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• acute or chronic severe renal insufficiency (glomerular filtration rate <30 mL/min/1.73m2), or
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CONTRAINDICATIONS: History of a prior allergic reaction to a gadolinium-based contrast agent.

IMPORTANT SAFETY INFORMATION:

WARNING: NEPHROGENIC SYSTEMIC FIBROSIS (NSF) Gadolinium-based contrast agents increase the risk of nephrogenic systemic fibrosis (NSF) in patients with:

• acute or chronic severe renal insufficiency (glomerular filtration rate <30 mL/min/1.73m²), or

• acute renal insufficiency of any severity due to the hepato-renal syndrome or in the perioperative liver transplantation period.

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In clinical trials, a small increase (2.8 msec) in the average change from baseline in QTc was observed at 45 minutes. These QTc prolongations were not associated with arrhythmias or symptoms. Caution should be used in patients at high risk for arrhythmias due to baseline QTc prolongation.

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Survey of R.T.s With Doctorates: Barriers To Conducting Research

KIMBERLY L METCALF, EdD, R.T.(R)(T)
ROBERT D ADAMS, EdD, R.T.(R)(T), CMD
BAHJAT QAQISH, MD, PhD
JESSICA A CHURCH, BS, R.T.(R)(T)

Background  In today’s health care environment, the need to attract and retain doctorate-holding radiologic science practitioners and provide them the tools and resources necessary to pursue professional research funding and publication cannot be underestimated. To date, however, there have been few studies on the possible barriers that interfere with both research and professional publishing among these highly educated individuals. A review of the literature reveals that the overall lack of research and professional publishing by radiologic science professionals holding doctorates can itself become a barrier in that low academic productivity is associated with a perceived lack of professionalism, lack of respect from external health professions and the lack of creation of new knowledge.

Purpose  To characterize the barriers to publishing and research by doctorally prepared radiologic science practitioners using a national survey instrument. In addition, this study sought to measure the predictive value of select individual, workplace and leadership variables that could influence the ability of radiologic technologists and radiologic science educators to conduct research, publish their findings and seek grant funding for new research.

Results  We compared our survey findings for radiologic science practitioners to those of other health care groups in an attempt to determine which demographic variables may best be used to promote, rather than hinder, research, publishing and grant writing.

The doctoral degree symbolizes the “pinnacle of advanced learning and scholarly enquiry, demonstrated by subject expertise and the creation of new knowledge.” Furthermore, Conn suggested that attainment of a doctoral degree should be considered a minimum requirement for being able to conduct research and publish scholarly articles effectively. Radiologic technologists with doctoral degrees make up only a small percentage of the American Registry of Radiologic Technologists (ARRT)-registered population. An ARRT report dated March 19, 2009, stated that the number of credentialed technologists was 289,007 (K Hendricks, director of strategic communications at ARRT, oral communication, April 20, 2009), and of this population, only 0.15% (n = 440) held doctorates. Expectations are that these individuals, however small a subset, should lead the way to knowledge building and future growth of the radiologic science profession. However, Legg and Fauber reported dismayingingly low research and scholarship activity among radiologic technologists and other allied health professionals holding doctorates. Further, a lack of publishing was cited by Dowd as “the most common failure of responsibility in radiologic science research.” A lack of research and publications typically is attributed to various barriers, both within and outside the workplace.

With external recognition of the profession hinging on the scholarly and research accomplishments of doctorate holders, it becomes that much more important to identify barriers that impede scholarly productivity among members of this highly educated group. Accordingly, this study examines the factors that influence the research and professional publication activity of doctorally prepared radiologic science practitioners, focusing on barriers within the workplace and possible factors that predict these barriers.

Literature Review

A literature search for “barriers to publication” identified a list of barriers potentially applicable to the
radiologic sciences, and suggested that the ability to overcome or eliminate these obstacles was associated with greater academic productivity among doctorate holders in the form of research, publishing and grant writing. Although there were a number of articles specific to radiologic science educators, few studies related to radiologic science professionals holding doctorates who were not educators. For that reason, articles specific to other doctoral-level, noneducator medical practitioners also were included and reviewed. While the barriers to research faced by professionals in other areas of medicine were not identical to those for professionals in the radiologic sciences, there were several relevant similarities. Many of these barriers were considered in the development of our survey instrument.

Sources for articles and dissertations included EBSCO Host; Biomedical Reference Collection: Basic, Pre-CINAHL, CINAHL; Health Source – Consumer Edition; Health Source – Nursing/Academic Edition; Nursing and Allied Health Collection; Medline; Psych Info; and ERIC databases. The time frame of the search was limited to the years 1988 to 2008.

According to Willis, nurses typically face 2 types of barriers when writing for publication. “Personal factors, such as inadequate knowledge and writing skills, lack of confidence, and low motivation for writing for publication, and situational factors, such as limited time, energy, and other resource constraints” commonly interfere with writing.7 Willis further identified personal barriers, including thoughts and feelings, understanding of the writing and publication processes and personal work habits. Situational barriers include time and personal energy, as well as availability of other resources, such as emotional support, institutional culture, presence or absence of mentoring, size and quality of work space and financial support.6

**Personal Barriers to Writing for Publication**

In a study by Pololi et al, personal barriers that physicians in academic medicine experienced included a lack of confidence in their writing ability and sensitivity to their writing being criticized by others.7 These barriers are even more difficult to overcome for physicians who do not already have adequate research skills. As a rule, these skills are not taught in a consistent manner during medical school.8,9 Typically, clinician educators were introduced to much research-oriented content during their medical training, yet invariably did not receive instruction on how to conduct research. According to Windish and Diener-West, “This can hinder clinician educators as they wish to develop, analyze and disseminate their scholarly work.”10

**Situational Barriers to Writing for Publication**

One of the most commonly cited situational barriers to research activity is insufficient time to devote to writing.11,12 In a general internal medicine residency program in which promotions were based on number of research publications, distractions such as travel, income tax returns, class preparation, family time on days off and “other” were listed as reasons for not writing.13 In organizations such as social service agencies, scholarly productivity is neither expected, rewarded, nor supported, financially or otherwise. Writing for scholarly publication is seen “as ‘nice’ but not necessary.”7 Often, workloads are such that faculty members — women in particular — feel they have absolutely no time to write while at work. Instead, they find they must use time at home to squeeze in writing, frequently at the expense of family time.14

Situational barriers also include lack of support from college administration in the form of limited workspace, limited funding and lack of faculty mentoring for research and writing.6,8,15 Levine et al found that “Lack of faculty time, … resident interest, and technical support” were major interferences with completing research.11 “The interaction of age and experience on time required to prepare for classes during their younger years and time required to fulfill administrative tasks in their older years” is typical in academia14 and greatly influences the amount of time available for research activity. Researchers who are more experienced and successful should serve as role models for how to best integrate research into a busy schedule. Mentorship is an effective way for someone less experienced to learn from a more experienced peer.17

**Overcoming Barriers to Publication**

**Mentorship**

The American Heritage Dictionary defines a mentor as “a wise and trusted counselor or teacher.”16 Mentoring relationships are more prevalent today than 20 years ago because faculty now have the added stress of adjusting to momentous and ongoing changes in education delivery, such as more widespread use of the Internet and online teaching.17 Through mentoring, younger faculty can be coached by more senior peers in the ways of research. Fauber and Legg reported that when junior researchers are coached by more senior investigators, research productivity of the junior faculty...
member increases. In medical programs in which research is supported, “senior faculty... are expected to help doctoral students and junior faculty to develop a successful academic career. Such success requires scholarly publication.”

Other situational barriers include reluctance by faculty at 2-year community colleges to infringe on the territory of their counterparts at 4-year universities. Community college faculty consider scholarship as the responsibility of the universities and teaching the focus. Departmental expectations of service on committees, teaching and increasing pressure to procure grant funding for research can put a great deal of strain on the professional lives of medical and allied health faculty members. This kind of lifestyle may well serve as a disincentive to take up scholarly research and publishing for many.

Grant Funding
The need for faculty to obtain grant funding is becoming more critical to support the overall research enterprise and for faculty seeking promotion or tenure. Training in the grant writing process is one of the top career development needs of professionals in the medical field. The research dollars and career advancement obtained through successful grant writing more than compensate for the large investment of time and effort required to submit the grant. Legg and Fauber reported that in their study, respondents procured a total each of “more than $75 000 in grant money.” For U.S. radiologic science education programs sponsored by institutions with 3-fold missions, “the pressure to publish and write grants is going to increase.” Further, Temme et al stated that, “compared with the traditional faculty model, including other allied health professions, the vast majority of radiologic science education programs differ in that they do not have any type of accountability for publishing or research stimulus through professional grant writing.”

Methods
A survey instrument was developed by the authors with input from a statistician to determine the most appropriate question design. The goal of this survey was to examine barriers that may influence the research and professional publication activity of radiologic science practitioners holding doctorates. The survey questions were based largely on a literature review of factors frequently cited as barriers to conducting scholarly research in other health professions. Questions addressing basic demographic and professional information also were included. The instrument comprised a total of 25 closed-ended survey questions. Survey questions were divided into 3 sections. Section 1 was titled “Demographic Information,” and questions covered basic demographics, radiologic science occupation, membership in professional organizations and specifics of doctoral education and training. The second section was titled “Organizational Information,” with questions focusing on employment status and location of employment. The third section was titled “Publication Leadership Information,” and included questions on publication activity, grant writing and funding and barriers to conducting research and publishing.

A list of names and addresses of all ARRT-registered radiologic technologists holding doctorates was obtained from the ARRT. This mailing list included 440 names. After removing the first 2 authors’ names, the accessible population of doctorally prepared, ARRT-registered radiologic technologists totaled 438. The survey, along with a personalized cover letter explaining the purpose and significance of the study, was mailed to the 438 radiologic technologists with doctorates. To encourage and facilitate response, a self-addressed, stamped envelope was included in each packet.

Results
A total of 438 surveys were mailed to radiologic technologists holding doctoral degrees; 163 surveys were completed and returned, yielding an overall response rate of 37% (n = 163).

Limitations
Several limitations must be acknowledged prior to interpreting these findings, or their generalizability to other health professions. This study focused on the demographic profiles and scholarly achievements of radiologic technologists holding doctoral degrees, regardless of the type of doctoral degree or radiologic science specialty. The study population included all radiologic technologists with doctoral degrees currently certified by the ARRT. Those certified by other imaging-related registries such as the American Registry for Diagnostic Medical Sonography (ARDMS) or the Nuclear Medicine Technology Certification Board (NMTCB) were not included. Therefore, the findings of this study may not be generally applicable to radiologic technologists with doctoral degrees who have been certified by these other...
BARRIERS TO RESEARCH

registries. In addition, because the workplace organization and required job skills vary sufficiently between sonography, nuclear medicine technology and other radiologic science specialties, it is possible that different barriers to scholarly productivity might exist.

Demographic Information

Demographic data for radiologic technologists holding doctorates are presented in Tables 1 and 2. All of the respondents confirmed that they had earned a doctoral degree. Three-fourths of the respondents were aged 40 to 59 years. The sex distribution was 54% female respondents and 45% male, with the remaining 1% unspecified. At 84%, Caucasians composed the largest subgroup of respondents. African American (4%) and Hispanic/Latino (4%) groups made up the next largest cohorts. The remaining 8% of respondents were from other ethnic minorities.

At 67%, radiography was the largest primary radiologic science occupation for this group. The breakdown for the other primary occupations was as follows: nuclear medicine, 8%; radiation therapy, 7%; ultrasound, 5%; magnetic resonance imaging, 4%; and computed tomography, 3%. The data showed that most of the respondents belonged to multiple professional organizations.

The respondents were divided evenly between those who had earned their doctorates prior to the year 2000 and after 2000. Approximately 86% completed a thesis or dissertation as part of their doctoral studies. On the other hand, only 44% of respondents were required to complete a thesis or dissertation as part of their master’s degree program. A total of 80% of respondents completed their degree as traditional graduate students (66%) or through an executive program (12%); the other 20% earned their doctoral degree using an online or online/classroom format or in some other manner (2%). The specific doctoral degrees included the doctor of philosophy, PhD (47%); doctor of education, EdD (26%); doctor of jurisprudence, JD (15%); and doctor of medicine, MD (1%). A number of other doctoral degrees (11%) were included in the “other” category, such as doctor of ministry, DMin and doctor of pharmacy, PharmD.

Workplace Factors

Employment and workplace-related information for doctorally prepared radiologic science practitioners is presented in Table 3. The majority (86%) of respondents worked full time, 4% worked part time or per diem, and the remaining 9% did not specify their employment status. Instead, they selected “other,” which included, for example, working in another industry, having retired or being unemployed.

When asked to be more specific about their current job description, the following categories were noted: 36% full-time educators, 26% other, 20% full-time

| Table 1: Demographic Information: General |
|-------------------|-----------------|-----------------|
| **Characteristic** | **N (%)**       |
| **Age (years)**    |                 |
| 20-29              | 0               |
| 30-39              | 12 (7)          |
| 40-49              | 49 (31)         |
| 50-59              | 71 (44)         |
| 60-69              | 25 (16)         |
| Over 70            | 3 (2)           |
| **Sex**            |                 |
| Female             | 87 (54)         |
| Male               | 73 (45)         |
| **Ethnic Origin**  |                 |
| African American/Black | 6 (4)  |
| Native Indian/Alaskan Native | 3 (2)    |
| Caucasian/White    | 134 (84)        |
| Hispanic/Latino    | 6 (4)           |
| Asian              | 4 (3)           |
| Middle Eastern     | 2 (1)           |
| Other              | 5 (3)           |

*Percentages were rounded up to nearest whole number. Not every respondent indicated an answer to every question.
involved in both the clinical arena and in academia. A number also reported working 2 part-time jobs, and others worked both a part-time job and a full-time job. Approximately 55% of those surveyed about their job indicated it includes at least some teaching. Of

<table>
<thead>
<tr>
<th>Table 2: Demographic Information: Educationa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristic</strong></td>
</tr>
<tr>
<td><strong>Type of Doctorate</strong></td>
</tr>
<tr>
<td>Philosophy (PhD)</td>
</tr>
<tr>
<td>Education (EdD)</td>
</tr>
<tr>
<td>Law (JD)</td>
</tr>
<tr>
<td>Other: Pharmacy (PharmD), Ministry (DMin)</td>
</tr>
<tr>
<td>Medicine (MD)</td>
</tr>
<tr>
<td><strong>When Doctorate Earned</strong></td>
</tr>
<tr>
<td>Before 1990</td>
</tr>
<tr>
<td>1990 – 1995</td>
</tr>
<tr>
<td>1996 – 2000</td>
</tr>
<tr>
<td>2001 – 2009</td>
</tr>
<tr>
<td><strong>Dissertation Required in Doctoral Program</strong></td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td><strong>Thesis Required in Master’s Program</strong></td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td><strong>Type of Doctoral Program</strong></td>
</tr>
<tr>
<td>Classroom only (traditional graduate student)</td>
</tr>
<tr>
<td>Online only</td>
</tr>
<tr>
<td>Online and classroom</td>
</tr>
<tr>
<td>Executive (weeknights and/or weekends)</td>
</tr>
<tr>
<td>Other: changed programs, independent study</td>
</tr>
</tbody>
</table>

*aPercentages were rounded up to nearest whole number. Not every respondent indicated an answer to every question.

<table>
<thead>
<tr>
<th>Table 3a: Employment Information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristic</strong></td>
</tr>
<tr>
<td><strong>Employment Status</strong></td>
</tr>
<tr>
<td>Full time (32-40 hrs/week)</td>
</tr>
<tr>
<td>Part time (less than 32 hrs/week)</td>
</tr>
<tr>
<td>Per diem</td>
</tr>
<tr>
<td>Not specified</td>
</tr>
<tr>
<td><strong>Position</strong></td>
</tr>
<tr>
<td>Full-time clinician/practitioner</td>
</tr>
<tr>
<td>Part-time clinician/practitioner</td>
</tr>
<tr>
<td>Full-time educator</td>
</tr>
<tr>
<td>Part-time educator</td>
</tr>
<tr>
<td>Full-time administrator</td>
</tr>
<tr>
<td>Part-time administrator</td>
</tr>
<tr>
<td>Other: Outside of radiology</td>
</tr>
<tr>
<td><strong>Type of Institution</strong></td>
</tr>
<tr>
<td>Hospital</td>
</tr>
<tr>
<td>College (2 year)</td>
</tr>
<tr>
<td>University (4 year)</td>
</tr>
<tr>
<td>Doctoral/research university</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td><strong>Currently Tenured at Institution</strong></td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Not at institution</td>
</tr>
<tr>
<td><strong>Seeking a Tenure-track Appointment</strong></td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>N/A; don’t have tenure appointments</td>
</tr>
</tbody>
</table>

*aPercentages were rounded up to nearest whole number. Not every respondent indicated an answer to every question.*
these respondents, 32% taught in graduate-level universities, 31% taught in 4-year colleges, 16% taught in 2-year colleges, and 8% taught in hospital-based training programs. The remaining 13% indicated a variety of teaching institutions, including medical colleges, Bible colleges, dental schools, fitness facilities, vocational or technical schools and even one-on-one tutoring of high school students. About 14% of those surveyed were working toward a tenure-track faculty appointment, but 64% were not. The other 22% responded “not applicable” (N/A). There were 31 (27%) respondents who already were tenured at their institution and 59 (48%) who were not. The remaining 33 (27%) indicated that tenure was either not an option for them at their institution or that they had retired as professor emeriti with tenure (2%).

**Publication and Grants**

Publication and grantsmanship activities of doctorate-holding radiologic science practitioners are presented in Table 4. Approximately 73% of respondents have published in professional journals. Of all respondents, 32% had 1 to 3 publications, 16% had 4 to 5 publications, 10% had 7 to 10 publications and 15% had more than 10 publications in professional journals. When asked whether they had submitted manuscripts that were not accepted, 71% of the group reported no unaccepted manuscripts. Thirty-seven (24%) had 1 to 3 manuscripts not accepted, 5 (3%) had 4 to 6 not accepted and 2 (1%) had 7 to 10 that were not accepted.

A total of 125 of those surveyed responded to the question of whether they had ever applied for grant funding. Of these, 75 (60%) had not applied for a grant and 50 (40%) had. When asked whether they had ever been awarded grant funding, 50 respondents reported that they had received grant funding, which we could infer to mean 100% of those who applied for a grant received one. When asked how many total grant dollars had been awarded, nearly 25% of these respondents received more than $50,000 in grant funding (see Table 4 for a full breakdown). This totals to only 12 people out of not only doctorate-level R.T.s but of 220,000 certified professionals.

Only 13% of respondents reported being pressured by coworkers to include them as authors on manuscripts they were preparing for submission to professional journals. Slightly more (17%) had experienced pressure from a direct supervisor or other individual in a higher position to include them as an author.

Survey participants then were asked to rank on a 4-point scale (from “yes,” to “maybe,” to “doubtful” to “no”) the extent to which a number of potential barriers identified through our literature review interfered with their own ability or willingness to conduct research and publish in scholarly journals. These results are shown in Table 5. The barriers identified by this group as interfering the most (selected by at least 30% of respondents) with their scholarly productivity included the following:

- Lack of:
  - Time to write.
  - Energy or motivation to write.
  - Statistical technical support.
  - Faculty mentors.
  - Institutional or departmental support.
  - Funding.
- Limited knowledge of grant writing.
- Paperwork associated with grant writing.
- Research not being a job requirement.
- Research being viewed as low priority.
- Staff shortages at work.
- Major distractions such as travel.
- Competing job demands.

Several other barriers were identified by respondents who selected “other.” These included not enjoying writing or not being a good writer, insufficient faculty to help distribute a heavy teaching load and life transitions such as having children, moving or changing jobs.

Finally, survey respondents were asked about their comfort level with various skills typically required for successful writing for publication. These results are presented in Table 6. Most participants were quite comfortable with all but 1 of the components necessary for scholarly writing; approximately 30% indicated that they were uncomfortable with data analysis.

**Discussion**

The findings of this study suggest that, despite a stated desire to do so, many radiologic technologists holding doctoral degrees have conducted research or published in professional journals only minimally, if at all. About 15% of this already-small group is doing most of the scholarly research and writing in the radiologic sciences. The majority of respondents (83%) were not feeling pressure from their employers to publish, and only 23% reported that their research and publication record was considered as part of their annual faculty review process. Employer pressure to seek grant
Table 4a
Publications and Grants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Publications in Professional Journals</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>43 (27)</td>
</tr>
<tr>
<td>1-3</td>
<td>50 (32)</td>
</tr>
<tr>
<td>4-6</td>
<td>25 (16)</td>
</tr>
<tr>
<td>7-10</td>
<td>16 (10)</td>
</tr>
<tr>
<td>More than 10</td>
<td>23 (15)</td>
</tr>
</tbody>
</table>

| Manuscripts Submitted but Not Accepted              |       |
| None                                                | 110 (72) |
| 1-3                                                 | 37 (24) |
| 4-6                                                 | 5 (3)   |
| 7-10                                                | 2 (1)   |

<table>
<thead>
<tr>
<th>Pressure From Colleague To Be Included as Publication Author?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>21 (13)</td>
</tr>
<tr>
<td>No</td>
<td>136 (87)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure From Superior To Be Included as Publication Author?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>27 (17)</td>
</tr>
<tr>
<td>No</td>
<td>130 (83)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Have Applied for Grant Funding?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>50 (40)</td>
</tr>
<tr>
<td>No</td>
<td>75 (60)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Been Awarded Grant Funding?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>50 (40)</td>
</tr>
<tr>
<td>No</td>
<td>75 (60)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>If Yes, Size of Award?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 – 999</td>
<td>3 (3)</td>
</tr>
<tr>
<td>$1000 – $5000</td>
<td>4 (4)</td>
</tr>
<tr>
<td>$5001 – $15 000</td>
<td>8 (8)</td>
</tr>
<tr>
<td>$15 001 – $50 000</td>
<td>10 (10)</td>
</tr>
<tr>
<td>$50 001 – $200 000</td>
<td>10 (10)</td>
</tr>
<tr>
<td>Over $200 000</td>
<td>14 (14)</td>
</tr>
<tr>
<td>Responded, but no amount listed</td>
<td>53 (51)</td>
</tr>
</tbody>
</table>

*Percentages were rounded up to nearest whole number. Not every respondent indicated an answer to every question.*
funding was felt by only 19% of the survey respondents. Significant barriers have been identified that prevent doctorate-level radiologic science professionals from pursuing academic research and writing, and fundamental changes in radiologic science education, training and perception will be needed if this trend is to be reversed. Among the impediments to research and professional publication cited by these individuals

**Table 5a**

<table>
<thead>
<tr>
<th>Perceived Barriers to Research and Publishing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barrier</strong></td>
</tr>
<tr>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>Lack of interest in research</td>
</tr>
<tr>
<td>Research is not required for my job</td>
</tr>
<tr>
<td>Research is a low job priority</td>
</tr>
<tr>
<td>Lack of research skills</td>
</tr>
<tr>
<td>Insufficient graduate education to develop research skills</td>
</tr>
<tr>
<td>Research skills are outdated/rusty</td>
</tr>
<tr>
<td>Lack of time to write</td>
</tr>
<tr>
<td>Lack of energy or motivation to write</td>
</tr>
<tr>
<td>Lack of ideas to write about</td>
</tr>
<tr>
<td>Unfamiliar with publication process</td>
</tr>
<tr>
<td>Managing anxiety/frustration during writing/publication process</td>
</tr>
<tr>
<td>Discouraged by amount of editing/revisions required by journals</td>
</tr>
<tr>
<td>Lack of statistical support</td>
</tr>
<tr>
<td>Research findings not statistically significant</td>
</tr>
<tr>
<td>Fear of rejection</td>
</tr>
<tr>
<td>Lack of emotional support</td>
</tr>
<tr>
<td>Difficulties with coauthor(s)</td>
</tr>
<tr>
<td>Lack of faculty mentors</td>
</tr>
<tr>
<td>Pressure by employer to publish</td>
</tr>
<tr>
<td>Lack of departmental or institutional support</td>
</tr>
<tr>
<td>Lack of funding</td>
</tr>
<tr>
<td>Annual faculty review considers research and publication record</td>
</tr>
<tr>
<td>Employer pressure to procure grant funding</td>
</tr>
<tr>
<td>Limited knowledge of grant writing</td>
</tr>
<tr>
<td>Paperwork/bureaucracy associated with grant writing</td>
</tr>
<tr>
<td>Conflicts with committee work</td>
</tr>
<tr>
<td>Staff shortages at work</td>
</tr>
<tr>
<td>Major distractions (travel, competing work demands, etc.)</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>

*Percentages were rounded up to nearest whole number and adjusted to allow for a total of 100%.*
are employers assigning a low priority to or lack of expectations regarding research productivity; a lack of specific training in how to write and publish effectively during doctoral training; and a lack of sound mentorship from both doctoral advisors during graduate school and more senior, experienced professional colleagues in the workplace. In addition, there are the competing demands of balancing career with family life and, significantly, a perceived lack of respect on the part of the larger health care enterprise, academia or both for the importance and value of scholarly activities by radiologic science educators.

Less than 0.2% of all radiologic science professionals have earned a doctorate degree — nearly 40% of whom are educators — and of those, only 15% conduct research and publish with any regularity. When each of these professionals first decided to pursue a career in health care, they obviously developed a particular passion for radiologic science. As their careers progressed, this passion continued to motivate them to pursue 1 or more advanced degrees, culminating in a doctorate. Yet most of these uniquely motivated individuals’ passion to achieve further professional development in the form of conducting research and publishing was overpowered by 1 or more barriers.

An obvious mechanism to change this paradigm would be for the academic mentors of successful doctoral-level researchers and writers, as well as the individuals themselves, to give back voluntarily to their profession by training others in the ways of research and professional writing. They drive for scholarly achievement, passion for language and communication, positive attitude and persistence and expertise in value-based research and the publication process could be invaluable to their peers who face academic obstacles, as well as to more junior educators in need of positive role models and mentors.

Mentoring in the radiologic science profession must take place on 3 levels. First, faculty members must mentor their radiologic science students through both didactic and clinical training. Second, practicing radiologic technologists and supervisors in the clinical setting must mentor radiologic science students by teaching and modeling proper clinical skills and professional behavior. Third, radiologic science practitioners who conduct research and have published must be willing to share their experiences with others in the profession.

Radiologic science mentors must be willing to be generous with their time and expertise. Although a mentor can teach students or other practitioners how to write, conduct research, publish and deliver professional presentations, the relationship is much more than simply “teaching.” One hopes that mentors have learned from their own career-related mistakes and developed unique coping strategies and skills, and can impart this knowledge to others. Providing knowledge, guidance and feedback allows important learning to occur. The educator as mentor should help develop the minds of students and colleagues, feed their curiosity, and provide the tools, skill sets and creativity needed to lead fulfilling professional and academic

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Comfort Level With Factors Involved in Writing for Publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrier</td>
<td>Very Comfortable</td>
</tr>
<tr>
<td>Literature review</td>
<td>116 (79)</td>
</tr>
<tr>
<td>Research design</td>
<td>61 (42)</td>
</tr>
<tr>
<td>Statistical data analysis</td>
<td>43 (30)</td>
</tr>
<tr>
<td>Composing abstract</td>
<td>94 (65)</td>
</tr>
<tr>
<td>Proper use of citations</td>
<td>93 (64)</td>
</tr>
<tr>
<td>Paraphrasing</td>
<td>94 (64)</td>
</tr>
<tr>
<td>Designing tables</td>
<td>77 (53)</td>
</tr>
<tr>
<td>Creating figures</td>
<td>76 (52)</td>
</tr>
<tr>
<td>Adhering to journal format</td>
<td>69 (48)</td>
</tr>
<tr>
<td>Formatting the bibliography</td>
<td>84 (58)</td>
</tr>
</tbody>
</table>

*Percentages were rounded up to nearest whole number.*
lives. Ultimately, the mentor should help students or colleagues develop a strategic vision of what they can do, how they can do it and why the act of doing is so important not only for the individual, but also for the community at large.

Doctorate-level radiologic technologists cite the desire to balance career with family life as another obstacle to being successful at research and professional publishing. Striking a proper balance always is a daunting task, and one for which there is seldom a perfect solution. Also true, however, is the fact that successful researchers and writers have to, at times, “bring their work home with them,” especially when allowing time for such scholarly activities at work is either not valued or actively discouraged. Often, the consequences of lost family time because of the need to work can be minimized by, for example, using 1- to 2-hour blocks of time early in the morning to write. Family members still are asleep, which minimizes their resentment and keeps interruptions to a minimum. The writer is fresh, focused and motivated early in the day.

Perhaps the most unfortunate consequence of the lack of research and publishing among radiologic science professionals holding doctorates is the perception that the field must necessarily be “unprofessional” or worse, lacks academic rigor. A vicious cycle could result from this perception, because these very misconceptions about radiologic sciences fuel the lack of respect from the greater health care or academic community that some in the radiologic sciences report as barriers to their career advancement as researchers and writers. Mentors can play an important role in this regard as well; they must demand academic rigor from their students, and constantly stress the importance of research and publication ethics, proper research methodology, critical-thinking skills, resourcefulness, connectedness, proactivity and professional communication skills and conduct. It is only by example that a mentor can instill these values and skills that will serve the students for a lifetime. By doing so, mentors also arm their students with the tools to someday pass on this wisdom to the students’ peers and potentially their own students, and in so doing, help transform the profession as a whole.

References
15. Williams DN. The role of scholarship in the community college. 1991. ERIC Digest ED3582904.

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Computed Tomography Shielding Methods: A Literature Review

JESSICA RYANN CURTIS, BS, R.T.(R)(CT)

Objective To investigate available shielding methods in an effort to further awareness and understanding of existing preventive measures related to patient exposure in computed tomography (CT) scanning.

Methods Searches were conducted to locate literature discussing the effectiveness of commercially available shields. Literature containing information regarding breast, gonad, eye and thyroid shielding was identified. Because of rapidly advancing technology, the selection of articles was limited to those published within the past 5 years. The selected studies were examined using the following topics as guidelines: the effectiveness of the shield (percentage of dose reduction), the shield’s effect on image quality, arguments for or against its use (including practicality) and overall recommendation for its use in clinical practice.

Results Only a limited number of studies have been performed on the use of shields for the eyes, thyroid and gonads, but the evidence shows an overall benefit to their use. Breast shielding has been the most studied shielding method, with consistent agreement throughout the literature on its effectiveness at reducing radiation dose. The effect of shielding on image quality was not remarkable in a majority of studies. Although it is noted that more studies need to be conducted regarding the impact on image quality, the currently published literature stresses the importance of shielding in reducing dose.

Conclusion Commercially available shields for the breast, thyroid, eyes and gonads should be implemented in clinical practice. Further research is needed to ascertain the prevalence of shielding in the clinical setting.

Advancing computed tomography (CT) technology and its increased utilization in clinical practice has created great interest within the health care community. A 2005 report noted that CT scans constituted 11% of all medical x-ray exposures and contributed up to 67% of the general population’s total radiation dose. These figures clearly indicate the high exposures associated with CT scanning. Concerns about exposure and increased utilization have led to several published studies on the potential for radiation-induced cancer risks. Often, radiosensitive tissues (ie, eye, thyroid gland and breast) are subjected to increased radiation doses because of their exposure to low-energy scattered photons and their superficial location and proximity to the field of view. This is unfortunate, because these radiosensitive organs and tissues are exposed to radiation even though they often are not under direct diagnostic evaluation.

Despite widely published information on doses and risks associated with CT scanning, many radiologists, physicians and technologists remain doubtful of the risks and believe they are insignificant. A survey of physicians’ attitudes about risks and benefits of chest CT concluded that more than 90% of physicians either do not know or significantly underestimate the radiation doses associated with its use. The lack of understanding and acknowledgement of risks within the health care community has likely led to inconsistent and insufficient use of preventive measures such as shielding. For example, a study by Semelka et al on emergency departments described data showing that radiologists who performed CT examinations considered the radiation exposure to be of limited importance, and stated that radiologists were unaware of the amount of radiation that was delivered to patients by CT.

A trickle-down effect of unawareness regarding radiation safety has become increasingly problematic within the medical field. This author deduced from the literature that because the physicians who order and set protocols for CT exams often are unaware or unconvinced of the potential risks, radiologic technologists and other staff members may be similarly uninformed of the risks. Furthermore, they may not be provided the necessary resources to further their education on risks and effective preventive measures.

The purpose of this literature review is to examine the current research regarding the benefits and effectiveness of shielding for reducing risks to patients and improving safety when performing CT scans. Methods such as automatic exposure control and lowering tube
current have been discussed as effective techniques for dose reduction. Alternative methods, such as shielding, have received less attention in the literature. By researching the literature, concise recommendations can be developed to encourage the use of various shielding methods in clinical practice.

**Methods**

Searches were performed using the search engines PubMed and Cumulative Index to Nursing and Allied Health Literature. The following key terms were used in various combinations: CT, computed tomography, shielding, disadvantages, radiation safety and pediatric. The search produced a total of 501 articles. Because of continuing advancements in technology, this literature review was limited to studies published in the past 5 years. The search also was limited to articles published in English. The literature was further limited to articles that discussed shielding in CT, commercially available shields, including shields that met commercial standards based on manufacturer guidelines, and routine scans. After limiting the search, 9 relevant articles were identified for this literature review. Three articles discussing general information on CT dose and possible risks also were included, for a total of 12 articles.

Information gathered from each article included the following: effectiveness of the shielding method (including percentage of dose reduction), effect on image quality (presence of artifacts and noise), general arguments for the shield’s practicality and the overall recommendation for use in the clinical setting. The data on dose reduction are presented for each study to account for the fact that all studies did not follow the same protocols or use the same equipment.

**Discussion**

*Importance of Shielding*

A student perspective published in *Radiologic Technology* in 2007 by Voress stated, “Shielding is one of the fundamental methods used to reduce patient dose during radiologic examinations, yet it is often forgotten when positioning a CT patient.” The amount of radiation received has increased with the rapidly advancing technology of CT. Acquisition speeds have increased and so has image quality. In turn, use of CT scanning also has increased. It is very important to take preventive measures to attempt to keep doses as low as reasonably achievable (ALARA).

The biological effects of overexposure fall into 1 of 2 categories: stochastic effects (cell transforming) or deterministic effects (cell destroying). Deterministic effects have threshold doses, which means that effects do not occur below a certain dose. Above the threshold dose, the severity of the effects increases as the radiation dose increases. Stochastic effects are random effects from radiation that may cause cancer or genetic effects in irradiated individuals or their offspring. The published literature suggests that when discussing the risks associated with CT, the risk of stochastic effects is the main concern. However, this is not to say that deterministic effects are not possible. Debate continues on exactly how much of a risk is present for either type of effect. Any level of risk is important in discussing the need to shield, regardless of how high or low the risk.

The International Commission on Radiological Protection (ICRP) has developed tissue weighting factors to provide a scale for the various sensitivities of tissues within the body. Not all of the organs within our bodies react the same way when exposed to comparable amounts of radiation. Certain tissues are particularly radiosensitive and carry a higher risk of mutagenic risks when exposed to certain levels of radiation. Assigning tissues a weighting factor allows estimates of the tissues’ attributing risk to the body as a whole, in addition to the tissues’ individual risk for developing mutagenic effects. The breasts, gonads, thyroid and eyes are some of the most radiosensitive tissues in the body.

In addition to organ-specific radiosensitivity, one must consider the patient’s age. The radiosensitivity of tissues and organs in children and young adults is one of the primary reasons to shield. The radiosensitive organs mentioned above are even more sensitive at younger ages. Cells divide and grow rapidly through young adulthood, which increases susceptibility to effects from radiation. According to Hohl et al, “Infants and children are as much as 10 times more susceptible to carcinogenesis from radiation exposure than adults.” For example, breast tissue exposed to radiation from CT is an area of particular concern in girls and young women. Populations exposed to radiation doses similar to those received from CT scans have demonstrated increased incidence of breast cancer. The risk of carcinogenesis is higher the younger the patient is when exposed to radiation.

Although these issues regarding radiosensitivity are known, use of shielding for CT exams is not consistent in practice. It is possible that this is because conventional radiography shields are the only method available in a facility. In many practice settings, radiologic technologists may not know that commercially available...
in-plane bismuth shields have been created specifically for use in CT scanning.

In-plane bismuth shields serve as an additional filter that is placed on especially sensitive areas. The shields offer selective dose lowering for the underlying tissue, while still allowing enough x-ray beam to pass through to obtain a diagnostic image. Hohl et al found that the intention of the thin in-plane bismuth shield is different from the thick conventional lead shields. Conventional lead shields attempt to completely absorb the radiation. The in-plane bismuth shield simply hardens the beam’s energy distribution to decrease the superficial dose produced by soft radiation. Minimizing metal artifacts is an added benefit when using in-plane bismuth shields.

The benefits mentioned above may not provide enough motivation to use shielding in CT. However, as professionals, the ethical duty to abide by ALARA should. According to Hohl and Mahnkten et al, “Any protection measure that is easy to use, does not impair image quality, and significantly reduces x-ray exposure should be used.” Commercially available shields are easy to use, inexpensive and effective. Shielding radiosensitive superficial organs is a straightforward method of reducing radiation exposure.

**Shielding Methods**

The following sections discuss the commercially available shields that may be used during CT scanning. The discussion summarizes what the literature reported regarding the dose reductions that the shields provide, the effect on image quality and any debate concerning the shields’ use (eg, cost, ease of use, angling of the gantry or altering tube current). The discussion concludes with a concise chart showing when to implement the various shielding methods.

**Breast**

The breast tissue is among the most radiosensitive anatomy. Yilmaz et al stated that according to the study of Hopper et al, the average radiation dose to the breasts during thoracic CT was 0.022 Gy. Fricke et al found that radiation dose to the breasts in the pediatric population during multidetector CT was 0.017 Gy. These doses greatly exceed the American College of Radiology (ACR) recommendation of 0.003 Gy or less for a standard 2-view mammogram. These statements exemplify the importance of breast shielding during CT scanning. Mammography, which uses lower levels of radiation than CT, has a mandated maximum for radiation exposure. A CT chest scan dose is more than 3 times the typical mammography dose.

Further, Parker et al mentioned that chest CT is not performed to obtain diagnostic information about the breast, but to gather information about the lung parenchyma and the mediastinum. They also stated that dose to radiosensitive breast tissue is an unwanted byproduct because of the breasts’ superficial location. Grobe et al referred to a study of 1030 women with scoliosis who routinely underwent multiple thoracic spine radiography examinations as young girls. The study revealed a nearly 2-fold statistically significant increased risk for incidental breast lesions. CT scanning uses a higher radiation dose than spinal radiography, which introduces possible implications from performing chest CTs with no shielding. Commercially available shields have been offered to help reduce unnecessary exposure to the breast during CT.

Four articles from the literature review discussed commercially available breast shields and their effectiveness (see Figure 1). These articles included assessments of shielding breasts of patients and on phantoms. Dose reduction ranged from 40.53% to 61%. These studies included various options for using spacers to improve image quality. A spacer is a foam insert placed between the patient and the shield to provide more distance between the shield and the patient. Use of shielding without spacers caused some artifacts in the superficial tissues, but did not affect the diagnostic quality of the image. For example, Yilmaz et al noted minimal artifacts over the shield and breast tissue but not in the lung parenchyma.

An article by Geleijns et al questioned the use of in-plane bismuth shielding, stating that it contributes to significant noise. The authors contended that altering the tube current provides a better theoretical option for reducing radiation exposure. However, this option is hypothetical and more research should be conducted to assess its true effectiveness compared with the statistically sound dose reductions found with the breast shield.

There is overall agreement in the literature that breast shielding contributes to a significant reduction in patient overexposure to radiation and does not deteriorate image quality. However, the literature does not agree on the effects of breast shields on image quality. Therefore, more research in this area would be beneficial.

**Gonads**

The gonads are highly sensitive to radiation. Weighting factors are assigned to tissues in the body.
method during conventional radiography for many years. However, gonadal shields are not widely used in routine CT scanning, possibly because it is considered difficult to protect the gonads from a multidirectional x-ray source.

Two articles in the literature review discussed gonadal shielding. The literature and information on gonadal shielding is limited by the fact that research only has been published on male shielding. A study performed by Hohl et al. used testicle capsules for shielding, which also found testicle capsules reduced dose 96% and had thresholds for temporary sterility of men at 0.15 Sv for a single exposure. Hohl et al. used capsules that completely surrounded the testicles and resulted in a dose reduction of 96%. The authors recommended shielding when the gonads are subjected to scatter radiation during an upper pelvic or abdominal scan. Overall, they concluded that gonadal shielding is easy, quick, inexpensive, and effective at reducing dose to the gonads.

Figure 1. Example of breast shield showing placement during CT scanning. Image courtesy of AttenuRad CT Shields, F&L Medical Products, Vandergrift, PA.

Figure 2. Two sizes of gonadal shields used to protect the testicles during CT scanning. Reprinted with permission from The American Journal of Roentgenology. Hohl C, Mahnken AH, Klotz E, et al. Radiation dose reduction to the male gonads during MDCT: the effectiveness of a lead shield. AJR Am J Roentgenol. 2005;184(1):128-130.
The current literature discusses available gonadal shielding methods to protect patients from the multidirectional x-ray source associated with CT scanning. The shielding methods are easy to use and well tolerated by patients. The dose reduction values reported in the literature indicate that commercially available shields are effective. There is agreement that gonadal shielding should be incorporated into routine clinical use for abdominal and upper pelvic exams. However, the literature conflicts on whether shielding should be used during routine pelvic exams; more research should be conducted.

Thyroid

Three articles in the literature discussed commercially available thyroid shields for CT scanning. One study explored the effectiveness of an in-plane bismuth shield using a 1-cm spacer (not specified per manufacturer’s guidelines) to reduce the beam-hardening artifacts the shield may produce. Scans also were performed using the shield without a spacer. Routine neck CT protocols were used and images were tested for noise to assess quality. The percentage of dose reduction for the thyroid gland using a shield without a spacer was 35.8% compared with 31.3% when using a spacer. The skin dose reduction was 45.5% without a spacer and 40.2% with a spacer.

Hohl et al found evidence of significant beam hardening artifacts that reduced the image quality in the subcutaneous tissue when using thyroid shields. Using a spacer significantly reduced beam-hardening artifacts. Whether to use spacers appears to remain debatable. The authors stated, “The comparison of bismuth shielding with and without spacers showed that the spacer can effectively prevent deterioration of the image quality in the superficial tissue due to beam-hardening artifacts.” However, the question remains of whether the superficial tissue is of diagnostic importance. One school of thought states that all anatomy scanned is of diagnostic importance, and the other says that the areas of interest are the only ones of diagnostic significance. Hohl et al found that thyroid shields are easy to use, inexpensive and effective. The authors contend the thyroid should be shielded when CT scans of the neck are performed.

A second article by McLaughlin and Mooney reported on use of a commercially available shield, but not a spacer, which resulted in dose reduction of 57%. The authors also noted that the artifacts produced by the thyroid shield were slightly distracting, but did not interfere with image interpretation. They found that the dose reduction was significant and that it correlated with a reduction in the overall risk of the patient developing cancer. Overall, they found use of the thyroid shield to be beneficial with no loss of image quality. Furthermore, they stated that the shield is inexpensive and easy to use, making it suitable for routine clinical application.

A third article by Geleijns et al found the beam-hardening artifacts and noise caused by the shield to be fairly prominent in the images. The authors concluded that the in-plane bismuth thyroid shield should not be used. They stated that a theoretically higher dose reduction could be achieved by altering the tube current and further that altering the tube current would yield the same level of artifacts and noise in the image, while reducing the dose even more.
Theoretically, altering the tube current may provide positive results. However, the recent literature appears to favor shielding as a proven method with statistically significant substantiation.

More research should be performed on tube current modification as a supplemental dose reduction method. The use of foam spacers is mentioned in the literature, but a detailed discussion is lacking and more research would be beneficial. Despite uncertainties regarding use of spacers to improve image quality, the literature currently recommends the use of thyroid shielding during routine scans of the chest and neck with or without a spacer.

Eyes

When the eye is exposed to ionizing radiation, cells located at the front of the lens can be damaged or destroyed. The affected cells migrate to the back of the lens, where they can collect and form an opacity that may impair vision and lead to cataracts. The lens of the eye is one of the most radiosensitive human tissues, according to the ICRP and the National Research Council’s Committee on the Biological Effects of Ionizing Radiation. Perisinakis et al explained that during a CT exam of the head, the dose to the lens of the eye may range from 0.03 Gy to 0.13 Gy. Further, the threshold for ophthalmologically detectable opacities following a single x-ray exposure has been reported to be 0.5 to 2 Gy. The National Radiological Protection Board has proposed a threshold value of 1.3 Gy for radiogenic induction of an eye lens cataract following acute x-ray exposures. These threshold values are for adults and may be even lower for infants and children. According to Persinakis et al, the head CT is a common exam ordered for pediatric patients, and more than 10% of all CT examinations are performed in infants and children aged 0 to 15 years. The authors also reported that head CT scans constitute 45% of all CT scans performed. Head CTs are ordered to investigate trauma, tumors, congenital abnormalities, metabolic disorders and inflammatory lesions. The accumulated doses combined with the frequency of head CTs and the radiosensitivity of the eye lens create a concern for adult patients and an even greater concern for pediatric patients.

These findings make it imperative to shield the eyes during CT scans. Furthermore, to comply with the ALARA principle, it is important to follow any available method to reduce patient exposure. Angling the gantry reduces the dose to the lens, but not all exams allow for gantry angling. For example, orbital, sinus and mastoid studies do not allow the gantry to be angled to ensure proper representation of possible air-fluid levels. The radiologic technologist should angle the gantry only if the patient cannot be positioned properly. The use of lead shields for the eyes is important in these studies because the lens of the eye often is included in the scan field but is rarely the organ of interest (see Figure 4). Four studies were identified in the literature review that discussed the use of commercially available shields for the eyes. Some focused primarily on the percentage of dose reduction, although others also included the shields' effects on image quality. At least one study explored shield use for adult or pediatric patients. Studies were performed on phantoms and patients. Radiation dose was monitored through the use of thermoluminescent dosimeters (TLDs). The studies explored various shielding positions to determine the position that reduced dose most yet maintained optimal image quality.
CT SHIELDING METHODS

The studies reported some variation in the percentage of dose reduction, but in general agreed that the shields reduced the amount of radiation exposure to the lens of the eye. For example, a study on pediatric phantoms by Perisinakis et al found that shielding in combination with angling the gantry reduced dose < 1%.\(^1\) In contrast, the dose reductions of nonangled scans ranged from 33.1% to 37.4% for pediatric patients aged infant to 15 years, with an average of 34%.\(^1\)

A study by Grobe et al found a 28.2% to 43.2% reduction in dose to the lens in men.\(^1\) Other studies, such as one by McLaughlin and Mooney, found an 18% dose reduction in adults.\(^9\) Perisinakis et al noted that the shield did not lead to significant additional dose reduction because the gantry was angled in their study.\(^1\) Despite differences in the percentage of dose reduction, the studies generally concluded that the shields significantly reduced dose to the lens of the eye, specifically when the gantry was not angled.

The evidence suggests that eye shielding has a negligible effect on image quality. Perisinakis et al stated that the shield did not cause any significant artifacts and did not affect the images’ diagnostic value.\(^1\) Grobe et al concluded that in the absence of other restrictions, such as reduced image quality caused by artifacts in the vicinity of the shielding, use of shields is advisable, especially if the eyes are directly exposed.\(^13\) McLaughlin and Mooney found that the eye, and therefore the eye shields, typically were not included in the imaging field and therefore did not affect image quality.\(^9\) If slight artifacts were present, they did not affect the diagnostic quality of the image.\(^9\)

The study by Geleijns et al was the only study that concluded eye shields should not be used. The authors acknowledged that the noise created by the eye shield has only a modest effect on image quality and that the shield reduced dose by 27%.\(^9\) However, they also stated that the threshold dose for radiation-induced cataracts is never reached when performing CT brain scans, even when multiphase scans are performed.\(^12\) The authors maintained that the 27% reduction in lens dose achieved by selective shielding may be of minor importance in avoiding radiation-induced cataracts. Image artifacts, costs and extra waste caused by the disposable eye shields are additional arguments against the use of eye shields.\(^9\) However, the authors also stated that the increase in noise caused by the eye shields was “only modest.”\(^12\) Geleijns et al suggested the use of tube current modulation as a better alternative, given its theoretical success.

More research needs to be conducted to assess which is a more beneficial dose reduction method.\(^12\)

There is agreement in the literature that dose reduction to the eye lens depends on the position of the shield, whether the eye is being scanned through the primary beam and whether the gantry is angled. The overall impression from the literature is that shielding of the eyes when the gantry cannot be angled is important when performing routine scans of the head.

Conclusion

This literature review investigated commercially available shielding methods. The literature revealed consistent debate regarding altering the tube current in place of using shields; it also revealed that such suggestions were based on theoretical data. Based on a review of the literature, shielding provides statistically significant dose reductions for the breast, thyroid gland, eye and gonads. Further, it was reported that the shielding methods available for use in CT are cost-effective and easy to use.

There were discrepancies in the literature regarding the effects on image quality when using breast, gonadal and thyroid shields. Consequently, additional research should be devoted to exploring the effects on image quality in more detail. It appears from the current literature that the effects on image quality are minimal and the use of shields should not be impeded.

Based on the data present in the literature, it is this author’s contention that commercially available shielding methods should be adopted into routine clinical practice. The Table summarizes the suggestions for shielding reported in the literature.

The biological effects of ionizing radiation and the difference between stochastic and deterministic effects have been discussed thoroughly in the published literature. Although the evidence is not definitive regarding potential carcinogenic or mutagenic effects from the doses of radiation received when undergoing a CT scan, this does not suggest that currently available preventive measures should not be taken. The history of medicine is replete with evidence-based research and recognition that detailed data may lead to changes in practice for the sake of patient safety. Radiation exposure should not be any different.

The possibility of radiation-induced carcinogenesis is real and we all must be proactive in its prevention. In the example of women who had routinely undergone multiple thoracic spine radiography examinations as young girls for scoliosis screening, data revealed a
Image quality as it relates to use of shields with CT scanning needs to be investigated in more detail. Many questions arise in the literature when discussing image quality and published information on this topic is vague. There is disagreement regarding the use of shields for the breasts, gonads and thyroid. Disagreement concerns the use of spacers to improve image quality of superficial tissues, whether superficial tissues are considered diagnostically significant and the general effects of shields on image quality.

According to the literature, the use of spacers would improve image quality and still ensure dose reduction for the patient. However, it is not clear exactly how much image quality will be improved. It also is unclear from the literature exactly how much image quality currently is affected. Further investigation of these topics would be beneficial.

Deterioration in image quality from shielding often was found in the superficial tissues in published studies, although some of the effects were not of diagnostic importance. It is imperative to determine what is considered “diagnostically important” when assessing the effects shields have on image quality. More research should be conducted to assess the effects shields have on the diagnostic quality of the images.

Implications for Further Research

It is apparent from the literature review that there are many gaps in research and practice. The following suggestions recommend where professionals in the field should focus their energy to ensure that patients are being exposed to as little radiation as possible when having a CT scan.

This literature review investigated commercially available shielding methods. Other methods, such as automatic exposure control, altering tube currents or these methods combined with the use of shielding, were not within the scope of this review. However, these methods should be reviewed in future research because they may reduce patient dose even further.

Further research also is needed to explore the frequency of use of various dose reduction methods. The literature has not addressed precisely what shields are available in the clinical setting or how they are being used. Nor has the literature addressed whether the tube current is being modified to reduce dose when shields are not used. These questions are of primary importance in a discussion of ways to reduce radiation-induced cancer risks for patients undergoing CT scanning.

A better assessment of pediatric shielding needs to occur because the majority of the literature focuses on the use of shields on adults. The literature indicates that pediatric patients are at increased risk for radiation-induced cancer, yet studies have been geared primarily toward adults.

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<tr>
<td><strong>Computed Tomography Shielding Suggestions</strong></td>
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<tr>
<th>Radiosensitive Organ</th>
<th>Examinations That Should Include Shielding</th>
<th>Exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes</td>
<td>Routine, vascular, orbital, sinus and mastoid studies</td>
<td>When gantry can be angled to avoid direct beam to lens</td>
</tr>
<tr>
<td>Thyroid</td>
<td>Routine chest and neck studies</td>
<td>None</td>
</tr>
<tr>
<td>Gonads</td>
<td>Abdomen, upper pelvis</td>
<td>Routine pelvis</td>
</tr>
<tr>
<td>Breasts</td>
<td>Chest</td>
<td>None</td>
</tr>
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nearly 2-fold increased risk for breast cancer.\textsuperscript{13} It can be argued that there is not enough evidence to deduce similar results from higher doses and inadequate shielding in CT examinations, but on the other hand, there is no evidence discounting the effects of radiation from CT scans.
from further research are available, radiologic technologists should take the time to shield. By using shields, they help protect their patients from unnecessary radiation exposure without sacrificing diagnostic quality of the images.

References
The emergence of CT scanning as a routine diagnostic and radiation therapy planning tool has improved patient care by increasing the anatomic detail and diagnostic information available to clinicians. An increase in patient demand, availability and reimbursement practices have contributed to a dramatic escalation in the number of scans performed each year, and the risk and clinical justification for many of these procedures now is under debate. This Directed Reading will review recent events and trends in CT imaging and patient radiation dose, dosimetry, the biological effects of ionizing radiation, the principles of radiation safety and strategies for managing patient dose.

This article is a Directed Reading. Your access to Directed Reading quizzes for continuing education credit is determined by your area of interest. For access to other quizzes, go to www.asrt.org/store.

In October 2009, the U.S. Food and Drug Administration (FDA) issued a nationwide alert that advised hospitals to review safety protocols for computed tomography (CT) scans. This warning followed the discovery that a hospital in California had inadvertently exposed 206 patients to elevated CT radiation doses over an 18-month period during scans ordered to assess suspected strokes. Two months later, the FDA announced that additional cases had been identified at the hospital, and that at least 256 patients had received up to 8 times the intended radiation doses.

The magnitude of the radiation overdoses and their effect on patients were described by the FDA as “significant.” At least 82 patients experienced skin burns (reddening) and patchy hair loss, and affected patients face a possible increased cataract risk. In December 2009, the FDA announced that it was investigating similar reports of CT radiation overdoses at undisclosed facilities in other states.

“This situation may reflect more widespread problems with CT quality assurance programs and may not be isolated to this particular facility or this imaging procedure,” the FDA advisory warned. Although early reports indicated that equipment malfunction caused the incidents, the FDA subsequently announced that the overdoses involved CT imaging equipment from more than 1 manufacturer. This fact suggested that human error and lapses in safety practices and protocols, rather than faulty equipment, caused the errors. The FDA urged hospitals to report similar adverse events via its MedWatch Website (www.fda.gov/Safety/MedWatch/HowToReport/default.htm).
Regulatory Response

In February 2010, the FDA announced a sweeping new regulatory initiative to reduce medical radiation exposures from CT scans and nuclear medicine and fluoroscopy procedures. Citing patients’ increasing lifetime medical radiation doses, the agency declared its goal of eliminating unnecessary imaging procedures and ensuring the “careful optimization” of medically necessary imaging exams. Planned regulations were announced, including new requirements that CT scanners and fluoroscopic equipment record and display settings and dose for each scan performed and that patient doses be stored permanently in electronic health records.

As part of an FDA patient education initiative, the agency also announced development of a patient medical imaging history card, distributed via the FDA Web site, that will allow patients to track their imaging history and present it to referring physicians. The FDA also declared its support for a national dose registry and revised, uniform accreditation for radiology departments.

“Each patient should get the right imaging exam, at the right time, with the right radiation dose,” the agency’s white paper stated. “This registry will help define diagnostic reference levels where they do not yet exist, validate levels that do exist, and provide benchmarks for health care facilities to use in individual imaging studies.”

The headlines and response were just the latest chapter in global news media coverage of radiation risks associated with CT scanning. Other recent examples have included warnings about the radiation effects from full-body CT screening sought by “worried well” patients who have no symptoms of disease, and for whom the net clinical benefits of imaging are questionable. More recently, medical literature and the news media have scrutinized the wide variation in radiation doses of routine CT exams and the cumulative dose of repeated CT scans.

CT Proliferation

Since its introduction in 1973, CT scanning technology has dramatically improved the diagnostic quality and clinical utility of images that yield increasingly precise and rapidly acquired images. Slip-ring conductors preceded development of continuous gantry rotation and single-motion helical CT image acquisition. Image postprocessing advances allowed 3-D, volumetric imaging and images constructed from multiple view angles from 1 data acquisition set. However, sharply increasing patient radiation dose is the cost for these advances and the widespread availability and popularity of CT.

CT scans are increasingly common procedures that constitute a greater proportion of Americans’ annual exposures to ionizing radiation, representing as much as 67% of the medical imaging radiation dose to patients in some facilities. The annual population-wide medical radiation dose in the United States increased by an estimated 750% between 1980 and 2009. Up to 72 million CT scans are performed annually in the United States, based on 2006 and 2007 data. Medical imaging now represents nearly one-half (48%) of Americans’ radiation exposure, compared with less than 2% from occupational exposures. The remaining 50% of radiation exposures come from background, cosmic ray and environmental sources.

CT scans represent more than one-half of Americans’ annual medical imaging radiation exposures and 25% of the general population’s overall radiation exposure. Animal and epidemiological studies of occupational and atomic bomb survivors indicate that even relatively low doses of ionizing radiation can cause cancer, particularly leukemia and myeloma, and blood disorders such as aplastic anemia. Guidelines for nuclear industry and health care workers call for monitoring radiation exposures, which are and restricted to no more than 50 mSv a year and no more than 100 mSv every 5 years.

Yet patient exposures to medical imaging-related ionizing radiation rarely are monitored or systematically restricted. Complicating matters further, surveys of health care personnel strongly suggest they sometimes fail to comply with protocols and procedures designed to minimize radiation exposure. In addition, many clinicians have not received adequate training in radiation protection, a longstanding problem in U.S. health care. This may partially account for radiation doses from the same CT procedure varying up to 13-fold among patients at the same institution.

These trends toward increased utilization of CT imaging are not limited to the United States, according to recent analyses reported at the World Health Organization’s International Conference on Children’s Health and the Environment. Similar trends are evident in Asia and Europe.

Between 2000 and 2007, an estimated 3.1 billion medical procedures involving ionizing radiation were performed worldwide, with the United States accounting for 12% of that total. The average worldwide medical
radiation dose each year now is 0.6 mSv, approximately twice the estimated average worldwide dose estimated in 1996 — and double the current average annual medical radiation dose in the United States. The frequency of diagnostic radiologic examinations in the United States has increased 10-fold since 1950.15

These trends concern many researchers and clinicians because of the higher radiation doses to patients from CT scans compared with other imaging modalities, including conventional radiography.8,10,14 For example, doses from chest CT scans are up to 100 times those delivered in a routine chest radiograph.10 The U.S. annual medical radiation dose for each individual increased about 6-fold between 1980 and 2006 alone, from 0.5 mSv to 3.0 mSv, largely due to CT scanning.20

A study of CT scan doses at 4 hospitals found that radiation exposure from a given CT procedure at a single hospital can vary from 6 to 22 times, with an average variation of 1300%.10 In another 2009 nationwide study of health insurance records for nearly 1 million Americans aged 18 to 64 years, 68.8% had received medical imaging-related radiation exposures over a 3-year period. Although most of those Americans received low cumulative radiation doses (<3 mSv), 20% received moderate doses of > 3 to 20 mSv.15 Conventional radiography represented 71% of imaging procedures for the study population but only 10.6% of the total radiation dose.15 CT contributed disproportionately to patients’ radiation doses compared with other imaging modalities. For example, CT examinations of the abdomen, pelvis and chest accounted for nearly 38% of this patient population’s total annual dose. CT and nuclear imaging represented 21% of procedures and 75% of the total radiation dose.15

Overall, 2% of the 952,420 adults whose records were reviewed had received radiation doses that were high (>20 to 50 mSv) or very high (>50 mSv), which exceeded regulatory limits for the annual occupational exposures permitted for health care and nuclear industry workers.15 Annual average exposures from medical imaging radiation were higher for women, at 2.6 mSv, than for men, who received 2.3 mSv. Women younger than 50 years were more likely than men the same age to have received high and very high radiation doses.15

Cumulative annual radiation doses were higher among older patients (5 times higher, on average, for patients aged 60 to 64 years vs those aged 18 to 34 years). However, younger patients also received many CT scans; one-half of patients aged 18 to 34 years had undergone CT scanning during the 3-year study period.15

The annual incidence rate for medical imaging radiation exposures among enrollees included in the study was moderate for 193.8 enrollees per 1000 per year, high for 18.6 per 1000 and very high for 1.9 per 1000. Extrapolating results from their study to the entire U.S. population, the authors estimated that 4 million American adults were exposed to high levels of medical imaging radiation during the study’s 3-year span.15

The annual rates of CT scanning appear to be growing most rapidly among young adults, who experienced a 25% increase in CT scanning between 2004 and 2009, based on recent data reported in Australia.5

Models of Radiation Risk

The biological effects of medical radiology have become better understood in the past century.21 Improved safety protocols and equipment designs have reduced the risks of medical radiation.

CT Radiation Dose

Radiation refers to the energy emitted by an ionizing radiation source, while radiation dose quantifies the ionizing radiation energy delivered to a given volume of tissue (or other mass). Several units of measure describe radiation levels, including the unit of absorbed radiation dose in grays (Gy), or the delivery of 1 joule of energy to 1 kg of mass.12 The gray replaced an older unit of measure, the radiation absorbed dose or rad (1 Gy = 100 rad).

Aspects of CT scans that challenge efforts to quantify radiation dose include complex beam contours and patient movement through the x-ray beam. Because most scanners have a fan-shaped beam with a narrow cross-section, the dose distribution is usually wider than the nominal slice width.22 A single image slice acquisition involves a bell-shaped distribution of radiation with marginal “tails” known as penumbrae. The overlap of each slice’s penumbra contributes significantly — up to 50% greater than a single scan’s peak dose — to an examination’s overall radiation dose. The actual amount varies substantially depending on slice thickness and intervals (see Figure).12,22

In CT exams, the cumulative, summed dose represented by each beam’s penumbral region creates an oscillation-like dose curve, with the midpoint or average known as the multiple scan average dose (MSAD). The MSAD can be estimated using the radiation dose distribution of a single slice applied to a plastic cylinder phantom, a calculation that yields the most common CT dose description, the CT dose index (CTDI).
CTDI is calculated from a single axial scan dose, divided by the total nominal beam width, or the width of each active channel multiplied by the number of active channels. CTDI takes beam gaps and overlaps into consideration. The detailed calculus involved in determining CTDI is described elsewhere.\(^{12,23}\)

Although the FDA does not require that CT manufacturers display CTDI calculations on the monitor, most scanners display CTDI in mGy near the scan time and have acquired slice thickness readouts.\(^{12}\) However, radiologic technologists should remember that the CTDI is a calculated estimate or index, not an empirical measurement of actual patient dose. CTDI does not take into account anatomical variations of individual patients, such as target organ volume. Therefore, actual CT radiation dose for children or adults with very short stature, for example, may be as much as 600% higher than the dose that the CTDI indicates.\(^{12,24}\) Nor does CTDI reflect tissue-specific radiosensitivities or the resulting radiation risks.

Effective dose estimates the total amount of radiation absorbed by heterogeneous tissues, calculated as the weighted sum of the dose to irradiated organs and tissues.\(^{12}\) Effective dose, once expressed as roentgen equivalent man (rem) units, now is expressed in sievert (Sv) or millisievert (mSv) units. Table 1 lists representative examples of effective doses for selected CT exams.

Tissue weighting factors allow CT radiation doses to be calculated and adjusted in light of tissue-specific vulnerabilities, which minimizes the risks to patients (see Table 2). The complex mathematical models called Monte Carlo simulations that calculate effective dose involve the radiation beam, target scan volume, gantry motion and the tissue weighting factor values that reflect target organs’ varying radiosensitivities.\(^{12}\) In summary, the calculated radiation dose delivered to each organ volume is multiplied by the relevant tissue weighting factors; the sum of these products is the effective dose.

Even at the same settings and with the same patient undergoing the same CT examination, dose distributions and intensities can vary between scanners.\(^{22}\) To address these variations, phantoms and dosimetry methods can assist in measuring patient radiation doses.

**Biological Effects**

Energy from ionizing radiation can break chemical bonds in DNA and proteins, either directly or by releasing gene-damaging free radicals and ions. The resulting short-term tissue damage can include skin burns and hair loss, with cataract formation as a form of long-term damage. Carcinogenesis (cancer induction) is another long-term effect that follows damage to the genes that control cell division (mitosis) or programmed cell death (apoptosis).

Genetic damage and carcinogenesis are stochastic outcomes of ionizing radiation. In other words, a given exposure may or may not damage genes in a manner that eventually induces cancer.\(^{25,26}\) Because DNA repair mechanisms exist, it does not necessarily follow that radiation damage to genes will induce carcinogenesis.
Increased CT Utilization

CT is performed with increasing frequency because of its availability, patient demand and self-referral, defensive medical practices driven by concern over lawsuits and reimbursement practices. In turn, multidetector CT (MDCT) scanners that have become more available and more widely used are exposing patients to 30% to 50% more radiation than single-slice CT scanners. Adherence to radiation safety protocols and procedures is becoming increasingly important as a growing proportion of the population routinely is exposed to diagnostic radiation and with doses increasing as more individuals receive more CT scans. What’s more, attention to the special risks radiation can pose to the health of children demands particular scrutiny.

Despite a decline in the overall rate of inpatient diagnostic imaging procedures between 1993 and 2002 because of decreasing use of conventional radiography, regulations related to nuclear and toxic waste management and occupational exposures.

Table 1

<table>
<thead>
<tr>
<th>CT Examination</th>
<th>Typical Effective Dose (mSv)</th>
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<tbody>
<tr>
<td>Head</td>
<td>1-2</td>
</tr>
<tr>
<td>Chest</td>
<td>5-7</td>
</tr>
<tr>
<td>Abdomen and pelvis</td>
<td>8-11</td>
</tr>
<tr>
<td>Colon (CT colonoscopy)</td>
<td>6-11</td>
</tr>
<tr>
<td>Coronary calcium scoring</td>
<td>2-4</td>
</tr>
<tr>
<td>Coronary artery CT angiogram</td>
<td>9-12</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Tissue Weighting Factor</th>
</tr>
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<tbody>
<tr>
<td>Bone marrow</td>
<td>0.12</td>
</tr>
<tr>
<td>Breast</td>
<td>0.12</td>
</tr>
<tr>
<td>Prostate</td>
<td>0.12</td>
</tr>
<tr>
<td>Lung</td>
<td>0.12</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.12</td>
</tr>
<tr>
<td>Colon</td>
<td>0.12</td>
</tr>
<tr>
<td>Heart</td>
<td>0.12</td>
</tr>
<tr>
<td>Kidneys</td>
<td>0.12</td>
</tr>
<tr>
<td>Gonads</td>
<td>0.08</td>
</tr>
<tr>
<td>Liver</td>
<td>0.04</td>
</tr>
<tr>
<td>Esophagus</td>
<td>0.04</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.04</td>
</tr>
<tr>
<td>Brain</td>
<td>0.01</td>
</tr>
<tr>
<td>Salivary glands</td>
<td>0.01</td>
</tr>
<tr>
<td>Bone surface</td>
<td>0.01</td>
</tr>
<tr>
<td>Skin</td>
<td>0.01</td>
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the number of inpatient CT and nuclear medicine exams ordered increased significantly during the same period.\textsuperscript{13} This has generated new scrutiny on CT dose, particularly for pediatric patients. It has been estimated that 10\% of the CT scans performed each year in the United States — at least 6 million — are performed on children.\textsuperscript{15}

In the past, a majority of CT scans were ordered to locate and stage tumors or confirm diagnoses in symptomatic patients or to assess treatment response.\textsuperscript{23} In such cases, the benefits of a given diagnostic imaging exam usually far exceed the potential harm of irradiation from that exam, and CT technology has improved patient care significantly by increasing the anatomic detail and diagnostic information available to clinicians. However, younger patients face larger lifetime risks of cancer from a single dose of radiation than older, particularly elderly, patients, and the cumulative risks of repeated irradiation can substantially increase their lifetime cancer risks.\textsuperscript{35}

The proliferation of CT exams has increased the number of images acquired per examination, along with increases in the number of separate examinations that individual patients undergo. Early CT examinations consisted of 20 to 50 acquired images, whereas contemporary CT studies frequently can acquire 1000 images.\textsuperscript{12}

Early CT either helped confirm or rule out suspected pathology. Today, post-treatment cancer surveillance in asymptomatic patients and screening healthy patients with repeated CT scans (ie, full-body scans) is becoming more of a routine practice in much of the United States\textsuperscript{31} (Joseph Tuscano, MD, clinical and research oncologist and associate professor, University of California Davis, Sacramento, written communication, September 10, 2009). Patient demand and reimbursement considerations appear to drive overutilization of CT for screening and surveillance, respectively (Tuscano, written communication, September 10, 2010). Clinicians who purchase their own imaging equipment are 4 times more likely to order imaging exams, for example. Also, rates for cancer surveillance with CT jump when patients reach age 65 years and Medicare reimbursement becomes available.\textsuperscript{31} Increases in routine CT surveillance may become a major source of rapidly increasing health care costs.\textsuperscript{37}

Screening asymptomatic populations with risk factors for a given disease involves exposing many healthy individuals to irradiation, which increases the risk-to-benefit ratio of such exams. In turn, this has led to efforts to develop lower-dose CT procedures for screening compared with diagnostic scans.\textsuperscript{25,35} Surveillance of patients for post-treatment disease recurrence falls into a gray zone between diagnostic scans (in which higher radiation doses may be justified) and screening scans (in which lower doses are justified). The ASRT opposes the use of full-body CT as a screening tool.\textsuperscript{28}

**CT and Cancer Risk**

Determining the cancer risk associated with CT exams remains a contentious matter. The cancer risk from a single CT scan is relatively small, particularly for adults. An estimated 1 patient per 2000 will develop a fatal cancer from any CT scan, compared with a general cancer risk of 1 in 5 for the U.S. adult population.\textsuperscript{55} However, examinations that involve higher doses correspond to greater lifetime cancer risks for patients. For example, a CT scan of the heart can cause 1 case of cancer in every 270 women aged 40 years and 1 per 600 men aged 40 years. In contrast, head scans represent a lower risk of 1 cancer in 8100 women scanned and 1 in 11,000 men scanned. These risks are twice as high for individuals aged 20 years as for those aged 40 years.\textsuperscript{10}

Moreover, repeated CT scans can substantially increase a patient’s risk, and when large, asymptomatic populations are irradiated, even a small individual cancer risk can translate to numerous avoidable cancers in the general population and become a public health issue.\textsuperscript{35} A 2007 study suggested that up to 2\% of cancers in the United States may be attributed to CT procedures.\textsuperscript{39} No guidelines indicate how often individuals should undergo CT or nuclear medicine scans for screening or surveillance purposes, Dr Tuscano said (written communication, September 10, 2009). Repeated CT screening and surveillance imaging may appreciably increase patients’ risk of subsequent cancers. Yet that risk declines sharply with advancing age and particularly among the elderly, owing to the decades-long latency period of many radiation-induced tumors.\textsuperscript{8} (J Tuscano, written communication, September 10, 2009).

The increased risks to individual patients who undergo repeated diagnostic imaging procedures are not trivial. A 2008 review of radiologic imaging practices at Brigham and Women’s Hospital in Boston, Massachusetts, for example, found that some patients have received dozens of CT scans, leading hospital officials to estimate appreciable increases in those patients’ lifetime cancer risks.\textsuperscript{10} The review found that 5\% of patients had received at least 22 scans in the 2 decades studied. One 45-year-old woman had received 70 CT
examinations over 22 years, increasing her overall lifetime cancer risk by 10%. Another patient’s 62 CT scans, which involved radiation exposure to her chest, head and spine over 20 years, increased her lifetime risk of cancer by 4%, Aaron Sodickson, MD, told a journalist. Whether these results reflect nationwide trends is unclear because radiation doses vary significantly among hospitals and scanners, even for the same CT procedures.\(^{23,41}\)

Following the chart review, Brigham and Women’s Hospital administrators decided to track and notify clinicians of patients’ medical imaging histories and imaging-attributable cancer risks. Very few hospitals currently track patient irradiation histories or make these data available to clinicians.\(^{40}\) No national registry currently exists to track patient radiation exposures from CT or other diagnostic medical imaging in the United States.

**Tissue Radiosensitivities**

Tissues and organs are not equally susceptible to radiation damage. As noted previously, these different tissue radiosensitivities involve corresponding differences in the cancer risks that CT scans pose to different patient anatomies. Ova and testes are less sensitive to radiation than lung tissue or bone marrow, for example, and liver tissue is less radiosensitive than bone marrow or lung tissue (see Table 2). The International Commission on Radiological Protection revised tissue radiosensitivity weighting factors in 2006. For example, salivary glands were added as radiosensitive tissues. Also, weighting factors for gonads were changed from 0.20 to 0.08 and breast tissue weighting factors were changed from 0.05 to 0.12.\(^{26,46}\)

Tissue radiosensitivities and tissue weighting factors are treated as though they are identical for men and women.\(^{46}\) However, because weighting factors for embryos and fetuses have not been established, they likely would be different from the adult factors.

Facilities should regularly employ medical physicists to evaluate equipment function, verify scanner calibration and confirm that the institution’s effective doses do not exceed reference dose CTIDs. Few dose guidelines are available, but the American College of Radiology lists reference dose CTIDs of 75 mGy for adult head CT scans, 25 mGy for adult abdominal CT exams and 20 mGy for pediatric abdominal exams.\(^{42}\)

**Age at Exposure**

Age at the time of exposure modulates the risk of radiation-induced cancers in complex but important ways. Generally speaking, radiation-induced cancers among adults have long latency periods. Decades may pass between exposure and cancer diagnosis — thus, older adults have a lower risk of developing radiation-induced cancers because they might not survive long enough to develop the diseases.

Whereas CT heart scans can result in an estimated 1 cancer case for each 270 women age 40 years, for example, that number may be as high as 1 per 135 for women aged 20 years.\(^{10}\) Reports have shown that breast cancer risk is elevated among Japanese atomic bomb survivors and patients undergoing frequent diagnostic chest radiography and fluoroscopy, particularly among those whose irradiation occurred when they were younger than 20 years.\(^{13,44}\)

Ionizing radiation delivered to fetuses and children poses a greater risk of genetic damage, and hence, cancer, than it does among adults. This is in part because rapidly developing and growing organisms are undergoing rapid cellular division and their DNA is therefore more frequently uncoiled and more vulnerable to damage. Radiation-induced teratogenesis, or disruption of normal fetal development other than carcinogenesis, can occur in embryos as young as 2 weeks of gestation and through week 15 of gestation. This can result in brain abnormalities, retarded head and body growth and mental retardation.\(^{35}\) Between 8 to 15 weeks of gestation, fetal development is believed to be particularly vulnerable to the teratogenic effects of radiation, particularly for doses > 200 mSv.\(^{15}\)

The causes of childhood cancer are poorly understood but likely multifactorial, involving more than 1 acquired genetic mutation.\(^{45-47}\) In childhood leukemia, it appears that a prenatal genetic mutation typically is followed by a separate, postnatal mutation that triggers development of leukemia. One well-established and consistently reported risk factor for childhood cancers is ionizing radiation from prenatal exposure to medical radiation.\(^{48}\) Prenatal exposure to x-rays has consistently been considered a risk factor for childhood leukemia, for example, although an association between diagnostic radiation and adult leukemia is inconclusive.\(^{76-56}\)

Children are up to 10 times more sensitive to radiation damage overall than adults. Even a single CT scan is believed to significantly increase lifetime risk of fatal cancers.\(^{51}\) For example, a single abdominal CT scan on a 1-year-old child carries an estimated lifetime cancer risk of 1 in 1000.\(^{53}\) Yet for decades, children have been imaged using adult CT protocols.\(^{12,52}\)

Cancer risk varies by age among children; the estimated lifetime cancer risk attributable to pediatric head
CT correlates significantly and negatively with patient age. Younger children face greater lifetime risks than older children. Therefore, in many cases, the radiation doses from pediatric CT examinations outweigh their clinical benefits or image quality justifications.

Some pediatric patient populations, such as children with inflammatory bowel diseases, routinely receive CT scans despite the long-term risks. In a 2-year study of 965 children with Crohn disease and ulcerative colitis, for example, 34% of pediatric patients with Crohn disease and 23% of patients with ulcerative colitis received moderate doses of radiation from imaging. CT scans accounted for 28% of Crohn disease examinations and 25% of the ulcerative colitis exams, leading the authors to express concern over long-term radiation risks faced by children with these diseases.

Because approximately 6 million CT scans conducted each year in the United States are performed on children, researchers are concerned about what this represents collectively. A relatively small risk for an individual patient may result in hundreds or thousands of additional cancer cases across the entire pediatric patient population. They also assert that observing the ALARA principle for CT scan doses, particularly among children, is a public health imperative.

Some epidemiologists have called for a nationwide effort to collect data on fetal and childhood radiation doses from CT and other diagnostic imaging modalities to estimate pediatric and lifetime cancer risks attributable to these procedures. In addition, several organizations took a proactive stance in 2007. The ASRT was a founding member of the Alliance for Radiation Safety in Pediatric Imaging, a coalition of 34 health care organizations dedicated to reducing unnecessary medical radiation doses among children through the use of alternative imaging modalities and child-appropriate CT scanning protocols. The Alliance’s Image Gently campaign (www.imagegently.org) has organized professional workshops and produced brochures and an imaging tracking card that parents can use to record and share their children’s imaging histories with their physicians. The campaign also has published child-sized protocols for CT exams.

**Communicating Risk**

Although the literature offers substantial empirical evidence of the importance of the ALARA principle and the potential harm of unnecessary radiation exposures, clinical practices have been slow to adopt the principle. This could be partly driven by economic realities and reimbursement considerations, but also may be due to referring physicians and patients alike underappreciating the potential risks of unjustified or repeated radiological imaging. Clinicians frequently succumb to the demands of self-referring or insistent patients who seek reassurance through screening and diagnostic imaging. Clearly communicating radiation risk to patients and referring clinicians represents a key component of the aggressive implementation of both the ALARA principle and the ethical and legal obligation of securing a patient’s informed consent.

**Informing Referring Clinicians**

Referring clinicians often are more familiar to, and trusted by, their patients than radiological personnel, with whom patients meet only after imaging referrals. Therefore, patients may take statements on the risks of avoidable radiation, particularly in cases of repeated CT imaging, more seriously when they come from a physician they know. Because all medical personnel have a role in informing patients of the radiation risks related to imaging examinations, it is imperative that referring clinicians receive clear information on these risks.

The public health benefits of an ALARA mindset are best achieved when referring physicians consider the risks along with the potential benefits in deciding to refer patients for radiology examinations. Surveys show that referring clinicians do not receive adequate training in radiation protection, are frequently unaware of the relative radiosensitivities of different tissues and organs and often do not appreciate the long-term health risks of radiation exposure. Emerging health information technology and data management tools can help alert physicians to the risks of repeated CT imaging referrals. In addition, when diagnostic information is available from alternative imaging modalities that do not use ionizing radiation, that information should be offered to referring clinicians.

**Educating Patients**

Patients should be made aware of the calculated dose of their planned examination, the relative radiosensitivities of target organs, the effects of age and gender on the resulting risks and whenever possible, the relative risk of cancer posed by the scheduled exam.

Popular news media coverage of CT risks alarms some patients and may cause reluctance to undergo CT scanning. Although the risks of CT imaging should be objectively described to patients, they also must be provided with a context that helps them judge these risks.
such as the overall lifetime cancer risk (approximately 1 in 5 overall) that they face from factors other than medical imaging, for example. They also should be informed of any alternative imaging modalities available to them. Radiologic technologists should assure patients that they will apply the ALARA principle to their examination, and these reassurances should reflect the precautions taken to protect the patient and attending medical personnel.

Educating patients about their right to request their radiological imaging histories from physicians, and to ask the ordering physician whether the benefit of a repeat exam outweighs the risk of their cumulative radiation dose indirectly reminds referring clinicians to consider radiation dose.

Managing CT Dose

In addition to communicating risk to patients and improving awareness of CT exposure issues among referring clinicians, imaging personnel should routinely practice the ALARA principle. Applying ALARA day to day involves multiple safety and dose-management practices, starting with eliminating unnecessary CT scans, particularly for children and when an alternative imaging modality is available that meets clinical needs.

Quality Control and Assurance

All states regulate the registration and use of x-rays to some degree. Most states also have regulations requiring that radiology departments maintain quality assurance (QA) and quality control (QC) programs. QA programs assess how human performance affects image quality and patient dose, whereas QC ensures that the imaging and image processing equipment functions properly.

Updated software from manufacturers that ensures that equipment maintenance and performance monitoring, CT scanners should be evaluated by a qualified medical physicist when they are installed. After installation, a medical physicist must monitor equipment performance periodically (at least annually) and prepare a written report that is kept on file in the imaging department. State and local government regulations also should be reviewed because they may require more frequent monitoring.

The periodic equipment performance review must determine patient radiation dose from each scanner and independently confirm the manufacturer’s display CTDI measurements. Head, abdomen and pelvic exam doses should be assessed and compared to available, published reference doses to ensure that a facility’s CT scanners are not systematically overexposing patients to ionizing radiation. A medical physicist also must check equipment to confirm performance after service, repair, tube or detector assembly replacements, or other events that could change radiation dose or image quality.

Routine QC monitoring of equipment performance should confirm the accuracy of alignment lights and check for:

- Slice thickness.
- Table-to-gantry alignment.
- Table incrementation accuracy.
- Display devices, including image display monitor fidelity.
Dosimetry (eg, CTDI readout and reference doses for representative exams).

Safety (a visual inspection of equipment and workload assessments).

Scatter radiation measurement when workload or parameters change or if CT fluoroscopy is performed.

QC monitoring also includes ensuring image quality: high-contrast spatial resolution, low-contrast sensitivity and resolution and artifact and noise evaluations.

Time, Distance and Shielding
In general, radiology staff minimize exposure to patients and health care personnel through practices and procedures that reflect 3 factors:

- **Time.** Reduce radiation dose by minimizing the exposure time.
- **Distance.** Increase the distance between the radiation source and the individual by employing the inverse square law.
- **Shielding.** Protect patients and medical personnel from the radiation source with all appropriate and available barriers.

Protection includes lead aprons and lead-lined barriers around control consoles that minimize scatter radiation. Particularly when patients are young, shielding should protect the thyroid, breast, eyes and reproductive organs. Dosimetry studies in radiology departments indicate that medical personnel should routinely protect themselves during CT exams with lead aprons, gloves and thyroid shields. ASRT’s official position is that radiologic technologists should use shielding for all CT and fluoroscopic procedures.

CT beam collimators and image intensification technology also minimize radiation exposures by reducing the width or height of a beam’s dose distribution curve. Collimators help to limit x-ray beam exposure to a patient’s targeted anatomy, which reduces exposure to other tissues. The drawback of collimation is that it can increase image noise. Boundary margins around target tissues should be as close to the edge of targeted organs as possible. Beam collimation is one of several operator-controlled CT parameters that affect image quality and patient radiation dose. The following are other operator-controlled parameters:

- X-ray tube current (mA).
- Peak kilovolts (kVp).
- Scan time (seconds).
- Tissue volume.
- Pitch (in helical scanning).

QC reviews should include periodic assessments of scan protocols to identify opportunities to reduce mA, and the necessity of pitch factors less than 1.0 should be scrutinized.

Image Quality vs Dose
Image quality refers to how accurately acquired CT attenuation data that is reconstructed into a visual image depicts actual anatomic features. The central trade-off of radiation dose management and the ALARA concept stems from image quality correlating positively with radiation dose. Slice thickness, mA and pitch all modulate radiation dose. Increasing bed interval, or the distance traveled during 1 helical CT revolution around the patient, reduces radiation dose.

The amount of anatomical detail required for a specific clinical purpose should guide whether to select CT and determine the parameters and dose used in CT scans. However, reducing the dose also reduces an image’s detail and its potential diagnostic value. Poor-quality images require repeat examinations and increase a patient’s cumulative radiation dose.

CT scanners are designed to rapidly acquire detailed data from large volumes rather than encourage operator restraint. The full capabilities of the technology often are unnecessary and relatively little attention has been paid to implementing the ALARA principle compared with the attention focused on developing technology that maximizes image quality. However, manufacturers have developed dose-reduction mechanisms such as beam modulation to accommodate differences in tissue volumes.

Efforts to reduce radiation dose, along with errors in measuring, positioning and discontinuity, can degrade image quality. Increased image detail (sharpness) requires a higher radiation dose because it involves smaller sampling intervals. Poor calibration and evaluation of spatial resolution, which is performed using high-contrast line bar pattern phantoms, can compromise image sharpness. This illustrates the somewhat complex relationships between QC, image quality and dose reduction.

CT image contrast refers to the visualization of small attenuation differences between or within target tissues. CT scans are 4 to 6 times more sensitive in demonstrating image contrast than traditional radiographs and often yield superior diagnostic information. As with sharpness, increased image contrast requires higher radiation doses. Image noise is inversely proportional to the square root of dose, so reducing image
noise by one-half increases dose by 400%,12,60 Noise also increases with patient body mass (thickness), which requires increased radiation doses to maintain image contrast and allows reduced radiation doses for smaller patients.

**Dosimetry**

Radiation exposure can be indirectly estimated or directly measured with dosimetry tools such as an x-ray sensitive film badge or a reusable thermoluminescent dosimeter (TLD) badge containing lithium chloride crystals. TLDs absorb x-ray energy and release light energy in wavelengths that indicate radiation levels. Indirect bioindicators of radiation exposure, such as genetic and biomolecular tests that quantify actual biological damage from radiation, generally are used in epidemiological studies of occupational exposure rather than in clinical settings.

In contrast to direct dosimetric measurements, CTDI and reference levels derived from phantom measurements are guides or benchmarks that provide comparison values. Therefore, these reference levels are not always an adequate substitute for patient dose estimates. The clinical necessity of CT scanning should be carefully assessed, particularly for pregnant women, children, small adults and patients undergoing repeated CT scans. If CT is deemed clinically necessary, patient-specific radiation doses should be determined. If possible, a medical physicist should be consulted before the planned exam. Pelvic CT scans should be avoided when possible for pregnant women, although pregnancy is not an absolute contraindication.12 Patient-specific dose calculations include the patient’s height, weight, body mass index, lateral width and the specific parameters of the planned examination, including target organ volumes and tissue radiosensitivities.12

Patient- and exam-specific radiation doses are frequently approximated using phantoms and a pencil ionization chamber. The ionization chamber is a long, thin and thin-walled chamber connected to a conducting wire. The ionization chamber can be inserted into a phantom to estimate patient organ-specific and scan-specific radiation dose from particular CT equipment by measuring the radiation delivered throughout the dose distribution curve.22 Because the ionization chamber is positioned perpendicular to the radiation beam, and therefore parallel to the patient’s longitudinal axis, it can measure the entire width of the beam.

During phantom irradiation, some air molecules in the chamber lose electrons and become ionized; these free electrons are conducted via the ionization chamber’s wire and quantified using an attached electrometer. The electrical charge measured by the electrometer, $Q$, is directly proportional to the delivered radiation dose.22

Ionization measurement of MSAD (multiple scan average dose) requires a phantom of the appropriate volume for the exam (eg, a 15-cm thick or long, 16-cm diameter head-size phantom for a head CT or a 15-cm thick, 32-cm diameter body phantom for chest exams). The phantom is placed in the same scanner that will be used for the patient in question, with the phantom axis parallel to patient axis. The same positioning equipment, such as a head positioner or holder, should be placed with the phantom. Phantoms have a “+” or “x” array of 5 chambers through the phantom’s long axis, with openings on the phantom’s flat face. The pencil ionization chamber is placed in a hole in the phantom to measure the dose, with each end of the chamber flush to the faces of the phantom. Acrylic plugs fill the other phantom chambers. The pencil chamber is connected to the electrometer, which should be set to the “charge” or “integrate” mode.22 A single scan slice is acquired, and the electrometer measures the $Q$ charge.

Because dose can vary between regions within anatomical target volumes, dose estimation should be performed with the ionization chamber in different phantom positions (holes). The chamber is moved to a different chamber position in the phantom between subsequent scans. If bidirectional CT scanners’ clockwise and counter-clockwise doses differ — as is typical — it is important to acquire 1 scan in each direction and at each chamber position in the phantom. An average of the 2 $Q$ measures should be calculated for each chamber position.22

An accredited medical physicist or dosimetry calibration lab should calculate the conversion factor.22 As noted, the pencil ionization chamber is moved to the subsequent phantom position and the MSAD measurement is repeated, without moving the phantom’s position. MSAD measurements should be acquired for all configurations, techniques and anatomies (head and body) involved in the planned patient examination.

CT staff should keep data sheets that note the date, specific scanner and brand used, CT scan technique performed, scan duration, phantom size and chamber location, $Q$, and conversion factor values, the planned number of scans and scanner settings, such as kVp, mA, slice width and bed interval.
Cumulative Dose Tracking

ASRT has joined many national societies in calling for all imaging facilities to document patient radiation doses for CT and fluoroscopic examinations and for mandatory reporting of medical radiation errors. Several health information technology mechanisms for reminding referring clinicians and radiologic technologists to consider patient radiation doses have been proposed. The proposals include enlarging, or otherwise making more prominent, the CTDI reading on CT scanner displays, adding an alert feature to notify CT operators when the recommended dose level is exceeded and adding a warning feature that prevents CT scans from being performed at radiation levels considered dangerous.

Digitally archived imaging exams should include radiation dose information. Hospitals’ electronic health records systems do not automatically calculate or record cumulative patient doses, let alone automatically alert physicians to cumulative doses when a patient is referred. Since 2003, the Harvard Vanguard Medical Associates physicians’ group has tracked patient CT scan radiation doses in its Digital Imaging and Communication in Medicine (DICOM)-based system, allowing physicians to access the data and calculate cumulative patient doses upon patient request.

Such systems, and more sophisticated mechanisms that may automatically notify referring clinicians and imaging departments of patients’ cumulative doses, are likely to become more common in the near future. Policymakers have identified developments in health information technology, including universal electronic health records, as a priority for cost-containment. Tracking cumulative patient doses would reduce patient risks and overutilization of CT by clinicians. Ideally, electronic health records would include not only patient dose but the type and technique of CT scans and other imaging examinations, to avoid unnecessarily repeating imaging exams.

Conclusion

Improvements in the safety of radiological imaging equipment and procedures have reduced the risks of medical radiation and incidence of radiology-related illnesses in the past century. However, rising per-capita use of CT in the United States, the increasing use of CT with younger adult and pediatric patients and the emergence of routine CT surveillance and screening procedures have created a perfect storm that has led to higher medical radiation doses and attributable cancer risk among U.S. patients.

Observing radiation safety procedures and practices, and routinely and aggressively following excellent QA and QC programs, represent basic but crucially important ways to reduce the risks patients face from CT imaging. Many referring clinicians are unaware of the radiation risks that CT scans pose. Two medicolegal and ethical imperatives — the principles of ALARA and informed consent — demand that referring clinicians and patients be informed of the relative risk, and when possible, the cumulative risk, of medical radiation that CT examinations represent. Many patients will have read or heard news accounts of concern in the medical community about the long-term cancer risks of repeated CT scanning, and may be reluctant to undergo needed CT imaging. Therefore, patients also must receive information they can use to judge the relative risk of a given CT exam, and weigh this against the clinical need for imaging. All else being equal, a single radiation dose represents a greater lifetime cancer risk to younger patients than older ones.

CTDI readouts on CT scanners estimate the likely patient radiation dose from an examination, but should not be mistaken for patient-specific radiation doses. The CTDI may underestimate the true patient exposure, particularly in children and small adults. For these patients, and pregnant women, patient-specific doses should be calculated using tissue-weighted radiosensitivities and phantom scans. Because the dose delivered to the same patient for the same CT exam may vary between scanners, phantom dose calculations should be undertaken on the same equipment scheduled for the patient’s examination whenever possible.

Future developments in dose management and cumulative dose tracking will likely help curb unnecessary scans, but cannot replace the day-to-day vigilance of imaging department personnel in ensuring adherence to the ALARA principle.

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May/June 2010, Vol. 81/No. 5 RADIOLoGic TECHNOlOgy

RADIATION DOSE IN CT


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Directed Reading Continuing Education Quiz

Radiation Dose in Computed Tomography

To receive Category A continuing education credit for this Directed Reading, read the preceding article and circle the correct response to each statement. Choose the answer that is most correct based on the text. Transfer your responses to the answer sheet on Page 456 and then follow the directions for submitting the answer sheet to the American Society of Radiologic Technologists. You also may take Directed Reading quizzes online at www.asrt.org. Effective October 1, 2002, new and reinstated members are ineligible to take DRs from journals published prior to their most recent join date unless they have purchased a back issue from ASRT. Your access to Directed Reading quizzes for Continuing Education credit is determined by your Area of Interest. For access to other quizzes, go to www.asrt.org/store.

*Your answer sheet for this Directed Reading must be received in the ASRT office on or before this date.

1. As of December 2009, at least _______ patients were identified by the U.S. Food and Drug Administration as significantly affected by computed tomography (CT) radiation overdoses at a California hospital; some patients received radiation doses up to _______ times the intended dose.
   a. 212; 4
   b. 256; 4
   c. 212; 8
   d. 256; 8

2. CT scans represent as much as _______ % of patients' medical imaging radiation dose to patients in some facilities.
   a. 37
   b. 47
   c. 57
   d. 67

3. Which of the following statements is true regarding Americans' radiation exposure?
   a. More than 2% of radiation exposure is occupational.
   b. CT scans represent less than one-fourth of Americans' annual medical imaging radiation exposures.
   c. Medical imaging represents nearly one-half of Americans' radiation exposure.
   d. About 80% of radiation exposure is from environmental sources.

4. Guidelines for nuclear industry and health care workers call for restricting radiation exposures to no more than _______ mSv a year and no more than _______ mSv every 5 years.
   a. 25; 50
   b. 50; 100
   c. 100; 150
   d. 150; 200

Continued on next page
5. Recent analyses indicate that trends toward increased utilization of CT imaging are limited to the United States.
   a. true
   b. false

6. The U.S. annual medical radiation dose for each individual increased about 6-fold between 1980 and 2006 alone, largely due to _______.
   a. CT scanning
   b. digital radiography
   c. mammography
   d. scatter radiation

7. According to a 2009 nationwide study of health insurance records for nearly 1 million Americans, the following findings are true except:
   a. The annual radiation exposure incidence rate was high for 18.6 per 1000 study enrollees.
   b. Women received higher annual average exposures from medical imaging than men.
   c. Cumulative annual radiation doses were higher among patients aged 18 to 34 years than among older patients.
   d. The authors estimated that 4 million adults were exposed to high levels of radiation over a 3-year period.

8. The unit of absorbed radiation dose is _______.
   a. sievert (Sv)
   b. gray (Gy)
   c. joule (J)
   d. Curie (Ci)

9. A single image slice acquisition involves a bell-shaped distribution of radiation with marginal “tails” known as _______.
   a. oscillation
   b. bed interval
   c. threshold
   d. penumbrae

10. The dose curve midpoint or average is known as the _______.
    a. bed interval
    b. threshold
    c. multiple scan average dose (MSAD)
    d. CT dose index (CTDI)

11. Which of the following is true regarding CTDI?
    a. It is an empirical measurement of actual patient dose.
    b. It is a calculated estimate or index.
    c. CTDI reflects tissue-specific radiosensitivities.
    d. CTDI takes into account target organ volume.

12. _______ is a long-term effect of radiation exposure when damage occurs to genes that control cell division or programmed cell death.
    a. Carcinogenesis
    b. Macular degeneration
    c. Burnt skin
    d. Hair loss

13. Which of the following CT procedures has the highest typical effective dose?
    a. chest exam
    b. abdomen and pelvis exam
    c. coronary calcium scoring
    d. coronary artery angiogram

14. Proponents of the hormesis hypothesis argue against:
    1. the linear/no threshold model.
    2. an unknown exposure threshold.
    3. firm government regulations regarding nuclear and toxic waste management and occupational exposures.
    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2 and 3

Continued on next page
15. Which of the following tissues or organs is most sensitive to radiation?
   a. thyroid
   b. liver
   c. skin
   d. bone marrow

16. Early CT examinations consisted of up to _______ acquired images, whereas contemporary studies frequently can acquire _______ images.
   a. 25; 500
   b. 50; 1000
   c. 75; 1500
   d. 100; 2000

17. Between 8 to 15 weeks of gestation, fetal development is believed to be particularly vulnerable to the teratogenic effects of radiation, particularly for doses > _______ mSv.
   a. 50
   b. 100
   c. 200
   d. 400

18. A 2-year study showed that at least 25% of imaging exams in children with _______ and _______ were CT procedures, causing concern about long-term radiation risks for these patients.
   a. Crohn disease; juvenile arthritis
   b. Crohn disease; ulcerative colitis
   c. leukemia; ulcerative colitis
   d. juvenile arthritis; leukemia

19. Surveys have shown that referring clinicians:
   1. do not receive adequate training in radiation protection.
   2. are frequently unaware of the relative radiosensitivities of tissues and organs.
   3. often do not appreciate the long-term health risks of radiation exposure.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2 and 3

20. According to the Directed Reading, a _______ should establish reference radiation levels for the facility’s most common procedures.
   a. radiologic technologist
   b. medical dosimetrist
   c. medical physicist
   d. radiologist

21. Examples of quality control (QC) monitoring to ensure image quality include:
   1. high-contrast spatial resolution.
   2. low-contrast sensitivity and resolution.
   3. artifact and noise evaluations.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2 and 3

22. _______ help to limit x-ray beam exposure to a patient’s target anatomy, reducing exposure to other tissues.
   a. Shields
   b. Collimators
   c. CTDIs
   d. Screens

Continued on next page
23. Increasing bed interval, or the distance traveled during 1 helical CT revolution around the patient, reduces radiation dose.
   a. true
   b. false

24. Image noise is inversely proportional to the square root of _______.
   a. dose
   b. scan time
   c. MSAD
   d. mA

25. When conducting an ionization measurement of MSAD, if bidirectional CT scanners’ clockwise and counter-clockwise doses differ, it is important to:
   a. acquire only 1 scan in 1 direction and 1 chamber position in the phantom.
   b. acquire 1 scan in each direction and at each chamber position in the phantom.
   c. acquire 2 scans in 1 direction and 1 chamber position in the phantom.
   d. acquire multiple scans during the day in either direction.

For your convenience, the evaluation and answer sheet for this Directed Reading now immediately follow the quiz. Just turn to Pages 455 and 456.
Directed Reading Evaluation
Radiation Dose in Computed Tomography

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Thank you for taking the time to complete this survey. Your opinion helps us serve you better. Your comments will remain confidential and will not affect the scoring of your Directed Reading (DR) test. Choose only ONE response for each question. Use a blue or black ink pen. Do not use felt tip markers. Completely fill in the circles.

1. What is your primary area of practice?
   ○ Administration/Management ○ Education ○ Quality Management ○ RIS/HIS/Information Systems
   ○ Bone Densitometry ○ Magnetic Resonance ○ Radiation Therapy ○ RN
   ○ Cardiovascular-Interventional ○ Mammography ○ Radiography ○ Sonography
   ○ Computed Tomography ○ Nuclear Medicine ○ Research ○ Other

2. Which of the following best describes the highest educational level you have attained?
   ○ Student who has not yet taken Registry exam ○ Associate degree ○ Master’s degree
   ○ Certificate ○ Bachelor’s degree ○ Doctoral degree (e.g., Ph.D. or Ed.D.)

3. Why did you choose to complete this DR?
   ○ Interested in the topic ○ Topic pertained to my area of practice ○ Other
   ○ DR had the right number of CE credits ○ Needed CE credits immediately

4. How relevant is this DR to your practice?
   ○ Extremely relevant ○ Very relevant ○ Relevant ○ Somewhat relevant ○ Not relevant

5. How beneficial is this DR to your professional or personal development?
   ○ Extremely beneficial ○ Very beneficial ○ Beneficial ○ Somewhat beneficial ○ Not beneficial

6. How would you rate the level of difficulty of this DR?
   ○ Too difficult ○ Somewhat difficult ○ Just the right level ○ Somewhat easy ○ Too easy

7. How would you rate the length of this DR?
   ○ Too long ○ Somewhat long ○ Just the right length ○ Somewhat short ○ Too short

8. Did this DR meet your expectations?
   ○ Yes ○ No ○ Partially

9. Would you recommend this DR to a colleague?
   ○ Yes ○ No

10. Overall, how valuable are the Directed Readings to you?
    ○ Very valuable ○ Considerably valuable ○ Valuable ○ Slightly valuable ○ Not very valuable

If you have comments 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.
# Radiation Dose in Computed Tomography

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# CE Answers Section

**Note:** For true/false questions, A=true, B=false.

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Expires: June 30, 2012
Approved for 1.5 Category A CE Credits

No Photocopies Accepted
After reading this article, readers should be able to:

- Review ankle joint anatomy and the role of ligament structures in providing stability.
- Describe the role of imaging in patient diagnosis, treatment planning and follow-up.
- Discuss classification systems for ankle injury patterns.
- Determine when surgical reduction and internal fixation of ankle fractures is required and complications that may result from surgery.
- Describe rehabilitation techniques and functional recovery prognosis.

Injuries to the ankle are common in the general population and in athletes. It is estimated that 260,000 Americans sustain an ankle fracture each year and that ankle fractures occur in about 100 per 100,000 people in major cities. They constitute 21% of all sports-related injuries. One study reported that the incidence of ankle fractures has increased in recent decades, especially among the elderly.

Ankle fractures often are complicated by associated ligamentous injuries that must be repaired to ensure joint stability. The most common cause of ankle injury is excessive inversion stress. Fractures also may result from abnormal stress applied to the joint or when the strength of the bones is insufficient to support normal stress. Two classification systems, the Lauge-Hansen and the Danis-Weber, or Weber, are used widely to aid in the diagnosis and treatment of ankle fractures resulting from an acute injury. Several other fracture types do not fit into these classification schemes, including stress fractures and pathologic fractures. Diagnostic imaging techniques used to evaluate these injuries may include conventional radiography, magnetic resonance (MR) imaging, computed tomography (CT), radionuclide bone scanning and ultrasonography.

Stable fractures are effectively treated with casts and removable braces. Unstable fractures must be reduced promptly and accurately to optimize healing and minimize the length of hospital stay. When surgery is required, a wide variety of fixation devices and surgical techniques are used for open reduction and internal fixation of the ankle. Following surgery, these fractures also are treated with a period of immobilization, then rehabilitation to attempt functional recovery of the joint. Patient age, severity of injury, quality of treatment and use of rehabilitation interventions are parameters used to predict the outcome of ankle fractures.

Epidemiology

Ankle fractures are common to all groups of the population. Most ankle fractures are inversion injuries caused by sports activities or simple falls. Several...
studies have shown that the incidence of ankle fractures has continued to rise, especially in postmenopausal women. The peak age range for men to suffer ankle fractures is 15 to 24 years, whereas the peak age range for women is 65 to 75 years. The injuries also occur frequently in the pediatric population. According to Davis, fractures of the ankle make up 5% of all pediatric fractures and 15% of physeal injuries with a peak incidence between 8 and 15 years. Sports that reportedly lead to unstable ankle fractures include football, baseball, cheerleading, softball, wrestling, basketball, gymnastics, motocross, rock climbing, rodeo, rugby, soccer and volleyball.

Risk factors for ankle fracture include obesity, diabetes, osteoporosis, prior injury and the level and type of physical activity. Falls are more common in the elderly, but one study reported that a higher rate of falls did not correlate with an increased rate of ankle fractures. Obesity is a risk factor for ankle fractures in children and adults and also is a predictor of poorer outcome following ankle fractures in adults. Type 2 diabetes has been associated with increased rates of foot and ankle fractures and corresponds to a higher fracture severity. Osteoporosis also is a risk factor for ankle fracture and subsequent refracture. Known risk factors for osteoporosis include female gender, older age, lower body mass index and a family history of the disease.

The risk of refracture also is significant for elderly patients. Center et al found that refracture risk of low-trauma ankle fracture in men and women was equal to the initial fracture risk of a man 20 years older or a woman 10 years older. For example, a woman who is aged 60 to 69 years has the same refracture risk as a woman aged 70 to 79 years has of initial fracture. Refractures reported in this study were most likely to occur in the first 2 years following the first fracture. The authors reported that incidental low-trauma fractures are a sign that subsequent osteoporotic fractures are likely and that these patients should receive preventive therapy.

**Ankle Anatomy and Biomechanics**

The ankle comprises 3 bones: the distal tibia, distal fibula and talus. It also includes the joint capsule and supporting ligaments (see Figure 1). The tibia and fibula are long bones, whereas the talus is short and squarish in shape. Long bones have a shaft called the diaphysis, which is located between 2 larger ends called the epiphyses. The metaphysis connects the diaphysis and epiphyses. The diaphysis is made up of compact bone that surrounds a medullary cavity containing marrow. The epiphysis consists of spongy bone covered by compact bone. Hyaline cartilage covers the end of each epiphysis.

Longitudinal growth occurs between the epiphyseal line and the epiphysis at the epiphyseal cartilage (growth plate). The growth is stimulated by growth and sex hormones. The plate ossifies and becomes the epiphyseal line when longitudinal growth ceases. The density and thickness of bone may change at any time because of hormonal influence, such as growth hormone, parathyroid hormone or cortisol. Changes in osteoblastic (bone producing) and osteoclastic (bone resorbing) activity also affect bone density (the amount of calcium and other minerals present in the bone). Accessory ossification centers may be mistaken for fractures in the developing ankle and foot of a pediatric patient. The most common is located posterior to the talus and is called the os trigonum. Usually
ossification centers appear to have a regular shape and have a well-defined cortex on radiographs.\textsuperscript{19}

Joint Mechanics

Two separate articulations allow movement at the ankle. The true ankle joint, also known as the talocrural joint or mortise joint, consists of articulations between the lateral malleolus of the fibula, the inferior surface and medial malleolus of the tibia and the talus.\textsuperscript{1,18,19} The mortise is formed by the inner and distal articular surfaces of the tibia and the fibula, which serve as a roof over the talus, creating a uniplanar hinge joint.\textsuperscript{21} The medial and lateral malleoli allow controlled plantar flexion (as when pointing the toes down and lifting heels off the floor) and dorsiflexion (as when pulling the toes up from the floor).\textsuperscript{19,21} The talus is slightly wider anteriorly, making the ankle more stable when in dorsiflexion because the talus is effectively locked between the malleoli.\textsuperscript{1,19} The posterior malleolus, located on the posterior aspect of the tibia, may be fractured in association with other ankle fractures or ligament injuries. Posterior malleolus fractures often are associated with fibula fractures and are considered to be unstable.\textsuperscript{7} The talus and calcaneus are connected to the malleoli by the lateral and medial collateral ligament complexes.\textsuperscript{19}

The tibiofibular syndesmosis joint allows slight widening between the tibia and fibula. The syndesmotic ligament is located between the tibia and fibula at the level of the tibial plafond (ceiling). This ligament allows 1-2 mm of widening at the mortise during plantar flexion and dorsiflexion.\textsuperscript{21} The posterior and anterior tibiofibular ligaments strengthen this joint.\textsuperscript{19}

The gliding movements of the intertarsal joints allow other slight movements of the ankle joint.\textsuperscript{18} The subtal joint often is included in ankle injury evaluation because it is where inversion (facing the sole of the foot inward) and eversion (facing the sole of the foot outward) occur. The joint comprises the talus and the calcaneus.\textsuperscript{7}

The distal tibia absorbs the compressive loads and stress placed on the ankle.\textsuperscript{21} Joint motion is guided and stabilized through a close interaction between the geometry of the ligaments and the shapes of the articular surfaces.\textsuperscript{22} Ankle stability is largely the role of the ligament structures. The deltoid ligament stabilizes the medial side of the ankle and has superficial and deep components.\textsuperscript{1} The superficial component consists of the tibiotalar, tibiocalcaneal and tibionavicular ligaments. The deep component is the primary medial stabilizer of the ankle. Eversion or external rotation of the ankle may damage this ligament.\textsuperscript{1}

Laterally, 3 major ligaments resist inversion, anterior displacement of the talus and internal rotation. They are the anterior talofibular ligament, the calcaneofibular ligament and the posterior talofibular ligament. The anterior talofibular ligament resists inversion when the ankle is in plantar flexion and the calcaneofibular ligament resists inversion when the ankle is in dorsiflexion.\textsuperscript{1}

Computer models used to design ankle prostheses demonstrated that during dorsiflexion, some fibers within the calcaneofibular and tibiocalcaneal ligaments rotate isometrically around their origins and insertions while all other more anterior ligament fibers slacken. During plantar flexion, however, the more posterior ligament fibers slacken. In addition, the point of articular contact moves from the posterior part of the mortise in plantar flexion to the anterior part in dorsiflexion. This causes the talus to roll forward during dorsiflexion and backward during plantar flexion.\textsuperscript{22}

There are 2 fat pads around the ankle that are useful for detecting joint effusion and injury on radiographs: the anterior (or normal) pretalar fat pad and the posterior pericapsular fat pad.\textsuperscript{22} Beneath the anterior pretalar fat pad is a fibrous, synovium-lined capsule that is attached to the tibia, fibula and talus. When injured, it secretes synovial fluid that distends the fibrous capsule and causes displacement of the fat pad. Similarly, the posterior fat pad, located within the space between the posterior tibia and talus bones, is displaced when a joint is injured, but requires more fluid build-up in the fibrous capsule that displaces the fat pad to be noticeable.\textsuperscript{23}

Fracture Patterns

When a fracture occurs, the rigid structure and continuity of the bone or bones involved also breaks.\textsuperscript{20} The ring principle may be used to describe the injury pattern of the ankle joint and its supporting ligaments. This means that when a fracture or ligament rupture occurs on 1 side of the joint or “ring,” another fracture or rupture is likely to be present elsewhere.\textsuperscript{19} Blood vessels within the bone are damaged as well as surrounding soft tissues. The fractured bone undergoes 5 stages of healing: hematoma formation, granulation tissue formation, callus formation, bony callus formation (ossification) and remodeling.

After ankle fracture, a hematoma first forms between the ends of the bone fragments and an inflammatory response develops. The hematoma serves as the basis for a fibrin network to support and promote granulation tissue growth. New capillaries extend...
into the granulation tissue and phagocytic cells, which remove debris. During the granulation tissue formation stage, fibroblasts, which lay down new collagen fibers, move to the site. Chondroblasts start to form cartilage as well. The bone fragments then are held together by this delicate procallus or fibrocartilaginous callus during the callus formation stage. Osteoblasts then begin to generate new bone to fill in the gap and osteogenic activity eventually transforms the fibrocartilaginous callus into bony callus. The repaired bone then is remodeled in the final stage by osteoblastic and osteoclastic activity in response to mechanical stresses on the bone. Over time, mature compact bone replaces the excess callus.  

**Medical History and Evaluation**

During initial evaluation of a patient suffering from an ankle injury, the clinician should obtain a detailed medical history that includes the mechanism of injury. Ankle fractures may be mistaken for sprains. Some fractures, including the “snowboarder’s fracture” are difficult to distinguish on physical examination from a lateral ankle sprain. Ankle-inversion trauma may result in physeal injuries in children, which may lead to joint deformity if not properly diagnosed and treated.  

Patients with ankle fractures frequently have pain, swelling and an inability to bear weight on the affected ankle. If the ankle is dislocated, it should be manipulated as soon as possible to restore the anatomy and reduce risk of neurovascular compromise and skin necrosis. This reduction must be performed by a trained clinician and adequate analgesia should be given to the patient. The neurovascular status of the foot should be assessed both before and after the manipulation. Radiologic technologists should ensure that the joint is immobilized before imaging.  

Syndesmosis injuries often are associated with ankle fractures and are important to detect because the ligament structures are crucial for ankle stability. Patients often have pain, ecchymosis (large purplish patch of blood under skin) and swelling in the lateral aspect of the ankle, and are unable to bear weight on the affected ankle. They also may have swelling on the medial side when a deltoid injury or medial malleolus fracture is present. An external rotation test may be performed to confirm a syndesmosis injury. It is performed by rotating the patient’s foot externally, which reproduces pain at the ankle.  

When fracture is suspected, the American College of Radiology (ACR) recommends using the Ottawa Ankle Rules to determine whether radiographs are needed. The rules state that the patient must meet 1 of 3 criteria for radiographs to be deemed appropriate. The criteria include:

- Inability to bear weight immediately after the injury.
- Point tenderness over the medial malleolus, on the talus or calcaneus, or the posterior edge or inferior tip of the lateral malleolus.
- Inability to walk 4 steps in the emergency department.

Other imaging modalities may be used when the results of conventional radiography are inconclusive or in cases of multiple trauma.  

**Diagnostic Imaging**

Conventional radiography is considered the most appropriate initial and low-cost examination for suspected ankle fractures and associated syndesmosis injuries. Other more sensitive and more expensive imaging exams may be used to better identify ankle injuries or for treatment planning. These include CT, MR, ultrasonography and radionuclide bone scanning. Imaging techniques also are used during surgery for open reduction of fractures and during follow-up examinations to monitor healing.  

Both conventional radiography and CT are considered low-dose exams. The effective dose for radiography of the extremities is about 0.01 mSv and 1.0 mSv for a multidetector CT (MDCT) exam. It still is important to minimize radiation exposure to the patient. An important method for reducing exposure during conventional radiography is to collimate the x-ray beam to the anatomic area of interest. This also reduces scatter, which improves image contrast. Gonadal shielding also is required during extremity imaging because the shielding does not interfere with diagnostic information. This reduces the gonadal dose to 0. Radiologic technologists also should verify that female patients are not pregnant before imaging to reduce the risk of radiation exposure to the fetus. If it is necessary to perform an exam on a pregnant patient, the radiographer should carefully position lead shields over her abdomen and tightly collimate the x-ray beams.

**Radiography**

Based on the ring principle, it is likely that the patient with an ankle fracture has multiple injuries. Therefore, when a medial joint fracture is detected and the patient has associated lower leg pain, the
entire lower leg may be radiographed with anteroposterior (AP) and lateral projections to rule out a fibula fracture. The ACR recommends AP, lateral and 15° to 20° internal oblique (mortise) projections with additional projections added in questionable cases. The additional projections may include a 45° internal oblique or an off-lateral and a 45° external oblique radiograph, which may help demonstrate the malleoli and the tibiofibular articulation. Stress studies of the ankle can verify the presence of a ligament tear.

For a true AP projection, the radiologic technologist positions the patient supine on the exam table with the affected limb extended fully and no rotation. The ankle joint should be flexed, with the long axis of the foot placed vertically to the table. The technologist should center the central ray midway between the malleoli and perpendicular to the ankle joint (see Figure 2). When more of the leg needs to be imaged, the radiographer can use a larger cassette, but still should center the central ray at the joint and place a flat contact shield over the extended radiation field to prevent backscattered radiation from reaching the imaging plate. This projection may demonstrate ruptured ligaments or other types of separations if either the tibiofibular or talofibular articulations are shown in profile (see Figure 3). In a normal ankle, the tibiofibular articulation overlaps the anterior tubercle and the talus slightly overlaps the fibula, but no there is no overlapping of the medial talomalleolar articulation.
Rotating the ankle laterally or medially during patient positioning obscures the medial mortise. If the ankle is rotated laterally, the tibia and talus will be more superimposed over the fibula and the posterior aspect of the medial malleolus will be seen laterally to the anterior aspect. Medial rotation causes minimal superimposition of the fibula over the talus.

The degree of openness of the tibiotalar joint also indicates whether the ankle is properly positioned. If the proximal lower leg is elevated, the anterior tibial margin will be projected distally, which results in a narrowed tibiotalar joint space. If the distal lower leg is elevated, the anterior tibial margin will be projected proximally to the posterior margin, which results in an expanded tibiotalar joint space. During dorsiflexion, the talus is wedged into the anterior tibial region, which results in a narrow-appearing joint space; during plantar flexion, the calcaneus is moved proximally, resulting in a talocalcaneal superimposition.

Mediolateral or lateromedial positioning of the patient facilitates the lateral projection. For mediolateral positioning, the patient is supine and rotated toward the affected side until the ankle joint is lateral and the patella is perpendicular to the horizontal plane. The technologist should place a support under the patient’s knees to maintain this position and place the foot in dorsiflexion to prevent lateral rotation of the ankle. The central ray should enter the medial malleolus and be projected perpendicular to the joint. For lateromedial positioning, the patient is supine with the body turned away from the affected side until the extended leg is lateral. This position offers improved detail because the joint is closer to the cassette. The patella should be perpendicular to the horizontal plane and, if necessary, the technologist should place a support under the patient’s knee. The perpendicular central ray should enter one-half inch superior to the lateral malleolus. The technologist should include the lower one-third of the tibia and fibula, the entire calcaneus and all the tarsal bones to the base of the fifth metatarsal in the lateral radiograph. The medial and lateral talar domes should be superimposed and the lateral malleolus should be seen more inferior to the medial malleolus (see Figure 4).

If the talar domes are not superimposed, the lower leg or foot may be rotated or the lower leg may not be parallel to the cassette. The lateral talar dome will appear proximal to the medial talar dome when the proximal tibia is further from the table than the distal tibia. The medial talar dome will appear proximal to the lateral dome if the distal tibia is further from the table than the proximal tibia. Evaluating the height of the longitudinal arch can help determine which dome appears proximal. The navicular bone superimposes over most of the cuboid bone when the lateral dome is proximal and very little of the cuboid bone when the medial dome is proximal.

For the AP oblique projection of the mortise joint, the radiographer should place the patient in the supine position with the entire leg and foot angled 15° to 20°
medially, until the intermalleolar plane is parallel with the cassette. The foot should be in dorsiflexion so that the plantar surface of the foot is perpendicular to the leg. The central ray should be perpendicular to the joint and enter midway between the malleoli (see Figure 5).18

On the AP mortise view, the mortise joint space should be uniform, with the lateral joint space visible and the fibula not overlapping the talus.18,19 When the ankle has been properly positioned, the space between the medial mortise and tarsi sinus (opening between the calcaneus and the talus) should be visible (see Figure 6). The ankle may be under-rotated if the tarsi sinus is not visible, and over-rotated if the tarsi sinus is visible but the medial mortise is closed.23 Widening of the joint space may be due to medial ligament rupture associated with a fracture.19

It is important that the lower leg be parallel with the exam table for proper visualization of the tibiotalar joint space. When accurately positioned, the anterior margin of the distal tibia should be about 3 mm proximal to the posterior margin. When the proximal tibia is elevated, the joint space will appear narrowed or obscured. Elevating the distal tibia makes the tibiotalar joint space appear expanded and demonstrates the tibial articulating surface.21

The radiographer can obtain the 45º medial-oblique projection with the patient supine and with the affected limb fully extended and rotated internally 45º. It is important that the foot remain in dorsiflexion so that the ankle is at nearly 90º flexion. The foot may be supported by a foam wedge. The central ray should pass perpendicularly midway between the malleoli. The resulting radiograph clearly demonstrates tibiofibular syndesmosis and the distal tibia and fibula without superimposition over the talus. For the 45º lateral oblique projection, the patient is positioned the same as for the medial oblique except the leg is rotated externally 45º. This projection is useful for determining fractures at the subtalar joint and the superior aspect of the calcaneus.18

Stress radiographs usually are requested when a patient has suffered an inversion or eversion injury. The patient is placed supine with the injured leg extended and the ankle in dorsiflexion. The radiographer must turn the foot opposite the site of the injury and obtain an AP radiograph with the perpendicular central ray passing midway between the malleoli.18 If the applied stress is too painful for the patient, the physician or orthopedic surgeon may inject a local anesthetic into the sinus tarsi.9 When a ligament has ruptured on the side of the injury, the radiograph will demonstrate a widening at the affected joint space.18

Computed Tomography
According to the ACR, CT is not recommended for initial evaluation of suspected ankle fractures. However, CT has proven to be an effective diagnostic tool in cases of high-energy multiple trauma or when joint effusion is present without a visible fracture on radiographs.25 CT also is frequently used for surgical treatment planning. Haapamaki et al reported that MDCT is superior to radiography in cases of multiple trauma or when complex ankle fractures are suspected.27 Advantages of this modality are that ankle positioning is not critical
Figure 6. Oblique projection of the ankle. The entire ankle mortise joint is seen in profile.

ankle exams required 2 consecutive scans in perpendicular orientations. This technology can produce 3-D images in numerous planes from the raw isotropic data collected in 1 acquisition. The data can be reconstructed to any plane of choice for the reviewer, including axial, coronal, sagittal and infinite oblique planes.

Patient positioning is not as critical because of the ability to reformat the data. This adds to patient comfort and reduces the need for repeat exams. These improvements over single-slice CT reduce the need for sedation of pediatric patients and lower radiation dose to the patient. The protocol for a pediatric ankle evaluation using 16-slice MDCT is 120 kV, 20 to 80 mAs (depending on patient weight), with 0.5 second rotation time, 0.75 mm collimation and 0.75 mm thick sections at 0.5 mm intervals. The raw data are transferred to a workstation for reformatting into 3-D CT images. The entire process of 3-D manipulation of the data set and interpretation of the results usually takes less than 5 minutes.

One study described MDCT as an important tool in evaluating musculoskeletal disease in pediatric patients. Children who are afraid benefit from shorter scan times. The exam is useful for defining the extent of displacement of the physeal component in Salter fractures or displacement involving the epiphyseal plate. Determining the extent of physeal displacement also assists in decisions regarding whether the patient will need internal fixation. Identifying when surgery is needed for Salter injuries is an added benefit of CT because the injuries are associated with growth arrest. CT also can be useful for follow-up to assess the development of deformities or premature physeal closure, compartment syndrome and ligament laxity.

Techniques for manipulating CT data include volume rendering, shaded surface display and maximum intensity projection. These techniques better display anatomic relationships and disease processes of soft tissues in the foot and ankle joints. One report stated that 2-D multiplanar reformatted images most often were used for diagnosis, especially of small fractures. Volume rendering helps depict the relationships between ankle tendons and the bony structures beneath. When a fracture extends to the articular surface, shaded surface display may be used to isolate the fractured surfaces from overlapping structures.

MDCT is useful for postoperative open reduction and internal fixation evaluation. Streak artifacts due to x-ray attenuation from orthopedic hardware have been a problem in the past. The attenuation would lead to
missing data on reconstructed axial images. With 3-D imaging, data reformation into other planes weights the true signal over the randomly distributed artifact, enhancing the true signal and reducing the metal-related artifact on volume-rendered 3-D CT images.28

CT arthrography may be used to delineate cartilage covering and loose bodies within the joint. It also is an effective tool for diagnosing pediatric stress fractures because it demonstrates endosteal bone response, which may otherwise resemble a tumor.29

Atesok et al described the use of intraoperative CT imaging using the Siremobil Iso-C3D (Siemens Medical Solutions, Malvern, Pennsylvania).30 The device is a mobile fluoroscopic C-arm with a specially designed computerized image processing workstation. The C-arm has a motor unit that transports it steadily and continuously over a 190° arc for visualization of a 119 mm area. A set of 2-D fluoroscopic images in fixed angular steps is recorded during this rotation. The images are transported from the C-arm to the hard disk and then to a computerized workstation. Multiplanar CT images and a 3-D reconstruction set are available 5 seconds after scanning. According to the study, surgeons could identify unacceptable reduction and inappropriate position of joint fragments, enabling them to make corrections during surgery instead of having to perform a second surgery.30

CT or MR imaging can determine the extent of a stress fracture and assist with treatment planning and follow-up. CT is less sensitive than MR but is useful for determining the extent of the fracture and when surgical repair is required. A CT scan may show the disruption on the bony cortex and evidence of periostitis.31

Magnetic Resonance Imaging

The usefulness of MR imaging to detect fractures has been debated. Campbell and Warner stated, “MR imaging is exquisitely sensitive for detection of fractures.”33 Remplik et al, however, found no statistical difference in detection of acute fractures of the distal extremities between MR and conventional radiography.32 MR is used to evaluate ligament or tendon injuries associated with ankle fractures33-34 and is an effective tool for evaluating questionable joint stability. Gardner et al found that the appropriate clinical application of MR findings still is unclear because of the debate regarding which combination of ligament injuries results in joint instability.33

MR imaging of the ankle is performed with an extremity coil. The technologist should place the patient in a supine position and the affected extremity in a neutral position. The scan sequences used depend on the pathology in question. Fluid sensitive T2-weighted fat-suppression and short T1 inversion recovery (STIR) sequences may demonstrate effusion. Gardner et al used transaxial T2-weighted fast-spin-echo, sagittal T1-weighted spin-echo, fast inversion recovery and coronal fast-spin-echo imaging sequences. In the study, an MR radiologist used the axial T2-weighted images to evaluate the syndesmotic, talofibular and deltoid ligaments to determine whether the ligaments were intact, partially torn or completely torn.33

MR imaging provides better spatial resolution and specificity than CT for evaluating stress fractures and can detect minor stress reactions on a STIR sequence or fat-suppressed T2-weighted fast spin echo sequence.33 Muthukumar et al suggested a T1-weighted sequence and an edema-sensitive sequence or a T2-weighted sequence with frequency-selective fat suppression for evaluating stress fractures. The authors described the appearance of a stress fracture as a line of low signal intensity on all MR sequences. The most common pattern demonstrated was a fatigue-type fracture demonstrating the fracture line surrounded by an ill-defined zone of edema. When evaluating ankle stress injuries, MR best demonstrates viability, bone marrow response and mechanical stability. MR also is noninvasive, uses no ionizing radiation and can be performed more quickly than scintigraphy.33

Scintigraphy

Scintigraphy, or radionuclide bone scanning, can show a stress fracture 1 to 2 weeks before it may be detected radiographically but the modality is nonspecific.34 Little patient preparation is needed for these exams. Patients are instructed to wear normal clothing, but to remove all metal objects both outside and inside of the clothing so the objects do not cause artifacts that could appear as pathologic conditions on the images. Radioactive tracers are injected and localize in areas of increased osteoblastic activity. The tracers emit gamma rays that are detected with a gamma, or scintillation, camera. The camera transforms the gamma emissions into images that are recorded on a computer or film.

The radiopharmaceuticals commonly used to evaluate bone pathology are technetium Tc 99 hydroxymethylene diphosphonate 99 and 99mTc methylene diphosphonate. The adult dose is 20 mCi (740 MBq) and the pediatric dose is adjusted according to the patient’s weight. The time between injection of the radiopharmaceutical and the bone scan is 2 to 3 hours and the
scan takes approximately 30 to 45 minutes.\textsuperscript{54} Differential diagnoses may include bone infection or tumor.\textsuperscript{7}

**Ultrasoundography**

Ultrasoundography is an effective tool for evaluating bony avulsion at a ligamentous insertion and ankle ligament integrity. It is much less expensive than MR imaging for evaluating the same anatomic region, costing only 19\% of the professional and technical fees charged for MR. Inversion injuries often result in lateral ankle ligament tears, most commonly the anterior talofibular ligament, followed by the calcaneofibular ligament. Additionally, chronic ankle joint instability may result from sprains. The diagnostic accuracy of ultrasound for anterior talofibular tears has been reported to be 90\% to 100\%. Accuracy is lower for calcaneofibular tears (87\% to 92\%) and anterior tibiofibular tears (85\%).\textsuperscript{35}

Three categories have been created for ultrasound classification of sprains. Mild acute sprains result in a normal or slightly thickened ligament. The moderate to severe (partial tear) sprains show an anechoic area where partial interruption in the ligament has occurred and the ligament remains taut on examination. In the complete ligamentous tear, there is a complete avulsion of fibers appearing as a hypoechoic gap.\textsuperscript{36}

Regardless of the modality used, careful elicitation of the patient history and clinical findings are key to image analysis.\textsuperscript{8} Alternative diagnoses to ankle fracture include tendinitis, strain, sprain, claudication, infection and tumor.\textsuperscript{33}

**Classification of Ankle Fractures**

According to Skinner, “The purpose of any classification scheme is to provide a means to better understand the extent of injury, describe an injury, and determine a treatment plan.”\textsuperscript{21} Neither the Lauge-Hansen nor the Weber classification system encompasses all fracture types.\textsuperscript{21} Isolated fractures of the talus, stress fractures and pathologic fractures are some examples that are not included in these schemes.\textsuperscript{20,21} The Salter-Harris anatomic system commonly is used to classify pediatric ankle fractures.\textsuperscript{13} Ankle fracture dislocations may be called bimalleolar when the medial and lateral malleoli are involved and trimalleolar when the posterior malleolus also is fractured.\textsuperscript{21}

**Lauge-Hansen**

The Lauge-Hansen system was created to enable prediction of the mechanism of injury and pattern of ligament injury based on the radiographic appearance of ankle fractures.\textsuperscript{35} The system is based on foot position (pronate or supinate) and the direction of force applied (adducting, abducting or externally rotating) at the time of injury.\textsuperscript{21,37} It was derived after studying cadaver feet placed under different stresses and in different positions. Lauge-Hansen determined that injury to the ligaments and bones occurred in a predictable sequence when placed under a deforming force.\textsuperscript{37} The time at which the deforming force ceases during the injury sequence determines the degree of injury.\textsuperscript{37} The 4 basic mechanisms of injury described by the Lauge-Hansen system are\textsuperscript{21,37}:

- Supination-adduction.
- Supination-inversion.
- Pronation-abduction.
- Pronation-external rotation.

Another type of injury later was added to the system to describe the mechanism for tibial plafond fractures, called the pronation dorsiflexion injury.\textsuperscript{37} A drawback to this classification scheme is the difficulty patients have stating exactly how their foot was positioned at the moment of injury.\textsuperscript{37}

A study by Gardner et al found that of the 59 ankle fractures they evaluated, only 49 fit into Lauge-Hansen categories and that 26 of these had ligament injuries that were not predicted by the Lauge-Hansen scheme.\textsuperscript{33} The authors compared MR images with radiographs to determine the extent of soft-tissue injury in these patients. They suggested using the Lauge-Hansen system simply as a guide for the diagnosis and management of ankle fractures and using MR imaging to evaluate atypical injuries and plan surgical treatment.\textsuperscript{35}

Arimoto and Forrester devised an algorithm based on the Lauge-Hansen system to improve the diagnostic usefulness for radiologists.\textsuperscript{7} They determined that the direction of deforming force could be derived from reviewing the radiograph for the presence and location of a fibula fracture, including its location in relation to the tibial plafond and the direction of the fracture. The medial and posterior malleoli then were evaluated to help establish the type of force applied and degree of injury completeness. The authors claimed that the algorithm helps radiologists accurately diagnose fractures and ligament tears based solely on the radiographic exam even without full knowledge of the mechanism of injury.\textsuperscript{37}

**Danis-Weber**

The more current and less cumbersome Weber classification scheme is based on the location of the fibula fracture and is divided into 3 basic fracture types.
■ **Type A.** An avulsion fracture of the fibula distal to the joint line with the syndesmotic ligament left intact and the medial malleolus either normal or with a shear-type fracture pattern.

■ **Type B.** A spiral fracture of the fibula extending from the joint line in a proximal-posterior direction up the fibular shaft. The tibiofibular joint syndesmosis is usually intact. The medial or posterior malleoli may sustain avulsion fractures or be intact. When the medial malleolus is not fractured, the deltoid ligament may be torn.

■ **Type C.** A fibula fracture proximal to the syndesmotic ligament complex with disruption of the syndesmosis. The medial malleolus also includes an avulsion fracture or deltoid ligament rupture; a posterior malleolus avulsion fracture may be present.

Posterior malleolar fractures also may be classified as the posterior-oblique type, medial-extension type or the small-shell type. One study reported that CT was preferred over radiography for determining the size of a posterior malleolar fracture fragment because the angle of the fracture line is highly variable and the fracture lines often are irregular.

### Other Types of Fractures

Ankle fractures that are not included in the Lauge-Hansen or Weber schemes include fractures of the lateral process of the talus (a common snowboarding injury), stress fractures of the distal tibia or distal fibula and medial malleolus and pathologic fractures.

Lateral process fractures of the talus usually result from an external rotation force while the ankle is in fixed dorsiflexion and inversion. There are 3 basic types of lateral process fractures of the talus:

■ **Type I.** An extra-articular fracture of the anterior/inferior aspect.

■ **Type II.** A nondisplaced simple fragment extending from the talofibular joint surface to the posterior subtalar joint surface. Type IIb helps to differentiate a displaced fragment with the Type II pattern.

■ **Type III.** A comminution of both the fibular and posterior subtalar articulating surfaces. These fractures are best demonstrated on lateral and internal oblique radiographs and CT.

An extra-articular fracture of the talus avulsion is an extra-articular fracture of the talus which is not displaced. It is usually caused by an ankle sprain or an inverting force on the ankle resulting in a tear of the deltoid ligament.

A stress fracture may be partial or complete and is caused by the repetitive application of stress at a level lower than the amount required to fracture the bone in a single loading. Stress fractures begin with an increased rate of osseous remodeling. Resorption and rarefaction follow, and focal trabecular microfractures occur. They can progress to a linear stress fracture and a periosteal or endosteal response. Stress fractures often present with vague, poorly localized and aching-type pain. They are common in sports that cause repetitive load to the lower extremity, such as track and field, distance running, court-based sports and dancing.

Factors that have been associated with the etiology of stress fractures include an underlying medical disorder, lack of flexibility, poor strength or muscle imbalance, rapid changes in athletic training, increased physical activity, failure to wear proper shoes while exercising, diet and artificial training surfaces or switching from one type of training surface to another.

Symptoms usually develop over the course of 2 to 3 weeks, but may occur sooner or last longer. The patient may have localized pain, redness, swelling and warmth and palpable periosteal new bone with reduced mobility in the affected joint. The sensitivity of radiography is only 15% to 35% for initial evaluation of stress fractures and 30% to 70% during follow-up. Whether the stress fracture is detected depends on how much time has elapsed since the injury developed and the type of bone involved. These fractures are easier to detect in cortical bone than cancellous bone.

### Salter-Harris

The Salter-Harris classification system divides injury patterns in skeletally immature patients into types I through V (see Figures 7 and 8). They are described as follows:

■ **Type I.** This is a physeal injury without radiographic evidence of bony injury.

■ **Type II.** Has a fracture line that extends transversely through the physis and exits proximally through the metaphysis.

■ **Type III.** The fracture line traverses the physis and exits distally through the epiphysis.

■ **Type IV.** The fracture line traverses the epiphysis and physis and exits the metaphysis.

■ **Type V.** This is a crush injury to the physis.

Injuries to the syndesmosis are common with ankle fractures and are divided into types I through III. A type I syndesmosis injury presents with normal...
alignment of the ankle and stability is maintained on supine inversion/eversion stress views. A type II appears stable on nonstressed views, but demonstrates widening and instability on stress views. The type III shows widening of the medial clear space and often widening at the tibia-fibula articulation.¹³

**Pathologic Fractures**

Pathologic fractures are caused by bone tumors or osteoporosis and occur spontaneously or with little stress on the bone. Most primary bone tumors are malignant. Osteosarcoma, Ewing sarcoma and chondrosarcomas are some examples of primary bone tumors. Treatment of primary bone tumors often requires amputation or excision, sometimes followed by chemotherapy. Secondary bone tumors usually result from metastatic spread of breast, lung or prostate cancers.⁰⁰

**Treatment**

Several methods are available for managing ankle fractures. Most emphasize the importance of early and accurate reduction of the joint and initiation of joint motion as soon as possible. Jelinek and Porter described the priorities for managing ankle injuries. They stated that the ankle first should be evaluated for adequate blood flow, which is demonstrated by normal flesh color and palpable pulses. Provisional reduction of marked deformity or dislocation should be completed next. This may be performed on site by a trained emergency responder or by a physician in the emergency department. Next, a clinician should care for open wounds or soft-tissue injuries. It is only after these issues have been addressed that precise reduction of skeletal deformity and repair of any associated injuries can take place. Rehabilitation and the
care of potential complications are the final steps in fracture management. Jelinek and Porter wrote that joint mobilization as soon as possible, without compromising the reduction, is key to achieving an optimal functional outcome.15

Others have reported similar management, but specifically that 4 criteria must be met for optimal treatment. The first criterion is to reduce dislocated fractures as soon as possible. Next, all joint surfaces should be restored precisely. The fracture must then be held in a reduced position during the period of bone healing.21 Lastly, joint motion should be initiated as early as possible, although there is debate over exactly when to initiate motion.15

According to Gardner et al, “The first decision to make when treating ankle fractures is whether surgical reduction and fixation are necessary. The most important underlying factor in this decision is whether the ankle is stable or unstable.”9 Bimalleolar, trimalleolar, fracture-dislocations and some isolated fibula fractures that present with more than 5 mm of medial clear-space widening or syndesmotic widening radiographically are considered unstable.10 The integrity of the ligament structures is important for determining overall ankle joint stability. Stable fractures usually are treated successfully with conservative care, but unstable fractures require internal fixation to maintain joint reduction until the fracture(s) have healed.10 A consideration in treating athletes is how rapidly the patient desires a safe return to sports, and surgery often establishes stability sooner. The type of hardware chosen for surgical fixation depends on the degree and type of injuries.13

Approximately 25% of ankle fractures are treated with surgical stabilization each year in the United States.3 When surgery is indicated for treatment, it is best performed as soon as possible to reduce the risk of complications, such as blistering or swelling, and extra costs of an extended hospital stay. One study reported that the total length of hospital stay for patients undergoing surgery within 48 hours of diagnosis was 5.4 days, compared with 9.5 days when surgery was delayed more than 48 hours.4 Surgical risk factors include infection and reaction to the osteosynthetic material used to correct the fracture.5

Patients with stable undisplaced fractures, such as isolated Weber A or B fractures with no talar shift or medial joint tenderness, often are given an ankle brace or elastic support for comfort and are encouraged to fully bear weight immediately.11 A wide variety of hardware is available for surgical fixation. Porter et al reported that they treated Weber A injuries with retrograde intramedullary 4.5mm or 5.5 mm cannulated screw fixation after anatomic reduction.40 Clinicians may choose to follow up patients with these fractures to be certain no talar shift occurs.11

If a fracture is potentially unstable, such as an isolated Weber B or C fracture, the patient’s ankle may be placed in a below-knee back slab to allow for swelling. A back slab has a plaster back that extends from the tibial tubercle posteriorly to the calf, ankle, heel, sole and toes. The slab is left open on top to allow for swelling, but a soft bandage is wrapped around the back slab and anterior portion of the lower leg and ankle to keep it in place. After a 1-week follow-up appointment with imaging of the ankle to ensure adequate positioning of the joint, the back slab usually is replaced with a lightweight cast. Immobilization with no weight bearing for the initial 6 to 8 weeks is required.11

Unstable injuries that require surgical stabilization include bimalleolar or trimalleolar fractures, dislocated fractures and lateral malleolar fractures with deltoid ligament injury, syndesmosis injury or talar shift. Surgery to restore the fibular length and mortise integrity should be carried out as soon as possible or once significant swelling has subsided. During surgery, the syndesmosis is evaluated clinically and with fluoroscopic imaging. When instability of the syndesmosis is suspected, repair may be performed by passing 1 or 2 screws from the distal fibula to the tibia (see Figures 9 to 11).11

Jelinek and Porter described treating Weber B injuries with anatomic reduction and anterior-to-posterior lag screw fixation, and a posterolateral one-third semitubular antiglide plate. They also described stabilizing the fibula for Weber C injuries with a lateral plate and occasionally a 2.7 mm or 3.5 mm lag screw; the plate thickness depends on the amount of comminution and length of fracture. When the syndesmosis remains unstable to external rotation stress the authors recommend placing 1 to 2 cannulated syndesmosis screws (size 4.5 mm) through the lateral fibular plate and across the 3 cortices. They also use these techniques for bimalleolar fractures with additional direct repair of the deltoid ligament, which is achieved with 2 size 1 Vicryl (Ethicon Inc, Somerville, New Jersey) absorbable horizontal mattress sutures in the deep deltoid and 2 size 0 Vicryl sutures in the superficial deltoid.12 Patients should not fully bear weight for 6 to 12 weeks following deltoid ligament repair, at which time the screws are removed.11,13 A below-knee cast is applied and patients are encouraged to elevate the foot to prevent swelling. Some clinicians,
medial malleolar fracture is present. Advantages to this approach stem from the direct visualization of the posterior fragment, which promotes anatomical reduction and better inspection for osteochondral fragments and talar chondral damage. The approach also allows the orthopedic surgeon to clean the fracture of interposed callus or periosteum when surgery has been delayed.41

Open fractures must be treated with debridement, irrigation, antibiotics and internal fixation. Because of the likely contamination of these wounds, intravenous broad-spectrum antibiotics may be required. Complications for these wounds include swelling, infection and soft tissue loss, which may inhibit skin closure over the orthopedic hardware.11

Talbot, Steenblock and Cole described a technique for fixation of trimalleolar ankle fractures.41 They stated that repair of the posterior malleolus is indicated when the fracture involves more than 25% to 35% of the distal tibia’s articular surface. Instead of using the more standard supine approach to access the posterior fragment, they suggested using a posterolateral approach in which the patient is placed in the prone position with a bolster under the ipsilateral hip or in the lateral decubitus position if no medial malleolus fracture is present. Advantages to this approach stem from the direct visualization of the posterior fragment, which promotes anatomical reduction and better inspection for osteochondral fragments and talar chondral damage. The approach also allows the orthopedic surgeon to clean the fracture of interposed callus or periosteum when surgery has been delayed.41

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Treatment of stress fractures includes rest, flexibility exercises and use of nonsteroidal anti-inflammatory drugs (NSAIDs). Return to activity is progressive and usually takes 6 to 12 weeks. A chronic nonunion fracture may require surgery and bone grafting.1
They support the use of a removable brace because patients have been shown to return to normal activity sooner and because, unlike casts, braces do not require special orthopedic services for placement or removal.\(^9\) When physeal injuries occur, however, open reduction and internal fixation may be required to decrease the risk for physeal arrest and enhance articular congruity. Surgery is recommended when displacement is > 2 mm at the articular surface or 3 to 4 mm at the physes after closed reduction or if any rotational or angular deformity is present.\(^1\)

Age is a predictor of outcome. One study determined that patients older than 40 years had a less functional recovery than younger patients. Another study claimed it was more important for elderly patients to recover function of the ankle joint as quickly as possible because bone mass density, proprioception and muscle force already reduced because of their age. Severely dislocated fractures also have a poorer prognosis.\(^5\) Diabetes increases the rate of in-hospital mortality, in-hospital postoperative complications, length of hospital stay and the total cost of treatment for ankle fractures. On average, patients with diabetes are in the hospital 1 day longer than patients without diabetes and incur approximately $2000 more in charges for treatment.\(^3\)

Rehabilitation and Functional Recovery

A wide variety of rehabilitation interventions are available, with the goal of obtaining functional recovery of the joint.\(^2,15\) According to Egol et al, factors predicting functional recovery at 1 year include younger age, male sex and absence of diabetes.\(^10\) A review of current intervention techniques found that there is no consensus regarding which immobilization device works best, when weight bearing ideally should begin or how effective postimmobilization stretching and manual therapy are. This review reported that after surgical fixation, beginning exercise while in a removable brace improved activity limitation but also led to a higher rate of adverse events.\(^2\)

Initial Rehabilitation

Rehabilitative exercises may begin during or following immobilization, depending on joint stability and whether open reduction and internal fixation was required.\(^2,15\) Postoperative rest, use of ice, compression and elevation of the ankle help decrease swelling and reduce pain.\(^15\) Gentle exercise or weight bearing, manual therapy and more rigorous exercise may be prescribed.\(^2,15\) Egol et al recommended bearing weight...
ANKLE FRACTURES

lates strength, decreases risk for muscle atrophy and motion is the controlled ligament stress, which stimulation. They reported that the benefit of early range of motion in patients who had undergone open reduction and internal fixation of ankle fractures allowed for complete and quick recovery of range of motion and decreased the risk of early degenerative joint disease. In their study they used a CPM machine for at least 8 hours a day and overnight. When applied to the treated ankle, it alternated the foot and ankle between 5° of dorsiflexion and 10° of plantar flexion. Over a 2-week period, the passive movements were increased to maximum dorsiflexion and plantar flexion. At follow-up, the authors reported an average of 52° range of motion in patients who received CPM compared with 34° for the control group.

Obremskey et al reported that adult patients make significant improvements in functional return up to 1 year after open reduction and internal fixation. Functional factors they evaluated included mobility, return to daily activities and work and emotional status. Their study suggested that the most drastic improvements are made during the first 2 postoperative months, but significant improvements are made in all areas for up to 6 months. Emotional status continued to improve for up to 1 year. Being more than 50 years of age was related to a worse functional outcome and longer time until return to work, but did not correlate with increased risk for complications in this study. Egol et al also reported their patients had significant improvement in functional recovery with little or no pain after 1 year. Patients who were older than 40 years, had diabetes and were women had delays in healing.

Another study by Egol et al evaluated the time it took for patients to recover braking function with a driving simulator after open reduction and internal fixation of unstable ankle fractures. The authors reported that it took 9 weeks for patients to perform at the level of the control group. Jelinek and Porter described a 3-phase process for postoperative rehabilitation of unstable ankle injuries in athletes. The first phase focuses on soft-tissue inflammation and edema, and emphasizes pain control, decreasing inflammation and restoring of joint range of motion. They proposed placing the patient in a walking boot with a Cryo Cuff (Aircast, Austin, Texas) for cold and compression immediately after surgery. The patient receives instructions to rest, elevate the ankle and use the Cryo Cuff while awake. The patient also is told to perform toe curls, knee bends and leg lifts every 1 to 2 hours to prevent thrombosis. At 1 week following surgery, the wound is evaluated and the physician checks stability on radiographs. Additional activity, such as light biking, range of motion exercises, light resistive tubing exercises and stretching are prescribed. The patient may be told to begin partial weight bearing with axillary crutches, which progresses to full weight bearing in a boot. At about 2 weeks, when the patient can walk without a
Sensory neuropathy, delayed union, loss of reduction of the syndesmosis and infection. Patients with diabetes and those who are elderly often have poorer outcomes. Open and comminuted fractures also have a higher rate of postoperative problems. Prolonged immobilization may cause muscle atrophy, arthrofibrosis, cartilaginous degeneration and bone atrophy. The fear of reinjury may limit patients’ return to preinjury activity levels.

A study by Saltzman et al suggested that proper alignment of the subtalar joint is crucial to long-term strength of the ankle. The authors stated that ankle arthritis is associated with rotational ankle fractures and that it is relatively rare to develop primary ankle osteoarthritis because of ankle articular cartilage properties. Thangarajah et al reported that postoperative infections are more prevalent in patients who smoke or who have had bimalleolar injuries. Superficial infections were treated with oral antibiotics. Patients with a deep infection, diagnosed through microbial confirmation of an organism, were readmitted to the hospital and were treated with surgical washout and debridement, removal of hardware or intravenous antibiotics.

Conclusion

Ankle fractures are common in people of all ages and activity levels and in both sexes. Optimal treatment planning and delivery are made possible through detailed patient evaluation and understanding of the mechanism of injury. Quality diagnostic imaging, including radiography and appropriate use of other imaging modalities, aids in ankle fracture evaluation and management.

References


Limp in the boot, a stirrup brace with an athletic shoe replaces the boot and the biking program is increased to 30 to 40 minutes per day. The brace should be worn for 2 to 6 weeks during all types of activity, then only during athletic activity for 6 to 12 more weeks, depending on the fracture type.15

Strengthening Exercises

The second phase of rehabilitation includes flexibility and functional strengthening with cardiovascular conditioning, proprioceptive training and light sport-specific functional training. Rehabilitation usually begins about 1 month after operative fixation. New exercises may include standing calf stretches, balancing exercises, double-to-single leg calf raises, elliptical exercise and stair-climbing exercise. Resistive tubing exercises also may increase in repetition and include more directions. The patient should use a stair or incline board for the calf-stretching exercises. The balancing exercise program progresses from wearing a shoe to a bare foot on a hard surface and holding for 60 seconds. Soft surfaces or a balance board may be introduced last. Bicycling exercises may be exchanged for elliptical and stair-climbing exercises at this point.15

Return to Normal Activity

The third rehabilitative phase involves a gradual return to sporting activity with maintenance of flexibility and strength and proper body mechanics. This phase usually begins 2 months after surgery. The patient may transition into running exercises once he or she can use a stair-climbing or elliptical machine for 30 minutes, 4 to 5 days a week without complication. The return to running and sport-specific functions should be gradual.15

Regardless of a patient’s age, activity level and underlying disease or conditions, it is important to counsel patients and their families about the expected functional recovery after an ankle injury. By identifying patients who are at risk of delayed or limited recovery, physicians can develop altered care strategies.10

Complications

The risk of complication from ankle fracture depends on injury severity and quality of fracture reduction and stabilization.11,13 Arthritic changes, stiffness, infection, malunion, nonunion, synostosis formation, deep vein thrombosis and thrombophlebitis are common complications. Surgical complications include sensory neuropathy, delayed union, loss of reduction of the syndesmosis and infection. Patients with diabetes and those who are elderly often have poorer outcomes. Open and comminuted fractures also have a higher rate of postoperative problems.11 Prolonged immobilization may cause muscle atrophy, arthrofibrosis, cartilaginous degeneration and bone atrophy. The fear of reinjury may limit patients’ return to preinjury activity levels.15

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References

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Diagnosis and Treatment Of Ankle Fractures

To receive Category A+ continuing education credit for this Directed Reading, read the preceding article and circle the correct response to each statement. Choose the answer that is most correct based on the text. Transfer your responses to the answer sheet on Page 482 and then follow the directions for submitting the answer sheet to the American Society of Radiologic Technologists. You also may take Directed Reading quizzes online at www.asrt.org. Effective October 1, 2002, new and reinstated members are ineligible to take DRs from journals published prior to their most recent join date unless they have purchased a back issue from ASRT. Your access to Directed Reading quizzes for Continuing Education credit is determined by your Area of Interest. For access to other quizzes, go to www.asrt.org/store.

*Your answer sheet for this Directed Reading must be received in the ASRT office on or before this date.

1. The peak age range at which men suffer ankle fractures is _______ to _______ years.
   a. 8; 15
   b. 15; 24
   c. 25; 34
   d. 35; 44

2. _______ separate articulations allow movement at the ankle joint.
   a. Two
   b. Three
   c. Four
   d. Five

3. Posterior malleolar fractures are associated with _______ fractures and are considered to be unstable.
   a. calcaneus
   b. talus
   c. fibula
   d. tibia

4. The _______ ligament stabilizes the medial side of the ankle.
   a. anterior talofibular
   b. calcaneofibular
   c. posterior talofibular
   d. deltoid

5. Because of the risk of neurovascular compromise and skin necrosis, dislocated ankles should be:
   a. left alone.
   b. wrapped tightly in an elastic bandage.
   c. manipulated as soon as possible.
   d. casted immediately.

6. The Ottawa Ankle Rules state that radiographs are appropriate when a patient meets any of the following criteria:
   1. inability to bear weight immediately after injury.
   2. point tenderness over the medial malleolus, on the talus or calcaneus or the posterior edge or inferior tip of the lateral malleolus.
   3. inability to walk 4 steps in the emergency department.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2 and 3

Continued on next page
7. It is likely that a patient with an ankle fracture has multiple injuries based on the _______ principle.
   a. circle
   b. ring
   c. Weber
   d. Salter

8. Stress studies of the ankle can verify the presence of a ligament tear.
   a. true
   b. false

9. For an AP oblique projection of the mortise joint, the radiographer should angle the leg and foot _______º medially and the foot should be in _______.
   a. 10 to 15; plantar flexion
   b. 10 to 15; dorsiflexion
   c. 15 to 20; plantar flexion
   d. 15 to 20; dorsiflexion

10. Stress radiographs usually are requested when a patient has suffered from the following ankle injuries:
   1. inversion.
   2. eversion.
   3. crush.
      a. 1 and 2
      b. 1 and 3
      c. 2 and 3
      d. 1, 2 and 3

11. Multidetector computed tomography (MDCT) is a useful tool for evaluating the extent of _______ of the _______ component in Salter fractures.
   a. displacement; physeal
   b. displacement; metaphyseal
   c. completeness; physeal
   d. completeness; metaphyseal

12. According to the Directed Reading, streak artifacts from orthopedic hardware are less of a problem than in the past because:
   a. all orthopedic hardware now is made of plastic.
   b. magnetic resonance (MR) imaging has replaced radiography and CT.
   c. 3-D imaging techniques reduce metal imaging artifacts.
   d. window leveling overrides artifacts on final images.

13. On MR images, a _______ fracture appears as a fracture line of low signal intensity surrounded by an ill-defined zone of edema.
   a. pathologic
   b. Salter
   c. fatigue-type
   d. trimalleolar

14. The diagnostic accuracy of ultrasonography in evaluating ankle injury is highest for _______ tears.
   a. anterior talofibular
   b. anterior tibiofibular
   c. calcaneofibular
   d. bimalleolar

15. The Lauge-Hansen system is based on the following circumstances at the time of injury:
   1. patient age.
   2. foot position.
   3. direction of the force applied.
      a. 1 and 2
      b. 1 and 3
      c. 2 and 3
      d. 1, 2 and 3

Continued on next page
21. Lateral process fractures of the talus usually are repaired with open reduction and internal fixation when the fracture is displaced by more than _______ cm.
   a. 0.5  
   b. 1.0  
   c. 1.5  
   d. 2.0  

22. On average, patients with ankle fractures who have diabetes are in the hospital _______ day(s) longer and incur approximately $ _______ more in charges for treatment than patients with ankle fractures who do not have diabetes.
   a. 1; 500  
   b. 1; 2000  
   c. 2; 1000  
   d. 2; 4000  

23. According to Egol et al, factors that predict functional recovery of the joint at 1 year include:
   1. younger age.  
   2. male sex.  
   3. absence of diabetes.
   a. 1 and 2  
   b. 1 and 3  
   c. 2 and 3  
   d. 1, 2 and 3  

24. Jelinek and Porter found that early range of motion and weight bearing in athletes who had undergone open reduction and internal fixation led to delayed healing.
   a. true  
   b. false  

20. Open reduction and internal fixation of posterior malleolar fractures is recommended when the posterior fragment is more than _______ % to _______ % of the tibial plafond.
   a. 15; 20  
   b. 20; 25  
   c. 25; 30  
   d. 30; 35  

   a. lateral-to-medial  
   b. medial-to-lateral  
   c. posterior-to-anterior  
   d. anterior-to-posterior  

18. Patients with _______ fractures often are given an ankle brace or elastic support and encouraged to bear full weight immediately.
   a. stable undisplaced  
   b. unstable undisplaced  
   c. stable displaced  
   d. unstable displaced  

17. _______ fractures often present with vague, poorly localized and aching-type pain.
   a. Pathologic  
   b. Salter  
   c. Talus  
   d. Stress  

16. Type _______ in the Weber classification scheme describes a spiral fracture of the fibula extending from the joint line in a proximal-posterior direction up the fibular shaft.
   a. A  
   b. B  
   c. C  
   d. D  

Continued on next page
25. Examples of proprioception exercise techniques include:
   1. weight bearing.
   2. single leg stance.
   3. double leg stance.
      a. 1 and 2
      b. 1 and 3
      c. 2 and 3
      d. 1, 2 and 3

26. _______ may cause muscle atrophy, arthrofibrosis, cartilaginous degeneration and bone atrophy.
    a. Prolonged immobilization
    b. Early weight bearing
    c. Early range of motion exercises
    d. Prolonged use of nonsteroidal anti-inflammatory drugs

27. Ankle arthritis is associated with _______ ankle fractures.
    a. stress
    b. osteoporotic
    c. compression
    d. rotational
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Printed answer sheets are now located after the quiz questions. These can be mailed to ASRT at the address on the answer sheet. See Pages 456 and 482.
Directed Reading Evaluation
Diagnosis and Treatment of Ankle Fractures

10803 - 02 310565

Thank you for taking the time to complete this survey. Your opinion helps us serve you better. Your comments will remain confidential and will not affect the scoring of your Directed Reading (DR) test. Choose only ONE response for each question. Use a blue or black ink pen. Do not use felt tip markers. Completely fill in the circles.

1. What is your primary area of practice?
   - Administration/Management
   - Bone Densitometry
   - Cardiovascular-Interventional
   - Computed Tomography
   - Education
   - Magnetic Resonance
   - Mammography
   - Nuclear Medicine
   - Quality Management
   - Radiation Therapy
   - Research
   - RIS/HIS/Information Systems
   - RN
   - Sonography
   - Other

2. Which of the following best describes the highest educational level you have attained?
   - Student who has not yet taken Registry exam
   - Associate degree
   - Bachelor's degree
   - Certificate
   - Master's degree
   - Doctoral degree (e.g., Ph.D. or Ed.D.)
   - Needed CE credits immediately
   - Other

3. Why did you choose to complete this DR?
   - Interested in the topic
   - Topic pertained to my area of practice
   - Other
   - DR had the right number of CE credits
   - Needed CE credits immediately

4. How relevant is this DR to your practice?
   - Extremely relevant
   - Very relevant
   - Relevant
   - Somewhat relevant
   - Not relevant

5. How beneficial is this DR to your professional or personal development?
   - Extremely beneficial
   - Very beneficial
   - Beneficial
   - Somewhat beneficial
   - Not beneficial

6. How would you rate the level of difficulty of this DR?
   - Too difficult
   - Somewhat difficult
   - Just the right level
   - Somewhat easy
   - Too easy

7. How would you rate the length of this DR?
   - Too long
   - Somewhat long
   - Just the right length
   - Somewhat short
   - Too short

8. Did this DR meet your expectations?
   - Yes
   - No
   - Partially

9. Would you recommend this DR to a colleague?
   - Yes
   - No

10. Overall, how valuable are the Directed Readings to you?
    - Very valuable
    - Considerably valuable
    - Valuable
    - Slightly valuable
    - Not very valuable

If you have comments 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.
Diagnosis and Treatment Of Ankle Fractures

10803 - 02

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A passing score is 75% or better.
Take the quiz online at www.asrt.org for immediate results and your CE certificate.
If you don’t have Internet access, mail your answer sheet to ASRT, PO Box 51870, Albuquerque, NM 87181-1870.
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New or rejoining members cannot take DR quizzes from journals published before their most recent join date unless they purchase access to the DR quiz.

Identification Section

We need your Social Security number to track your CE credits. Please fill in your SSN in the boxes on top, then fill in the circle corresponding to each number under the box. The circles must be filled in accurately.

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Member Information Section

To ensure proper credit please PRINT the following information.

Name ________________________________
Address ______________________________
City ________________________________
State _______ ZIP _____________
Work Phone __________________________
Home Phone __________________________

CE Answers Section

USE A BLUE OR BLACK INK PEN. Completely fill in the circles.

Get immediate Directed Reading quiz results and CE credit when you take your test online at www.asrt.org/DRQuiz.

Note: For true/false questions, A=true, B=false.

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4 ○ ○ ○ ○ ○ 14 ○ ○ ○ ○ ○ 24 ○ ○ ○ ○ ○
5 ○ ○ ○ ○ ○ 15 ○ ○ ○ ○ ○ 25 ○ ○ ○ ○ ○
6 ○ ○ ○ ○ ○ 16 ○ ○ ○ ○ ○ 26 ○ ○ ○ ○ ○
7 ○ ○ ○ ○ ○ 17 ○ ○ ○ ○ ○ 27 ○ ○ ○ ○ ○
8 ○ ○ ○ ○ ○ 18 ○ ○ ○ ○ ○
9 ○ ○ ○ ○ ○ 19 ○ ○ ○ ○ ○
10 ○ ○ ○ ○ ○ 20 ○ ○ ○ ○ ○

No Photocopies Accepted
Study Tests RFID Tag Safety

Researchers in Switzerland recently tested how radio frequency identification (RFID) devices interact with computed tomography (CT) and magnetic resonance (MR) imaging. RFID technology has been used in hospitals to track blood bags, drugs, dispensers and other small containers or documents. The technology also has been used in the design of patient wristbands.

Researchers at the department of surgery at the Hospital of the Canton of St Gallen in Switzerland tested 2 types of RFID transponders by attaching each to a cardboard box and conducting MR and CT scans of the tags. The group was interested in determining potential effects of scanning on the tags’ performance. Even after exposing some tags to 2 hours of 1.5 or 3.0 T scanning, there was no loss of function or data alteration in the RFID tags.

In addition, researchers attached an RFID tag to the skin of a volunteer near the wrist and conducted a scan to analyze image quality and signal loss. The tags resulted in minimal artifacts (see Figure) of a shadowing effect. However, the authors determined that the shadows did not interfere with the diagnostic quality of the images. Finally, the researchers conducted tests to determine whether placement of the tag near a patient’s skin might cause tissue temperatures to rise. They found temperatures increased no more than 1.5º C.

The authors concluded that patients can safely wear the studied RFID wristbands in 1.5 T and 3 T MR scanners. The study appeared in the February 2, 2010, online journal *Patient Safety in Surgery* (www.pssjournal.com).

**Figure.** Qualitative image artifacts. MR imaging findings in a volunteer with the RFID tags positioned on the dorsum of the wrist (A, B) and on the volar aspect of the wrist (C, D). Axial T1-weighted spin-echo MR image (600/13; number of signals acquired, 1; field of view, 90 mm) shows only minimal geometric distortion and susceptibility artifacts on skin and underlying subcutaneous tissue (arrowheads in A and C). Axial T2-weighted Flash 2-D gradient-echo MR image (400/15; number of signals acquired, 2; field of view, 90 mm) shows increased susceptibility artifacts on skin and underlying subcutaneous tissue and tendons (arrows in B and D). Interpretation of articular structures is not compromised. Image courtesy of BioMed Central. Steffen T, Luechinger R, Wildermuth S, et al. Safety and reliability of radio frequency identification devices in magnetic resonance imaging and computed tomography. Patient Saf Surg. 2010;4(2):1-9. www.pssjournal.com/content/pdf/1754-9493-4-2.pdf. Accessed March 31, 2010.
The State of Forensic Radiography

In 1896, Judge Owen E Lefevre of the District Court of Denver, Colorado, became the first U.S. judge to admit radiographs into evidence in a civil case, stating that, “…Modern science has made it possible to look beneath the tissues of the human body, and has aided surgery in the telling of the hidden mysteries. We believe it to be our duty…to so consider it in admitting in evidence a process known and acknowledged as a determinate science.”

The early lead of Judge Lefevre and 20th century courts served as the basis for today’s use of imaging examinations in forensic examinations and as legal evidence. Forensic radiography is more than imaging of human remains or bullet fragments; it is the application of diagnostic imaging technology and examinations to questions of law. In the United States, however, the definition, scope and use of forensic radiography examination results are poorly described (see Box 1). Although radiography is one of the most common scientific methods used to accumulate and analyze forensic evidence, forensic radiography is not recognized formally as a forensic science discipline in the United States.

Forensic Radiography Task Force

In 2007, the ASRT formed a Forensic Radiography Task Force, the purpose of which was to gain recognition for forensic radiography in the United States and to encourage development of continuing education in forensic sciences for radiologic technologists. Representatives of forensic radiography practice and education discussed technologist membership in the American Academy of Forensic Sciences, international recognition of forensic radiography, educational opportunities in forensic radiography and responses to U.S. disasters through regional Disaster Mortuary Operational Response Teams, or DMORT.

The task force members (see Box 2) designed an ASRT Forensic Radiography Survey that was sent to all 720 National Association of Medical Examiners (NAME) members in September 2008. A total of 77 NAME members responded to questions about radiographic equipment and performance, interpretation and quality of radiographic procedures at their facilities. Most medical examiners (88.3% [95% CI, 82.3%-94.3%]) indicated that images were produced at their facilities. The survey results were shared with NAME and distributed to task force members.

In March 2009, task force representatives met with forensic radiographers and educators in the United Kingdom. The U.K. radiographers shared information on equipment, maintenance, documentation, forensic radiography guidelines and protocols and education programs (Connie Mitchell, MA, R.T.(R)(CT), assistant professor and radiography program director, Nebraska Medical Center School of Allied Health Professions; and Linda K Holden, MS, R.T.(R)(QM), RDMS, FASRT, director of radiography department, Western Medical Associates in Casper, Wyoming, written communication, March, 2009).

Task force members met again in October 2009 to discuss suggestions for improving the quality of forensic radiography in the United States and plans to develop an educational framework for forensic radiography. They also guided development of a white paper on the state of forensic radiography in the United States, which has been published on the ASRT Web site.

Scope of Forensic Radiography

Regardless of the current state of forensic radiography in the United States, 1 fact remains clear: the law has influenced medicine, and medicine has influenced the law. Specifically, early
Box 1

Explanation of Terms

The term forensic radiology is used throughout this report rather than forensic radiology to address the work of the personnel who perform the imaging examinations. Radiology refers to the broad field of medical imaging, but radiography refers to the recording or conducting of the examinations. It is common in radiologic and other medical fields to use the term “imaging” to refer to a hospital’s radiology department or the use of radiography and other diagnostic imaging modalities to examine patients. In the forensic sciences field, forensic imaging generally encompasses preparation and examination of all photographic and videotaped evidence and preparing court exhibits vs radiography or diagnostic imaging specifically; therefore, the term is not used and all medical imaging specialties are encompassed under forensic radiography in this article.

use of medical x-rays was influenced when the courts legitimized radiographs as credible evidence and, in turn, radiographs have helped influence legal decisions.1 As a result, forensic radiography is used not only in postmortem study to help determine cause of death or injury,2,3 but also to help identify remains at local medical examiner offices or at the scenes of mass casualties. Radiologic evidence may be used in civil and criminal court cases ranging from fraud to assault. Increasingly, professionals involved in autopsies and identifications rely on use of computed tomography (CT).4,5,6 Performance of these examinations may take place in a medical diagnostic setting or in a forensic pathology setting. For example, most radiographic examinations of the more than 1 million U.S. victims of child abuse each year occur in the radiology suites that support our nation’s hospital emergency departments.7,8 The documentation from these injuries that are performed by radiologic technologists may be used as part of evidence for criminal proceedings, child protection cases or other forms of litigation.9 Reported incidence of domestic abuse likely is much lower than actual incidence among women. Radiologic technologists may not be aware that they are imaging patients who have injuries resulting from domestic violence. Nevertheless, the actions of imaging professionals may be pivotal in identifying injuries and abuse, as well as to the patients receiving help.10 The radiologic technologist produces the images and documentation that create a chain of evidence for these patients.11

Smuggled drugs may be incidental findings when patients who have been assaulted or in motor vehicle accidents are imaged.12 Imaging also has been used to detect other ingested materials and to identify nonballistic material in the body, such as knife blades and needles.13 Functional neuroimaging evidence has been used in criminal cases to support insanity defenses, claims that a defendant was incompetent to stand trial or for pleas of leniency in sentencing; the imaging information is an adjunct to behavioral and clinical data.14

Autopsies can help identify cause of death and trace evidence, pinpoint factors contributing to causes of accidents and provide information for relatives of the deceased on hereditary diseases.15 Radiologic science is used commonly in postmortem autopsies and as part of mass casualty forensic efforts. Examples include human identification, searching for foreign materials in corpses and documenting injuries.16

As clinical use of sectional imaging methods such as CT and magnetic resonance (MR) has increased, many forensic centers have begun to evaluate these technologies as potential tools in postmortem investigations. Worldwide, a small number of centers have adopted protocols that involve routine use of CT and MR scanning at shared mortuary locations. The use of CT has evolved into the virtual autopsy (or “virtopsy”) concept. This involves a complete forensic investigation using CT and MR imaging combined with 3-D reconstruction and postprocessing. The images are taken before the conventional autopsy begins.17,18 Multidetector CT (MDCT) scanners increase volume acquisition of data sets along the same axes, which may be measured in 2 and 3 dimensions. The resulting reconstruction closely resembles standard autopsy.19

Those who use virtual autopsy have stated that postmortem CT is a noninvasive alternative to standard or refused autopsy. An invasive autopsy may be refused by the deceased person’s family, often based on religious doctrine.20 Researchers still are comparing virtual autopsy with standard autopsy results, as well as comparing virtual autopsy to use of standard autopsy plus adjunct CT.21 In general, postmortem sectional imaging is becoming increasingly accepted in the field of forensic pathology.22

MDCT is effective at evaluating projectile entry and exit locations, projectile path and associated tissue injury to characterize penetrating and perforating injuries. The method has limitations compared with clinical application, such as the inability to use contrast to better distinguish among soft tissues and vascular structures.
MDCT usually is performed in the supine position, which can affect projectile tracks and organ shifts. However, the technique is noninvasive and potentially can enhance investigations.24

MDCT can replace radiography in helping to process and identify remains for mass casualty identification. Mobile MDCT units have been used to replace radiography and fluoroscopy; the full-body postmortem scan can be completed in about 15 minutes. Single-body or multiple-fragment bags can enter the scanner unopened if necessary. Technologists can scan the images of deceased individuals and remains at higher resolutions because there is no concern for patient exposure.21

U.S. Forensic Radiography

As of 2004, the U.S. forensic system varied considerably by state, with 16 states and the District of Columbia having a centralized statewide medical examiner system, 14 using a county coroner system, 7 a county medical examiner system and 13 a mixed county medical examiner/coroner system. At that time, 8 states had hybrid systems of coroners and a state medical examiner office that performed medical-legal duties. Forensic pathologists in most large cities serve as medical examiners and pathologists.25

In the ASRT Forensic Radiography Survey conducted in 2008, 88.3% of respondents reported using radiographic equipment at their facilities. Most use fixed radiographic equipment in a dedicated room and a wet processor; others have no access to fixed equipment. A majority of respondents also have access to portable equipment. Nearly 46% have digital radiography equipment on site and approximately 27% have fluoroscopic equipment at their facilities. Only 14% of respondents reported having an on-site CT scanner and nearly 70% reported having no access to CT scanners.7 According to a report from the National Research Council of the National Academies, about one-third of medical examiner and coroner offices do not have the radiography equipment in-house that is necessary to identify diseases, bony injuries, projectiles or identification features in decedents.25

Box 2
ASRT Forensic Radiography Task Force

Nancy Adams, BSRS, R.T.(R), Chairman
Clinical coordinator for the radiography program at Itawamba Community College in Fulton, Mississippi, and x-ray section leader for the Region 4 Disaster Mortuary Operational Response Team (DMORT).

Tania Blyth, MHS, R.T.(R)(M)(CT)
Director of clinical education for the diagnostic imaging program at Quinnipiac University in Hamden, Connecticut.

Dale E Collins, MS, R.T.(R)(M)(QM), RDMS, RVT
Sonographer in Anchorage, Alaska, and faculty member of the University of Arkansas for Medical Sciences medical imaging department, serving as clinical coordinator for the university’s radiologist assistant program.

Linda K Holden, MS, R.T.(R)(QM), RDMS, FASRT
Imaging director at Western Medical Associates in Casper, Wyoming, and chairman of the ASRT Board of Directors.

Linda W Jainniney, BS, R.T.(R)(T), ROCC
Radiation oncology manager at the AnMed Health Cancer Center in Anderson, South Carolina.

Stephanie Johnston, MSRS, R.T.(R)(M)(BS)
Director of the Breast Center of Texoma in Wichita Falls, Texas.

Thomas R King, BSRS, R.T.(R)
Imaging projects coordinator for Salem Hospital in Salem, Oregon, and member of the Region 10 DMORT.

Diane Mayo, R.T.(R)(CT)
Quality assurance coordinator in diagnostic imaging at St. Dominic Hospital in Jackson, Mississippi, and president of the ASRT Board of Directors.

Connie L Mitchell, MA, R.T.(R)(CT)
Assistant professor and radiography program director at the University of Nebraska Medical Center in Omaha, past president and chairman of ASRT, and member of the Mass Fatality Committee of the Omaha Metropolitan Medical Response System.

James B Temme, MPA, R.T.(R)(QM), FASRT
Associate director of radiation science technology education at the University of Nebraska Medical Center in Omaha and president-elect of the ASRT Board of Directors.
Staffing and Personnel Qualifications

Among duties of forensic pathologists is employing and often interpreting radiographs.\textsuperscript{25} When asked “who performs imaging at your facility” in the ASRT Forensic Radiography Survey, 44.1\% of respondents reported that a forensic lab assistant performs this task. Approximately 34\% stated that a registered radiographer conducts their imaging examinations.\textsuperscript{7}

Postmortem examinations are conducted on deceased patients, which eliminates concerns for patient safety. Still, positioning, imaging protocols and techniques must be considered for all forensic radiography examinations. Training and experience in these matters help ensure that examinations are of a quality high enough to allow examinations’ admission as solid and convincing evidence.\textsuperscript{8,9,10}

Personnel safety also is a consideration. Personnel should be protected when necessary and their exposure should be monitored through badges and dosimetry reporting. The person conducting an examination must know basic information, such as where a primary x-ray beam travels when positioning a C-arm so that the bulk of radiation is absorbed by a primary barrier.\textsuperscript{6} The ASRT Forensic Radiography Survey revealed that nearly 36\% of respondents produce radiographs in a room that is not dedicated to radiography and structurally shielded with lead walls or equivalent shielding. In addition, nearly 15\% of respondents reported that they do not have a radiation safety program that includes personnel monitoring via badges and regular reports; 10\% of respondents said they do not have radiation protection devices, such as lead aprons, available.\textsuperscript{7}

It is likely that CT and MR imaging will be used increasingly in the forensic setting.\textsuperscript{8,9} These imaging modalities are complex in nature and specific curricula and specialty certifications are available in the radiologic science field to accommodate training in the principles, physics and instrumentation involved in use of these advanced imaging technologies. Each also requires particular safety considerations.\textsuperscript{26} The equipment is sophisticated; a mobile CT scanner involves interaction of electrical, mechanical and ionizing radiation systems. CT scanning at the site of a disaster can greatly improve victim identification but those conducting the examinations must understand issues such as x-ray tube cooling and slice thickness.\textsuperscript{27} For their own safety, they also must understand the principles of radiation protection. National and international accreditating organizations support the certification of all personnel who operate CT equipment.\textsuperscript{28}

MR scanners present safety issues to patients and personnel, and their use requires extensive attention to site design and access control. If non-MR personnel enter restricted areas with ferromagnetic objects or equipment, the high-strength magnet housed in the scanner can violently pull objects into the equipment’s bore, causing injury to personnel and major equipment damage. Accidents can occur even when the magnet is not in use.\textsuperscript{29}

The ASRT continues to emphasize the importance of establishing minimum standards by the federal government for personnel who perform medical imaging exams and deliver radiation therapy treatments through support of the Consistency, Accuracy, Responsibility and Excellence in Medical Imaging and Radiation Therapy (CARE) bill.

Personnel Training and Education

The United States lags behind many other nations in forensic radiography education. Preliminary data from the Bureau of Justice Statistics’ crime laboratory census reported that the training and continuing education budgets of the United States’ 50 largest laboratories were less than one-half of 1\% of their total budgets. According to the National Institute of Justice (NIJ), a shortage of qualified personnel, as well as funds to educate personnel, is one of the largest challenges facing the forensic community regarding death scene investigations.\textsuperscript{30}

For the majority of personnel performing forensic radiography exams in medical examiner offices, there is no formal education program for radiography. With the exception of facilities that cooperate with affiliated radiology departments that employ registered technologists, many medical examiner and coroner offices use forensic or morgue assistants to conduct their radiographic examinations. These staff members usually are trained on the job for laboratory and radiography duties and the training varies from one location to another.\textsuperscript{2,30}

There is little formal forensic radiography education in the United States for radiologic technologists. There is some course work, such as courses offered at Quinnipiac University in Hamden, Connecticut. Quinnipiac courses include scope of forensics, preservation of evidence, identification and presence of trauma or child abuse. Currently, students can earn up to 7 credits in forensics as part of their work toward a bachelor’s degree in radiologic sciences (Tania Blyth, MHS, R.T.(R)(M)(CT), clinical coordinator for diagnostic imaging, Quinnipiac University, oral communication, Oct. 23, 2009).
Global Perspective

The United States lags behind Europe, Australia and Japan in forensic radiography. Other countries have more education and use more advanced forensic technology. There are only 2 departments or institutes specific to forensic radiology for physicians in the United States compared with 100 to 150 such institutes in Europe.²⁵

The International Association of Forensic Radiographers (IAFR) was formed in the United Kingdom in 1998 to “promote best practice in forensic radiography through education, training, research, communication and coordination of forensic radiography both in the United Kingdom and internationally.” The IAFR is recognized as a global leader in promoting and developing forensic radiography. Most IAFR members have clinical backgrounds and some have been involved in imaging at national and international incidents. The IAFR has established a systematic process to ensure that a response team is available to provide forensic radiography services in large-scale disasters without draining local resources.³¹

Nearly all forensic radiography of live patients in the United Kingdom occurs in National Health Service (NHS) hospitals. Much of the postmortem radiography occurs in mortuaries attached to NHS hospitals, so it also largely is performed by registered radiographers (Mark Viner, MSc, FCR, Fellow of Cranfield University Forensic Institute and senior manager at Barts and The London Hospitals, London, England, written communication, December 2009).

In 2008, the Society and College of Radiographers (SCoR) and IAFR produced the Guidance for Radiographers Providing Forensic Radiography Services as an in-depth outline for all U.K. radiographers and radiographic facilities to follow regarding forensic examinations.³ To ensure continuity, the SCoR and IAFR guidelines provide standard definitions and specify involved modalities, including digital and analog radiography, dental radiography, fluoroscopy, CT, MR, ultrasound and nuclear medicine. SCoR and IAFR guidelines also emphasize the need for prompt imaging services and provide recommendations on location of postmortem examinations.³,¹⁵,³²,³³

Only “specially qualified persons” can perform an examination on a body.¹,³² The SCoR and IAFR guidelines name medical imaging professionals with forensic training as “the most appropriate professionals to undertake forensic radiography examinations.” All radiographers interested in working on forensic cases must maintain clinical competence and be a member of an organization such as SCoR or IAFR.³

Conclusion

With the advent of virtual autopsy and increasing reliance on radiography in forensics, it is clear that more evidence, collaboration and education are needed.²⁵ The time has come to increase awareness of forensic radiography as a formal tool in the forensic investigator’s arsenal. With this in mind, the ASRT suggests the following:

■ Begin efforts to improve awareness of the use, scope and value of forensic radiography within the radiologic and forensic science fields.

■ Improve collaboration among the diagnostic medical imaging and forensic pathology communities.

■ Address the education of personnel performing forensic radiography.

The ASRT white paper on forensic radiography is a good first step toward improving awareness and collaboration. The ASRT also has prepared an educational framework that provides gap analyses for those involved in forensic radiography and to guide educators who prepare personnel in forensic and medical settings. The framework has been reviewed by a group of educators and is in draft form for public comment. To begin addressing continuing education needs, a Directed Reading on forensic radiography was published in the March/April issue of Radiologic Technology.

Other suggestions may take time to implement because of the complex system under which our medical and legal systems interface. Ultimately, the goal is to raise the level of quality of forensic radiography in the United States. More than 100 years after Judge LeFevre entered x-rays into evidence, questions remain as to how experts and jurors interpret what the images may demonstrate,¹ but the information radiologic technology can produce in the hands of a skilled operator is no less critical or dramatic.◆
References


PACS: Past, Present and Future

As Dundas stated, the picture archiving and communication system (PACS) continues to evolve as a new and exciting frontier in radiology with its ability to store a digital image and allow access to previous images for comparison. From small rural settings to large urban areas, PACS is a common term. According to Ranahan, the effectiveness of a PACS system depends primarily on who plans and uses the system. Although the transition to this new digital environment is quite complex, a literature search indicates that facilities value their PACS and believe the conversion is worth the time, effort, expense and learning curve.

This article reviews the important contributions, challenges and benefits of PACS and provides historical and practical information for radiologic technologists who work with PACS on the job or anticipate PACS purchases or installations.

Literature Review

An electronic search was conducted using the PubMed and Cumulative Index to Nursing and Allied Health Literature databases. The inclusion criteria were articles that focused on PACS and were published in the past 5 years. Articles that were nonspecific were excluded. There are many and varied aspects to PACS; this literature review focused on the most recent literature on common current topics to produce the most current information rather than a complete history. Key search terms included “PACS and future,” “PACS and hospitals,” “cost and PACS and installation,” “software and PACS conversion,” “PACS issues,” “DICOM and PACS,” “PACS installation” and “PACS and digital dashboard.” This search generated more than 100 articles. Seventy-four articles were discarded based on the exclusion criteria, which left 24 articles for the literature review.
Before PACS, the typical radiology department or imaging center was filled with view boxes, film, file rooms, darkrooms and reading rooms. These facilities often had view boxes in the hallways to make room for more exam rooms or equipment in the reading areas. PACS has generated space and cost savings while increasing revenue and readability. The installation of a modern PACS has helped decrease patient turnaround time and led to improved patient care by generating exam reports faster.¹

Dundas believed that converting to a PACS confers many benefits,¹ considering that analog film is outdated and facilities using film-screen radiography are increasingly rare. Because manufacturers have lowered the cost of these systems, installations have increased even in rural areas. Statler found at Mercy Medical Center in Des Moines, Iowa, that the benefits of PACS integration were the ability to immediately attain images and eliminate film storage.⁷

While evaluating film-screen radiographs vs PACS for readability, Roos et al found that the technical factors of a film-screen radiograph did not contribute to errors in radiologist interpretation.⁸ Regarding diagnostic time, Dundas and Weiss stated that the hard-copy method of image interpretation was comparable to interpretation with PACS, depending on the radiologists’ experience with both film and PACS.¹³ Radiologists’ ability to manipulate PACS images can aid in interpretation.⁶

Disadvantages

Although PACS is evolving into a more user-friendly system, the challenges are becoming more evident. While possessing many benefits, PACS has some questionable attributes. Paskins and Rai discovered that digital dictation and teaching files added to storage needs, which could compound PACS issues. They reported that compared with hard-copy images, which generally were readily available, the main disadvantages of PACS were the digital image file access speed and the system’s susceptibility to crashing.

Challenges to clinicians who work with PACS include time management, communication skills and image interpretation. When a physician is hurrying to the emergency department, words heard from another physician may slip his or her mind and the images just read may be mixed up with a similar case from the day. According to Mates et al, this scenario is not unheard of in busy departments.⁹ Other communication issues have included faxing reports and reassurance that the report has been received and read.

Prepurchase Considerations

Cost

A common rule with PACS is to set aside approximately 15% of total radiology department revenue per year for upgrades and maintenance and to maintain an adequate service contract with PACS manufacturers.⁸ To justify spending for PACS, many purchasers demonstrate how these costs may be offset. Statler identified a savings of $100 000 annually from eliminating film processing and storage.⁷ In 2003, Advocate Christ Medical Center in Oak Brook, Illinois, invested $4 million dollars in a PACS and spent $330 000 to maintain the system. Before the PACS, Advocate employed 30 librarians to catalog images, but reduced that number to 6 after the PACS was installed.⁷ According to Roos et al, the need for fewer employees attributed to the decrease of $490 000 in labor costs for 2003.⁸

Installation

Before installing a PACS, radiology departments should carefully assess existing physical space and capital infrastructure. If a facility requires new construction to house the PACS, optimal space for future upgrades must be considered and incorporated into the plan. The cost to change cabling and modify computer rooms dramatically increases the cost of PACS installation for some facilities.¹⁰ It can be easier to construct new, dedicated PACS reading rooms and computer rooms rather than to modify existing rooms. Many hospital employees believe that when a PACS is installed, the reading rooms, file rooms and other storage areas disappear. In fact, these areas remain but require less space because of their decreased use.

Electrical systems often require upgrading from 110 volts to 220 volts to power PACS servers and data rooms; in some instances, an isolation transformer is required. The additional electrical systems required to power PACS and servers increase the temperature of a PACS equipment room. Installing a dedicated air conditioning system can counter the heat produced by the PACS personal computer (PC). The PC can emit 600 watts, which is comparable to the heat discharged by a hair dryer. Keeping the room at a moderate temperature with low humidity helps ensure optimum performance and minimizes premature equipment failure. In addition, a nonsparking port should be installed in a surgical suite to prevent the risk of fire from flammable gases.

Facilities now use specific lighting controls, including a dimmer, at viewing workstations. These controls allow for partial or complete darkness to enhance
readability on PACS monitors or full light for cleaning staff. Radiologists need telephone lines at reading workstations and data ports are necessary at computer terminals in hospital hallways. The workstations and ports allow access to the PACS through wired and wireless devices, such as smart phones. Proper advance planning can minimize these costs and reflect a well-conceived installation or upgrade to PACS.7,10

Staff at facilities installing a PACS also must consider the data connection to the server because transferring digital image information requires a large bandwidth. The cabling needs to increase to accommodate a newer PACS setup and diagnostic imaging studies with multiple images. Typically, category 6 cabling has been installed to transfer images and information at a faster rate. Computers with CD burners allow patients to take their images with them. Facilities also should consider the need to import CDs that patients may supply.11

Successful Implementation

Lepanto et al found that a PACS was beneficial only when the dictations per radiologist increased or remained constant, which kept revenue level.13 In one study, a report turnaround time before PACS installation of 3.7 days was reduced to 2.6 days immediately after PACS installation and dropped to 1.5 days at 1 year after installation.7 A combination of appropriate training, a smooth conversion and ongoing PACS management is necessary to ensure efficiency and success.

Training

The success of a PACS depends on the training its users receive. Proper training ensures a smooth conversion and makes future upgrades and technological advancements easier to implement.1 Radiology departments are more efficient and more thorough with PACS after the initial training phase, according to the literature.1 7 Therefore, training should be continuous for PACS users.

Dundas suggested that the PACS installation process should involve training all appropriate hospital staff, not only radiology department staff. When the Baltimore Veterans Administration Medical Center in Maryland installed a PACS, the steps required from the initial radiology order to the final report were reduced from 59 to 9 because of the PACS.8

Paskins and Rai surveyed 4 hospitals regarding a group of rheumatology physicians who were not yet using PACS.5 A 5-point Likert scale showed common results among the hospitals. Out of 100 respondents, 50% stated that they had not been trained on PACS. Sixty percent of those respondents stated that they had not been offered training. In addition, 85% often were unable to retrieve data, 75% believed that PACS was responsible for clinical delays and 70% found that patients had to be brought back to the radiology department because their images were inaccessible on PACS.6 The top 2 disadvantages of PACS were poor reliability and image access. Mates stated that these issues would have been less severe if the referring physicians had been properly trained.7 Weiss found that the most important people to receive training on PACS were the end users.5 The usability of the system was found to be only as effective as those trained.

Conversion to PACS

Once the staff and leadership of a facility decide to implement PACS, a PACS administrator, or appropriate designee, is responsible for planning the installation. During the transition, workflow must be redirected to ensure images are available at all times. The PACS administrator should work with radiologists and managers to create and implement a contingency plan in the event an image is lost. It is imperative to back up all historical images and data before going live with PACS.

A PACS installation can take several months to complete. Department personnel should be aware that many departments may be affected by this transition. Once images are acquired primarily through digital radiography or other digital modalities, they are sent to a database management system, or servers. This system stores and archives the images, which then can be sent to workstations or burned on CD-ROMs. A local area network (LAN) connects stations throughout a hospital or through high-speed phone lines to remote sites.14

Because everyone involved at the Baltimore VA Medical Center conversion had their own schedules, Roos et al found that the best approach was to assign a separate project manager with the sole responsibility of installing and coordinating the system.8 The project manager coordinated the installation with input from representatives of all disciplines. A cardiologist, orthopedic surgeon, neurologist and hospital administrator also were involved. Dundas and Amor found that hiring external consultants helped ensure a smooth process.1,5 External consultants handled the planning and business details and addressed the hardware needs.

One study compared 100 radiology patients in a PACS setting vs a non-PACS setting.11 According to Zacharia et al, the PACS turnaround time and the time

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from image capture to image interpretation status were significantly less for the PACS facility.\textsuperscript{11} The authors found that the PACS facility had a turnaround time of 3 hours and 40 minutes compared with a non-PACS facility time of 25 hours and 19 minutes.\textsuperscript{11}

**PACS Responsibility**

Each PACS installation is customized and requires that a number of people participate to optimize the installation process and minimize errors. Although a hospital’s information technology (IT) department generally is responsible for the PACS, departments such as clinical (biomedical) engineering also may oversee aspects of the system.\textsuperscript{1,15} Errors can occur between local and remote servers if IT and clinical engineering departments do not coordinate their efforts effectively. Amor found that communication gaps decreased when responsibility was combined.\textsuperscript{15}

**PACS Today**

As PACS becomes more common in practice, its influence spreads. For example, mammography traditionally required a designated hard-copy workstation even after some PACS installations. This practice is changing, largely because of increased use of digital mammography and higher-resolution monitors.\textsuperscript{6}

In studies such as the one by Zacharia et al, which involved 100 patients, increased film retrieval rates and efficient image interpretation were only a few of the reported benefits of PACS.\textsuperscript{14} Technology upgrades, such as the digital dashboard, digital imaging and communications in medicine (DICOM) and radiology information systems (RIS) have helped PACS users become more efficient.\textsuperscript{2,9,16} The proven challenges and benefits of the technology are summarized below.

**Radiologist Workstations**

The modern setup for radiologist workstations comprises 2 side-by-side monitors at about a 30° angle to each other. Mates et al observed that monitors normally are positioned vertically, although some radiologists prefer a horizontal orientation.\textsuperscript{7} If the radiologists’ eyes move away from the image in the middle of a read, their eyes must readjust to another light source. This can lead to errors in interpretation when the radiologist returns to the initial image. Thus, the fewer times a radiologist looks away from the screen, the fewer mistakes are made in diagnosis.\textsuperscript{5} PACS manufacturers have resolved this problem by streamlining the user interface. By reducing the drop-down menus, which are common in a Windows environment, they decreased the readers’ need to readjust their eyes. Nourmeir found that these changes increased efficiency and accuracy.\textsuperscript{12} Some radiologists also prefer a lower-resolution monitor next to the 2 high-resolution monitors for reading text and other tasks.\textsuperscript{5}

**Software**

Manufacturers and users continue to work on developing systems with nonproprietary software. Software that was not specific to a manufacturer benefited Mercy Medical Center. The facility wanted to ensure that the chosen PACS would be compatible with existing or future software and computer systems. Statler suggested that using matched software with a common language allows images to be viewed anywhere in the world.\textsuperscript{7} The same images also can be distributed and viewed on several monitors in digital format. For example, because Mercy is in an urban setting, its outlying clinics could transfer images to be evaluated via teleradiology. A wireless PACS also was installed in the hospital. Health Insurance Portability and Accountability Act (HIPAA) regulations and Joint Commission compliancy were not concerns because only authorized users can access images and all users are monitored.\textsuperscript{7}

**Web-based Applications**

Web-based applications support remote image viewing by allowing radiologists to access information and images on a computer from a remote location to answer questions or review a case (vs make a final interpretation). Mates et al upgraded their hospital information system and integrated a PACS, which solved communication and reporting problems. The application allowed staff to open the patient’s chart, files and images to assist with diagnosis. The data remained tied to the patient’s unique identifier in the electronic record with text boxes that could be filled in with the appropriate information during dictation.\textsuperscript{9}

The Windows-based application operates on the existing Web-based PACS. A Web-based viewing program provides resolution approximately one-third that of in-house PACS monitors. Although a Web-based system is one-tenth the cost of PACS, it has significantly decreased results. A positive aspect of this system is that any of the imaging stations, either in-house or at a remote site, can display remote files and folders. Although many users may manipulate PACS images throughout the hospital, a dedicated server handles the workload. Because the workflow does not slow the
system, it seamlessly communicates through the dedicated server. In addition, Paskins and Rai believed that the processing power of a PACS can be maintained by using a read-only computer incapable of performing complex tasks.

Database Searches

Morgan and Chang described a comprehensive database research tool that helps improve turnaround time for PACS searches by using keywords. The method involves researching information, such as a particular tumor and images, that is relevant to a keyword that appears on the screen. The authors compiled different patient lists in PACS and those who were seen on an outpatient visit would not come up in the general list that contained only inpatients. The 2 lists and searches then were combined for a better match. Classifying and describing the cases during dictation led to more accurate search results.

DICOM

DICOM is the standard for distributing and viewing medical images used by most imaging equipment manufacturers. The primary difference between a DICOM image and any other image format is that DICOM images contain patient-specific information and other pertinent information referred to as a header. This technology helps with dictation, transcription and the ability to verify information. The National Electrical Manufacturers Association (NEMA) created DICOM to improve the compatibility and workflow efficiency of imaging and information systems. To view the images, a common PC must contain a dedicated DICOM browser. These browsers are expensive; however, free alternative browsers are available online for small clinics and physician offices. Generally, these DICOM browsers are classified for viewing, teaching and serving as mini-PACS servers. Each browser must be chosen for a specific purpose to avoid errors.

Marcus et al stated that the DICOM standard has image file formats, data transport, printing and querying specifications. Most PACS systems are entirely DICOM based. PACS uses Health Level 7 (HL7) to generate images. The HL7 and DICOM integrate for faster and more precise communication. The DICOM eye is a specific software format that converts images from other file formats (eg, JPEG or BMP) into DICOM format. It also supports converting video to images so that DICOM-compliant equipment can send images or information through Internet and intranet servers. To maintain efficiency, the system keeps the images in a digital format. Integrating PACS and a DICOM standard when entering information into a patient’s electronic record ensures that the order number and patient name are copied electronically to all images, which reduces the possibility of mislabeling images.

Digital Dashboard

Faster scanners and more detailed images have made the PACS efficient but more complex because radiologists are expected to read images with fewer errors in dictation. A cluttered screen can lead to errors and missed studies, but the digital dashboard is helping solve this problem.

This technology includes a control panel that brings to the radiologist’s attention the status of processes running, open cases or cases that still are being dictated. For example, if a case is not closed within a specific amount of time, an alert sounds to notify the physician currently reading at that monitor. Digital technology for the dashboard allows a person to monitor many different components on 1 screen and set alarms to notify physicians when an emergency case arrives in the system. The real-time aspect of this approach optimizes radiologist efficiency and helps prevent them from overlooking critical and timely studies.

The dashboard also can monitor a radiologist’s unsigned reports and nondictated cases to help manage workflow. A dashboard aids departments in managing priority cases. This can help ensure that certain critical areas of care, such as the intensive care unit and emergency department, receive the appropriate priority from digital voice recordings. In addition, a link to a Web site or conference information can be included in a patient’s PACS file. This further enhances a radiologist’s ability to pass along useful information to a colleague who interprets studies of the same patient in the future. To save time, radiologists can select predetermined statements from a drop down-menu of common annotations and notations. The name and credentials of any physician who modifies the exam are electronically stamped on the image, which ensures consistent reading and evaluation of images. Mates et al observed that this feature also aids in education.

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After the technologist completes the examination, there is an option to annotate or make changes postprocessing that go into the patient’s folder before the radiologist interprets the images. These features may include digital annotation of thumbnail images and insertion of digital voice recordings. In addition, a link to a Web site or conference information can be included in a patient’s PACS file. This further enhances a radiologist’s ability to pass along useful information to a colleague who interprets studies of the same patient in the future. To save time, radiologists can select predetermined statements from a drop down-menu of common annotations and notations. The name and credentials of any physician who modifies the exam are electronically stamped on the image, which ensures consistent reading and evaluation of images. Mates et al observed that this feature also aids in education.

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The dashboard also can monitor a radiologist’s unsigned reports and nondictated cases to help manage workflow. A dashboard aids departments in managing priority cases. This can help ensure that certain critical areas of care, such as the intensive care unit and emergency department, receive the appropriate priority from
radiology. The key to the dashboard concept is optimum design, with some software offering customization for individual radiologists.  

Surgical Suite

When hospitals adopt PACS, the surgical suite often is one of the last departments to implement the technology. Yet surgeons can benefit from PACS through immediate access to images that show pathology and previous studies while the patient is under anesthesia. The blending of modern technology with a critical clinical department has shown the full capabilities of PACS. The St Mary’s/Duluth Clinic (SMDC) Health System in Minnesota comprises 4 hospitals and 20 clinics. SMDC decided to install a PACS in the operating suite, which generated concerns, such as the type of monitor displays and how to make the environment physician friendly.

Dallessio observed that by recruiting a member from every surgical department, the surgeons collectively decided monitor number, size and placement. Portability and a 40-inch monitor were necessary for the surgeons, so they integrated 2 solutions. A mobile cart with 2 monitors measuring 19 in each provided portability and a large 40-in monitor was fixed to the wall with a bracket that could move 3 ft in any direction. The large monitor offered other staff in the room the same view as the surgeon, which made the PACS monitor a teaching tool. The upgrade also helped the surgeon be more attentive to the patient instead of looking away at view boxes. A PACS system trainer was available for the first few months to ease the transition.

The SMDC Health System upkeep was relatively inexpensive. Software upgrades came with the system and SMDC secured a 24-hour service contract with a guarantee to replace any faulty monitor. The operating suite proved to be a suitable PACS environment with the right planning. Dallessio reported that having the appropriate staff on hand to identify and solve issues made the PACS environment a welcome addition to the operating suite.

Portability

Modern PACS stations can be portable while maintaining high transmission speeds. For example, a physician can view an image on a portable device, such as a smart phone. Although these images are not diagnostic quality, they are of high enough resolution for an initial read. Weiss found that since image reading has become portable, its ease of use allows immediate consultation with other physicians or staff and the patient, when appropriate. Because time is crucial in emergencies, some personal digital assistant (PDA) companies have interfaced Web-based technology that allows access to PACS images. Kim et al reported that PDAs can bypass a PACS network that is down by allowing a user to take a picture of the screen at the modality workstation. Although this can distort the image, it may be acceptable for a first read in an emergency situation. The attending physician in the emergency department can pull an image from the workstation and screen capture the image. This image is compressed in a multiresolution format and transmitted to a remote physician, who decompresses the image on a PDA and reviews the same image as the on-site physician. The user interface for the PDA supports PACS options such as image magnification, contrast adjustment and rotation. Special algorithms encrypt the images to ensure HIPAA compliance.

Confidentiality

As mentioned, adhering to HIPAA regulations is a concern when a facility implements and uses PACS. Liu et al explained that a more accurate and complete log file can be created by using separate servers for each PACS data set, from images to patient information. If the PACS administrator tries to enter new images, an error message appears. This also is true if a technologist at attempts to change patient accession numbers or date of birth. The technology has advanced to recognize each individual’s role in the PACS environment. If an error occurs or suspicious activity is recorded, the system alerts the user and administrator. The more sophisticated PACS detect intrusions by recognizing commands as a flowchart and make decisions without any unnecessary error messages.

Manufacturer Support

PACS manufacturers provide support forums with almost instant answers to questions. To get the most value from an application, the PACS administrator can go online and find answers. A busy forum, according to Nagy, does not necessarily mean a problem system. An active forum shows the manufacturer’s commitment to a successful PACS system. The best systems also have helpful documentation that is written from the user’s point of view.

The Future of PACS

Weiss stated that although the past standard of PACS transmission was megabytes (MB) per second, the terabyte (TB) per second generation is here. Approximately...
Integration with RIS

By integrating PACS and RIS, radiology departments can decrease turnaround time for patients and their exam results. If the systems do not communicate properly, the result can be down time, a problem a facility must address in advance. For example, at one facility, accession numbers and medical record numbers were not attached properly, which slowed down the radiologists’ ability to read studies and required reworking the information. The root of the problem was that the PACS and RIS communication were out of date. The hospital addressed the issue by finding a manufacturer that accommodated off-the-shelf servers and other equipment and integrated RIS and PACS.

By integrating the systems, the hospital freed money for other aspects of the process. They increased the number of reading stations from 7 to 12 and added a dedicated server that allowed remote access to the PACS for community outpatient centers. Online storage capacity also increased from 0.5 TB to 2.5 TB with the potential for 5 TB, which allowed viewing data from the entire information record, not just the preceding 4 months. The efficiency and image retrieval of the new system were out of date. The hospital addressed the issue by finding a manufacturer that accommodated off-the-shelf servers and other equipment and integrated RIS and PACS.

The integration increased speed and efficiency and decreased labor. The faster the computer system, the sooner patients’ diagnoses are available.

Voice Recognition

Hospital systems and manufacturers continue to test true integration of voice recognition systems. Main Line Health in Pennsylvania added Powerscribe (Nuance Corporation, Burlington, Massachusetts) to its PACS. The voice recognition system reduced typing by radiologists and increased workflow. Radiologists went through 7 weeks of training as the system recognized specific speech patterns and were allowed to opt for self-editing or using a transcriptionist. The system reduced report turnaround time to 3 hours compared with 23 hours average time before voice recognition was implemented. Costs also decreased because Main Line Health reduced the number of transcriptionists from 12 full-time positions to 5 part time. According to Schildt, Main Line Health has saved approximately $500 000 per year since adopting this technology.

Conclusion

Several factors help overcome the challenges of purchasing and implementing PACS. Managers and radiologic technologists who consider a PACS purchase should focus on several key aspects and pieces of advice offered by current PACS users. When the hospital deliberates the purchase, staff should weigh the benefits and costs. The installation process must be planned thoroughly to ensure adequate space and infrastructure for the entire system.

Training PACS users is critical to success because involving hospital-wide users decreases the learning and adoption curve. It also is important to purchase open technology that is compatible with existing PACS or open to future upgrades. Most modern computers can display PACS images, but radiologists must have a reading room with high-resolution monitors.

While solving PACS issues, radiologic technologists and other implementation staff should consider technical and workflow issues to offset a possible work force decrease. Although a rough road ahead is expected when initiating the PACS process, with proper planning and foresight the benefits from this innovative technology are more than worth the effort for most facilities.

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Ensuring Quality and Safety

The recent hearing on medical radiation before the U.S. House of Representatives Energy and Commerce Committee’s Subcommittee on Health and the public meeting of the Food and Drug Administration highlighted both the importance of and the different approaches to assuring quality and safety in medical imaging and radiation therapy. The important role played by those who design, install, maintain and train users of equipment and various systems-based quality improvement and control mechanisms were noted in the discussions. Ultimately, however, the individual professionals who serve as the interface between the systems and the patient represent the most important factor in the equation. Ensuring the qualifications of these individuals upon entry to the profession and as they progress through their careers is clearly the keystone to assuring patients of quality and safety.

There are various mechanisms for ensuring the qualifications of individuals. Developing standards that define what it means to be qualified typically is driven by professional organizations and consumers of the services provided. The standards are enforced by employers, state governments, the federal government or third-party payers. These standards may be applied at either the individual level (as in certification and licensing) or at the aggregate level (as in practice and facility accreditation).

**Mechanisms for Ensuring Qualifications**

Certification is typically a profession-driven mechanism applied to individuals. It is voluntary because the profession does not have a way to mandate that all individuals performing a particular role meet the specified standards. Certification typically is administered at the national level, which provides standardization and consistency. Educating those in the profession to achieve buy-in regarding the importance of demonstrating personal qualifications by meeting and maintaining quality standards is the most effective tool for promoting voluntary certification. Over time the expectation develops within the profession, among employers and among consumers that individuals will be certified. Although voluntary, certification often becomes a de facto requirement for working in the profession for most practice settings. An example of this mechanism is ARRT’s certification programs.

Licensure is typically a state-driven mechanism applied to individuals. Regulating which individuals may practice a profession within a state is considered part of a state’s responsibility to protect its citizens. The introduction of regulatory mechanisms such as licensing may be driven by professionals within the state or by consumers of the service or their representatives. One challenge created when individual states develop licensure is maintaining consistency of standards across states. Interstate inconsistencies may create barriers to professionals moving from one state to another. It also may create different standards of patient care from state to state.

Accreditation typically is a profession-driven mechanism applied at the aggregate level (as in practice or facility accreditation). Practice accreditation standards typically include requirements for personnel, as well as requirements regarding several other aspects of the practice. Practice accreditation initially is voluntary because the profession does not have a way to require that all practices meet specified standards. Promoting voluntary practice accreditation as a professional responsibility, as a useful quality improvement tool and as an effective marketing tactic are all productive approaches to gaining buy-in from the profession. Examples of practice accreditation programs are those for computed tomography (CT) offered by both the American College of Radiology (ACR) and the Intersocietal Accreditation Commission (IAC).
Deemed Status of “Voluntary” Standards

In this era of economic constraints, maintaining a licensing program can present a challenge for states. One approach to minimize the associated expenses of a state licensure program is to adopt the existing standards of a national certification program, sometimes with additional state-specific requirements. This has the effect of giving the voluntary certification standards a mandatory character in that state. To the extent that a state licensure program requires certification by the national body with no additional provisions or exceptions, certification and licensure become functionally equivalent within the state. More than three-fourths of states currently have a regulatory mechanism for controlling who can perform radiographic procedures and all those states recognize certification in some fashion, although not all recognize national certification standards “as is” as the sole standards for licensure.

The federal government normally does not create national licensure programs for those professions practiced within a state. However, the federal government exercises its influence over the practice of professions within states. For example, the federal Consumer-Patient Radiation Health and Safety Act of 1981 encouraged states to adopt standards for imaging and radiation therapy. The law did not include an effective enforcement mechanism and although most states now have licensing laws for radiography (some adopted prior to 1981 and some after), several states still have not enacted licensing laws. Inconsistencies exist even among states with licensing laws. For example, not all radiologic modalities are regulated by all states that have laws covering radiography. The ASRT has been leading a coalition of professional organizations to lobby for more effective federal legislation over the past decade. The CARE (Consistency, Accuracy, Responsibility and Excellence in Medical Imaging and Radiation Therapy) bill would link standards of educational preparation and credentialing for individuals performing medical imaging or radiation therapy to federal funds received by states to induce states to adopt licensure requirements more consistent with national standards. With its focus on the qualifications of individuals, CARE could be characterized as following a certification model as opposed to a practice accreditation model.

The Medicare Improvements for Patients and Providers Act of 2008 (MIPPA) adopted a practice accreditation model to address quality and safety. MIPPA is federal legislation linking Medicare payment for the technical component of CT, magnetic resonance (MR) imaging, positron emission tomography (PET) and other nuclear medicine procedures to practice accreditation. This portion of the law will take effect in 2012 and applies to procedures performed in the outpatient setting. Rather than specify standards that practices must meet to become accredited, MIPPA called for the Secretary of Health and Human Services to evaluate and recognize practice accreditation programs administered by nongovernmental organizations. The practice accreditation mechanisms of the ACR, IAC and The Joint Commission have been recognized. This, in effect, makes the voluntary practice accreditation standards mandatory for this particular set of circumstances (ie, CT, MR, PET and nuclear medicine procedures performed in outpatient settings for Medicare patients).

The Mammography Quality Standards Act (MQSA) is yet another example of a federal program that addresses imaging quality by setting and enforcing standards in a particular modality. MQSA focuses on the practice level and specifies that an FDA-issued certificate is required for lawful operation of a mammography facility. Only an FDA-approved accrediting body can issue such a certificate. The practice standards cover multiple aspects of the practice, including radiologic technologist qualifications. In contrast to the MIPPA model, in which the standards for accreditation are not specified in detail, but are left up to the recognized accreditors, MQSA spells out the standards. The enforcement mechanism includes both a carrot for compliance (ie, reimbursement) and a stick for noncompliance (ie, prosecution).

Deemed status for certification standards and practice accreditation standards also occur via a nongovernmental enforcement mechanism administered by private, third-party payers. There is an obvious interest on the part of insurers to pay only for procedures that lead to effective diagnoses and treatments, an important element of which is the quality of the procedure. Requiring that the individuals performing the procedures meet professional standards helps ensure quality. Certifying individuals or accrediting facilities as an important indicator of quality can be used as a prerequisite for reimbursement under pay-for-performance models.

Summary

The certification model addresses quality and safety by directly targeting the qualifications of individuals. The practice accreditation model takes a more global approach to quality and safety and addresses the qualifications of individuals and standards for additional components of the quality chain. Although both certification
and practice accreditation fundamentally are voluntary, the programs may become mandatory when enforcement mechanisms are linked to the programs via state or federal legislation or via private reimbursement policies, effectively resulting in mandatory standards.

The CARE bill takes a certification approach to quality and safety by focusing on the qualifications of the individual. MIPPA takes an accreditation approach by focusing on the practice. MQSA is somewhat of a hybrid in that it takes an accreditation approach, but spells out standards for the individual that the accreditor must follow. If the practice accreditation standards require that all technologists employed in the practice be certified in the modalities performed, then the practice accreditation model and the certification model become functionally equivalent in terms of personnel qualifications. To the extent that practice accreditation models are less prescriptive regarding personnel standards, the certification model results in more stringent standards.
A Quick Look at MR Imaging

MRI AT A GLANCE. 

This book was written to educate and re-educate magnetic resonance (MR) technologists and radiologists about the physics of magnetism, the structure of the atom, resonance, signal generation and echo physics. This easy-to-carry, soft-covered book is a dynamic, well-written textbook.

The content, in actuality, is outside of my frame of reference. My career was in computed tomography (CT) and angiography, but I found it easy to understand, and I was able to comprehend the outlined MR principles. This manual takes more than just a glance; it deserves the full attention of the reader. The diagrams are well done and the colorful figures are well thought out and explain the complicated physics in a concise manner.

The content flows easily from principle to principle with updated figures. There are 62 chapters or explanations, beginning with electromagnetism and continuing through signal generation and relaxation mechanisms. The T1- and T2-weighted principles have very clear images of the brain showing the difference in proton densities. There are concise instructions on the use of fast or spin echo, gradient echo and signal-to-noise ratio. The MR student or physician can pick up this book at any time for a refresher regarding this complex, invaluable technology. It pays to keep current and this manual certainly will do the job.

I was particularly interested in the chapter on contrast-enhanced MR angiography. My husband has had 2 cerebral MR exams, one with gadolinium and one without. It was interesting to find out that gadolinium is a T1 shortener that enhances the blood. This clarified the images we were shown. Even though I do not specialize in MR, I enjoyed learning about a modality that is on the forefront of today’s medicine.

Appendix 1 explains artifacts and their remedies. Appendix 2 lists acronyms and abbreviations; I had no idea that the field of MR had so many. The glossary is an alphabetical list of expressions used in MR imaging. I also was pleased to see that the author addressed issues such as claustrophobia, bioeffects, screening and safety procedures.

This is an important textbook and I would recommend that every radiology department have it available for students, technologists, physicians and laypeople. MRI at a Glance is an invaluable review aid.

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FUNDAMENTALS OF MEDICAL IMAGING. 
2nd ed. Suetens P. 2009. 253 pgs. 
Cambridge University Press. 
www.cambridge.org. $108.

At first glance, it is obvious that the intended audience for Fundamentals of Medical Imaging is physicists, engineers, biomedical scientists, computer scientists, medical practitioners and mathematicians. The book was not written for radiologic technologists,
although the terminology may sound familiar to technologists and radiologic science educators. However, the terms are presented in a more scientific format that explains the physical principles and applications of how technology works rather than how to manage the equipment from an operator's point of view.

The reader of this text must have a strong background in physics, math or engineering to understand the context. Pages throughout the text present multiple mathematical formulas, as well as more than 300 colorful illustrations, graphs and charts that accompany the reading.

The author is a professor of medical imaging; chairman of the Medical Imaging Research Center in the University Hospital, Leuven, Belgium; and head of a division for image and speech processing at an electrical engineering department in Belgium. Other contributors to this book are the authors' colleagues from the imaging research center.

This text is the second edition of a book originally published in 2002. The second edition includes an appendix of questions for each chapter with short answers, explanations, calculations and graphs on a companion Web site. The supplemental Web site also includes additional images, 3-D slide animations and other supportive resources.

The book is medium size and lightweight and the font is small, especially for the figure descriptions. The headings and subheadings are easily recognized. More importantly, the content of this book adds to the body of knowledge by explaining the scientific principles of how medical imaging works technically and mathematically.

The book is well organized. The first chapter is dedicated to defining digital imaging and discusses mathematical image operations, as well as image quality. The next 5 chapters feature special imaging, including computed tomography (CT), magnetic resonance (MR) imaging, nuclear medicine and sonography. The chapter for each modality has an introduction, theory of physics instrumentation, theory of image formation, clinical use, image quality, biologic effects and safety and future expectations section. Most of the content is dedicated to equipment design and engineering. The final 2 chapters discuss image analysis and software applications for 2-D and 3-D imaging in CT and MR. Furthermore, data acquisition and postprocessing techniques for diagnosis, therapy planning and surgical intervention are featured.

One of the book's strongest points is the up-to-date material. The author includes the latest technical advances and software applications in radiography and special imaging. For example, in the radiography section, the author states that ultrasonography, CT and MR have replaced examinations such as arthrography, myelography, cholangiography, cholecystography and pyelography. The CT chapter features 4 dedicated CT scanners for oral and maxillofacial exams, breast CT and specially designed mobile scanners for spine and orthopedic and head and neck exams. Electron beam tomography is discussed, as is dual-source CT. The future use of a positron emission tomography (PET)/MR scanner also is mentioned.

The book does not present material concerning patient care-related issues, but the author includes a brief section concerning biologic effects and safety for each modality that includes radiation safety for CT, precautions with ferromagnetic objects in MR imaging and radioactive material precautions in nuclear medicine. The author includes a short section about future expectations for each modality at the end of each chapter.

The book does not include chapters on mammography, radiation therapy or bone densitometry.

Radiologic science educators could use this book as a reference to help define terms when teaching radiologic physics to advanced-level students. This reviewer would not recommend adopting Fundamentals of Medical Imaging for radiologic science core courses.

Tammy Curtis, MSRS, R.T.(R)(CT)
Radiologic Sciences Program Faculty
Northwestern State University
Shreveport, Louisiana
Editorial Review Board Membership

In August each year, the Editorial Review Board (ERB) for Radiologic Technology appoints new members. We are beginning our search for new members to begin terms August 1. The ERB is a group of ASRT members who volunteer to serve as reviewers for the peer-reviewed manuscripts submitted to Radiologic Technology. You may be interested in becoming a member, but may have some questions about the ERB, how to become a member and the responsibilities of the ERB.

What Are the ERB Mission And Goals?

The mission of the Radiologic Technology Editorial Review Board is to promote and support scholarly inquiry and dissemination of knowledge that contributes to the body of knowledge in the radiologic sciences. To accomplish this mission, ERB members are expected to:

- Support writers in the radiologic sciences.
- Ensure quality of published articles that build and strengthen the body of knowledge in the radiologic sciences.
- Establish, evaluate and revise ERB policies and procedures.
- Acknowledge excellence in publication.
- Collaborate with ASRT staff on publication issues.
- Collaborate with the ASRT Education and Research Foundation to support scholarly activities within the radiologic science profession.

What Are the Qualifications of An ERB Member?

ERB members demonstrate publishing experience and the broadest interests of the ASRT’s membership with representation from the various radiologic science disciplines. Our goal is to have members who reflect the diverse modalities and interests of our profession. To be considered for membership on the ERB, you must be an ASRT member. Additionally, you must have experience in writing or editing professional materials. Preference is given to candidates who have published a peer-reviewed article. The chairman of the ERB selects appointees.

What Are the Responsibilities Of an ERB Member?

The primary duty of an ERB member is reviewing manuscripts submitted to the peer-reviewed section of the Journal. Members must be willing to commit the appropriate amount of time required to conduct reviews properly, typically several hours each month. When reviewing a manuscript, ERB members provide a thorough evaluation of the submitted manuscript with clear feedback and advice for the author. Reviewers are expected to be honest, constructive and courteous when providing feedback.

All ERB members are expected to take an active role in all matters related to the ERB. This includes communicating with the ERB chairman and other members, participating in meetings and conferences and reviewing manuscripts according to established policies and time frames. The expertise of the ERB members is very important; therefore, members should remain competent in their area of expertise.

The review process requires confidentiality from all ERB members. Additionally, to maintain the integrity of the review process, members must disclose any conflicts of interest or potential bias. In addition to manuscript review, ERB members should review each issue of the Journal and call any problems to the editor’s attention. Also, ERB members should assist in recruiting new members to the ERB.

How Long Is the ERB Term?

A 1-year training period is completed at the beginning of an ERB member’s
first term. After acceptable completion of training, mem-
bers serve 2 additional years on the ERB. At the end of
the first term, members are eligible to serve a second
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How Do I Become an ERB Member?
If you are interested in being considered for ERB
membership, please submit a current curriculum vitae
and a letter of interest addressing your qualifications,
areas of expertise in the radiologic sciences and the
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me at carwilel@nsula.edu. Please contact me at
carwilel@nsula.edu if you have any questions. ◆
A number of years ago, when I was approached for my current teaching position, I had no idea what I was getting into. I remember thinking, “Physics… you would like me to teach physics?” Then I thought that if I had passed the course, why not teach it? That was just the beginning. Equipment operation and maintenance, image production and evaluation and other basic subjects may not be those courses that radiologic science students clamor for, but a few years and 5000 Microsoft PowerPoint slides later I am not sorry that I took on such a challenge. As educators, what we teach has to be something we truly enjoy.

Creating a More Interesting Lesson

I enjoy teaching, but realized early in my career that there were some classes I did not look forward to. Some lessons were more difficult to grasp than others and I found myself describing the material to my students as “rather dry.” How could I expect students to look forward to class and understand the material if I did not enjoy teaching it? Then I decided to do something about it. I now use several approaches for creating a more interesting classroom.

Familiarity

A familiar object can help explain a concept. For instance, a hair dryer needs rectification to have variable heat. Although the use and scope of radiography equipment differs from the hair dryer, this exercise helps demonstrate the rectification concept. A student pointed out that rectifier and hair dryer rhyme, which serves as a memory device. Using words in this manner can make it easier to remember certain terms. Our motto at New Hampshire Technical Institute is “We are all teachers. We are all learners.” Indeed, I learn a great deal from my students.

Devices such as a coffee pot, refrigerator or toaster oven can demonstrate the resistance concept. I often receive a puzzled look when explaining that a resistor is a device that impedes the flow of electricity. Then when I explain the concept in terms of an object that students use every day, it does not seem so abstract.

If instructors can make some of the concepts we are teaching a little more familiar, the students should be able to grasp and retain them more easily. For example, the question “If Derek Jeter ran 30 m in 15 seconds, what would his velocity be?” helps students to understand the concepts, and at the same time makes the lesson more interesting.

Creativity

One theory instructors often discuss in exposure class is that a radiologic technologist cannot overcompensate with peak kilovoltage (kVp) to make up for insufficient milliampere-seconds (mAs). If the technologist does not use enough mAs, the image will have a mottled-looking appearance. Creating analogies to help explain theories that students often find difficult to grasp is a proven method for retention and also improves attention to the lesson at hand.

To illustrate the theory behind quantum mottle, I use this example: A girl has just baked a cake and needs to ice it, but the icing won’t cover the cake. Her mother walks in and tells her that the spatula she is using is just not big enough. So the girl uses a larger spatula, which still doesn’t work, and then a larger spatula. The size of the spatula does not make any difference. If there is not enough icing, you simply will not be able to cover the cake. This is exactly the theory behind quantum mottle. If a technologist does not use enough mAs, he or she is spreading the x-ray photons too thin. The icing represents the mAs and the spatulas represent the kVp. It does not make any difference how high the kVp is because if the technologist does not begin with enough mAs, the radiograph will exhibit an uneven density and be an inferior image.
such as a witch flying in on a broom during October, I try to take every opportunity to add a little humor. It breaks up and even wakes up the class. Inserting funny answers into exams can relieve the stress and anxiety of test taking. For example, I use my name as a possible multiple choice option for the person responsible for the discovery of x-rays.

**Application to the Clinical Setting**

We want our students to apply what they learn in the classroom to the clinical setting. Our labs are the perfect place to practice this. I usually coordinate what we have learned in the classroom in a particular week to execute in my weekly lab. Whether we are illustrating the effects of quantum mottle, applying the 15% rule while performing radiography, or showing the difference in the strength of the beam by performing the anode heel effect, we make these lessons virtually real. I cannot count the number of times I hear a student say, “Now I get it!”

By taking time to use creative tools in the classroom and then helping students apply the lessons taught in clinical labs, instructors help students discover how complex radiologic science concepts will work when the students eventually stand behind the operator console.

**Conclusion**

By using these teaching techniques, I also have found that I enjoy my job more. I feel that my efforts at creativity are paying off and I keep this phrase in mind: If your lessons are drab, then your class will be drab. If your lessons are fun, then your class will be fun. If your classes are memorable, then your lessons will be memorable. Isn’t this exactly what we are striving for?  

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I present this lesson complete with cupcakes and spatulas of varying sizes, relating the spatulas to corresponding 50 kVp, 70 kVp, 80 kVp or even 120 kVp settings. The exercise helps the students grasp the concept.

**Class Participation**

I bring gadgets into the classroom that I think will help students to understand a concept. When teaching electricity principles in equipment maintenance and operation class (lovingly referred to as physics), I bring in balloons or hair combs to electrify and pick up pieces of paper to illustrate static electricity. When discussing magnetic properties, I bring elementary magnetic games to the classroom to illustrate the basic concepts of magnetism. I have constructed makeshift armatures to demonstrate the difference between a generator and a motor. These seemingly simple examples actually help the students and are the lessons that they remember.

When teaching pathology, I turned the entire lecture on the gastrointestinal series into a script with parts for each student. The response was overwhelming. The students enjoyed participating, and they learned from the exercise.

Games are a great way to review material before a test, whether playing bingo (of course in radiography, we play “x-ray”), “Jeopardy” or a game of the instructor’s creation. The options are limited only by the instructor’s imagination. I have even sent my students on a scavenger hunt to look for various tools and devices.

**Visuals**

I have used vegetables and sliced them in different ways to show the difference between conventional tomography and computed tomography (CT). For example, I slice a cucumber lengthwise from top to bottom to demonstrate conventional tomography. I then slice another horizontally to demonstrate cross-sectional anatomy.

When I teach contrast, I dress completely in black and white. I walk into the classroom and before beginning the lecture, I ask the students, “When I was dressing this morning, was I thinking high contrast or low contrast?” I then don a gray tweed jacket and again pose a question to the class. “If I get cold and decide to put on this jacket, am I thinking high contrast or low contrast?” Their answer is undoubtedly low contrast.

**Humor**

Whether it is a funny experience I had as a radiologic technologist or a picture I sneak into my slide shows,
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The University of South Alabama, Department of Radiologic Sciences, invites applications for a full-time twelve-month non-tenure track faculty position, available January 3, 2011. Didactic and clinical instruction required. Qualifications include ARRT certification in radiography, Masters Degree (Doctoral Degree preferred), previous teaching experience, three years clinical experience. Multi-disciplinary ARRT certification preferred. Deadline for applications is September 3, 2010, or until the position is filled.

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Computed Tomography

Computed tomography (CT) is a sophisticated imaging technique that can show anatomy at different levels within the body. During CT imaging, the x-ray source rotates around the patient, and each rotation produces a single cross-sectional “slice,” like the slices in a loaf of bread. CT allows physicians to see a horizontal piece of the body, just as if you were taking a slice of bread out of a loaf.

Computed tomography scans, also called CT scans, are used to diagnose many conditions. They may be used to examine the head to check for bleeding, tumors, blood clots or signs of stroke. In other parts of the body, CT may be used to tell whether a growth is solid or fluid-filled, determine an organ’s size and shape and evaluate many different diseases.

During the Examination

Examination time can range from 10 minutes to more than an hour, depending upon the part of the body being examined and whether or not a contrast agent is used. For a head scan, you will be asked to remove eyeglasses, dentures, jewelry and barrettes or hairpins because metal can interfere with the imaging. For a body scan, you will be asked to remove all clothing and put on a hospital gown.

The CT technologist will position you on the scanning table. If you are undergoing a head scan, the technologist will place your head in a cradle to help prevent movement. You will be secured onto the table with a safety strap. The technologist will guide the scanning table into the CT unit, which is a machine with a large circular hole in the center. The CT technologist will not be in the room during the scan, but will be able to see you and you will be able to communicate through an intercom system.

As the x-ray tube rotates around you, you will hear a whirring sound. The exam table will move slightly to reposition you for each scan, but it moves so slowly that you might not even notice it. The technologist will tell you when each scan sequence is beginning and how long it will last. You should remain as still as possible during the sequence, and for certain scans you may be asked to hold your breath for a few seconds. Even the slightest movement can blur the image, so it’s important to remain still.

When the exam is complete, your CT scans will be given to a radiologist, a physician who specializes in the diagnostic interpretation of medical images.

Postexamination Information

After your images have been reviewed, your personal physician will receive a report of the findings. Your physician then will advise you of the results and discuss what further procedures, if any, are needed.

Patient Preparation

Your personal physician or the radiology facility where you are scheduled to have your CT procedure will give you instructions describing how to prepare for your exam. You will be asked whether there is a chance that you might be pregnant. If you are pregnant, your health care provider will help you weigh the benefits of having a CT scan vs the risks. You may be asked about your medical history and your general health.

Before your examination, a CT technologist will explain the procedure to you and answer any questions you might have. A CT technologist, also known as a radiologic technologist, is a skilled medical professional who has received specialized education in CT imaging techniques.
Tomografía Computadorizada

La tomografía computadorizada (TC) es una técnica sofisticada de producción de imágenes que muestra la anatomía en distintos niveles dentro del cuerpo. Durante la producción de imágenes de TC, la fuente de rayos X gira alrededor del paciente y cada rotación produce una única “rebanada” transversal, como si fuera una rebanada de pan. La TC le permite a los médicos ver un pedazo horizontal del cuerpo, como si se estuviera sacando una rebanada de un pan.

Las tomografías axiales computadorizadas, también conocidas en inglés como ‘CT scans,’ son utilizadas para el diagnóstico de muchos problemas. Pueden utilizarse para examinar la cabeza para constatar la presencia de hemorragias, tumores, coágulos de sangre o señales de apoplejía. En otras partes del cuerpo, la TC puede usarse para saber si un bulto es sólido o si contiene fluidos, determinar el tamaño y forma de un órgano y evaluar muchas enfermedades distintas.

Preparación del Paciente

Su médico personal o establecimiento de radiología en el que tenga marcado su procedimiento de TC le dará instrucciones sobre cómo prepararse para su examen. Se le preguntará si es posible que esté embarazada. Si está embarazada, su proveedor de atención médica la ayudará a pesar los beneficios del examen de TC versus los riesgos que presenta. Se le podrá preguntar sobre su historia clínica y su salud general.

Antes de su examen, un tecnólogo en TC le explicará el procedimiento y responderá a sus preguntas. El technólogo en TC, también conocido como tecnólogo radiólogo, es un profesional médico especializado en estudios de imágenes de TC.

Durante el Examen

El tiempo del examen puede variar entre 10 minutos y más de una hora, dependiendo de la parte del cuerpo que se esté examinando y si se utiliza o no un agente de contraste. Para un examen de la cabeza, se le pedirá que se saque las gafas, dentaduras, alhajas y hebillas de cabello, pues el metal puede interferir en las imágenes. Para un examen del cuerpo, se le pedirá que se saque toda la ropa y vista una bata de hospital.

El tecnólogo en TC lo(a) posicionará sobre la mesa de examen. Si se trata de un examen de la cabeza, el tecnólogo colocará su cabeza en un soporte para evitar que se mueva. Se lo(a) sujetará a la mesa con una tira de seguridad. El tecnólogo guiará la mesa de examen hacia adentro de la unidad de TC, que es una máquina con un gran agujero circular en su centro. El tecnólogo en TC no estará en la sala durante el examen, pero podrá verlo(a) y comunicarse con usted a través de un intercomunicador.

A medida que el tubo de rayos X gira a su alrededor, escuchará un zumbido. La camilla de examen se moverá levemente para reubicarlo para cada exploración, pero se mueve tan despacio que tal vez siquiera lo note. El tecnólogo le dirá cuándo comienza cada secuencia de exploración y cuánto durará. Usted debe permanecer lo más inmóvil posible durante la secuencia, y para ciertas exploraciones se le podrá pedir que no respire por unos segundos. Hasta el movimiento más leve podrá hacer que la imagen resulte borrosa; por lo tanto, es importante que se mantenga inmóvil.

Cuando finalice el examen, se le entregará sus exploraciones de TC a un radiólogo, médico especializado en la interpretación diagnóstica de imágenes clínicas.

Información de Pos-examen

Una vez analizadas sus radiografías, su médico personal recibirá un informe de los resultados. Su médico luego conversará con usted sobre los resultados y discutirá qué procedimientos futuros, si los hubiera, serían necesarios.
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CT Basics:

- **Module 1** – Fundamentals
- **Module 2** – Equipment and Instrumentation
- **Module 3** – Data Acquisition
- **Module 4** – Image Processing and Reconstruction
- **Module 5** – Patient Safety
- **Module 6** – Image Quality
- **Module 7** – Procedures
- **Module 8** – Cross-sectional Anatomy of the Head and Neck
- **Module 9** – Cross-sectional Anatomy of the Chest, Abdomen and Pelvis
- **Module 10** – Additional Applications

Successfully complete all 10 for-credit modules and receive a diploma from the ASRT!

**Also available:** Institutional version licensed for education and staff trainings.
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