiography material, and increase overall student engagement. After the first year with the e-book curriculum, success was apparent.

The cost of books has been cut nearly in half. Prior to the e-book curriculum, radiography students spent $1000 or more on required books for the program. The cost of the radiography e-book package is around $500 and is available for purchase at the campus bookstore or through the e-book publisher, Elsevier. With 1 purchase, students in our pilot e-book program were able to obtain the required materials for all 5 semesters before the start of the program, rather than having to purchase books at the beginning of each semester.

Since the WKCTC radiography program moved to an all e-book curriculum, there have been no issues with financial aid for the students. We also changed the policy to require laptops in the program. This has ensured that financial aid covers students' laptop purchases. Another interesting outcome is that the students engage in "note sharing," a unique characteristic of the e-book curriculum. The note-sharing practice has provided an inimitable way of learning radiography material because the students can view notes created by the faculty within the e-book, as well as share notes with each other related to book material. For example, instructors may highlight an area of text and add a note stating that the information will be important in answering questions on the next exam.

Student engagement also has increased with the use of e-books and new computer technology within the program. Compared to previous semesters, student-to-student interaction and student-to-instructor interaction have grown through note sharing, e-mails, text messages, and other forms of communication.

These improvements did not involve years of research and development, but they did require collaborative efforts off and on for several months from many participants, including the leadership at WKCTC, the program coordinator, faculty, staff, students, and other interested parties. The contributions of everyone involved made it possible to tip the balance of the e-book initiative in the direction of success with the fewest headaches.

Findings and suggestions for transitioning to an e-book curriculum are included in the **Box**.

Getting Ahead of Change

The transition to an e-book program in the radiography program at WKCTC has been a great success. With the support of many, we have been able to give our students the opportunity to learn in a new and exciting way while saving their backs, literally — the books for the radiography program weighed more than 30 lbs — and money. The response from students has been positive regarding the move to e-books. Approximately 95% of our incoming students already have laptops. As a result, most students only have the e-book package expense. Also, many of our students are experienced with e-books from high school or e-readers, so using the e-books at a higher education institution seems natural to them.

With the radiography program's success, other programs in the Allied Health and Personal Services Division at WKCTC have begun moving to an e-book curriculum. Our advice to them has been to be open to the change and prepare for the initial work and adjustment period involved. As educators are aware, change is going to happen, and preparing and being ahead of change is a much easier process than being run over by change.

David Heflin, MS, R.T.(R), RDMS, RVT, is an assistant professor and coordinator of the radiography program at West Kentucky Community and Technical College in Paducah, Kentucky. He has been a radiographer and sonographer for more than 20 years and is a guest lecturer for local and state conferences on sonography and radiography. He is studying educational policy studies and evaluation at the University of Kentucky.

Box

Research

Finding a single publisher who can meet the program's overall needs best is a crucial preliminary step in moving to an e-book delivery format. A consistent publisher allows for continuity in implementation and content. This practice may require changing a text, which was the case for our program, and the need for faculty to be open to this type of change is critical to work toward a smooth transition to e-books.

Buy-in

Get everyone to buy into the transition to e-books and any required text changes upfront — especially the program faculty — and include them in the decision-making process. It may be a bit more time-consuming, but it will pay off. Buy-in by program faculty is critical if the transition to e-books is to be positive.

Collaboration

A good relationship with your e-book representative is critical for a smooth transition. Collaboration between your representative, the college bookstore manager, program faculty, students, and the program coordinator is vital to help prevent unforeseen issues and confusion, primarily for students.

Implementation

Implementing the e-books in the program and individual classes takes time and energy. This is where your previous steps (research, buy-in, and collaboration) will pay off. The advice, help, and buy-in of others will help get the e-book transition started and headed in the right direction.

Communication

Communication should be ongoing before, during, and after the transition to e-books. The communication must be open and honest throughout the process and should always be in a positive tone. Issues and problems are going to happen, but with quality communication throughout the e-book transition, things will go much more smoothly.

A Bibliometric Analysis of *Radiologic Technology* (1963-2011)

Essam H Mattar, PhD
Elwin R Tilson, EdD
M Gary Sayed, EdD, PhD

Although some of the radiologic science modalities, such as radiography and fluoroscopy, are as old as the discovery of radiation, the profession is still evolving in terms of its contribution to scientific literature. *Radiologic Technology*, which is a core journal in the radiologic sciences, plays a significant role in the growth of the profession by providing a venue for academics and practitioners to publish their research and other scholarly works.[1] It also plays an important role in disseminating that work among the larger community of radiologic science specialists and other health care professionals.

Background

Scientometrics is a branch of informatics. It is the science of measuring and analyzing the state of scientific disciplines and their productivity.[2] In practice, scientometrics uses bibliometric methods. Bibliometrics is a set of quantitative methods that use mathematical and statistical techniques to analyze the literature. It quantifies the development and impact of a discipline through its publications, or the impact of a journal, a group of researchers, or a specific paper. It also can quantitatively evaluate a researcher's productivity and impact in his or her discipline.[3]

Bibliometric evaluation and quantification of literature is becoming increasingly important in most disciplines, even though there is controversy about the nature of the indicators used.[4] Such assessments are used for promotion and tenure evaluations, hiring decisions, grant funding evaluations, and programmatic or institutional rankings. Although bibliometrics is now almost nonexistent in the radiologic sciences, the growth of the profession and the increased emphasis on academic measures suggest it will become more important in the future.[4]

There are 3 laws of bibliometrics commonly used to describe or predict publication activity: Bradford's law, Lotka's law, and Zipf's law. How frequently authors publish in a given field is predicted by Lotka's law.[5] Bradford's law helps determine the core journals in a profession.[6] Zipf's law describes the distribution of words in articles about a particular topic.[7]

According Bradford's law, a relatively small number of journals are responsible for a large percentage of the articles published on any given subject and are considered core journals. Bradford's law of scattering is a technique to determine the core journals in a discipline. Using this technique, journals are rank ordered based on the number of articles published on a given topic and then typically divided into 3 zones or groups, each with about the same number of articles. Bradford posited that the number of journals in the first zone was related to the numbers of journals in the subsequent zones. He described this relationship as $1 : n : n^2$, where n is the ratio of the number of journals in the first zone compared with the second zone.[8]

For example, if there are 8 core journals in a discipline that produced 32 articles for a given timeframe and the number of journals necessary to populate the next zone with about 32 articles was 24, the ratio n would be 24/8 or 3. Therefore, to populate the next zone with about 32 articles, it would take approximately 3^2 (the ratio squared) times the number of journals in zone 1. This works out to 9×8, or about 72 journals. Mathematically, this is described as:

$$R(r) = iy_0$$

where R(r) represents the accumulated articles on a given subject matter, R represents the accumulated journals on a given subject matter, i the number of Bradford zones, and y_0 productivity of the journals of the nucleus.[9]

Lotka's law describes the relationship between the number of authors and the number of articles they publish in journals. This relationship, like Bradford's law, gives exponentially diminishing returns. It states that the number of authors publishing a given number (n) of articles is about $1/n^2$ of those publishing only 1 contribution and that about 60% of all authors only publish a single paper.[10] This means that in a typical field, 60% of authors only publish a single article, 15% ($1/2^2 \times .60$) of authors publish 2 articles, 7.5% publish 3 articles, etc. As with Bradford's law, this is not statistically accurate but gives an estimate that is approximately correct over large numbers of authors. Mathematically, this relationship can be described as:

$$A(R) = A(1)/R^2$$

where A(R) is the number of authors that publish R works, R is the number of works that an author publishes, and A(1) is the number of authors that publish only 1 work.[9]

The last of the laws is Zipf's law, which is used to predict the frequency of words in a text. This is useful both to researchers and indexers. To calculate the relationship predicted by Zipf's law, all the words in a document must be listed and arranged in order of decreasing frequency. When the rank of a word is multiplied by the frequency of that word in the document, a constant is created. A mathematical formula for this relationship is:

$$F = k_z/R$$

"where F is the frequency of appearance of a word in a text, R is rank, and kz is the Zipf constant."[9] In practice, this means that authors tend to use some words a lot and others less so. According to Bailon-Moreno et al, Zipf's law is related to the principle of least effect, so authors use more common words that are shorter and easier to pronounce.[9]

Bibliometric Indicators

Several bibliometric indicators are used in evaluating the literature. Among the most widely recognized is the journal impact factor, which was developed in 1972 by Eugene Garfield, founder of the Institute for Scientific Information (ISI).[11] The impact factor is defined as the ratio of the number of citable articles in a journal for a specific year to the number of citations that refer to that journal in the subsequent 2 years.[12] For example, if a journal published 28 articles in 2008, that number would be compared to the number of times during 2009 and 2010 that those articles were cited in other works. Normally, impact factor analyses are performed using data from the science citation index, which, for a given journal X and year Y, records the average number of times other journals' articles have cited journal X in the 2 years preceding year Y.

The science citation index maintains in its database a list of about 4000 journals in various scientific fields. At present, *Radiologic Technology* is not included in this list and does not have a formal impact factor. As a comparison, based on data from the ISI Web of Knowledge, *Radiology* has an impact factor of 6.069, the *Journal of Nuclear Medicine's* (JNM) impact factor is 7.022, and *The New England Journal of Medicine* (NEJM) has an impact factor of 53.48. Normally, multidisciplinary science journals such as *Nature* or NEJM tend to have high impact factors, while specialized core journals tend to be at the lower end of the scale, as in the case of *Radiology* and JNM. Among the examples cited in this paragraph, NEJM is considered a general topic medical journal, hence its relatively high impact factor.[13]

Other bibliometric indicators include the Eigenfactor Score,[14] h-index or Hirsch number,[15] citation impact,[16] and citation index.[17] The **Box** lists some of these indicators, briefly defines them, and recommends sources of information on each. These indicators offer unique advantages, but also suffer from inherent limitations that are beyond the scope of this article.[4]

The aim of this study was to use bibliometric techniques to characterize the radiologic science literature from 1963 through 2011 as published in its core journal, Box

Some Bibliometric Indicators and Their Definitions

Impact factor – a measure of the importance (impact) of a journal determined by the average number of citations per article cited in other journals for the previous 2 years.
Eigenfactor score – a score based on an algorithm that uses the number of citations of an article and the relative importance of the journals.
H-index – a measure of the impact of a specific author, institution, or even country. Measures both the number of articles published and the average number of citations per article of that work.
Citation impact – measures a count of the number of times an article, an author, or a journal are cited by others.
Citation index – a citation database allowing researchers to cross articles, authors and their citations.

Radiologic Technology, at an aggregate level. The aim is to provide a baseline for future analyses of scientific literature in the radiologic sciences and to provide data on publication productivity, scholarly endeavors, and trends.

Literature Review

Thousands of peer-reviewed publications appear annually in scholarly journals focused on various disciplines. The proliferation of scientific publication prompts questions about the regularity and rate of scientific productivity among authors in scientific journals or in a given field. It also brings into question how such productivity compares with other specialties within the field. Questions on patterns, content, and productivity rates are of interest to researchers in academic disciplines as they chronicle the literature's development in a given field. Such questions can be answered through bibliometric analyses, which allow an understanding of publication trends in a discipline or on a specific topic and at an aggregate level.[18]

Bibliometrics has been used to characterize the literature in a specific journal or scientific discipline in recent years. Most such reviews focused on core journals and citation analysis.[19-23] Other studies detailed content reviews characterizing the literature on specific topics.[18] A recent study used bibliometric analysis to evaluate the standing of scientific journals with regard to their prestige, influence, and other parameters.[22] Researchers in this study essentially compared bibliometric indicators associated with leading journals and their possible utility in the physical and rehabilitation medicine literature. Among their findings was the observation that journals cannot be subsumed under a single indicator.[22] Another researcher reported that longitudinal analysis of citation data provides relevant information on research and sheds light on publishing trends in a given field.[24]

Crawley-Low prepared a list of core journals in veterinary medicine using bibliometric techniques.[21] This study analyzed the citation patterns common among researchers who publish in the *American Journal of Veterinary Research*. He devised a method of classifying cited items into 3 theoretical zones: 24 journals produced 7361 cited articles in zone 1; 139 journals produced 7414 cited items grouped in zone 2; and 1409 journals produced 7422 cited items in zone 3. Hence, a relatively small number of journals produced about one-third of all citations, in accord with Bradford's law.

In another bibliometric analysis, Anyi and colleagues reviewed a single journal, the *Malaysian Journal of Computer Science*.[25] They used quantitative measures to study 272 articles published in the journal between 1985 and 2007. Certain indices, such as the journal's distribution and reference, were subjected to Bradford's law to explain journal scattering and assist in indicating the extent of Web citations. They also employed Lotka's law in their analysis to explain author productivity, identification, and listing of core authors of the journal.

Methods

This study was conducted using the ISI Web of Knowledge (www.webofknowledge.com) by Thomas Reuters. The Web of Knowledge is the premiere citation index for scientific journals. A search was conducted with the publication name limited to *Radiologic Technology* in early February 2012. After search artifact citations were eliminated, 2329 publications were located. The oldest publication in the index was from July 1963. The newest in our search was from December 2011.

These 2329 publications were then categorically analyzed for the following factors: document type, author frequency, publication by year, language, and subject area. Descriptive statistics for each of these parameters were derived from the index. For the author frequency, data were combined if the same author was listed under 2 slightly different names. For example, J B Reid, Jerry Reid, and J Reid were combined. For the subject area, several similar areas were combined. For example, 5 related areas were combined into a single behavioral and psychological issues area.

Results

Document Type

Because of inconsistencies and duplications in the classifications, the exact number of publications in each category is not known. Duplicate designations and classifications account for 27% of the total entries, which artificially raised the total number of articles to 2954. In *Radiologic Technology*, there are several types of articles, including original research, reviews/continuing education, case reports, editorials, and others. The Web of Knowledge index indicated that 2161 (73%) were articles, but this includes continuing education and literature review articles. The breakdown for all document types appear in **Table 1**.

Table 1

Document Types, Numbers, and Percent Distributions

Type	Total	% Distribution
Article	2161	73
Biography	22	1
Case report	90	3
Editorial	21	1
Letter	106	4
Reference material	46	2
Review	315	11
Other	193	7
Totals	**2954**	**100**

Author Frequency

The 20 top-ranked authors by frequency produced 637 of the 2329 (27%) publications between 1965 and 2011. The first ranking author was Steven Dowd, who contributed 53 articles. The next 4 most prolific contributors were Reid JB (47), Malott JC (31), Tilson ER (29), and Fodor J III (28), as shown in **Table 2**. The publication period range for the 20 top-ranked authors varied from a low of 1 year for Culinan A and Cullinan J to a high of 30 years for Eastman TR. The average number of years of publishing with the journal for all 20 top-ranked authors was 9.43. The earliest start date for this group was 1965 and the latest start date was 2011. Only 12 out of the 44 most prolific authors were active within the preceding 2 years. More than half of the 20 top-ranked authors had publications in the past 10 years.

Publication and Citation by Year

The number of documents published yearly has been on an upward trend but has not been consistent. The number of documents published in the top 20 years of the journal was 1266 (54%). The peak year was 1997, when 84 documents were published. The lowest count for the top 20 years was 47 documents for the years 1978 and 1980, with the average being 63 documents per year. Over the past 20 years, a total of 1219 documents were published, with 3 periods of growth followed by a contraction. The number of documents published grew from 38 in 1991 to 84 in 1997. In 1998, the number dropped to 54 and grew back to 62 over the next 4 years, when another contraction occurred. In 2002 and 2003, only 47 documents were published per year. Between that time and 2009, the trend was increasing except for 1 year. In 2010 and 2011, the trend is again negative, with 70 and 69 documents being published, respectively (see **Figure 1**).

One area in which the journal has had consistent growth despite the swings in the number of documents published is in the number of citations of its articles in the past 10 years. The first citation to a journal article occurred in 1967. There were no citations of articles from 2001 or 2002, 5 citations for 2003 growing to 60 citations for 2010 articles and 53 for 2011 (see **Figure 2**). During that time, 218 articles were cited with an average citation per article of 0.36 and an h-index of 5. **Table 3**

Table 2

Top 20 Ranked Authors

Rank	Most Prolific Authors	No. Articles	Contribution Period	Duration (years)
1	Dowd SB	53	1982-2001	19
2	Reid JB	47	1990-2011	21
3	Malott JC	31	1980-1989	9
4	Tilson ER	29	1982-2001	19
5	Fodor J III	28	1999-2011	9
6	Furlow B	24	1999-2011	12
7	Peart O	23	2002-2011	9
8	Newman J	21	1996-2000	4
9	Frank ED	18	1979-1991	12
10	Long B W	18	1988-2001	13
11	Hulse SF	17	1975-1992	17
12	Shagham JY	16	1999-2011	12
13	Geissler K	15	2002-2010	8
13	Gray JE	15	1975-1990	15
13	Reitherman R W	15	1991-1995	4
14	Widger JI	13	1965-1978	13
14	Stears JG	13	1979-1990	11
15	Legg JS	12	2002-2010	8
15	Hobbs DL	12	2005-2007	2
16	Church EJ	11	2002-2010	8
16	Daniels C	11	1997-1999	2
16	Devos D	11	1995-1997	2
16	Johnston J	11	2008-2011	3
16	Odle TG	11	2003-2011	8
17	Cross DS	10	1996-2000	4
17	Eastman TR	10	1969-1999	30
18	Aaron L	9	2006-2011	5
18	Cox LA	9	1996-2001	5
18	Hage SJ	9	1972-1989	17
18	Sweeney RJ	9	1972-1980	8
18	Tanenbaum BG	9	1996-1998	2
19	Warner SL	8	1971-1989	18
19	Davidhizar R	8	1997-2001	4
19	Dreesen RG	8	1970-1991	21
19	Fay M	8	1979-1996	17
19	Martin NJ	8	1992-1997	5
19	Rodgers AT	8	1997-2000	3
20	Gurley LT	7	1969-1980	11
20	Burns CB	7	1982-1993	11
20	Cullinan A	7	1994-1995	1
20	Cullinan J	7	1994-1995	1
20	Kowalczyk N	7	2005-2011	6
20	Reynolds A	7	2007-2011	4
20	Vanderford V	7	1999-2001	2

provides a summary of citation data and comparisons with other allied health journals, including the *American Journal of Occupational Therapy, Physical Therapy, Respiratory Care*, the *Journal of the American Academy of Physician Assistants*, and the *Journal of Allied Health*.

Language

One interesting note is that *Radiologic Technology* is listed as a multilanguage publication. In addition to 2329 documents published in English, 25 documents were published in Spanish. These are the patient education handouts that were published in both English and Spanish.

Subject Areas

The total for the topical subcategories is greater than 100% because of documents being listed in multiple categories. A clustered topical list of subcategories is shown in **Table 4**. As expected, most publications (2046 or 35%) are in the radiology, nuclear medicine, and medical imaging subcategories. The next most common subcategories are clinical medical topics (806 documents or 14%), behavioral and social sciences (638 articles or 11%), and education and educational research (462 publications or 8%).

Discussion

The annual distribution of the 2329 total documents published in *Radiologic Technology* between 1963 and

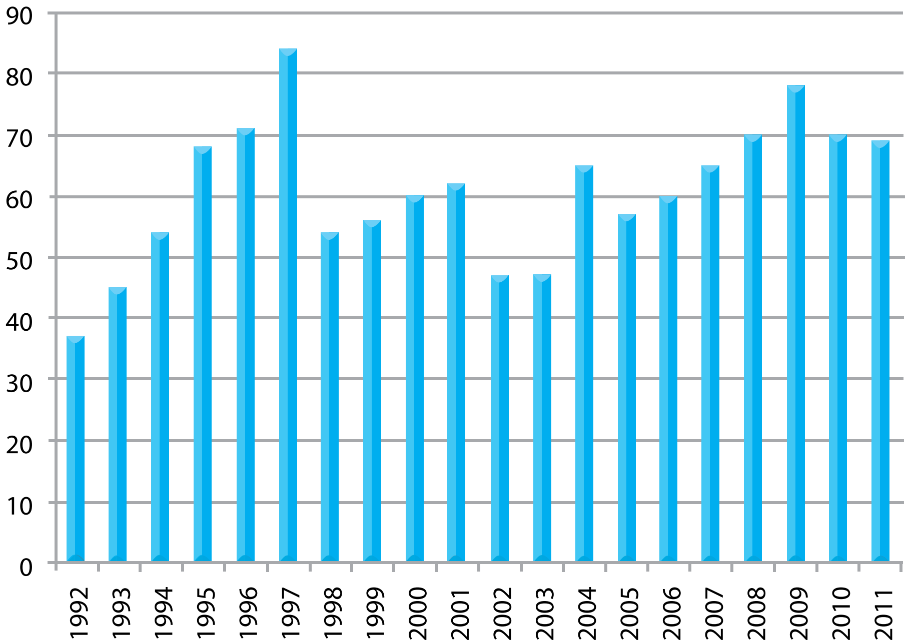

Figure 1. *Total number of publications per year.*

2011 varies considerably. A snapshot view of the annual publication frequency distribution from 1992 through 2011 shows that the journal's output was lowest in 1992 (total = 37) and greatest in 1997 (total = 84). There was a major increase in the number of articles between 1992 and 1997, but for reasons that are not clear in the record, there was a 37% drop in numbers between 1997 and 1998. Since that time, there has been an erratic but persistent trend toward more articles being published each year.

Radiologic Technology does not have a formal citation index because so few articles in this journal are cited elsewhere. Between 2001 and 2011 there were 253 total citations, with an average of 25 per year. There has been a dramatic increase in the number of citations per year from 1967, when the first citation was recorded, to 2011.

A majority of the articles for the journal are written by a minority of authors, as predicted by Lokta's law. Interestingly, 27% of the most prolific authors have published in the past 2 years. The most prolific author, Dowd, has not published in the past decade, but 2 of the top 5 most prolific authors, Reid and Tilson, are still active.

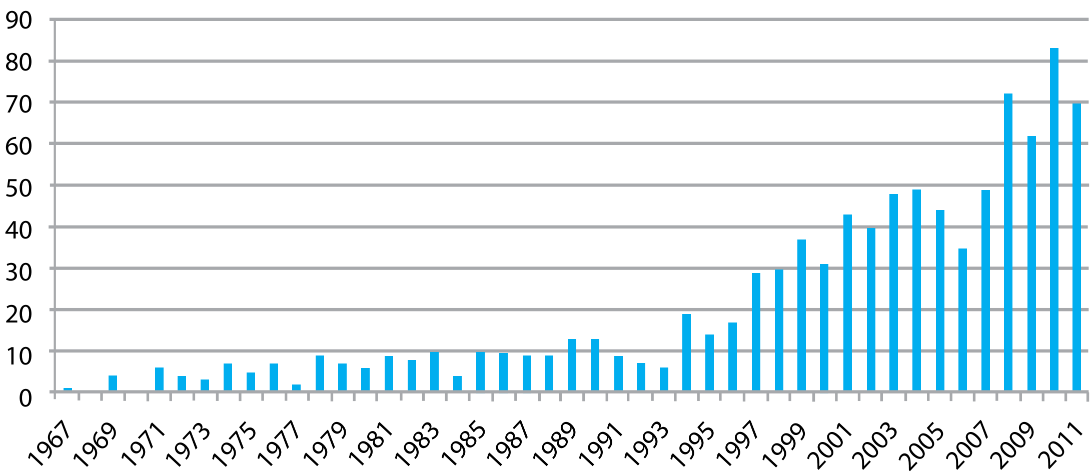

Figure 2. *Total number of citations per year.*

Table 3

Comparison of *Radiologic Technology* With Some Peer Allied Health Journals

Journal	Citing Articles	Citing Articles Without Self-citations	Average Citations/Item	H-index
Radiologic Technology	911	911	0.41	9
American Journal of Occupational Therapy	2590	2218	5.32	22
Physical Therapy	10 117	9319	8.59	48
Respiratory Care	5398	4862	4.74	32
Journal of the American Academy of Physician Assistants	294	105	0.36	5
Journal of Allied Health	218	218	0.36	5

The content of the journal varies, with the majority (84%) of the articles being in the broad areas of radiology, nuclear medicine, and medical imaging. However, almost half of the articles also were listed as various medical specialties such as orthopedics or neurology. Approximately one-third of the articles were categorized as being in the behavior or psychology areas, and about one-fifth of the articles were on education topics. Overall, the journal has a good mix of topics and authors, and its citation rate appears to be steadily increasing — a highly positive outcome.

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Table 4

Clustered Topical List

Topics/Subject Area	n (%)
Radiology, nuclear medicine, and medical imaging	2046 (35)
Education and educational research	480 (8)
Health care sciences and services	462 (8)
Behavioral and social sciences	638 (11)
Information and computer science	214 (4)
Occupational health/safety	179 (3)
Basic medical sciences	485 (8)
Medical, clinical topics	806 (14)
Surgical, clinical topics	257 (4)
Physical sciences	157 (3)
Business and economics	84 (1)
Other	61 (1)

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Esophageal Achalasia

Olive Peart, MS, R.T.(R)(M)

A 64-year-old man presented with complaints of chest pain, substernal pressure, dysphagia, and mild nausea. A gastroscopy revealed achalasia and a massively tortuous esophagus. A computed tomography (CT) scan and an upper gastrointestinal radiography exam were used to confirm this diagnosis.

The CT study revealed food and contrast media within a dilated portion of the esophagus above a narrowing of the esophagus at the esophagogastric junction (see **Figure 1**). The dilation and obstruction of the distal esophagus was most consistent with achalasia, seen on the upper gastrointestinal radiograph as a parrot beak deformity (see **Figure 2**).

Esophageal achalasia can be caused by damage to the sphincter muscle nerves of the esophagus. As a result, there is poor relaxation of the sphincter muscles, and the esophagus cannot move food down to the stomach easily.

The treatment is a transhiatal esophagectomy with gastric pull-through. The lower esophagus is removed and the upper end of the stomach is pulled into the chest and connected (anastomosed) to the remaining esophagus (see **Figure 3**). About 48% of patients have no difficulty eating or adverse effects from the operation. However, possible postoperative complications of this procedure are anastomotic leak, pyloromyotomy leak, atelectasis, pneumonia, or mild dysphagia.[1]

Figure 1. *Computed tomography scan showing a dilated esophagus.*

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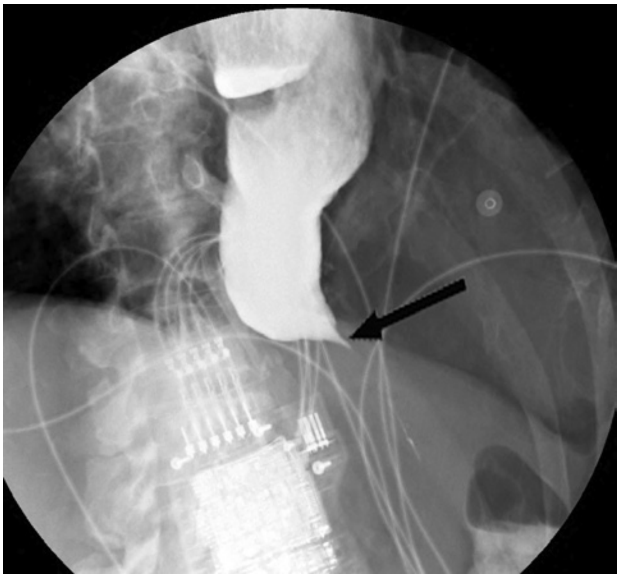

Figure 2. *Upper gastrointestinal radiograph showing a parrot beak deformity.*

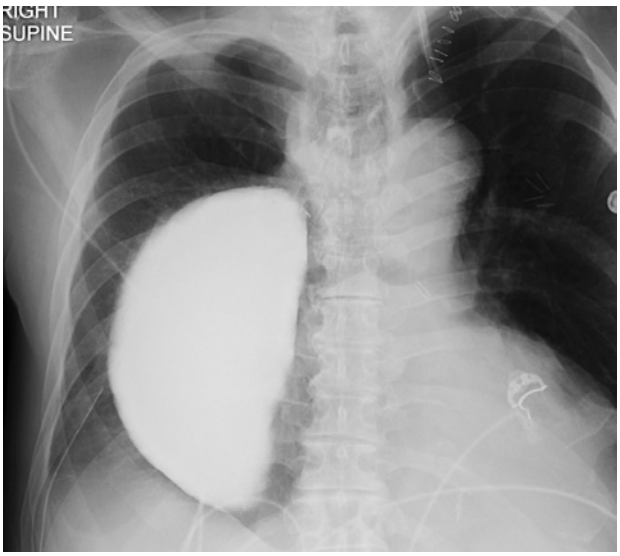

Figure 3. *Upper gastrointestinal radiograph of the stomach in the chest.*

Spanish for Professionals in Radiography, Lange Q & A: Mammography Examination, *and* Mammography and Breast Imaging: Just the Facts.

Thanks to James Carroll, a student in the Stamford Hospital Program in Radiography, for submitting this month's technical query.

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Summary of ARRT's 2012 Practice Analysis for Bone Densitometry

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In support of its mission to promote high standards of patient care, the American Registry of Radiologic Technologists (ARRT) produces examinations that candidates must pass to obtain initial certification. These examinations assess the knowledge and cognitive skills underlying the intelligent performance of the tasks typically required for entry-level practice. To keep pace with current practice, ARRT periodically conducts practice analyses, also known as job analyses. Practice analysis is the process of determining what tasks compose a job. A committee of experts then uses the task list to shape a certification examination's clinical experience requirements, which are part of the certification's eligibility requirements, and content specifications, which guide an exam's creation.[1] This type of analysis is the key component in ensuring that examination scores are valid for job certification programs.[2]

ARRT has been conducting formal practice analysis studies for several decades to keep all of its certification examinations current.[3] For its postprimary examinations, ARRT conducts large-scale comprehensive practice analysis updates about every 9 years, with 2 smaller-scale interim practice analyses at 3-year intervals. This article briefly summarizes the results of the recent comprehensive practice analysis for ARRT's bone densitometry (BD) certification.

Numerous methods can be used to conduct a practice analysis.[4,5] This practice analysis, as with most ARRT practice analyses, used 2 sources of information: data from a large-scale survey and input from the BD Practice Analysis Advisory Committee. The committee included practicing BD technologists from different areas of the United States. The committee used the results of the survey to guide decisions about which items to retain on the BD task list. The survey data is extremely beneficial to a practice analysis because it gives information about a large number of diverse practices.[1] The committee then used the task list to modify the exam content specifications and clinical experience requirements. The following is a brief summary of this process.

Practice Analysis Survey

The advisory committee first met in February 2010 to create the practice analysis survey, which asked how frequently each respondent conducted 48 specific clinical activities related to BD (not responsible, yearly, quarterly, monthly, weekly, and daily). The survey also asked about types of scanning equipment and demographic information. In July 2010, ARRT staff mailed the survey to a stratified random sample of 1400 registered technologists (R.T.s) who had indicated that BD was either their primary or secondary discipline of practice. R.T.s returned 684 useable surveys for a 48.9% return rate.

Survey Results

More than 75% of respondents indicated that they were responsible for 30 out of the 48 clinical activities. This indicates a high level of agreement about the role of a BD technologist across a wide variety of practices. More than 90% indicated responsibility for proximal femur and posteroanterior lumbar spine dual-energy x-ray absorptiometry (DXA) scans. In addition, 88% were responsible for forearm DXA scanning. Vertebral fracture assessment (VFA) and pediatric DXA scanning were 2 previously unsurveyed tasks for BD that had moderately high responsibility levels, with more than 40% of respondents indicating that they were responsible for these activities. Slightly less than two-thirds (64.9%) of respondents used a picture archiving and communication system (PACS) to archive and access patient scans, so BD clearly has made the move to digital imaging. Finally, 31.3% of respondents reported using a Fracture Risk Assessment Tool (FRAX) score in practice. This percentage is large considering that FRAX scores are relatively new to BD.

Implementing the Survey Results

The advisory committee met again in fall 2010 to review the results of the survey and revise the BD task list, exam content specifications, and clinical experience requirements. Major additions to the task list based on the reported practice frequency were VFA and pediatric BD scans; both of these new tasks had relatively high responsibility levels. The advisory committee also added the tasks "Perform cross-calibration between new/existing machines" and "Utilize FRAX tool to assess 10-year fracture risk." The committee believed that, although infrequent, cross-calibrations were critical enough to practice in BD to be on the task list. The committee indicated that the use of FRAX in bone density reports was greatly increasing, so it also went onto the final task list. One notable that the committee took off of the task list was using non-DXA bone density measurement technologies (eg, quantitative ultrasonometry, radiographic absorptiometry, and quantitative computed tomography) because all technologies surveyed other than DXA had less than 10% reported use.

Based on these changes, the advisory committee changed the BD examination content specifications. Specifically, it removed section A.5.C., "Methods for Evaluating BMD (basic concepts and major features)," because the survey indicated that methods other than DXA are no longer commonly used and DXA is covered elsewhere in the content specifications. The committee added the following sections to match the new items on the task list: A.5.D., "FRAX (WHO Fracture Risk Assessment Tool)"; A.5.F., "Pediatric/Adolescent Scanning"; and B.7.C., "Cross-Calibration." The advisory committee also made minor editorial changes to the content specifications. The new content specifications document will guide the content of the BD examination through the next practice analysis update.

The advisory committee also made changes to the clinical experience requirements, which candidates must fulfill to be eligible to become certified. The following are the 4 most significant changes:

- The committee increased the maximum time allowed to complete the clinical experience requirements from 12 to 24 months to be consistent with ARRT's other certifications.
- The number of required repetitions for quality control tests increased from 10 to 25 because the advisory committee believed that there should be an increased emphasis on quality control in the clinical requirements.
- The committee removed the infrequently used elective procedure "Directly observe an experienced operator perform DXA scans of the forearm." The committe determined that this elective was not clinically active enough to be a legitimate experience elective.
- The committee added "Perform DXA scan on pediatric patient (age 5-19 years)" as an elective procedure, as this is now a task on the task list.

ARRT's Board of Trustees reviewed the changes to the content specifications and clinical experience requirements during a meeting held in January 2011. The Board also looked at public feedback from a survey form on ARRT's website, where interested parties could make comments about the proposed changes to the BD documents. The Board approved the changes and they went into effect in July 2012.

Conclusion

ARRT recently completed a comprehensive practice analysis in BD. An advisory committee used the results of a practice analysis survey to update the content specifications and clinical experience requirements for BD certification. Practice analysis keeps ARRT's clinical experience requirements and examinations consistent with current practice, and ARRT will continue to keep its certification programs grounded in the tasks required for practice to support its mission to promote high standards of patient care.

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The authors would like to give special thanks to all of the R.T.s who completed the survey. Without their participation, the ARRT could not make properly informed decisions about current practices in BD. The success of this practice analysis reflects the fact that they gave time from their busy schedules to help promote high standards of patient care. The authors also would like to thank members of ARRT's support staff who assisted in organizing the BD practice analysis meetings.

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A detailed report of the BD practice analysis, including the design of the survey and statistical analyses, can be found at www.arrt.org/Practice-Analysis. The revised content specifications are available at www.arrt.org/Content-Specifications. For the revised clinical experience requirements, visit www.arrt.org/practice-analysis/clinical-experience-requirements.

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Safety Matters

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Safety is an issue that receives a great deal of attention in the medical community. As medical professionals, we learn how to maintain the safety of our patients, the public, and ourselves in the workplace. Policies and procedures are implemented to ensure that appropriate measures are taken to avoid unsafe practices. However, students in medical imaging and radiation therapy programs are learning to become medical professionals. They do not begin their respective programs already knowing appropriate safety practices. These skills must be taught.

Unlike regional accreditors of colleges and universities, the Joint Review Committee on Education in Radiologic Technology (JRCERT) accredits medical imaging and radiation therapy programs. Because the accreditation process involves peer review, site visitors and JRCERT staff evaluate programs based on the standards, their knowledge of the profession, and components of a quality educational process. One component of a quality radiologic science education is the inclusion of policies and procedures that safeguard students (see **Box**).[1,2]

A major benefit of JRCERT programmatic accreditation is the assurance that the program has met a standard of excellence established by the profession to provide the knowledge, skills, and professional values required to deliver safe, high-quality diagnostic or therapeutic radiologic services to patients. The JRCERT specifically addresses student safety in terms of radiation protection and other clinical hazards. Students and the public can have confidence that policies are in place to protect against improper use of radiation-producing equipment and assure there are no other safety issues.

Evaluating Radiation Safety

Radiation protection and safety is a cornerstone concept that students must learn, embrace, and practice. Not only do they learn the concepts of radiation protection and the organizations that establish policies and dose limits, but they must use that knowledge to ensure patients always receive an exposure consistent with the "as low as reasonably achievable" (ALARA) concept. It is 1 thing to have didactic knowledge of radiation protection, as evaluated on a written test, but another to practice and embrace the concept. Practice takes place in the laboratory and the clinical setting. When using an energized laboratory, students must be supervised and wear dosimeters, as in the clinic. In both the laboratory and the clinic, evaluation of radiation safety practices is paramount:

- Does the student use exposure factors that reduce dose to the patient?
- Does the student use shielding or collimation?
- Does the student explain the procedure to the patient to reduce movement?
- Is the patient positioned appropriately for the procedure?

These behaviors usually are measured on monthly or end-of-rotation evaluation forms. They also may be included in the competency evaluation. Regardless

Box

JRCERT Radiography and Radiation Therapy Objectives That Address Safety

4.1 – Assures the radiation safety of students through the implementation of published policies and procedures that are in compliance with Nuclear Regulatory Commission regulations and state laws as applicable.

4.2 – Has a published pregnancy policy consistent with applicable federal regulations and state laws, made known to accepted and enrolled students, and contains the following elements:

- Written notice of voluntary declaration.
- Option for student continuance in the program without modification.
- Option for written withdrawal of declaration.

4.3 – Assures that students employ radiation safety practices.

4.5 (Radiation Therapy), 4.7 (Radiography) – Assures sponsoring institution's policies safeguard the health and safety of students.

4.6 (Radiation Therapy), 4.8 (Radiography) – Assures that students are oriented to clinical education setting policies and procedures in regard to health and safety.

of when the assessment occurs, educators must know that the student has embraced the concept of radiation protection and made it a value that will last a career. Program staff can evaluate whether graduates practice radiation protection after completion of their programs. Evaluation from an employer survey that indicates the graduate demonstrates practices consistent with ALARA might be a possibility.

Exposure Records

Accredited programs must provide students with their exposure record within 30 days of receiving the data.[1,2] Social Security numbers and dates of birth must be deleted from the record to ensure confidentiality. In addition, a threshold dose must be determined, which should be less than occupational exposure limits. This helps the program identify any potential misuse of equipment that could harm the student.

The threshold dose might indicate that a student has been exposed to more radiation than is acceptable and requires an investigation into the reasons why the dose was received. It could be that the student left his or her dosimeter in a radiography or treatment room, it passed through the baggage x-ray at the airport, or the student held patients during procedures. Whatever the reason, an investigation to determine if the student actually received an excess dose must be conducted and the student counseled.

Radiation Safety Curriculum

When examining radiation safety and protection instruction offered in the curriculum, the site visitors and JRCERT staff look to see if this instruction is only very briefly covered or if it is covered in a consistent manner throughout the curriculum, both in the classroom and in the clinic. Having radiation protection threaded throughout the curriculum helps assure that students are receiving this instruction on an ongoing basis. An important question to consider is when the instruction is offered. Do students have instruction in radiation protection before they go to the clinic or use the laboratory, or after?

Special Considerations

Pregnant students pose another challenge for program directors and clinical sites. Any student who conceives during an educational program must be aware of the consequences of radiation exposure. The policy developed by the program must follow federal guidelines that ensure voluntary declaration, with the ability to withdraw declaration at any time. The student must be allowed to complete the program without modification. Inherent in this policy is the underlying concept that the student is able to make knowledgeable decisions for herself and her unborn child based on knowledge. Many programs have the declared pregnant student meet with the program director or radiation safety officer as a means to ensure the student has full knowledge regarding radiation and fetal development. Any modification options she may choose must be shared with the staff in clinical settings so that a consistent clinical education is maintained. Declared pregnant students often are given a fetal dosimeter to be worn at waist level under a lead shield if 1 is needed for a particular exam.

Radiation safety is not the only safety practice addressed with students of JRCERT-accredited programs. At a minimum, programs must address emergency procedures, harassment, communicable diseases, and substance abuse. Different regions of the country may have different emergency procedures. For instance, in California, there should be a policy and procedure addressing earthquakes: What happens to students if a large earthquake happened while they were at school or in the clinic? In Oklahoma, an emergency might be a tornado, and in Florida, a hurricane. In addition to policies and procedures for natural disasters, students also must be knowledgeable of procedures for fire, electrical, chemical, and medical emergencies. If the college, university, or hospital has a policy about an armed individual on campus, the medical imaging or radiation therapy program should make certain the students are aware of the policy and know how to react safely.

Students should have clearly identified channels to report harassment, whether it is of a sexual nature or bullying in the classroom, clinic, or in cyberspace. Students also should be aware of the consequences if they participate in any of these activities. For students to learn, they need to be in a safe and supportive environment and feel safe to report incidents of harassment, which diminish their educational experience.

As health care workers, we often are warriors when it comes to working, even while sick. Unfortunately, this is not in the best interest of our patients and colleagues because the cold or flu can be passed around and spread even further to families — often necessitating time off to take care of young children. In radiation therapy, this can be even more devastating for patients with compromised immune systems. Students returning to the clinic after an illness, but still coughing, can be asked to wear a surgical mask to protect others. This information needs to be relayed to the clinic for the safety of staff and patients. Although an educational program cannot regulate clinical staff, it can use published policies to ensure that students will not spread communicable diseases to radiographers, therapists, or patients.

Substance abuse should not be tolerated in the medical imaging and therapy professions. Although many clinics require a drug screening prior to entry, students must know the consequences of substance abuse at any point in the program. In addition, they should know the reporting procedures if they work with a drug-impaired radiographer, therapist, or another student. While this presents an ethical dilemma for the student, it is an exercise in doing what is right for the profession.

Conclusion

Safety does not stop at the classroom door, but continues into the clinic. When assigned to a clinical setting, students need to know the clinic's policies and procedures regarding hazards, emergency preparedness, medical emergencies, HIPAA, and standard precautions. Some hospitals have all-day orientation training for new employees that students are expected to attend; other clinics might have the clinical instructor in charge of new student orientation. When students are properly oriented, they are able to assist in an emergency situation and provide additional hands, eyes, and ears.

It is evident that just as safety is a major issue in health care, it also is a concern in the education of medical imaging and radiation therapy students. Programs should have policies that protect students in the classroom and clinical settings. Programmatic accreditation by the JRCERT assures that safety is addressed in the educational process and that students, patients, and the public are protected.

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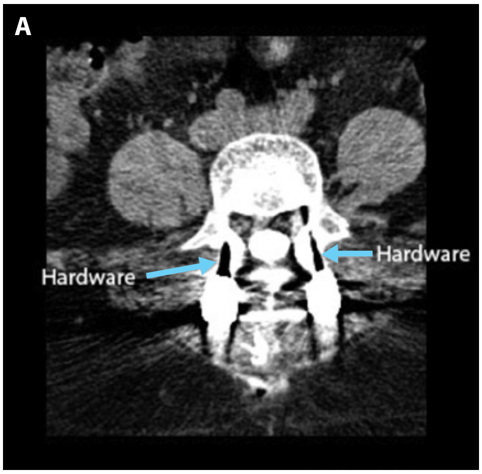

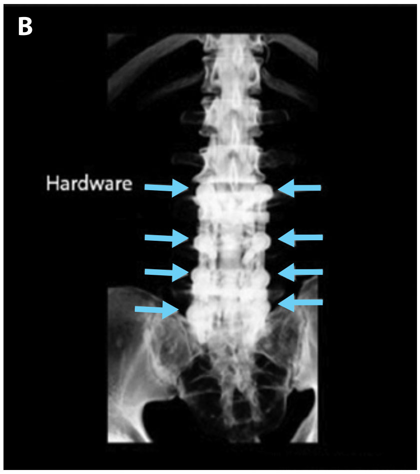

No, that is not an image of Darth Vader. This man was involved in a serious motor vehicle accident and underwent lumbar surgery at levels L3 to S1. A. The hardware used to stabilize the lower spine appears as dark areas in the bony portion of the spine. The hardware also created metallic artifacts that look like streaking across the soft tissue. This image is 1 of approximately 200 slices taken during 1 computed tomography scan. B. The images acquired during this study were used to reconstruct the rendered 3-D volume. The hardware in this image can be seen on the lateral aspects of the lower lumbar spine. Because this image is 3-D, it is easy to distinguish the 8 screws used to stabilize the patient's lower lumbar spine.

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