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1American College of Radiology Appropriateness Criteria 2014
2IMV 2014 MR Market Outlook Report

3This option is Pending 510(k) clearance, and is not yet commercially available in the United States.

4MR scanning has not been established as safe for imaging fetuses and infants less than two years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures.
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### ON THE COVER

“Old Oak Chest CT” is the last in a series of 6 paintings featured on the covers of Radiologic Technology by Lizzy Rainey, R.T.(R), of Lafayette, Indiana.

A single image from a computed tomography chest examination inspired this autumn landscape with the vessels taking on the shape of a grand, old oak tree with its massive, aged trunk. The familiar circular patterns of a chest scan are reminiscent of the oak’s crown allowing light to stream through its branches.
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Editor’s Note

Sharing Is Good

Lisa Ragsdale, MA, ELS

The American Society of Radiologic Technologists (ASRT) is a worldwide community of medical imaging and radiation therapy professionals dedicated to the advancement of their profession and quality patient care. To facilitate those goals, the organization has redesigned its networking and sharing site, the ASRT Communities, and has moved this aspect of the Web site to a new platform that offers additional features and improved functions.

Members can access the Communities through My ASRT to connect with other members in the online directory, participate in discussions, and review shared files. You can update your directory profile and choose what information you want to share. You even can import your information from LinkedIn. Upload your photo into your profile before October 1, 2015, and you will be entered into a drawing to win one of several “Sharing Is Good” themed prizes.

My ASRT is the entry portal for the redesigned Communities where you’ll be able to print a replacement membership card, get receipts for your ASRT purchases, and view your order history. You’ll see personalized messages about volunteer opportunities, job openings, and the latest discussions in the Communities to which you have subscribed. There are currently 18 communities across many interest areas and modalities.

Each member’s profile displays recognition ribbons. Ribbons initially are awarded for ASRT Foundation donors, volunteer service, and years of membership. Other ribbons can be earned when you participate in activities such as contributing to a discussion forum, sharing files, and commenting on shared files.

I encourage you to join the ones you want and get involved in the sharing. Ask questions, discuss trends and projects, and share files, photos, articles, and problem-solving ideas.

To help get you started, we have placed some discussion ideas in this issue of Radiologic Technology. Get involved with your ASRT Communities by visiting www.asrt.org/myasrt.

Lisa Ragsdale, MA, ELS, is the managing editor for Radiologic Technology and serves as an advisory board member for radiologic science administration online degree programs at Saint Joseph’s College in Standish, Maine.
Copper Filtration and kVp: Effect on Entrance Skin Exposure

James Barba, MA, R.T.(R)
Melissa Culp, MEd, R.T.(R)(MR)

Background  The selection of technical factors to produce an image is driven primarily by the patient, body part, and factors regarding the status of that patient or part. Analog receptor systems are restricted by the ranges of data they are able to record, as well as the quantity and quality of data required to record an image. Using digital receptors allows for a wider range of exposure factors because of the nature of the receptor systems and the data processing methods employed. Thus, factor selection can be more patient centered when using digital receptors to produce a radiograph.

Purpose  To explore the relationship between milliampere seconds (mAs), kilovoltage peak (kVp), and additional copper filtration with exposure indicators and entrance skin exposure (ESE) using both analog and digital receptors.

Results  Researchers conducted 2-tailed t-tests using Stata/IC version 11.2 software (StataCorp LP) to compare ESE from several trials using hip and knee phantoms. The analysis indicated that increasing kVp, adding 0.1 mm copper filtration, and correspondingly reducing mAs reduced ESE on a hip phantom by 64%, from 151 mR to 54.4 mR and reduced ESE on a knee phantom by 51%, from 27.2 mR to 13.4 mR.

Conclusion  Radiology departments and radiologic technologists can consider these data when creating dose reduction protocols. The wider latitude range of digital radiography can be used to minimize patient exposure while still producing images of diagnostic quality within the acceptable exposure indicator range stated by the manufacturer.

For each radiograph, the patient and body part to be screened should be the primary considerations when choosing exposure factors. When using analog film-screen systems, the kilovoltage peak (kVp) and milliampere seconds (mAs) are selected for optimal functionality within the sensitivities of the given system. Digital imaging systems allow for wider exposure latitude; thus, kVp and mAs selection is based primarily on the patient and body part thickness. A conscientious radiologic technologist can use the wider exposure latitude to reduce patient exposure.

This experiment explores the effect of mAs, kVp, and copper filtration on the exposure value produced and on the entrance skin exposure (ESE). The authors argue that it is necessary to focus on patient factors rather than receptor factors to minimize exposure. With the help of digital radiography, technologists can alter exposure factors to significantly reduce patient exposure while remaining within acceptable exposure value ranges and maintaining the overall diagnostic quality of the radiograph.

The purpose of this article is to give technologists options when selecting technical factors to reduce exposure to the patient without requiring postprocessing of a digitally acquired radiograph and to suggest methods to improve practice and patient safety and care. The results of this study are important to the entire radiology team, including managers, clinical technologists, health physicists, and radiologists. All members of the team might consider these results when creating dose reduction protocols.

Background  Because analog radiography uses intensifying screens and radiographic film, the production of a diagnostic image is linked to exposure factors based on both
the body part and the receptor. A technique is selected to produce an optically diagnostic image given both the part’s condition and the limitations inherent in the analog recording system. However, digital imaging, offers wider exposure latitude, and a histogram is applied to resultant data in the image production process.1–3 Technical factor selection in digital imaging should be based on the body part and on making an effort to minimize patient exposure and discomfort while producing a quality image for diagnostic interpretation. According to Seibert:

X-ray technique settings include kVp (peak kilovoltage of the x-ray tube and resultant x-ray beam spectrum), mAs (product of tube current in milliamperes and exposure time in seconds), x-ray tube filtration, beam collimation, and source-to-image distance (SID).4

In digital imaging, it is possible to use relatively higher kVp with lower mAs (compared to film-screen) and still achieve a diagnostic image with optimal exposure to the receptor.4 The benefit of this change is that a higher kVp increases the average energy of the beam going through the patient. The beam is composed of more high-energy photons; therefore, fewer lower-energy photons are present in the beam attenuated by the patient.4 The ability to increase kVp is limited by an eventual degradation of subject contrast.

Some literature recommends matching kVp to the type of detector. However, with some detectors this process would result in a lower kVp selection.6 Therefore, the authors argue that detector type should not be the only consideration in kVp selection for imaging. According to the American Association of Physicists in Medicine:

Unlike screen/film imaging, image display in digital radiography is independent of image acquisition. Inadequate or excessive exposure is manifested as higher or lower image noise levels instead of as a light or dark image. The final brightness of the image is controlled not by the exposure to the detector, but by post-processing applied to the acquired image data.5

In digital radiography, “independence of displayed contrast from kVp setting through adjustment of the display window width” is seen.1 Increases in kVp should be balanced with consideration for subject contrast.

Another relevant technical factor to consider is the added tube filtration. Historically, additional filtration was used in anatomical regions with high inherent subject contrast such as chest imaging or gastrointestinal barium procedures.5,8,9 Added filters can be made of aluminum, niobium, copper, and other materials, and they can be stacked or used individually. Additional filtration removes lower-energy photons from the beam that would contribute to ESE or be absorbed by the patient.10,11 Other studies analyzed the relationship between dose reduction and copper filtration in digital radiography. Hammer et al conducted an experiment in which added copper filtration of 0.3 mm was the independent variable and dose was the dependent variable. The result was a reduction in entrance dose with the addition of copper filtration.13

**Methods**

**Trial A: Hip Phantom**

In this experiment, a hip phantom was placed on the x-ray table with the thicker portion toward the cathode end of the tube. Anteroposterior (AP) radiographs of the hip phantom were obtained using the Bucky grid. During phase 1, the first radiographs were created using an analog film-screen receptor with a large focal spot, a 400-speed Kyokko 10 12-inch receptor (Kasei Optronix Ltd) and Fuji Super HR T30 film (Fujifilm Corporation). During phase 2, radiographs were created with a photostimulable phosphor 10 12-inch cassette (Fujifilm Corporation). A 40-inch SID and large focal spot were used for each exposure regardless of receptor type (see Figure 1).

In phase 1, technical factors were selected to create an image of the hip using analog film-screen. Initially, 5.0 mAs and 75 kVp were used. When the mAs was reduced to 2.5, the resultant image was not acceptable because of underexposure. For each exposure, the corresponding ESE was recorded using an ion chamber at the level of the anterior surface of the phantom; however, the phantom was removed so scatter would not contaminate the ESE measurement.

In phase 2, technical factors were employed to create a digital image of the hip with a corresponding acceptable sensitivity (S) value. Fuji systems have an S value that provides a numerical indicator of radiation exposure (mR). An S value of 200 is equal to 1 mR of exposure to the cassette.2,3 The resulting S value is an
average of exposure across the entire plate. The experiment used a range of \( S = 250 \) to 350 as acceptable for radiographs created using the Bucky grid. The factors of 14 mAs and 75 kVp were used to get an image with an \( S \) value of 270, which was within the defined acceptable range. The mAs was halved as the kVp was increased by 10 for additional exposures. When the image became visibly noisy, the mAs was increased to the previous setting, and 0.1 mm of copper filtration was added. For each exposure, the corresponding \( S \) value and ESE were recorded. The ESE was recorded using an ion chamber at the level of the anterior surface of the phantom; however, the phantom was removed so scatter would not contaminate the ESE measurement (see Table 1).

**Trial B: Knee Phantom**

The experiment was repeated with a knee phantom. The knee phantom was placed on the x-ray table with the thicker portion toward the cathode end of the tube. AP radiographs of the knee phantom were taken using the Bucky grid. During phase 1, radiographs were created using an analog film-screen receptor, large focal spot, and a 400-speed Kyokko 10 × 12-inch receptor with Fuji Super HR T30 film. During phase 2, radiographs were created with a Fujifilm photostimulable phosphor 10 × 12-inch cassette. A 40-inch SID and large focal spot were used for each exposure regardless of receptor type (see Figure 2).

<table>
<thead>
<tr>
<th>Image</th>
<th>mAs</th>
<th>kVp</th>
<th>SID</th>
<th>Focal Spot</th>
<th>Receptor</th>
<th>S No.</th>
<th>L No.</th>
<th>Filter</th>
<th>ESE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.0</td>
<td>75</td>
<td>40</td>
<td>Large</td>
<td>400 speed</td>
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<td>N/A</td>
<td>None</td>
<td>41.5 mR</td>
</tr>
<tr>
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<td>2.5</td>
<td>75</td>
<td>40</td>
<td>Large</td>
<td>400 speed</td>
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<td>N/A</td>
<td>None</td>
<td>21.2 mR</td>
</tr>
<tr>
<td>3</td>
<td>3.6</td>
<td>75</td>
<td>40</td>
<td>Large</td>
<td>400 speed</td>
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<td>N/A</td>
<td>None</td>
<td>30.2 mR</td>
</tr>
<tr>
<td>Phase 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>4</td>
<td>14</td>
<td>75</td>
<td>40</td>
<td>Large</td>
<td>PSP</td>
<td>270</td>
<td>2.4</td>
<td>None</td>
<td>151 mR</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>75</td>
<td>40</td>
<td>Large</td>
<td>PSP</td>
<td>348</td>
<td>2.4</td>
<td>None</td>
<td>119 mR</td>
</tr>
<tr>
<td>6</td>
<td>5.6</td>
<td>85</td>
<td>40</td>
<td>Large</td>
<td>PSP</td>
<td>419</td>
<td>2.3</td>
<td>None</td>
<td>779 mR</td>
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<td>2.8</td>
<td>96</td>
<td>40</td>
<td>Large</td>
<td>PSP</td>
<td>565</td>
<td>2.2</td>
<td>None</td>
<td>50.0 mR</td>
</tr>
<tr>
<td>8</td>
<td>5.6</td>
<td>96</td>
<td>40</td>
<td>Large</td>
<td>PSP</td>
<td>357</td>
<td>2.1</td>
<td>0.1 mm Cu</td>
<td>54.4 mR</td>
</tr>
</tbody>
</table>

Abbreviations: Cu, copper; ESE, entrance skin exposure; L No., value of latitude; PSP, photostimulable phosphor; S No., sensitivity value; SID, source-to-image distance.

---

*Figure 1. Trial A setup position for hip phantom. Image courtesy of the authors.*
In phase 1, technical factors were selected to create an image of the knee using analog film-screen. Initially, 1.25 mAs and 70 kVp were used. When the mAs was reduced to 1.0, the resultant image was not acceptable because of underexposure. For each exposure, the corresponding ESE was recorded using an ion chamber at the level of the anterior surface of the phantom; however, the phantom was removed so scatter would not contaminate the ESE measurement.

In phase 2, technical factors were used to create a digital image of the knee with a corresponding acceptable S value. The factors of 3.6 mAs and 70 kVp were used to acquire a radiograph with an S value of 277, which was within the defined acceptable range. The mAs was halved as the kVp was increased by approximately 10 for additional exposures. When the image became visibly noisy, the mAs was increased to the previous setting, and 0.1 mm of copper filtration was added. For each exposure, the corresponding S value and the ESE were recorded. The ESE was recorded using an ion chamber at the level of the anterior surface of the phantom; however, the phantom was removed so scatter would not contaminate the ESE measurement (see Table 2).

**Trials A and B**

The ESE was obtained by placing the ion chamber on the anterior surface of the phantom, then removing the phantom and making the exposure. By moving the phantom prior to measuring ESE, the authors could be confident that the resultant value was entirely from the primary beam because scatter from the body part being screened does not contribute to the measurement. For the hip phantom, the ion chamber was at a height of 21 cm from the table. For the knee phantom, the ion chamber was at a height of 10.5 cm from the table.

Each image was produced 25 times with the same image receptor—either the same 400-speed cassette for the film exposures or the same photostimulable phosphor image detector for the computed radiography exposures. After each exposure, the cassette was read by the plate processor and erased by an intense white light to ensure no residual latent image remained. Each ESE was measured 25 times with the same ion chamber. For all exposures, the central ray was perpendicular to the image receptor.

**Results**

This experiment provides a quantitative analysis of the dependent variable of ESE when independent variables of kVp and copper filtration are altered. Phase 1 data are demonstrated for comparison purposes only to show typical ESE for similar examinations with an analog system. Factors recorded include:

- mAs
- kVp
- SID
- Focal spot
- Receptor type (analog vs photostimulable phosphor).
Barba, Culp

Peer Review

Value. Value of latitude. Added filtration. ESE.

Tables 1 and 2 provide these data on an AP hip phantom and an AP knee phantom, respectively. Statistical analyses comparing ESEs from phase 2 trials were performed to see whether differences were significant using 2-tailed $t$-tests in Stata software. Within the hip and knee trials, the statistical analyses compared the resultant ESE with the following:

- Base kVp and no added filtration.
- Approximately 10 kVp increase and no added filtration.
- Approximately 20 kVp increase with added 0.1 mm copper filtration.

Each of the analyzed data sets had an S value within or close to the manufacturer’s recommended range.

The null hypothesis stated that a change in ESE would not be significant with increased kVp and copper filtration. The null hypothesis was rejected. In a 2-tailed $t$-test, the resultant $P$ value between the 2 groups was $P < .001$, suggesting that a significant difference existed between the ESE in trials 4 and 8. This result was found to be true with both the hip and knee phantoms.

ESE was reduced by 64% from 151 mR to 54.4 mR on a hip phantom by increasing the kVp, adding 0.1 mm copper filtration, and correspondingly reducing mAs. Likewise, ESE was reduced by 51% from 27.2 mR to 13.4 mR on a knee phantom by increasing the kVp, adding 0.1 mm copper filtration, and correspondingly reducing mAs.

Even with changes only to kVp and mAs, ESE was significantly different with a value of $P < .001$. As a result of increasing kVp by 10 and reducing mAs, ESE was reduced on the hip phantom by 48%, from 151 mR to 77.9 mR. Increasing kVp by 10 and reducing mAs for the knee phantom reduced ESE by 31%, from 27.2 mR to 18.9 mR.

Discussion

Phase 1 of each trial was conducted as a baseline to indicate the lower ESE values from diagnostic analog film-screen radiographs. When transitioning to phase 2, the same kVp was used with an mAs that resulted in an S value within the defined acceptable range of 250 to 350. The ESE values increased for both the hip and knee phantom when using this technique.

Trial A: Hip Phantom

By increasing the kVp from 75 to 85 and using a 50% reduction in mAs (from 11 to 5.6), the S value increased from 348 to 419, and the ESE dropped from 119 mR to 77.9 mR. The resultant image was underexposed according to the S value range; however, the lack of exposure to the image receptor did not have the same

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### Table 2

<table>
<thead>
<tr>
<th>Image</th>
<th>mAs</th>
<th>kVp</th>
<th>SID</th>
<th>Focal Spot</th>
<th>Receptor</th>
<th>S No.</th>
<th>L No.</th>
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<th>ESE</th>
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<td></td>
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<td>93</td>
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<td>PSP</td>
<td>297</td>
<td>1.6</td>
<td>0.1 mm Cu</td>
<td>13.4 mR</td>
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</tbody>
</table>

Abbreviations: Cu, copper; ESE, entrance skin exposure; L No., value of latitude; PSP, photostimulable phosphor; S No., sensitivity value; SID, source-to-image distance.
degree of impact on image appearance that would have occurred with an analog film-screen receptor.

To go a step further, the kVp was increased from 85 to 95 with an additional 50% reduction in mAs (from 5.6 to 2.8). The resultant image was underexposed according to the S value range and had a noisy appearance.

Finally, the kVp was left at 95, and the mAs was increased to 5.6. An additional 0.1 mm copper filtration was added to the tube. This filtration was readily available because it was included in the tube housing by the manufacturer. The authors turned the filtration dial from 0 to 0.1 mm Cu. With these factors, the S value was 357, which is close to the acceptable range. The ESE was 54.4 mR. The change in factors did not alter the image appearance to the extent that it would have with an analog film-screen receptor.

With digital radiography, using a higher kVp and copper filtration with lower mAs on the hip phantom was not detrimental to image quality. The ESE was reduced significantly by 64%. Even without the addition of the copper filtration, an increase of 10 kVp and a 50% reduction in mAs lowered the ESE by 48%.

**Trial B: Knee Phantom**

By increasing the kVp from 70 to 81 and using a 50% reduction in mAs (from 3.6 to 1.8), the S value increased from 277 to 340, and the ESE lowered from 27.2 mR to 18.9 mR. The resultant image was within the acceptable S value range.

Next, the kVp was increased from 81 to 93 with an additional 50% reduction in mAs (from 1.8 to 0.9). The resultant image was underexposed according to the S value range and had a noisy appearance.

Finally, the kVp was left at 93, but the mAs was increased back to 1.8. An additional 0.1 mm copper filtration was added to the tube. With these factors, the S value was 297, which is within the acceptable range. The ESE was 13.4 mR, and the change in factors did not alter the image appearance to the extent that it would have using film-screen.

With digital radiography, using a higher kVp and copper filtration with lower mAs on the knee phantom was not detrimental to image quality. The ESE was reduced significantly (by 51%). Even without the addition of the copper filtration, an increase of 10 kVp and a reduction of 50% in mAs lowered the ESE by 31%.

**Limitations**

Because a small sample size was used to acquire hip and knee phantoms, the results of this study are limited. Future studies could include data gathered retrospectively from actual patient examinations, or others might replicate this study using other types of digital detectors. In addition, future studies should include having a radiologist determine which technical factors produce diagnostically acceptable images for interpretation and whether contrast is still acceptable in the display window width.

**Conclusion**

In digital radiography, technical exposure factors are not limited by the restrictions of analog film-screen receptors. Technical factor selection should be driven primarily by the body part being screened. In this study, increasing the kVp by 10 and reducing mAs by 50% lowered the ESE while the exposure indicator remained within an acceptable range. In addition, this experiment increased kVp by 20, reduced the mAs by 75%, and added 0.1 mm copper filtration. These changes resulted in a dramatic reduction in ESE while still having S values within or near defined acceptable ranges.

This research supports previously published studies and known physics concepts. The results reaffirm conclusions by Siebert and the American Association of Physicists in Medicine that relatively higher kVp and lower mAs can be used (compared to film-screen receptors) to achieve a diagnostic image with optimal exposure to the receptor; therefore, fewer lower-energy photons are attenuated by the patient. The ability to increase kVp is limited by an eventual degradation of subject contrast. This experiment supports the work of Hammer et al that copper filtration reduces ESE.

Radiology departments and radiologic technologists can consider these data to create dose reduction protocols. The wider latitude range of exposure factors available when employing digital receptors can be used to minimize patient exposure while still producing diagnostic images within the acceptable exposure indicator ranges provided by the equipment manufacturer. This study is an affirmation of these concepts and a reminder of the important role of the radiologic technologist in patient dose reduction.
James Barba, MA, R.T.(R), is a retired clinical assistant professor from the division of radiologic science at the University of North Carolina at Chapel Hill. He received his radiography education at the Hudson Area School of Radiologic Technology, completing his studies in 1972. He has a master of arts in educational communication and technology from the Steinhardt School of Culture, Education, and Human Development at New York University in New York City.

Melissa Culp, MEd, R.T.(R)(MR), is adjunct assistant professor in the division of radiologic science at the University of North Carolina at Chapel Hill. Her teaching foci are radiographic positioning, pathology, and health care delivery. She has an interest in radiology’s effect on sustainable global health initiatives. She can be reached at melissa_culp@med.unc.edu.

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References


For Further Reading


Submandibular Duct Fistula Caused by a Large Sialolith: Incidental Finding in a Barium Swallow Study

Kathleen Ann Stanford, BS, R.T.(R)

**Background**  This case report details an incidental finding of a submandibular duct fistula to a patient’s posterior mouth floor found on a barium swallow examination that was performed to rule out gastrointestinal causes of substernal chest pain. The radiologist was unable to determine the cause of the filling defect at the time of the study. The patient’s history revealed that a large calculus of unknown size had been passed spontaneously through the floor of the mouth, rupturing the proximal gland duct and creating the fistula.

**Discussion**  Sialolithiasis is the formation of calculi in the salivary gland and is the most common disease of the salivary glands, with the submandibular glands affected more often than others. The condition is more common in men than in women and most often affects individuals aged between 30 and 60 years.

**Conclusion**  In general, the etiology of sialolithiasis is unknown. However, examining comorbidities and possible risk factors, such as tobacco use, and how they alter the saliva and the function of the salivary glands might lead to a better understanding of their cause.

The barium swallow is a fluoroscopic examination that demonstrates the anatomy of the oral cavity, as well as the pharynx, and assesses a patient’s ability to swallow. The study can reveal various abnormalities, including congenital malformations, diverticula, fistulas, inflammatory disease, cysts, foreign bodies, and benign or malignant lesions. Barium swallows are not intended to study the salivary glands; rather, sialography is used to assess the function of or abnormalities in the salivary glands.

Sialolithiasis is the formation of calculi in a salivary gland and is the most common disease of the salivary glands. Submandibular glands are affected by calculi more often than are parotid glands, followed by sublingual glands, and then by minor glands. Compared with other salivary glands, the submandibular gland has higher mucin levels, a larger duct, higher calcium levels, more alkaline saliva, and saliva that moves slower and against gravity, qualities that might contribute to calculi formation. In addition, intraductal calculi are more common than are glandular calculi. Sialolithiasis is more common in men than in women. Although the disease can occur at any age, it is most prevalent in people aged 30 to 60 years. The common presentation of sialoliths is pain and swelling in the gland from the obstructive nature of the calculus. Symptoms are particularly apparent during meals, when salivary secretion is most active.

Salivary calculi have both organic and inorganic components. Phosphate apatite is the mineral most often found in calculi and is present throughout. Whitlockite, a calcium phosphate, is the second most common material found in calculi, but it is found most often in the center of the calculi. The exact cause of calculus formation in the salivary glands is unknown. In general, calculi range in size from 1 mm to less than 1 cm.

Salivary fistulas are rare and usually are caused by calculi, direct trauma, or foreign bodies. Congenital salivary fistulas also have been documented.
Literature Review

Almasri reported the case of a 70-year-old man who had a neck fistula caused by an intact 2.3 cm × 1.7 cm calculus. In an analysis of 3 case studies, Asfar et al noted the case of a 55-year-old man with a calculus measuring 3.8 cm × 2.5 cm that created a fistula reaching from the submandibular gland to the oral cavity. Nemade et al reported on a 46-year-old man with a fistula formed by a 1.6 cm × 1.0 cm calculus. Akin and Esmer also reported a 4.5 cm × 3.0 cm calculus that had entirely eroded through the epithelial layer of the submandibular duct in a 45-year-old man. In a report by Sutay et al, a 22-year-old woman had a 3.7 cm × 0.7 cm “comma shaped” submandibular calculus that caused a fistula in association with sialadenitis.

The patient in this case report had a submandibular fistula created by a sialolith. Its discovery was incidental, unlike many other cases. Understanding how a fistula appears under fluoroscopy is of diagnostic value to radiologists and radiologic technologists.

Case Description

A 56-year-old woman presented with severe substernal and epigastric pain. She had a history of chronic back pain (possibly due to ankylosing spondylitis), chronic obstructive pulmonary disease, and visits to the emergency department for shortness of breath. During this complaint of chest pain, she had a stress test and the result was negative.

After a referral to a gastroenterologist, the patient underwent a barium swallow study to evaluate her for gastroesophageal reflux disease, hiatal hernia, or esophageal spasm. The fluoroscopy examination revealed a filling defect. A branching tract extending from the oral cavity had filled with and was retaining barium (see Figure). During the examination, the resident radiologist was uncertain what caused this branching appearance. The radiology report vaguely described it as “a contrast-opacified tract in the area of the right submandibular gland.” The barium swallow was considered otherwise unremarkable.

Upon review and referral to the otolaryngology department, the patient discussed her history of sialolithiasis. The patient had not had a recurrence of salivary calculi in 4 or 5 years, but prior to that time she had

Figure. Anteroposterior (A) and lateral (B) fluoroscopy images showing a branching tract retaining barium in the area of the submandibular gland. Images courtesy of the author.
passed multiple calculi, including a very large one. She reported that despite its large size, she passed it spontaneously. A physical examination by an otolaryngologist revealed a salivary fistula between the right submandibular gland and the posterior floor of her mouth—likely a ruptured proximal salivary gland duct caused by the ejection of the sialolith. Upon manipulation of the right submandibular gland, the physician noted that the posterior floor of the patient’s mouth had abundant, thin salivary outflow. Despite the negative stress test result, the physician recommended that the patient seek help from a cardiologist to rule out vasospastic angina as a cause of her chest pain. No treatment was recommended for the fistula.

Discussion

A sialolith is considered to be a giant salivary calculus if it is larger than 1.5 cm. In their literature review of giant sialoliths, Ledesma-Montes et al reported that the patients in all 16 of the case studies they analyzed were men. Those studies focused on salivary calculi measuring 3.5 cm or more. The patient in this study self-reported her experience with a large salivary calculus, so there is no accurate medical or radiographic record with which to estimate its size; this is a major limitation of the case report. Regardless, a case of large salivary calculus in a woman is an interesting finding when many sialolith case studies have reported the calculi in men. It is an especially rare case considering this patient’s calculi created a fistula and because the finding of a fistula occurred incidentally during a radiographic examination. Other cases in the literature review reported that the fistulas were discovered by oral cavity examinations. McFerran et al studied a patient who also had a right submandibular gland fistula to the oropharynx incidentally found by a barium swallow study. The 41-year-old woman in that study presented with a sensation of a lump in her throat that diminished when she swallowed and increased during periods of stress. A barium swallow study showed that the side branches of the duct were communicating with the oral cavity. The patient had no history of surgery to the area or sialolithiasis, and the origin was found to be congenital in nature.

In this case study, the patient’s report of her sialolith spontaneously passing through the oral cavity also should be noted. Of the patients discussed in the literature review, Sutay et al reported on the only one who did not require surgery to remove the calculus; that female patient’s calculus was removed transorally.

Examining comorbidities might help to understand the etiology of sialolithiasis. Smoking has been shown to decrease salivary antioxidants, such as peroxidase, and reduce phagocytic functions. A study by Huoh et al examined the demographic and comorbid conditions of 153 patients with sialolithiasis and reported that 44% of the sample had a history of smoking. Furthermore, both smoking histories and current smoking rates were higher in the sample than in the general population. However, smoking and sialolith size were not correlated. The patient in the study by Almasri had a 30-year history of heavy smoking.

The patient in this case report also was a heavy smoker for many years, smoking up to one pack a day. She had been advised to stop smoking since receiving her diagnosis of chronic obstructive pulmonary disease following an emergency department visit for dyspnea; she ceased smoking a few months later. The patient was using oxygen at 2 L/min via nasal cannula, 24 hours per day. Laforgia et al found in a study of 400 cases of sialolithiasis that 25% of those sampled had diabetes and 20% had hypertension. The patient in this case had a history of hypertension but was not diagnosed with diabetes.

Conclusion

Publication of images and case studies of rare findings is significant in improving accurate, timely diagnosis and can help radiologists and radiologic technologists better understand and recognize salivary fistulas in barium swallow examinations. Further study of the etiology of sialolithiasis, including causes of giant sialoliths, is needed. Examining comorbidities and possible risk factors, such as tobacco use, and how they alter the function of the salivary glands and saliva might improve understanding of the cause of salivary calculi.

Kathleen Ann Stanford, BS, R.T.(R), is an alumna of the University of North Carolina at Chapel Hill. She works at WakeMed Imaging Services in Raleigh, North Carolina.

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Reprint requests may be mailed to the American Society of Radiologic Technologists, Communications Department, at 15000 Central Ave SE, Albuquerque, NM 87123-3909, or e-mailed to communications@asrt.org.

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References


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DigiBit: A System for Adjusting Radiographic Exposure Factors in the Digital Era

William Ching, BAppSc  
John Robinson, BAppSc  
Mark F McEntee, PhD

Objective  To develop an exposure adaptation system for direct radiography that can accurately adjust exposure factors such as milliampere seconds (mAs), kilovoltage peak, and source-to-image distance for patients of differing size.

Methods  The DuPont Bit System was used to select the mAs for 60 combinations of exposure factors for an anthropomorphic pelvic phantom. The exposure index (EI) with a target value of 1500 ± 2% was used to evaluate whether each image was exposed correctly. The DuPont Bit System was then adapted for direct radiography so the mAs could be adjusted to achieve both the target bit value and the target EI.

Results  With the DuPont Bit System, an EI of 1500 ± 21.6% was achieved in all 60 radiographs, whereas the target EI of 1500 ± 2% was achieved in 16 radiographs. With the modified version of the DuPont Bit System, “the DigiBit system,” achieving the target EI increased to 38 out of 60 radiographs.

Discussion  The DigiBit system is an exposure adjustment system designed for direct radiography. In situations where automatic exposure control is not available, the DigiBit system allows adjustment of radiographic exposure. It is potentially a valuable tool for radiography.

Conclusion  The DigiBit system provides an accurate method of adjusting exposure factors for direct radiography.

Over the past 20 years, radiography has changed from film-screen to digital technology for image acquisition.\textsuperscript{1} Digital radiography, which encompasses both computed radiography (CR) and direct digital radiography (DDR), has many advantages. These advantages include more efficient data management (digital storage and transfer of images), wider exposure latitude, and postprocessing algorithms.\textsuperscript{2}

Radiographs now can be produced without the risk of decreased optical density (OD) because of underexposure or increased OD from overexposure. In the past, systems such as the DuPont Bit System were used to help select exposure parameters for film-screen radiography. Use of such systems declined with the introduction of digital radiography and the availability of automatic exposure control (AEC) devices. The increased latitude of digital systems, when combined with their image processing capability, has virtually eliminated the obvious signs of exposure error.\textsuperscript{3,4}

Overexposure and underexposure have equivalents in digital radiography with more subtle image appearances. Underexposure in digital radiography increases noise and potentially reduces the visibility of subtle pathology,\textsuperscript{5,6} whereas overexposure reduces noise while increasing patient dose.\textsuperscript{7,8} Ma et al demonstrated that an overexposure of as much as 139 times still can produce an acceptable quality image on a CR system.\textsuperscript{9}

As a result of concerns about underexposure and the perceived benefits of overexposure, the trend is toward increased exposures over time, or dose creep.\textsuperscript{7,8,10}

For any system to assist with prospective exposure selection effectively, it needs to be available before an examination, as is the case with the DuPont Bit System. However, the DuPont Bit System is designed for film-screen radiography only.

The AEC device controls x-ray exposure during radiography. It controls the amount of radiation and the time it takes to reach the detector by adjusting the milliampere seconds (mAs) at the x-ray tube and by terminating the exposure once a preset amount of
radiation has been detected by the AEC chamber(s). The AEC restricts the duration of the exposure, but other exposure factors such as kilovoltage peak (kVp), source-to-image distance (SID), and milliamperage (mA) must be set by the radiographer. The AEC might terminate exposure if a patient is incorrectly positioned over the AEC chamber(s) or if one or more incorrect AEC chambers are selected. The AEC can be used for table and erect Bucky examinations but not for non-Bucky or most mobile examinations.

According to a study by Gibson and Davidson, the number of optimal exposure factors selected decreased over 2 years in intensive and critical care units and emergency departments where an AEC was not available. This decrease occurred because radiographers overestimated the exposure factor adjustment required for changes in patient size. According to a study by Mothiram et al, between 77% and 82% of mobile chest radiographs were overexposed compared to less than 2% of radiographs taken in a department where an AEC was available. To avoid systematic overestimation of exposure when an AEC is unavailable, radiographers need a system to adjust exposure.

Many exposure adjustment systems have been proposed for film-screen radiography. These systems are used to select exposure factors to compensate for variations in patient size and physical condition when an AEC device is unavailable. The best way to do this is to provide the radiographer with an exposure adjustment system, which should include increases and decreases in exposure for large and small patients, for each radiographic examination. These exposure adjustment systems can be classified as simple or comprehensive.

Simple exposure adjustment systems involve one-step calculations such as the 25% rule, the 15% rule, and the 10-kVp rule. The 25% rule states that mAs is increased by 25% per centimeter increase in patient thickness. According to McLean and Targett, the increase in mAs varies between 20% and 30% and is dependent on other exposure factors such as kVp and the type of radiographic grid. However, a 25% increase in mAs per centimeter increase in patient thickness is appropriate for most radiographic examinations. The 15% rule states that when the kVp is increased by 15%, the mAs must be halved to achieve equivalent image quality. According to Al-Balool and Newman, the 15% rule is suitable only for patients and examinations where the thickness of the body part being imaged is 15 cm or less. They also report that the 15% rule fails once the beam energy reaches 100 kVp or higher. The 10-kVp rule, also called the “rule of thumb” or the “thumb rule,” indicates that the mAs must be halved for every 10-kVp increase. This is suitable only for a kVp range between 60 and 80; going outside that range produces a 3-kVp to 5-kVp error. The 15% rule adjusts for this error. These single-step calculations are simple.

Comprehensive systems—including the Supertech Slide Rule Technique Calculator Kit PB77 (Supertech, Inc), body habitus factor charts, the disc system, the Siemens point system, unit-step radiography, and the DuPont Bit System — require charts to be assessed, followed by simple calculations. The last 3 systems have a similar method of exposure adjustment. For the purposes of this study, we focused on the DuPont Bit System. The DuPont Bit System assigns arbitrary values, called bits, to exposure factor values such as patient thickness, kVp, and mAs. When one exposure factor is increased by a certain number of bits, it is necessary to compensate for the change by decreasing another exposure factor by the same number of bits. This process allows the radiographer to compensate for changes in patient size, clinical presentation, or pathology. It also can be used to adjust exposure factors to different imaging scenarios such as longer SIDs, shorter or longer exposure times, or a high-kilovoltage exposure technique. The DuPont Bit System has been described only in reviews, and assessment of its performance in the clinical setting has never been reported in the literature.

Only a few studies have addressed exposure adjustment systems for digital radiography. Allen et al found that the 10-kVp rule and a film-screen exposure adjustment system on CR equipment reduced the patient dose while maintaining equivalent image quality. Zhang et al developed an equation for pediatric examinations with DR that uses patient thickness to calculate the mAs required to achieve a target exposure index (EI) value. Their formula has the potential to significantly reduce pediatric patient entrance surface dose and dose area product (DAP) for DR (P < .005). Although their formula was comprehensive and showed positive

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results, it was a simulation only that applied the formula to exposures relevant to children up to 7 years of age.

Detector dose indices (DDIs) were developed by manufacturers as digital technology emerged. Because obvious signs of exposure error such as film whitening or blackening have been minimized, DDI values provide a feedback system for exposure selection. For example, Carestream uses an EI as a DDI; an overexposed image is indicated by an EI greater than the reference level, and an underexposed image has an EI less than the reference level. Zhang et al demonstrated that radiographers who selected exposures to achieve a target DDI were able to reduce the patient dose when compared with those who performed examinations without a target.

Although useful, DDIs are displayed only after an image has been processed and give a retrospective indication of overexposure or underexposure. For this reason, they have been used for quality control and audit.

The DuPont Bit System can be used with children and adults. However, no studies have assessed the DuPont Bit System for DR. The purpose of this study was to investigate whether the DuPont Bit System would be a viable option for adjusting exposure factors for DR. Ultimately, the authors modified the DuPont Bit System for DR and named it the DigiBit system.

**Materials and Methods**

To assess the accuracy of the DuPont Bit System in adjusting exposure factors, the authors obtained 500 radiographs of an abdomen-pelvis phantom (Kyoto Kagaku Co Ltd) with a tissue equivalence of a 70-kg man to simulate an average patient. The phantom is composed of simulated human bone encased in an epoxy tissue equivalent that has similar attenuating properties to human soft tissue. An 18 × 17 × 3 cm³ section of pork belly from a domestic farm pig (Sus scrofa domesticus) was added to the phantom to simulate an increase in patient thickness. Pork belly is composed of tissues similar to those found in the anterior portion of a human abdomen. Because pork belly is malleable, it molds to the contours of the phantom’s surface.

Images of the phantom were taken over a range of kVp, SIDs, and phantom thicknesses. An x-ray tube with a total filtration of 3.2 mm aluminium (Al) and 2 focal sizes (0.6 and 1.2 mm; Varian Medical Systems) was used. A DAP meter (PTW GmbH) was attached to the collimator and recorded the dose measurements. A high-frequency generator, model CMP200 DR (Communications & Power Industries), powered the x-ray tube. An antiscatter grid (Mitaya Manufacturing Co Ltd) with a grid ratio of 12:1, 80 strips of Al/cm, and a focal distance of 110 cm was used. The image receptor was a 35 × 43 cm² wireless gadolinium oxysulphide detector (Carestream DRX-1). The radiographs were displayed on a Dell monitor and archived using a Carestream picture archiving and communication system.

**Quality Control**

Quality control tests were performed at the beginning of the study to assess the accuracy and consistency of the kVp, the timer, and the x-ray tube output using a calibrated Xi base unit (Unfors RaySafe) and an R/F and MAM detector (Unfors RaySafe). The tests found that the x-ray tube performed within the acceptable clinical range. Before each testing session, the x-ray tube was warmed up and the detector calibrated.

**Experimental Design**

Radiographs were produced with different combinations of exposure factors: 60 kVp to 100 kVp in 10-kVp increments, 80 cm to 130 cm SID in 100-mm increments, and patient thicknesses of 18.5 cm and 21.5 cm. The initial exposure factors used to image the sacral area of the 18.5-cm thick phantom were 70 kVp, 2900 mA, 1.1 mSID, with the AEC indicating 25 mAs. Using the DuPont Bit System, the radiographer assigned a bit value to each exposure factor value. Adding the bit values of the initial exposure factors resulted in a target total bit value of 38.0. The target EI of 1500 was determined by using the initial exposure factors without the AEC to image the phantom (see Figure 1). An acceptable range of ± 2% of 1500 EI was chosen because it reflects the range of accuracy achievable with the exposure factor combinations available and is within accepted national and international tolerances for exposure parameters.

**Outcome Measures**

The total bit values, EI values, and DAPs were recorded for each exposure factor combination.
DuPont Bit System was used to select the mAs required to achieve a total bit value of 38.0 for each exposure factor combination (see Table 1). If the EI value was not 1500 ± 2%, the mAs were further adjusted to achieve this target EI value.

**Data Analysis**

The means for the total bit value, the EI and the DAP were calculated and normalized for comparison according to the formula: \( N_x = \frac{x}{\bar{x}} \), where \( N_x \) is the normalized value, \( x \) is the value to be normalized, and \( x \) is the mean of the value to be normalized. For example, a total bit value of 38.0 would be divided by its mean of 38.1, resulting in the normalized rounded value of 1.0. The data were plotted on graphs generated with Excel (Microsoft) software.

**Results**

The DuPont Bit System was used to adjust the mAs for 60 radiographs (2 thicknesses, 5 kVp settings, and 6 SIDs) with the aim of achieving the target total bit value of 38.0. When the phantom thickness was 18.5 cm, EIs of 1500 ± 13.2% were recorded (see Figure 2). However, when the phantom thickness was increased to 21.5 cm, EIs of 1500 ± 21.6% were recorded. In 6 cases, the error produced by the DuPont Bit System increased the EI by 300, which is 20% of 1500 and equates to double the DAP and double the mAs.

A total of 60 other radiographs achieved the target EI value of 1500 ± 2%. When the phantom thickness was 18.5 cm, total bit values of 38.0 ± 1.6% were recorded (see Figure 3). However, when the phantom thickness was increased to 21.5 cm, total bit values of 38.0 ± 3.2% were seen. Of these 60 radiographs, only 16 had both a total bit value of 38.0 and an EI of 1500 ± 2%. As before, in 6 cases the error produced equated to a doubling of the DAP and the mAs.

The exposure factor combinations that produced EIs of 1500 ± 2% were assessed. Modification of the bit values assigned to several exposure factor values produced total bit values of 38.0 ± 1.1%. Accuracy increased, as 38 of the 60 radiographs had a total bit value of 38.0. These values formed the baseline of the DigiBit system (see Table 2).

A comparison of the bit values assigned to kVp for the DuPont Bit System and the DigiBit system showed a deviation of kVp-bit values as kVp decreases or increases from 70 kVp (see Figure 4). A logarithmic trend-line was added to each system; the regression coefficients for both

---

**Table 1**

<table>
<thead>
<tr>
<th>kVp</th>
<th>kVp-Bit</th>
<th>mAs</th>
<th>mAs-Bit</th>
<th>SID</th>
<th>SID Bit</th>
<th>Thickness in cm</th>
<th>Thick Bit</th>
<th>Total Bits</th>
</tr>
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<tbody>
<tr>
<td>70</td>
<td>7</td>
<td>25 (26)</td>
<td>17.4</td>
<td>110 (112)</td>
<td>6.4</td>
<td>18.5 (19)</td>
<td>7.2</td>
<td>38.0</td>
</tr>
<tr>
<td>60</td>
<td>6</td>
<td>50</td>
<td>18.4</td>
<td>110 (112)</td>
<td>6.4</td>
<td>18.5 (19)</td>
<td>7.2</td>
<td>38.0</td>
</tr>
</tbody>
</table>

*aTotal bit value calculations to demonstrate exposure factor adjustments to compensate for a change in another exposure factor. The exposure factor values available on the Carestream system are shown.

bThe values listed in the DuPont Bit System are shown in parentheses.

Abbreviations: kVp, kilovoltage peak; mAs, milliampere seconds; SID, source-to-image distance.
DigiBit: A System for Adjusting Radiographic Exposure Factors in the Digital Era

Figure 2. Targeting a total bit value by using the DuPont Bit System to adjust the milliampere seconds (mAs) to compensate for changes in kilovoltage peak (kVp) and source-to-image distance (SID) with a patient thickness of 18.5 cm. A total bit value of 38.0 was the target, and the corresponding exposure index (EI) and dose area product (DAP) are displayed.

Figure 3. Targeting an EI by adjusting the mAs to compensate for changes in kVp and SID with a patient thickness of 18.5 cm. An EI of 1500 ± 2% was the target, and the corresponding total bit value and DAP are displayed.

Table 2

<table>
<thead>
<tr>
<th>Patient Thickness</th>
<th>Source-to-Image Distance</th>
<th>Kilovoltage Peak (kVp)</th>
<th>Patient Thickness</th>
<th>Source-to-Image Distance</th>
<th>Kilovoltage Peak</th>
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<tbody>
<tr>
<td>cm</td>
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<td>cm</td>
<td>Bits</td>
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<td>19</td>
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<td></td>
<td>130</td>
<td>6.0</td>
<td>102</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Changes made to adjust the DuPont Bit system for direct radiography.
curves were $R^2 = 0.9997$ and $R = 0.9994$. The difference between the DuPont Bit System and the DigiBit system lies in the rate at which the bit values increase; there is a 0.2-bit increase per 3% increase in kVp for the DuPont Bit System, and an approximately 0.3-bit increase per 3% increase in kVp for the DigiBit system (see Table 3).

The DAP followed the expected trend when targeting a total bit value of 38.0 and when targeting an EI of 1500 ± 2% (see Figures 2 and 3). The DAP decreased as the SID increased, which complies with the inverse square law. An increase in kVp reduced the DAP because the increased beam penetration allowed reduction in the mAs. The DAP increased as patient thickness increased; however, as kVp increased, the difference in the DAP between patient thicknesses of 18.5 cm and 21.5 cm decreased.

### Discussion

The DuPont Bit System achieved both target values: an EI of 1500 ± 2% and a total bit value of 38.0 ± 1.1% in 16 out of 60 radiographs when the mAs were adjusted to compensate for variations in kVp, SID, and patient thickness for a DR system. Modifications to the DuPont Bit System more than doubled its accuracy and produced an exposure adaptation system for DR that the authors named the DigiBit system.

When comparing kVp-bit values, those assigned to the DigiBit system were larger than those for the DuPont Bit System, particularly above 70 kVp. A higher kVp-bit value indicated that lower mAs are required to produce an exposure that achieves the target total bit value. The difference in kVp-bit values is likely because of the detective quantum efficiency of 70% for DR, which is greater than film-screen radiography at 25%. The kVp-bit values of the DigiBit system were smaller than those assigned to the DuPont Bit System below 70 kVp. This variation could result from the use of 70 kVp as the initial exposure factor, making it the crossover point on the graph for the DuPont Bit System and the DigiBit system (see Figure 4). A kVp of 70 was chosen because it is the most commonly used kVp for abdominopelvic radiography. Had a kVp of
60 been used, it would have created a different crossover point at 60 kvp.

A phantom study of the DuPont Bit System was conducted to allow control of potential patient variables, such as patient thickness and composition, and because multiple exposures would not produce adverse effects. Although the experimental design was suitable both for assessing the DuPont Bit System and for developing the DigiBit system, a clinical study is required to assess the feasibility of using the DigiBit system as a diagnostic and treatment planning tool. In their study of radiography of the clavicle, McEntee and Kinsella found that a posteroanterior projection of the clavicle produced a lower radiation dose than did an anteroposterior projection. They also found that radiographers performing both examinations in the clinical setting had to repeat the posteroanterior projection more frequently. This demonstrated that changing practice is not feasible without first educating and training the radiographers and that conducting a clinical trial with the Digibit system is necessary.

The limitations of the study include that only kVp, SID, and phantom thickness were addressed and only the sacrum was imaged. Assessment of other exposure factors such as beam collimation, tube filtration, radiographic grid, and pathology is required and might improve the accuracy of the DigiBit system. Assessments of other sections of the body such as the chest also are required. Furthermore, the efficacy of the DigiBit system should be assessed with other radiography equipment such as varied digital radiography capture systems, CR systems, and similar equipment produced by different manufacturers.

In the past, the image quality of film-screen radiography was heavily related to its OD. Studies that examined the accuracy of the 25% and 15% rules used OD to assess the images under experimental conditions where a diagnostic image had an OD of 1.3 to 1.5. With digital radiography systems, the level and width of the window can be manipulated. As a result, OD, which has a nearly fixed point in film-screen radiography, is variable in digital radiography and no longer a valid measure of image quality.

DDIs developed for digital radiography are an indirect measure of exposure to the detector and permit some measure of overexposure and underexposure. Although this approach does not provide an exact measure of image quality, it is the most suitable substitute for OD. Zhang et al compared the radiation dose among pediatric patients divided into 2 groups. The control group received standard radiographic examinations, and the intervention group received examinations programmed with a formula that selects the mAs to produce a specific EI value. They found that the intervention group achieved a 20% to 80% reduction in the entrance surface dose, thus indicating the benefit of an exposure adaption system that produces a targeted EI.

A target EI of 1500 ± 2% was chosen after making multiple exposures with the AEC. Because using the AEC resulted in a ± 2% variation in EI, the chosen target EI value could indicate that an acceptable image has been produced. However, methods for calibrating AEC devices vary, and calibration of the AEC could affect the compatibility of the results to past or future work.

The integration of digital systems into radiology departments resulted in the replacement of OD with detector air kerma values, or DDIs for AEC calibration. Determining the target value for calibration is challenging, as it depends on the clinical conditions being imaged. The target detector air kerma value, for example, depends on the radiography system used because the dose required to make an exposure with CR is greater than that with DR. Difficulty in target selection arises when an AEC system can be used with both CR and DR, which require different target values. One solution could be to design an AEC that is similar to one used for film-screen radiography but would have a selector for CR or DR instead of a selector for speed classes. DDIs must be calibrated against detector air kerma values before they can be used to calibrate the AEC. DDIs are appropriate for calibration because they follow a similar trend to the signal-to-noise ratio across kVp values.

The purpose of a radiographic examination affects the selection of a target DDL. For example, if the clinical indication for the radiograph is possible lung metastases, an ideal image would minimize noise and maximize image quality for an accurate clinical evaluation. For Carestream equipment, an increase in the target EI is necessary to achieve the ideal image to evaluate lung metastases. Conversely, an accurate clinical evaluation of prosthesis alignment can be achieved with greater noise,
and a decrease in the target EI is acceptable. Therefore, an AEC device set to achieve an EI of 1500 might be suitable to screen patients for lung metastases but will overexpose patients being imaged for prosthetic alignment. Manufacturers provide limited details about the calculation of their DDIs and little documentation concerning the optimal range. Carestream, for example, suggests an EI range of 1500-1800 for a pelvic examination but leaves the final range of acceptable EIs to the discretion of the radiographer. Thus, whether the selection of an EI of $1500 \pm 2\%$ for this study is appropriate is uncertain. Furthermore, the Carestream DRX was used because it was the only equipment available, which shifted the focus to the relationship between the EI value and the total bit value. Consequently, the results might not apply to radiography systems that use other types of DDIs such as the log of median of histogram for Agfa systems and the $S$ value for Fuji systems.

Furthermore, to work effectively, the DigiBit system requires that the thickness of the patient—the distance of the central beam's path from the anterior surface of the patient to the posterior surface—be measured. Two approaches suggested in the literature for film-screen radiography were the use of a calliper, as used for unit-step radiography, or a measuring tape or distance scale on the x-ray tube column. As early as 1959, Power described how to measure the thickness of a patient by attaching a scale to the x-ray tube column and moving the tube so it rests on the portion of the body to be imaged. When all of these issues are considered, it becomes evident that expanding the DigiBit system will allow radiographers to accurately adjust exposure factors to compensate for situations where an AEC device is unavailable.

The DigiBit system requires further investigation, and perhaps clinical trials, before it is implemented in practice. Research is ongoing to investigate other CR and DR image acquisition systems and other exposure parameters. Also of benefit would be assessing the current exposure selection accuracy of radiographers and comparing it to the DigiBit system. However, this study provides a good starting point for the development of an exposure adjustment system for digital radiography.

**Conclusion**

The DuPont Bit System did not provide consistent EI values when adjusting exposure factors. Therefore, it is not a suitable exposure-adjustment system for DR. In contrast, the DigiBit system has double the exposure adjustment accuracy of the DuPont Bit System and provides an accurate method of estimating exposure for changes in patient size for DR. A clinical trial should assess the feasibility of the completed DigiBit system as a diagnostic and treatment planning tool.

Mark F McEntee, PhD, worked as a radiographer in Dublin, Ireland. After completing his doctoral degree in dose optimization, he became a lecturer for University College, Dublin. He was president of the Irish Institute of Radiography and Radiation Therapy and an inaugural member of the Health and Social Care Professional Council. He served as senior lecturer at the University of Sydney in 2011 and associate professor of medical radiation science in 2015. He is involved in curriculum renewal, teaching, and research, including projects in computed tomography and mammography in Australia, Ireland, Portugal, and Malta.

John Robinson, BAppSc, is lecturer and course director of the undergraduate degree program in Medical Radiation Sciences, Faculty of Health Sciences, at the University of Sydney. He previously served as chief radiographer, deputy chief, and tutor for 2 hospitals. Robinson is pursuing a doctoral degree in factors affecting nodule detection in lungs and conducting research in visual perception, dose and image optimization, and exposure techniques.

William Ching, BAppSc, earned his bachelor of applied sciences degree in diagnostic radiography at the University of Sydney. Working with McEntee and Robinson, he wrote and published a systematic review and a study examining exposure adjustment system in radiography.

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2. Aufrichtig R. Comparison of low contrast detectability between a digital amorphous silicon and a screen-film.


Adverse Effects of Iodine-derived Intravenous Radiopaque Contrast Media

Eric P Matthews, PhD, R.T.(R)(CV)(MR)

Beginning with Resolution 91-4.04, and continuing through the current Standards of Practice, the American Society of Radiologic Technologists maintains that it is within the scope of practice and standard of care for a radiologic technologist to perform venipuncture and administer contrast media, radiopharmaceuticals, and intravenous (IV) medications where state law and institutional policy permit. Such actions must be undertaken only when a practitioner (eg, a radiologist) is immediately available to diagnose and treat allergic reactions.1,2

However, because “immediately available” and “present” are entirely different constructs, it is necessary for radiologic technologists to be aware of the ramifications of administering contrast media. This is especially important because adverse reactions to triiodinated benzoic-derived radiopaque contrast media (ROCM) occur randomly and are unpredictable. Although the use of nonionic low-osmolar agents has decreased the incidence of reactions, these contrast agents do not affect the possible severity of the reactions that do happen; furthermore, although most reactions are mild and self-limiting, severe reactions can occur with any patient at any time.3,4

Contrast Media History and Classification

The use of sodium iodide as a contrast medium began in clinical practice in the early 1920s. However, poor radiographic enhancement and high toxicity severely limited its use as a contrast medium. In the 1950s, the introduction of water-soluble sodium and meglumine salt derived from triiodinated benzoic acid greatly increased the daily use of radiographic contrast agents. Although these preparations were much less toxic than earlier preparations, they were hyperosmolar (with an average osmolality 5 to 8 times that of blood). By the 1970s, low-osmolality iodinated contrast media had been developed. The advent and prescription of both high-osmolar

After completing this article, the reader should be able to:

- Explain how radiopaque contrast media (ROCM) are classified.
- Discuss the distribution and excretion of ROCM.
- Describe various reactions and other adverse effects associated with ROCM.
- Summarize recommendations for using ROCM in special patient populations, including pediatric patients and those with certain medical conditions.
- Discuss treatment and prevention of adverse effects associated with the use of ROCM.
and low-osmolar contrast media have led to their being some of the most widely used drugs in the history of medicine. Each year approximately 70 million people worldwide receive IV iodinated contrast agents. In fact, iodinated contrast media are the most common IV pharmacologic agents of any type currently in use.

Osmolality and Ion State

ROCM typically are divided into categories based on their chemical composition and propensity to influence osmotic activity. These categories are defined as high or low osmolality and ionic or nonionic, depending on how they dissociate in solution. Ionic high-osmolality contrast agents dissociate into a cation (positively charged atom) and an anion (negatively charged particle) when in solution. The dissociation of ionic high-osmolality contrast agents is considered partially responsible for several of the adverse effects of contrast media. Nonionic low-osmolality contrast agents do not dissociate in solution. Regardless of whether a contrast medium has high or low osmolality and is ionic or nonionic, all of these substances have a high iodine content (11%-46%, on average). Jensen and Peppers noted that the movement and distribution of water between body compartments is controlled by osmolality. Osmolality often is used interchangeably with osmolarity to define osmotic activity, but this is inappropriate. Osmolality is the measure (concentration) of molecules by weight, while osmolarity is the measure (concentration) of molecules by volume. Although both can affect osmotic activity, or the transfer of water across a permeable or semipermeable membrane, ROCM are defined by the number of milliosmoles per kilogram of water. Therefore, osmolality should be used to describe ROCM.

High-osmolality contrast agents are those that attract water across a semipermeable or permeable membrane, such as cell walls. When highly osmotic ROCM are injected into the bloodstream, the body’s response is to transfer fluid from the extravascular space to the intravascular space in an effort to restore equilibrium in the osmotic pressure of the body. The effect of this action is to dilute the normal intravascular constituents and increase intravascular pressure. This normal osmotic transfer contributes to the adverse effects experienced with ROCM. High-osmolar contrast agents are ionic monomers containing 3 iodine atoms per molecule. These agents dissociate into a cation and an anion in solution. The anion, coupled with the positively charged cation, arises from a monomeric molecule that has 3 iodine atoms; the result is a 3:2 ratio compound (3 iodine atoms plus 2 charged particles) defined by the ratio of iodine atoms to osmotically active particles. Typically, high-osmolality ionic ROCM are derived from meglumine salts, sodium salts, or both, and they have an osmolality of around 1500 mOsm/kg H2O.

Low-osmolality contrast agents are defined by a sliding scale (low osmolality being relative) and typically have osmolalities ranging from 290 to 860 mOsm/kg H2O. All ROCM have a higher osmolality than blood, so high or low measures are used only to differentiate one ROCM from another and not from the substance into which they are being injected. Low-osmolality contrast agents exist in 3 primary forms: nonionic monomers, ionic dimers, and nonionic dimers. The primary standard by which low-osmolality contrast agents are measured is the outcome of their injection; they all result in one osmotically active particle per 3 iodine atoms. Therefore, low-osmolality contrast media result in a ratio 3:1 (sometimes referred to as a ratio 3.0) media.

Nonionic monomers were the initial attempt to reduce the osmotically induced adverse effects of contrast media and make them safer. Nonionic monomers have a single tri-iodinated benzene ring but lack a carboxyl side group; furthermore, they have an added hydrophilic hydroxyl group on one of the organic side chains. The effect of these chemical changes is that the monomers dissolve in water but do not dissociate (ionize) into a cation and an anion; therefore, they render a ratio 3:1 media with 3 iodine particles and one osmotically active particle.

Low-osmolar ionic contrast agents were the next major iteration in contrast media. These contrast media are formed from 2 benzene rings chemically joined and as such are considered dimers. Dimetric contrast media are formed when 2 ionic monomers are combined through elimination of (and sharing of) one carboxyl group. These contrast media exist with 6 iodine atoms and dissociate in the body into 2 osmotically active particles. Upon dissociation, the contrast media have
2 particles per 6 iodine atoms, which results in a ratio 6:2 contrast media. A ratio 6:2 medium, simplified, is a ratio 3:1 medium. The only commercially available ionic dimer is ioxaglate (Hexabrix).2,12,14 A major characteristic of low-osmolality ionic dimers is their exceptionally high viscosity. Of the commonly used contrast media, ioxaglate derivatives are the most viscous.

Viscosity is a measure of the resistance of a liquid to flow. This is sometimes categorized as the relative amount of friction a liquid causes. Viscous liquids are thicker than nonviscous liquids. Viscosity is measured in centipoises (cps), with water being the standard of reference, equal to 1 cps.4 Viscosity can be influenced by several external factors; heat is the one most applicable to ROCM. Heating the contrast media to body temperature prior to injection lowers the relative viscosity of the contrast media and makes it easier to inject. Less viscous contrast media can be injected more quickly than contrast media with a higher viscosity. The rate of injection, coupled with the viscosity of the contrast media, is associated with the flushing (warmth) that patients feel upon being administered contrast media. This is not a pharmacologic adverse effect, and warming the contrast media to body temperature before injection helps to reduce patient discomfort.5,14

The most recent innovation in contrast media is the use of nonionic dimers. Joining 2 nonionic monomers forms these contrast media. Nonionic monomers do not dissociate in situ, and when joined to form a dimer they remain connected following injection. The result is that there are 6 iodine atoms for every one particle. The iodine concentration is much higher per particle, but much lower within the bloodstream because of the decreased volume necessary to opacify tissue.5,12,14 The major effect of this is that, “for a given concentration, the nonionic dimers have the lowest osmolality of all the contrast agents.”5 The result of this lack of dissociation is a virtually isosmolar contrast medium with osmolality measuring up to 300 mOsm/kgH2O.4 The Table lists some of the most commonly used contrast media by category.

### Distribution and Excretion

Intravascular ROCM have a high molecular weight—generally between 600 and 1700. They also have very poor lipid solubility. The result of these 2 physical traits is that iodinated ROCM do not cross cellular membranes easily and stay primarily within the bloodstream. Typically, the blood-brain barrier prevents ROCM from being distributed into the normal central nervous system; however, in some cases trace amounts of ROCM enter the cerebrospinal fluid by crossing through the choroid plexus, a nerve complex in the brain.2

ROCM typically diffuse rapidly in the presence of relatively normal biophysical function. As a result of the rapid process of glomerular filtration, the primary means of ROCM excretion, 70% of the injected dose is cleared from the blood plasma within 2 to 5 minutes.6,16 Additional reverse diffusion takes place, moving fluid from the extracellular spaces into the plasma, diluting the contrast further. About 2 hours following injection, complete equilibrium takes place between plasma and the interstitial spaces. Four hours after injection, 75% of the dose will be excreted; over the subsequent 24 hours, between 90% and 100% of the measurable IV dose will be excreted by the kidneys.5,6,16 Generally, less than 1% of ROCM is excreted extrarenally. The exception is iodamide meglumine (Renovue), which is excreted principally through the hepatobiliary system.2

### Table

<table>
<thead>
<tr>
<th>Common Iodinated Contrast Agents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generic Name</strong></td>
</tr>
<tr>
<td>Ionic monomers:</td>
</tr>
<tr>
<td>sodium amidotrizoate</td>
</tr>
<tr>
<td>meglumine ioxithalamide</td>
</tr>
<tr>
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<td>iohixanol</td>
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### Adverse Effects of Contrast Media

Doses of ROCM are administered more than 75 million times a year, to about 15 million patients in the
United States alone.\textsuperscript{5,9} Reactions to ROCM derived from tri-iodinated benzoic acid occur in up to 54\% of injected patients. Adverse effects can be anticipated in 2\% to 17\% of routine patients receiving ROCM; adverse effects approach 60\% in patients who have exhibited a previous adverse reaction. Severe, life-threatening reactions occur in 0.1\% to 0.4\% of patients, with a mortality rate of approximately 1:75,000.\textsuperscript{5,9,17,18}

Reactions to ROCM fall into 2 major categories: systemic (idiosyncratic) and chemotoxic (nonidiosyncratic). Other, noncategorized reactions also occur and typically are associated with the act of administering the media (eg, air embolism) or contaminants in the media, rather than contrast media itself.

Idiosyncratic reactions are the most common and can be either immediate (acute) or delayed (latent). Immediate reactions are anaphylactoid in nature and do not involve the release of immunoglobulin E (IgE) antibodies; delayed reactions are anaphylactic in nature and do involve the release of IgE. Anaphylactoid and anaphylactic reactions are random. Both involve mast cell mediator release, and both escalate in severity without decisive intervention.\textsuperscript{18,19}

Typically, allergy-like reactions to contrast media are anaphylactoid in nature and do not arise from the iodine content of the contrast; indeed, numerous studies have demonstrated no correlation between seafood allergy and contrast allergy. Therefore, radiologic technologists should not perpetuate the myth that seafood allergy correlates with iodine or radiopaque contrast allergy.\textsuperscript{20,21}

Chemotoxic adverse effects generally are predictable and can be averted in most cases. These effects are directly related to the dose of contrast given and the physiochemical properties of the contrast agent used. Physiochemical properties include the osmolality, viscosity, salt content, calcium binding properties, and hydrophilicity of the contrast media. Some of these characteristics are beyond the control of the radiologic technologist; however, if the technologist is aware of them, they can be suppressed.\textsuperscript{4}

**Systemic/Idiosyncratic Reactions**

Systemic reactions typically occur following mast cell decomposition (degranulation) and release of their inherent mediators. Mast cells are connective tissue cells that contain a number of substances, some of which are preformed and stored, and others that are rapidly produced by submembrane phospholipids once the membrane of the cell is triggered. Mast cells are found throughout the body in skin, synovia, mesentery, surrounding blood vessels, and the gastrointestinal tract.\textsuperscript{2,19}

Histamine is the most prevalent preformed granule in mast cells. Histamine release also is the major early concern in mast cell degranulation. Histamine release results in smooth muscle contraction. Because of the locations of mast cells in the body, the action of histamine on surrounding tissue can be problematic. For example, smooth bronchial muscular contraction results in bronchospasm. Histamine release also increases capillary permeability, and in the respiratory system this might lead to laryngeal edema and stridor. People with asthma are at increased risk of respiratory compromise as a result of the action of histamine on the respiratory system. Histamine interacting with receptors in cardiac muscle can cause arrhythmias. Histamine release in the skin leads to pruritis, and redness is an adverse effect of histamine release in superficial capillaries near the skin’s surface. Pruritis is the cardinal symptom of a histamine-mediated reaction, and any report of itchiness by the patient should immediately alert the technologist to take decisive action.\textsuperscript{19,22}

In addition to histamine release, mast cell degranulation results in the discharge of many other substances. These substances are primarily the lipid mediators produced by the submembrane phospholipids in mast cells. They are produced very rapidly following mast cell triggering and are responsible for a host of secondary signs and symptoms associated with allergy-like reactions. Leukotrienes (commonly referred to as the slow-reacting substance of anaphylaxis), eosinophil and neutrophil chemotactic factors, kininogenase, bradykinin, platelet activating factor, and prostaglandins are produced and released during mast cell degranulation.

Leukotrienes, specifically LTD\textsubscript{4} and LTC\textsubscript{4}, cause bronchospasms that might lead to stridor, coughing, wheezing, and dyspnea in addition to those same symptoms caused by histamine; therefore, the symptoms become more pronounced and longer lasting. Platelet activating factor and the remaining lipid mediators...
cause warmth, redness, and various cardiac effects, including decreased output and tachycardia; the cardiac effects resulting from the lipid mediators lead to syncope and shock.\textsuperscript{2,9} Box 1 lists some common organ-specific and system-specific adverse effects of ROCM.

Anaphylactoid Reactions
Acute anaphylactoid contrast media reactions are those that occur within 60 minutes following injection. Typically, these reactions fall into one of 3 categories: minor, moderate or intermediate, and severe. Some authors specify death as a fourth category; however, it more accurately falls in the category of severe reactions because death is an outcome of an adverse reaction and not a spontaneous event. Anaphylactoid reactions do not require any previous exposure or sensitivity to an allergen (ie, iodine, in this case).

Minor reactions to iodinated radiographic contrast are the most common clinical manifestation.\textsuperscript{11} Minor reactions typically include any or all of the following:

- Flushing.
- Nausea.
- Vomiting.
- Pruritus.
- Headache.
- Mild urticaria.
- Arm pain.

Minor reactions do not generally require any therapeutic intervention beyond routine patient care, comfort, and monitoring. Most patients exhibiting only minor signs and symptoms fully recover within several hours.\textsuperscript{2,5,6,11}

<table>
<thead>
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<th>Box 1</th>
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<td><strong>Organ-specific and System-specific Adverse Effects From Iodine-based or Gadolinium-based Contrast Agents</strong></td>
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<td>Compartment syndrome — from extravasation</td>
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<td>Nephrogenic systemic fibrosis (NSF)</td>
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<td><strong>Thyroid</strong></td>
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<td><strong>Vascular System</strong></td>
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<td>Hemorrhage — due to direct vascular trauma from contrast injection or from the reduction in clotting ability</td>
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<td>Thrombophlebitis</td>
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</table>


Moderate reactions include any or all of the signs and symptoms found in mild reactions but to a heightened or more developed degree; mild signs and symptoms that progress become moderate reactions. In addition to the mild symptoms, patients undergoing an intermediate-level reaction might exhibit bronchospasm, moderate urticaria, chest pain, dyspnea, hypotension or hypertension, tachycardia or bradycardia, and other vasovagal responses. Patients exhibiting any signs of a moderate reaction generally require therapeutic intervention, but not admission
Adverse Effects of Iodine-derived Intravenous Radiopaque Contrast Media

Severe reactions occur in fewer than 1% of patients who receive iodinated contrast media. Generally, if a patient is going to develop a severe reaction to ROCM, the reaction is quite acute without a significant delay following administration. Indeed, the signs and symptoms of a severe reaction manifest within 20 to 30 minutes following injection in 95% of patients exhibiting this elevated response; virtually every fatal contrast reaction begins within 20 minutes.11,19 Patients who develop a severe reaction require rapid intervention because of life-threatening effects of the reaction. In addition to the signs and symptoms of mild and moderate reactions, severe reactions include laryngeal edema, severe bronchospasm, seizures, convulsions, paralysis, unresponsiveness, and cardiovascular collapse resulting in cardiopulmonary arrest. Without immediate and decisive intervention, death is the outcome of severe reactions to ROCM.17,19,23

Anaphylactic Reactions

Although the majority of contrast-induced reactions are pseudoallergic anaphylactoid reactions, there is no clear demonstration of the exact pathogenesis for contrast-induced reactions; therefore, the possibility that patients might exhibit a true anaphylactic response to contrast media should be addressed. The radiologic technologist should be reminded that anaphylaxis following contrast media injection is likely not a reaction to the iodine content of the ROCM but to some other substance in the contrast media, the injection solution, or to one of the tools of administration.10,21

The primary difference between an anaphylactoid reaction and an anaphylactic response is that anaphylactic reactions require a previous exposure to an antigen, whereas no previous exposure is required for anaphylactoid reactions. In the case of anaphylactic events, exposure to an antigen occurs during an initial sensitizing event (ie, the patient’s first exposure to the antigen iodine either via administration of ROCM or some other means). As a response to the sensitizing event, mast cells generate an antibody. This antigen–antibody complex response requires about 2 weeks to mature. Following this period, subsequent exposure to the antigen will result in catastrophic mast cell degranulation. The sequence of events, including the signs and symptoms previously discussed, are identical to an anaphylactoid response with one important difference: in the absence of intervention, true anaphylactic events almost always result in death.2,19,22 There have been few demonstrated true anaphylactic reactions to contrast media (as defined by the antigen–antibody complex), but studies have confirmed allergies to the contrast media solutions. Skin testing can confirm that the reaction response was anaphylactic in nature and define the antigen (which has never been shown to be iodine).19,24

Chemotoxic Reactions

Chemotoxic reactions are much easier to quantify than idiosyncratic reactions; they are predictable and can be partially managed—or even completely suppressed—in most circumstances. Chemotoxic effects generally result from the physical make-up and composition of the contrast (eg, viscosity), but they also might arise following faulty injection technique or because of unrelated patient pathophysiology. These types of adverse effects are the only outcomes that might be controllable by the radiologic technologist and that are foreseeable or predictable. Although all patients are at risk for chemotoxic reactions, individuals with debilitating disease and those who are medically unstable are the most likely to exhibit these effects.19 Of primary concern are patients with a recent or ongoing history of seizures, cardiovascular disease, renal dysfunction, or renovascular compromise.5,18

Effects that result from the ionic activity of contrast media arise from the cation content of the various agents. Hypotension and tachycardia, in the absence of other allergy-like signs and symptoms, are common adverse effects of contrast hypertonicity. Sickling of red blood cells in patients who have sickle cell disease also has been linked to hypertonicity. Myasthenia gravis, a chronic autoimmune neuromuscular disease, can be exacerbated as a result of the neurotoxicity of certain contrast media. Patients suffering from a pheochromocytoma, a rare tumor of the adrenal gland, are at increased risk of hypertension as a result of IV contrast media administration.5,23
Anecdotal evidence suggests contrast-induced nephrotoxicity is a direct effect of osmotic and chemotoxic interactions. Furthermore, there is evidence to infer that the probability of nephrotoxic events increases proportionally with dose. Regardless, it is known that nephrotoxicity averages 15% to 25% in patients with debilitating medical histories and might approach 90% in patients with multiple pre-existing conditions. Therefore, radiologic technologists should ensure that the pre-examination history includes renal function, blood pressure (to evaluate cardiovascular and/or renal vascular health), age, uric acid levels, hydration status, and recent previous contrast administration. The American College of Radiology (ACR) lists the following as risk factors for nephrotoxicity:

- Age older than 60 years – increased likelihood of contrast-induced nephrotoxicity.
- History of renal disease – including dialysis, renal transplant, having only a single kidney, history of renal cancer, or any type of renal surgery. Renal impairment is the most compelling risk factor for nephrotoxicity.
- History of hypertension requiring medical care.
- History of diabetes mellitus.
- Currently taking metformin or metformin combinations.

The ACR noted that metformin does not confer an increased risk of nephrotoxicity, but that metformin might lead to lactic acidosis in patients with renal failure. A patient with any of the previously described conditions should undergo preprocedural renal function testing (specifically an evaluation of serum creatinine) to stratify their risk of continuing an IV contrast-enhanced examination. A risk-benefit analysis always should be completed on these patients to confirm that the diagnostic information obtained from the examination will outweigh the risk of adverse effects.

The most significant adverse effects that might be directly correlated to the iodine in ROCM are hyperthyroidism and thyroid storm. Both of these diseases are clinical diagnoses arising from an increase in circulating thyroid hormones. Alkhaja et al noted that thyroid storm is a life-threatening condition associated with mortality rates as high as 30% and characterized by hemodynamic abnormalities, hyperpyrexia, dysrhythmias, and delirium. Thyroid storm typically is caused by a major stressful event or an increased iodine load, such as that following iodinated contrast administration.

Vasovagal Reactions

Vasovagal reactions occur for a variety of reasons and are not uniquely associated with IV administration of contrast. They can occur as a result of anxiety and have been known to happen before radiographic examinations (eg, when obtaining the informed consent). Vasovagal reactions commonly occur as a result of IV injections of all types.

Vasovagal reactions occur when baroreceptors and chemoreceptors located at the bifurcation of the aortic arch and carotid arteries are stimulated, typically in response to pain or fear. When stimulated, the baroreceptors and chemoreceptors cause the autonomic nervous system to induce bradycardia and produce a commensurate drop in aortic pressure. Typically, the drop in aortic pressure is a result of peripheral vasodilation which, when coupled with the bradycardia, produces hypotension. Hypotension coupled with bradycardia is the cardinal sign of a vasovagal response. Vasovagal reactions typically self-rectify but should be treated seriously because signs and symptoms might escalate. Close patient observation allows the radiologic technologist to determine whether the hypotension is progressing. Progressive hypotension leads to loss of consciousness, cardiovascular collapse, angina, seizures, and ultimately cardiopulmonary arrest.

Treatment of vasovagal reactions, if warranted, focuses on fluid replacement and the administration of atropine. Antihistamines and epinephrine have no effect on this type of reaction, so it is imperative that it be identified as vagal and not systemic. Treatment should:

[B]egin with 0.6 mg to 0.8 mg of atropine given intravenously, followed by repeated doses every minute (while monitoring pulse rate) until a maximum total dosage of atropine (3 mg for adults) is administered. Fluids should then be given intravenously as well.
Pulse rate should be used to determine the efficacy of the atropine dosage, because the patient might remain hypotensive for several hours. Diaphoresis and anxiety or apprehension are clinical manifestations of vagal reactions, and the decrease in these signs and symptoms might signal the rectification of the event.5,23,26

**Noncategorized Adverse Effects**

**Extravasation**

Extravasation is a well-known complication following parenteral administration of any substance, particularly radiographic contrast media. Any material that is injected or attempted to be injected intravenously can cause rupture or leakage of the substance from the selected vessel into the surrounding tissue; the leakage of this material into the surrounding fascia constitutes extravasation. Although all extravasation is painful, extravasated contrast media is toxic to extravascular tissue and produces an acute local inflammatory response. The response typically peaks within 24 to 48 hours.23 Research data are lacking for extravasation injuries in all modalities except computed tomography; however, studies in that field indicate extravasation rates approaching 1% even when proper injection techniques are applied.23,27,28 Therefore, it is important to understand the mechanism of extravasation injuries as a physiologic adverse effect of radiographic contrast injection.

Extravasation injuries are typically limited to the tissues immediately surrounding the injection site. As a result, the clinical experience is widely varied; however, swelling or tightness, and stinging or burning are cardinal signs of extravasation injury. If not treated, or if the amount of extravasated contrast is not minimized or the contrast media is high-osmolar, the consequences can progress from minimal swelling and erythema to skin ulcerations, soft tissue necrosis, or compartment syndrome. Compartment syndrome is an extremely painful mechanical compression of tissue as a result of the extravasated material that exerts pressure on blood vessels and limits blood supply.28,29

The severity of contrast media extravasation is determined by the clinical manifestations and the treatment protocols necessary to rectify the situation. In mild extravasation cases, patients experience pain, tenderness, swelling, mild erythema, and limited range of motion. Mild cases occur as a result of minimal amounts of extravasation, or in cases where the patient does not exhibit new signs or progression of initial signs after a period of observation. Patients with mild extravasation should be watched closely for 2 to 4 hours following the event and, in the absence of other issues, may be released under orders to report any change in their status immediately. Typically, mild extravasations resolve within 2 to 4 days and the patient has no lingering effects beyond minor tenderness.24-30

Clinically moderate cases of extravasation are defined by pain that persists or increases beyond 2 to 4 hours, or any of the following signs and symptoms:
- Skin ulcerations.
- Skin blistering.
- Altered tissue perfusion.
- Clinical worsening with persistent or increased swelling, firmness, or paresthesias.

Without treatment, moderate cases progress to severe cases of extravasation. In any case where surgical intervention is required or permanent deficits occur, the event is defined as severe. The worst adverse effect of extravasation, compartment syndrome, is exceptional.23,28,29

Compartment syndrome typically arises following large extravasations, but it is known to occur in the presence of smaller extravasations when they occur in less spacious compartments of the body such as the wrist (see Figure).23 In addition to the volume of contrast extravasated, the primary factors that influence the development of compartment syndrome are the osmolality and ionic or nonionic nature of the compound.27

Treatment for extravasation injuries varies widely. There are no clear-cut guidelines or recommendations on how best to treat these types of injury.23 As much contrast media as possible should be aspirated from the injury site prior to removing the cannula. Reintroduction of an aspiration cannula might be merited, depending on the volume of contrast present; however, success with both aspiration approaches has been limited. Elevating the affected limb (typically the arm) above the level of the heart decreases capillary hydrostatic pressure and allows more rapid resorption of the media, with a consequent decrease in edema around the injection site. No data has been collected in controlled
studies to support the efficacy of elevation, so the usefulness of this approach is anecdotal.\textsuperscript{23,28}

A common approach to treating extravasation injuries is the application of a moist cloth. Again, no experimental evidence exists to support the efficacy of either warm or cool cloths, but they work equally well in treating some of the manifestations of extravasation. Warm cloths increase absorption of the extravasated contrast and improve blood flow distal to the site by causing vasodilation. Cool cloths increase vasoconstriction, decreasing pain and swelling at the site.\textsuperscript{23,28} The only recommendation that exists for the use of either warm or cold cloths is presented by the Oncology Nursing Society, specifically for chemotherapy extravasation. This group endorses the use of cold compresses 3 times a day for 15 to 60 minutes following extravasation.\textsuperscript{28}

Surgical consultation and intervention is merited in the presence of severe incidents or with any of the following clinical manifestations:\textsuperscript{23,27,28}

- Progressive swelling or pain.
- Altered tissue perfusion evidenced by decreased capillary refill.
- Change in sensation in the affected limb.
- Skin ulceration.
- Blistering.

Surgical consultation might be merited in cases of extravasation involving 100 mL or more of contrast, although this guideline was recently revised by the ACR to include surgical consultation anytime there is concern for extravasation injury, regardless of the volume of extravasated fluid.\textsuperscript{23,28} If surgery is warranted, typical procedures might include incision and drainage, excision of any hematoma, and fasciotomy.\textsuperscript{27}

Although there is no definitive method of treating anything other than severe cases of extravasation, early diagnosis and intervention lead to positive outcomes. Therefore, identifying individuals who might be more prone to extravasation injuries could be of some help to the radiologic technologist. Patients at increased risk of extravasation include those who are incapable of timely, concise, and adequate communication, such as infants and small children, patients with altered consciousness, those of advanced age, and individuals for whom language might be a barrier. Individuals who are obese or who have had radiation therapy or chemotherapy also are at increased risk as a result of small-caliber or fragile veins. Injections that take place through indwelling peripheral IV lines that have been in place for longer than 24 hours also have demonstrated an increased risk for extravasation. Injecting into veins with multiple recent puncture sites also increases the risk of injury to the patient. Finally, injection into the hand, wrist, foot, or ankle has been shown to increase the risk of extravasation.\textsuperscript{23,28} Although administering contrast to all patients who could be at increased risk of extravasation cannot always be avoided, the technologist might limit these types of injuries by avoiding compromised injection sites.

Air Embolism

Air emboli are a known—and relatively common—adverse effect of IV injections of all types. Indeed, the first known death resulting from air embolism occurred in 1850.\textsuperscript{31} Clinically significant air emboli are potentially fatal; however, they are extremely rare and generally arise following the use of power injectors. Most insignificant air emboli arise following hand injection and are measured...
in a few milliliters of fluid. Although typically asymptomatic, the frequency with which air emboli occur and the possible catastrophic outcomes warrant further examination of the phenomenon.

Air emboli can occur in one of 2 ways: through either manipulation or use of a peripheral catheter. Manipulation, including the introduction or removal of a catheter, is the least common means of inducing an air embolism, and little is known about the microemboli that formed as a result of this mechanism. Manipulation-induced air emboli often are referred to as passive emboli. Most clinically significant air emboli form following use of a peripheral catheter; typically power injectors account for most (if not all) of the catastrophic embolic events that occur in this manner. Injection emboli are considered to be active in their origination.

When an air embolus forms, it is the result of a pressure gradient that occurs between the vascular space and ambient atmospheric air. The severity of the embolism depends on several factors, including the volume of air, the rate of air entry, and the patient’s relative position at the time of injection. In general, 50 mL of air is considered lethal, but emboli as small as 20 mL (at an extremely rapid injection rate) have proven fatal. The typical mechanism for death is precipitous cardiovascular collapse or myocardial infarction. However, fatalities also occur when neurologic deficits arise from stroke secondary to decreased cardiac output or paradoxical air emboli (ie, when the air embolus crosses from the right side of the heart to the left and enters systemic circulation).

Common clinical manifestations of air emboli include dyspnea, chest pain, pulmonary edema, tachycardia, hypotension, and expiratory wheezing. Less common symptoms can include shoulder pain, light-headedness, and nausea. Patients with compromised cardiac outflow might be at higher risk for catastrophic complications resulting from smaller air emboli; right to left intracardiac shunts and pulmonary arteriovenous malformations are the most common bloodflow problems that cause neurologic deficits arising from minute air emboli.

Treatment of air emboli requires immediate action. Injection should be stopped immediately, and if passive air entry is occurring, the opening should be occluded prior to any other intervention. Sterility of the catheter or site should not be a primary concern; in one published case study, the nurse used a wet wash cloth to occlude a tri-lumen catheter that was inadvertently cut at the skin surface and could not be removed. The cloth effectively formed an air-proof seal. The patient should be placed on 100% oxygen immediately; hyperbaric oxygen can be used in an effort to reduce the size of air bubbles, but it might not be immediately available. Furthermore, the patient should, if possible, be placed on his or her left side in a Trendelenburg position. If the patient cannot tolerate the Trendelenburg position, left lateral decubitus positioning has been shown to be only slightly less effective. Both of these positions reduce the differential pressure gradient between the vascular and atmospheric pressures while holding the trapped air bubbles in the apex of the right atrium. Holding the air in the apical portion of the right atrium prevents occlusion of the pulmonary artery.

Radiographic Contrast and Special Populations
Radiographic contrast is a widely used diagnostic tool and is preferred in imaging vascular structures; however, it is not completely safe and always should be used only after a risk-benefit analysis. The radiologic technologist, as the administering health care provider, provides the final safeguard against injecting individuals who are at increased risk or who are contraindicated to receive radiopaque IV iodinated contrast media. Patient screening is essential to minimize adverse effects.

Pregnant or Possibly Pregnant Patients
The interaction of iodinated contrast media with human fetuses is incompletely understood; no large studies on the interaction of iodinated contrast with placental barriers, fetuses, and birth mothers have been undertaken. However, gadolinium-based contrast agents have been shown to cross the placental barrier and arrive in the fetal bladder of primates within a short time in controlled trials. It also has been clinically demonstrated that iodinated contrast crosses the
placental barrier in measurable quantities. Although no definitive evidence links low-osmolality iodinated contrast to mutagenic or teratogenic effects, reports of hypothyroidism have been linked to fetal doses of ROCM in newborn infants. Therefore, it is best to err on the side of caution when dealing with pregnant or possibly pregnant patients.

All patients who fall into this category should be approved for examination by a supervising radiologist after it has been determined that the information requested by the ordering provider cannot be acquired without the administration of contrast media; the information directly affects the care of the patient, her fetus, or both during the pregnancy; and the referring physician believes it would be imprudent to delay obtaining the diagnostic information until after delivery. The approval to continue should be given in writing by the supervising radiologist.

**Pediatric Patients**

Pediatric and adult patients share the same risks relative to the administration of ROCM; however, some unique considerations should be addressed when imaging a pediatric patient. Neonates and young children have an increased susceptibility to osmotically induced fluid shifts, which might lead to an increased risk of pulmonary edema or cardiac failure; therefore, isosmotic contrast agents should be considered in these populations.

Because of the small-caliber needles used in younger patients, contrast viscosity is a primary concern. This is particularly true when large volumes or high rates of administration are required. The radiologic technologist should be cognizant of the catheter size to avoid vessel rupture or catheter failure.

The final difference the technologist should keep in mind is the physiologic effects that contrast has and the manifestations these can exhibit in children. In adults, warmth or minor pain at the injection site might be easily tolerated; in children these might result in movement to the detriment of the study or dislodgment of the IV access point. The former could result in the need for additional imaging, increasing the patient’s radiation dose; the latter might result in repeated venous access, increasing patient discomfort and psychological distress.

**Breastfeeding Women**

Literature discussing the excretion of iodinated contrast media into breast milk is extremely limited; however, studies have confirmed that breast milk does contain trace amounts of ROCM. The low lipid solubility of contrast media limits the amount of contrast media transferred into breast milk to less than 1% of the total administered dose. Furthermore, because of lipid solubility, less than 1% of an ingested dose is absorbed from the gastrointestinal tract; this results in a systemic dose to the infant of less than 0.01% of the IV dose given to the mother.

The ACR noted that the primary concerns resulting from this infant systemic dose are direct toxicity, allergic sensitization, or anaphylactoid reaction. However, these are theoretical concerns only; none have been clinically reported. Nevertheless, a breastfeeding woman might choose to limit or stop breastfeeding for 24 hours after the IV injection. Because of the excretion time of contrast media, cessation of breastfeeding for longer than 24 hours is not necessary. Mothers might consider expressing and storing breast milk before contrast administration for use during this period.

**Patients With Pre-existing Medical Conditions**

Many reasons might preclude a patient from receiving ROCM; however, there are fewer reasons a patient should always be excluded. Radiologic technologists must use their discretion regarding the decision about whether patients should or must be excluded, and always use every resource available, including nursing staff, physicians, and radiologists, to make an informed decision. Ultimately, the responsibility for injecting any material lies with the person controlling the injector or syringe.

Multiple risk factors might increase the likelihood that iodinated media will elicit an adverse reaction in a patient. The patients at greatest risk are patients with asthma and those who have a history of severe allergic or allergy-type reactions to contrast or any other allergen. Box 2 lists predisposing risk factors for adverse reactions following contrast media administration.

Patients taking certain medications are at increased risk of acute adverse reactions to ROCM. In the absence of complicating factors, metformin is not one of these medications and is not contraindicated in patients receiving ROCM. Risky drugs include those that interact...
with the contrast to create a synergistic effect and drugs that interact with contrast to form crystals and precipitates (see Box 3). If it is necessary to comingle these medications through a shared IV access line, extreme care should be taken to flush the line completely prior to each administration; such activity should be undertaken only under the direct supervision of a physician.\textsuperscript{5,11,14,18}

**Demographic Considerations**

Certain demographic groups have shown a higher incidence of acute adverse reactions to ROCM. For example, women and girls tend to have more reactions, and more severe reactions, than do men and boys. Individuals of Eastern Indian descent have a greater risk of adverse effects than individuals of European or African descent. The incidence of acute adverse reactions also is higher in individuals aged between 20 and 50 years; the fewest reactions occur in people aged less than 20 years.\textsuperscript{36}

**Box 2**

**Predisposing Conditions for Adverse Effects From Iodine-based Contrast Agent Administration**\textsuperscript{a,3,5,11,14,18}

- History of severe adverse reaction to previous contrast media administration.
- Asthma.
- Dehydration.
- Hay fever.
- Renal insufficiency.
- Heart disease.
- Renal disease.
- Cirrhosis.
- Sickle cell anemia.
- Polycythemia.
- Multiple myeloma.
- Interleukin-2 therapy.
- Mastocytosis.
- \(\beta\)-blocker therapy.
- Malignancy or malignant tumors.

\textsuperscript{a}This list is not exhaustive but includes the most commonly encountered predisposing conditions.

**Box 3**

**Common Medications Contraindicated for Patients Receiving Radiopaque Contrast Media**\textsuperscript{2,5,7,12,23}

<table>
<thead>
<tr>
<th>Drugs that increase coagulation time:</th>
<th>Antithrombin III</th>
<th>Dicoumarol</th>
<th>Heparin</th>
<th>Warfarin</th>
</tr>
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<tbody>
<tr>
<td>Drugs that might lead to lactic acidosis:</td>
<td>Metformin</td>
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<tr>
<td>Drugs that intensify and prolong hypotensive effects:</td>
<td>Calcium channel blockers, including diltiazem, nifedipine, verapamil</td>
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<tr>
<td>Drugs that increase the release of anaphylactoid mediators:</td>
<td>(\beta)-blockers, including atenolol, metoprolol, propranolol, timolol</td>
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<tr>
<td>Drugs that might increase the risk of nephropathy:</td>
<td>Diuretics, including acetazolamide, furosemide, spironolactone</td>
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<tr>
<td>Drugs that might increase the risk of adverse reactions:</td>
<td>Interferon</td>
<td>Aldesleukin</td>
<td>Interleukin-2</td>
<td></td>
</tr>
<tr>
<td>Drugs that are thrombolytic and increase coagulation time:</td>
<td>r-TPA – intravenous tissue plasminogen activator (alteplase)</td>
<td>Streptokinase</td>
<td>Urokinase</td>
<td></td>
</tr>
<tr>
<td>Drugs that may inhibit platelet formation:</td>
<td>Aspirin</td>
<td>Nonsteroidal anti-inflammatory drugs</td>
<td></td>
<td></td>
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<tr>
<td>Drugs that crystalize and form precipitates:</td>
<td>Cimetidine</td>
<td>Diazepam</td>
<td>Diphenhydramine</td>
<td>Ethanol</td>
</tr>
</tbody>
</table>

and decisive intervention. Early recognition of reactions requires the use of less medication to inhibit the reaction and results in a more positive outcome. Anyone
who administers contrast or cares for patients following contrast administration should be well-informed about the adverse effects of ROCM and managing acute reactions to these substances. Facilities where iodinated contrast is administered should have well-stocked emergency response carts readily accessible in examination rooms; furthermore, standard treatment protocols should be in place for managing patients who exhibit signs and symptoms of an adverse reaction. The following guidelines do not replace the positions, policies, or procedures of individual facilities.

**Prophylaxis**

The likelihood of an adverse reaction can be minimized in at-risk patients through the timely use of prophylactic premedication. Typically, corticosteroids are recommended for patients with a previous history of adverse reaction to ROCM and patients with a medical history that might predispose them to an acute reaction. Corticosteroids should be administered during the 24 hours prior to the study; at a minimum, 2 doses of corticosteroids should be administered beginning no later than 12 hours before the study. Single doses of corticosteroids given immediately prior to the study (ie, within 2 hours) have been shown to have no effect on minimizing the risk of contrast media reactions. Typically, 3 doses of 50 mg each of oral prednisone are suggested in the 24 hours preceding the study, with 50 mg of diphenhydramine given one hour before the study.

**Patient Evaluation**

The sooner a reaction occurs after injection, the more likely it will be severe. Therefore, patients should be evaluated continuously following contrast administration and this evaluation should continue for at least 20 minutes postinjection; an additional 1-hour evaluation is recommended, if possible. Evaluation always should be predicated on the patient’s current status compared with previous evaluations. Ongoing assessments should include an analysis of the patient’s:

- General appearance.
- Ability to speak (and if so, the quality of that speech).
- Breathing.
- Cardiovascular status (ie, pulse strength and pulse rate).
- Blood pressure.

The severity of a reaction can be immediately assessed by evaluating these 5 items. Any degradation of the patient’s physiologic state could indicate that an adverse reaction is taking place. If the radiologic technologist believes this to be the case, he or she should immediately seek assistance.

**Emergency Treatment**

When an adverse reaction occurs, getting help is the first and most important thing a radiologic technologist should do; everything else should be secondary to getting assistance as quickly as possible. Once help has been sought, the next steps depend on the patient’s condition, and many of these can and should be completed concurrently:

- Assess the patient to determine the progression of the reaction.
- Ensure or establish a patent airway, as needed.
- Ensure IV access.
- Prepare appropriate medications.

These treatment directions apply to both adult and pediatric patients. The radiologic technologist should chart all therapeutic treatments delivered to the patient, including oxygen.

After the radiologic technologist has ensured that help is on the way and has begun a secondary evaluation of the patient’s status, the technologist should be most concerned with the ABCs of cardiopulmonary resuscitation. The patient’s airway, breathing, and circulation should be evaluated and re-established if there is not a positive indication of cardiorespiratory effort. Every member of the radiology care team should be familiar with and certified to perform cardiopulmonary resuscitation.

**Oxygen Therapy**

If the patient has patent cardiopulmonary effort, administration of oxygen at a high flow rate should be considered. Oxygen is the immediate, first-line drug of choice for treating bronchospasm, laryngeal edema, hypotension without bradycardia, vagal reactions, and anaphylactoid reactions. Every patient who exhibits
signs of a reaction of any type should be administered oxygen, previous medical history notwithstanding. High-flow oxygen must be administered via a face mask; nasal cannulas are insufficient to deliver the rates of oxygen needed in emergency situations. Typical flow rates for oxygen delivery during the treatment of reactions should be greater than or equal to 6 to 10 L/minute delivered via face mask or partial rebreather mask. Some treatment protocols suggest even higher flow rates, up to 100% oxygen using rebreather masks.

**Intravenous Fluid Therapy**

Although oxygen is the first-line treatment for any reaction, hypotensive situations require advanced treatment, including fluid replacement. IV fluid delivery should begin immediately following the administration of oxygen therapy; fluid replacement has repeatedly been shown to be the most effective treatment for hypotension. Multiple studies have shown that fluid replacement alone is sufficient to treat most hypotensive events. In adults, 1000 mL of lactated Ringer’s or 0.9% (normal) saline solution should be infused rapidly to treat hypotensive emergencies. In pediatric patients, a maximum of 500 mL to 1000 mL of lactated Ringer’s or normal saline, calculated at the rate of 10 mL/kg to 20 mL/kg, should be infused. In all cases, IV fluid administration should be initiated prior to delivering any drugs.

**Pharmaceutical Intervention**

Pharmaceutical intervention is well within the scope of practice for radiologic technologists. The standards of practice, educational curricula, and national examining bodies of the radiologic sciences professions support the administration of medications in an emergent situation, so long as an independent practitioner (eg, a physician) is immediately available. The American Society of Radiologic Technologists issued opinion statements supporting the applicability of technologists injecting medications as needed “where federal or state law and/or institutional policy permits.” It is important to note that a physician does not have to be present, only immediately available, for a technologist to administer therapeutic medications; however, radiologic technologists should exercise extreme caution when making such a decision. The most commonly used drugs in the treatment of adverse reactions are epinephrine and diphenhydramine.

**Epinephrine**

Epinephrine is the first-line drug of choice for treating contrast reactions in all patients except pregnant women. It is unique in its ability to simultaneously invoke α-agonistic and β-agonistic pharmacodynamic effects. Alpha-agonists increase blood pressure by reversing vasoconstriction. Beta-agonists increase cardiac output and rate while reversing bronchoconstriction and inhibiting mast cell degranulation through the triggered release of cyclic adenosine monophosphate at the cellular level. Epinephrine comes in many forms, varieties, and concentrations; however, most emergency response carts contain 1:10 000 dilutions of epinephrine for IV use. Epinephrine diluted at 1:10 000 contains 1 mg of epinephrine per 10 mL of fluid.

The ACR has a specific treatment protocol for administering epinephrine in case of contrast reactions, and radiologic technologists should be familiar with the protocol. According to the ACR, pediatric patients should not be administered more than 0.01 mg/kg (0.1 mL/kg), to a maximum of 0.15 mg (1.5 mL) in patients weighing less than 30 kg, or a maximum of 0.30 mg (3.0 mL) in patients weighing more than 30 kg. The dose may be repeated every 5 to 15 minutes to a maximum of 1 mg cumulative total. Doses for adult patients are easier to calculate; the standard epinephrine dose for an adult patient is 1 mL to 3 mL of 1:10 000 dilution repeated every 5 to 10 minutes, up to a cumulative total of 10 mL.

Epinephrine also is available for intramuscular (IM) use. IM epinephrine is diluted at 1:1000, or 1 mg/mL. Dosing calculations are substantially easier using IM epinephrine. Standard dose rates are 0.5 mg for adults, 0.3 mg in children aged 6 to 12 years (more than 30 kg), and 0.15 mg in children younger than 6 years of age (less than 30 kg). However, the use of IM epinephrine is less common in radiology departments.

**Antihistamines**

Antihistamines are not effective in the treatment of acute life-threatening contrast reactions; however, they
are effective in treating skin reactions and delayed secondary reactions. Diphenhydramine is the drug of choice in the treatment of skin reactions. Dosage is standard, regardless of route (oral, IM, or IV), at 1 mg/kg to a maximum of 50 mg. In the absence of life-threatening signs and symptoms, the technologist should delay administering antihistamine medications until ordered to do so by a physician or advanced practitioner.

Conclusion

Iodinated ROCM are regularly used in the diagnosis and treatment of vascular structures. However, they can be dangerous and acute adverse reactions should be expected from every patient. A consequence of the propensity of radiographic contrast to cause severe, life-threatening reactions is that injection of these materials should never be taken lightly, nor should they be used in isolated settings or in the absence of the appropriate tools and knowledge to treat any possible adverse effects.

Radiologic technologists should be knowledgeable about the contrast media they are using, including the possible adverse effects of these drugs. Technologists also should understand relevant contraindications and patient histories that might indicate increased risk of reaction following injection.

Individuals who inject contrast should be trained in emergency life-saving measures and be prepared to take decisive action following every contrast media injection. All personnel engaged in patient care in radiology departments should know the location of emergency treatment tools (eg, emergency response carts, oxygen), be familiar with treatment protocols for adverse contrast reactions, and receive annual training in basic life support. These simple measures reduce the risks of contrast media injection and help increase favorable outcomes if an acute adverse reaction does occur.

Eric P Matthews, PhD, R.T.(R)(CV)(MR), EMT, is an associate professor at A.T. Still University’s College of Graduate Health Studies in Mesa, Arizona. Matthews completed his doctoral degree in education at Southern Illinois University in Carbondale, Illinois, with an emphasis in adult and vocational/technical education. He also holds master’s degrees in education (administration and supervision) and museum studies. Before joining the faculty of A.T. Still University, he was director of the radiography program at Southern Illinois University. Matthews has taught courses on medical and educational history, his primary research interests. He enjoys qualitative-historical research and has served as a subject matter expert for several state and national organizations, along with multiple museums on the topic of 19th century American medicine.

Reprint requests may be mailed to the American Society of Radiologic Technologists, Communications Department, at 15000 Central Ave SE, Albuquerque, NM 87123-3909, or e-mailed to communications@asrt.org.

References

Adverse Effects of Iodine-derived Intravenous Radiopaque Contrast Media


Adverse Effects of Iodine-derived Intravenous Radiopaque Contrast Media

1. When state and institutional policy permit, it is within a radiologic technologist’s scope of practice to administer contrast media only when:
   a. a practitioner is physically present in the imaging department to supervise the procedure.
   b. a practitioner is immediately available to diagnose and treat allergic reactions.
   c. he or she has completed advanced training and certification in contrast administration.
   d. his or her supervisor determines that the technologist is capable.

2. Among intravenous (IV) pharmacologic agents currently in use, iodinated contrast media are the _______ common.
   a. most
   b. second most
   c. fifth most
   d. least

3. Categories of radiopaque iodinated contrast media (ROCM) include all of the following except:
   a. high osmolarity.
   b. low osmolarity.
   c. ionic.
   d. nonionic.

4. Intravenous ROCM are typically highly lipid soluble.
   a. true
   b. false

5. Seventy percent of the injected dose of ROCM is cleared from the blood plasma within _______ minutes.
   a. 1 to 3
   b. 2 to 5
   c. 5 to 10
   d. 10 to 15

*Your answer sheet for this Directed Reading must be received in the ASRT office on or before this date.
6. One difference between anaphylactoid and anaphylactic reactions is the release of:
   a. IgE antibodies.
   b. histamine.
   c. slow-reacting substance of anaphylaxis (SRSA).
   d. leukotrienes.

7. Seafood allergies correlate with iodine or ROCM allergies.
   a. true
   b. false

8. ______ adverse effects are predictable.
   a. Chemotoxic
   b. Anaphylactic
   c. Anaphylactoid
   d. Idiosyncratic

9. ______ release is the major early concern in mast cell degeneration, which leads to systemic reactions.
   a. Histamine
   b. SRSA
   c. Prostaglandin
   d. Leukotriene

10. Which of the following is **not** a sign or symptom of minor anaphylactoid reactions?
    a. flushing
    b. nausea
    c. vomiting
    d. dyspnea

11. Which of the following is **not** a sign or symptom of severe anaphylactoid reactions?
    a. hyperosmia
    b. laryngeal edema
    c. paralysis
    d. seizures

12. ______ reactions require a previous exposure to an antigen.
    a. Anaphylactoid
    b. Chemotoxic
    c. Idiosyncratic
    d. Anaphylactic

13. The antigen-antibody complex required to elicit a true anaphylactic response requires approximately ______ week(s) to mature.
    a. 1
    b. 2
    c. 3
    d. 4

14. Chemotoxic effects can result from which of the following?
    1. the physical make-up and composition of the contrast (eg, viscosity)
    2. faulty injection technique
    3. unrelated patient pathophysiology
    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

15. The American College of Radiology lists which of the following as risk factors for nephrotoxicity?
    1. age older than 60 years
    2. history of hypertension requiring medical care
    3. history of lung cancer
    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3
16. Extravasated contrast media is toxic to surrounding tissue and produces an inflammatory response; this response usually peaks within ________ hours.
   a. 6 to 8  
   b. 12 to 24  
   c. 24 to 36  
   d. 24 to 48 

17. Which of the following are signs of extravasation?
   1. swelling  
   2. limited range of motion  
   3. pain  
   
   a. 1 and 2  
   b. 1 and 3  
   c. 2 and 3  
   d. 1, 2, and 3 

18. Mild extravasation cases typically resolve within:
   a. a day.  
   b. 2 to 4 days.  
   c. 3 to 5 days.  
   d. a week. 

19. A pressure gradient between vascular space and ambient atmospheric air results in a(an):
   a. extravasation.  
   b. catheter fragment.  
   c. air embolus.  
   d. hematologic deficit. 

20. Which of the following are mentioned in the article as particular concerns for pediatric patients receiving ROCM?
   1. increased susceptibility to osmotically induced fluid shifts  
   2. smaller-caliber needles and contrast viscosity  
   3. dislodgement of the IV due to patient movement  
   
   a. 1 and 2  
   b. 1 and 3  
   c. 2 and 3  
   d. 1, 2, and 3 

21. Which of the following medications are contraindicated in patients receiving ROCM?
   1. streptokinase  
   2. aspirin  
   3. diphenhydramine  
   
   a. 1 and 2  
   b. 1 and 3  
   c. 2 and 3  
   d. 1, 2, and 3 

22. Acute adverse reactions to ROCM are most common in which of the following age groups?
   a. infants and children from birth to age 3 years  
   b. older children and teenagers  
   c. adults aged 20 to 50 years  
   d. people older than 75 years 

23. The first thing a technologist should do when a contrast reaction occurs is:
   a. administer oxygen.  
   b. locate, reposition, and access an emergency response cart.  
   c. seek assistance.  
   d. administer diphenhydramine. 

continued on next page
Directed Reading Quiz

24. The first drug of choice for anaphylactoid reactions in the presence of patent cardiopulmonary effort is:
   a. diphenhydramine.
   b. corticosteroids.
   c. epinephrine.
   d. oxygen.

25. The standard dosage of diphenhydramine is _______ to a maximum of _______.
   a. 1 mL/kg; 25 mL
   b. 1 mL/kg; 50 mL
   c. 1 mg/kg; 25 mg
   d. 1 mg/kg; 50 mg
Thank you for taking the time to complete this evaluation. 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. Why did you choose to complete this DR?
   - O Interested in the topic
   - O Topic pertained to my area of practice
   - O Needed CE credits immediately
   - O Other

2. How relevant is this DR to your practice?
   - O Very relevant
   - O Relevant
   - O Somewhat relevant
   - O Not relevant

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

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

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

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

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

8. Overall, how valuable are the DRs to you?
   - O Very valuable
   - O Valuable
   - O Somewhat valuable
   - O Not very valuable

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An increase in cancer incidence among the world’s population prompted the need for new treatment techniques. The use of thermal energy is a highly efficient, cost-effective, and safe technique to destroy tumors resulting from a number of malignancies. Image guidance is necessary for interventional radiologists and surgeons to evaluate both preoperative and postoperative tumor status.

A standard treatment for many cancers is surgical excision of all or a portion of the affected tissue. However, many patients have contraindications or are otherwise poor candidates for surgical procedures because of factors such as comorbidities, tissue condition, and tumor characteristics. Ablative technologies, specifically radiofrequency ablation (RFA), provide a viable alternative to surgery. As a more targeted, localized, and less-invasive method than surgery and other standard therapies, RFA is gaining increasing acceptance in cancer therapy.

Hepatic Cancer

Hepatic cancer refers to a primary malignancy of the liver. If a malignancy spreads to the liver from another location within the body, it is considered metastatic or secondary liver cancer, also called liver metastasis. Primary hepatic cancer rarely metastasizes to distant sites but often develops into an advanced stage within the liver.

The World Health Organization’s International Agency for Research on Cancer estimated that 782,000 new cases of liver cancer would occur worldwide in 2012 and more than 740,000 deaths would occur from the disease, making it the second most deadly form of cancer globally. In the United States, age-adjusted primary liver cancer more than tripled between 1975 and 2011, most likely because of increased hepatitis C infections related to chronic intravenous drug use during the 1960s and 1970s, along with increasing rates of obesity and diabetes mellitus.

Hepatic cancer is the fifth most common cancer in men and the ninth...
most common cancer in women. The American Cancer Society estimated 35,660 new primary liver cancer cases would be diagnosed in the United States in 2015. Obesity, diabetes, alcoholic liver disease (cirrhosis), chronic hepatitis B, hepatitis C infections, and tobacco smoking are the most common risk factors for developing primary liver cancer. Additional risk factors such as aflatoxin B1 exposure and certain genetic disorders also can increase an individual’s risk for developing primary liver cancer. Aflatoxins are toxic metabolites produced by some fungi that can be found in foods and animal feed. Aflatoxins also are found in corn products and peanuts. In the United States, more than one-third of primary liver cancers are attributed to obesity and diabetes. Alcohol-related disorders contribute to one-fourth of primary liver cancers in men. Chronic liver disease induced by the hepatitis B or C virus accounts for most global hepatocellular carcinoma (HCC) cases.

The most common adult hepatic cancer is HCC. Other types of primary hepatic cancer are intrahepatic cholangiosarcoma, which involves the bile duct, and angiosarcoma and hemangiosarcoma, rare cancers of the liver’s blood vessels. Hepatoblastoma is a rare type of liver cancer that occurs in young children.

Metastases from colorectal cancer are the next most common cause of liver malignancy after primary HCC. Other primary cancers that tend to spread to the liver include melanoma and cancers of the following organs:

- Bladder.
- Breast.
- Kidney.
- Lung.
- Ovaries.
- Pancreas.
- Prostate.
- Stomach.
- Thyroid.
- Uterus.

Mortality for hepatic cancers, if left untreated, approaches 100% within 5 years. If diagnosed in an early stage, the 5-year survival rate for patients with primary liver cancer is 30%. Survival rates for metastatic liver cancer are based on the site of origin.

**Hepatocellular Carcinoma**

Hepatocellular carcinoma represents the most common histology of primary liver cancer, likely accounting for 70% to 90% of all primary liver cancer cases. HCC is associated with a high mortality rate. The peak age of incidence around the world for HCC is 50 to 70 years, and the cancer occurs much more often in men than in women, at a ratio of 4:1.

HCC develops from hepatocytes, which are epithelial liver cells that secrete bile. Several growth patterns and subtypes characterize HCC. The most common growth pattern in the United States is HCC that appears as several small malignant nodules vs a single tumor growing larger and invading other liver tissue as the disease progresses. Identification of subtype typically is not important in determining treatment options, with the exception of the fibrolamellar variant of HCC.

Fibrolamellar HCC is rare, constituting less than 1% of all HCCs, and it occurs most often in young women, although cases have been reported in children aged as young as 2 years and adults as old as 74 years of age. This form of HCC tends to occur in relatively healthy people who do not have underlying liver disease such as cirrhosis or hepatitis B infection. Diagnosis of fibrolamellar HCC is important because many patients can be cured with surgical resection of the liver. Patients who have fibrolamellar HCC generally have a better outcome than do patients with other forms of HCC.

Researchers and clinicians note that the strongest clinical risk factor for the development of HCC is cirrhosis of the liver; as many as 80% of HCCs develop in cirrhotic livers. Cirrhosis occurs when a chronically diseased liver develops scarring over time. Tumors can form when the liver attempts to repair the damage.

**The Role of Imaging in Diagnosing Hepatocellular Carcinoma**

Imaging plays a key role in diagnosing HCC, and an increasing number of patients are diagnosed at an asymptomatic stage. Prior to the early 1990s, HCC usually was diagnosed when the cancer was in an advanced stage. Decades ago, nuclear medicine scans of the liver often were used to demonstrate the presence of intrahepatic masses; however, these scans lacked...
sensitivity and specificity, especially for small tumors. For a time, angiography was used in diagnosis, but its role is now limited to administration of treatments such as chemoembolization.  

Clinical features of HCC include one or more of the following: right upper quadrant pain, weight loss, and worsening liver enzymatic state for patients with known cirrhosis. Although there is no widespread screening for HCC, physicians might recommend surveillance or screening, such as serum α-fetoprotein or abdominal ultrasonography (US) for patients at high risk for the cancer. Typically, this includes patients who have chronic cirrhosis.  

Medical imaging is used to diagnose and stage the tumor.  

HCC is suggested on imaging when a hepatic lesion exhibits arterial flow, internal septa, a mosaic appearance, a pseudocapsule, and hepatic arterial enhancement (see Figures 1 and 2).  

Imaging plays a role in HCC diagnosis, staging, treatment planning, and post-treatment follow-up. Aside from use of US as a surveillance tool for those at risk for HCC, computed tomography (CT) and magnetic resonance (MR) imaging are most often recommended for the diagnosis and characterization of HCC.  

CT, MR, and positron emission tomography (PET) imaging could be used to stage HCC. According to Ghanaati et al, selection of imaging modalities should be based on the particular imaging method’s sensitivity in detecting hypervascular lesions and enable differentiation of arteriopetal shunts from true lesions.  

Although transabdominal US is widely accepted, available, and cost-effective as a screening modality for HCC, it is not as sensitive or specific as other modalities for diagnostic imaging of HCC in patients with cirrhotic livers, limiting its effectiveness in high-risk patients. Contrast-enhanced CT or MR is preferred for screening high-risk patients and for diagnosis.  

Figure 1. Magnetic resonance (MR) images of the liver of a 52-year-old man with chronic liver disease during the arterial (A) and hepatocellular (B) phases. Findings include a cirrhotic liver and a lesion (blue arrows) with areas of enhancement (white arrow) and nonenhancing areas (ie, the mosaic pattern). The hepatocellular phase showed similar appearance with areas taking up gadolinium ethoxybenzyl diethylenetramine pentaacetic acid and others not. Reprinted from Focal hepatic lesions in Gd-EOB-DTPA enhanced MRI: the atlas. Campos JT, Sirlin CB, Choi JY. Insights Imaging. 2012;3:451-474. Published with open access at Springerlink.com.  

Figure 2. A. An arterial phase helical computed tomography (CT) image showing a minimally hyperdense lesion (arrow). B. This portal venous-phase CT scan shows that the lesion has faded and an enhancing pseudocapsule is present (arrow). C. An arterial phase T1-weighted fat-suppressed 3-D gradient-echo MR scan shows enhancement of the lesion and the mosaic pattern of hepatocellular carcinoma better than CT. The lesion is predominantly composed of 3 lesions enhancing to different degrees (arrows) tiled together like a mosaic. D. This portal venous-phase T1-weighted fat-suppressed 3-D gradient-echo MR scan shows an enhancing pseudocapsule encircling the mosaic of tiles and the confluent portions of each nodule forming a triangularly shaped enhancing fibrous septa (arrow). MR shows the pseudocapsule and fibrous septa better than CT. Reprinted with permission from Thng CH, Kuo YT. Hepatocellular carcinoma—issues in imaging. Cancer Imaging. 2004;4(2):174-180. 2004. doi:0.1102/1470-7330.2004.0063.
the past few decades, spiral CT and MR imaging with multiphase contrast enhancement have been used extensively.\(^\text{17}\)

According to El-Serag et al, triple-phase helical CT and triple-phase dynamic contrast-enhanced MR are the most reliable imaging modalities for diagnosing HCC.\(^\text{18}\) Because HCC tumors receive blood from the hepatic artery and normal hepatic tissue uses both arterial and portal blood, the presence of HCC under CT or MR is evident. On contrast-enhanced images, HCC is characterized by arterial enhancement with delayed tumor hypointensity. According to El-Serag et al, the hypointensity occurs as a washout during portal venous and delayed phases (see Figure 3).\(^\text{18}\) Although about 75% of HCC tumors display the arterial enhancement/hypointensity pattern, the remaining 25% of HCC lesions do not display these features and must be diagnosed with liver biopsy.\(^\text{18}\)

Studies comparing CT and MR efficacy in HCC characterization and diagnosis indicate that MR is a slightly better diagnostic tool; however, tumor size influences diagnostic effectiveness. Tumors larger than 2 cm have a 90% detection rate with MR, but when tumors are smaller than 2 cm, the MR detection rate drops to 33%.\(^\text{18}\)

In 2008, the American College of Radiology convened a committee to develop a standardized system for interpretation, reporting, and data collection when conducting CT and MR scans for HCC diagnosis.\(^\text{23}\) The previous lack of standardization had led to unfavorable consequences. For example, suboptimal imaging technique could render images inadequate for diagnosis, or the use of inconsistent terminology by radiologists to describe liver lesions could lead to interpretation errors across communication platforms.\(^\text{23}\) The standards, referred to as the Liver Imaging Reporting and Data System (LI-RADS), provide a comprehensive and standardized method for interpreting and reporting on CT and MR examinations in patients at risk for HCC.\(^\text{23,24}\)

Liver Metastases

In the United States and Europe, metastatic liver tumors are more common than primary liver tumors.\(^\text{3,25}\) Liver metastases from colorectal cancer are the most common, occurring in approximately 60% of colorectal
cancer cases.\textsuperscript{25,26} The reason the liver is a common metastatic site for colorectal cancer is that blood from the intestines flows directly to the liver through the hepatic portal vein.\textsuperscript{4}

Colorectal liver metastasis is considered a stage IV cancer. The metastatic lesions might be discovered either following colorectal cancer treatment or during initial colorectal cancer diagnosis.\textsuperscript{27} Approximately 25\% of all patients who have colorectal cancer have liver metastases at initial diagnosis, and 50\% develop distant metastases within 5 years of diagnosis.\textsuperscript{28} Up to 70\% of patients who have uncontrolled primary cancer have liver metastases.\textsuperscript{16,25,26}

Two-thirds of patients who have liver metastases from colorectal cancer have extrahepatic spread, and the remainder have metastases isolated to the liver. For those with isolated hepatic metastases, regional and local treatment options might be considered rather than systemic chemotherapy.\textsuperscript{27}

Secondary liver cancer often is more difficult to treat than primary liver cancer because cancer cells from the organ of origin possess different characteristics.\textsuperscript{29} Nevertheless, treatment techniques have improved, and advanced diagnostic imaging techniques allow for improved preoperative planning. Patients who have a limited number of intrahepatic lesions with minimal vascular involvement might be candidates for surgical resection. In some patients, preoperative chemotherapy improves resection success. RFA and cryosurgical ablation also can control metastatic tumors in the liver.\textsuperscript{10} For many patients, however, metastatic liver cancer is incurable, and palliative radiation therapy or chemotherapy is recommended.\textsuperscript{28,30}

**Standard Treatment Options for Hepatic Cancer**

Surgical liver resection remains the preferred standard treatment for all types of liver cancer, but fewer than 20\% of all patients are suitable surgical candidates.\textsuperscript{30} Patients typically are not candidates for surgical resection if they have:\textsuperscript{10}

- Multiple lesions.
- Tumors within areas of the liver that are not viable for resection.
- Minimal hepatic reserves.
- Comorbidities.

Patients who have primary liver cancer often have comorbidities such as cirrhosis, chronic hepatitis B or C infection, or diabetes mellitus that affect treatment decision making for HCC.\textsuperscript{11,32}

Patients who have hepatic resection often face considerable postoperative morbidity, significant costs, and only modest improvement in long-term prognosis.\textsuperscript{10} In fact, the average 5-year survivorship of individuals with a history of hepatic resection is 20\% to 40\%.\textsuperscript{10,33-35} Liver transplant is a limited option for early-stage and recurrent hepatic cancer because of inadequate access to donor organs.\textsuperscript{36,37} Radiation therapy and chemotherapy have been found ineffective in achieving long-term survival for patients with hepatic cancer; therefore, few therapeutic options exist other than minimally invasive endovascular or percutaneous therapies.\textsuperscript{12,25}

**Ablative Technologies**

Ablative therapy refers to a minimally invasive procedure used to remove or destroy abnormal tissue. Ablative therapies are performed most often in patients who have primary or metastatic liver or lung cancers. Ablative therapy also might be performed on patients who have benign and metastatic bone tumors, nodal metastases, adrenal tumors, and thyroid nodules. Typically, interventional radiologists perform ablation percutaneously under image guidance from US, CT, or MR imaging.\textsuperscript{10}

Several technologies are available for localized ablation. Examples of ablative therapies introduced in recent decades include percutaneous ethanol injection, microwave coagulation therapy, high-intensity focused US, laser-induced interstitial thermotherapy, cryoablation, irreversible electroporation, microwave ablation, and RFA. The inclusion of several of these techniques in clinical practice has expanded the number of patients eligible for liver-directed treatments.\textsuperscript{10,38,39}

Each type of ablative therapy relies on delivery of focal energy to a tumor to minimize damage to normal surrounding tissue and structures.\textsuperscript{25} RFA has emerged as the favored ablative therapy for treating patients with hepatic cancer because of its low morbidity and mortality rates and increased patient acceptance.\textsuperscript{40} RFA is the most commonly performed ablative therapy worldwide and is recognized as part of standard treatment for numerous
cancers. It is mostly performed on patients with primary and metastatic liver and lung cancer and early renal cell carcinoma. In the United States, RFA is the most widely used technique for in situ tumor destruction in the liver. RFA has proven to be a successful method for localized tumor ablation, exhibiting minimal complications and reducing trauma to patients. In a multicenter study of more than 2000 patients receiving hepatic RFA, mortality was less than 0.5% and major and minor complication rates were low, at 2% for major complications and 5% for minor ones. 

Radiofrequency Ablation

RFA is a localized, image-guided treatment that uses thermal energy to remove or destroy tumor tissue. The goal of RFA is to destroy the entire malignant tumor and a surgical margin of 1 cm without damaging surrounding tissue.

The use of radiofrequency waves in the body first was described in 1891 by Jacques d’Arsonval. He showed that when radiofrequency waves of alternating electrical current pass through living tissue, the temperature of the targeted tissue is elevated without inducing neuromuscular excitation. Rapidly alternating electrical currents passing through the tissue produces heat as a result of resistance from the tissue.

In the early to mid-1900s, d’Arsonval’s work led to development of tools such as the Bovie knife (Liebel Florsheim), which was designed to cauterize tissue to stop bleeding. The Bovie knife uses an electrical current that emanates from a small tip. The tip allows the electrical current to pass through the electrode into a patient’s tissue upon contact. The current arcs between the patient and the Bovie knife, which chars and destroys the contacted tissue. In 1908, Edwin Beer used radiofrequency coagulation to ablate urinary bladder tumors. In 1961, while studying histological changes in the livers of animal models, Lounsberry et al discovered that radiofrequency waves caused local tissue destruction with uniform necrosis.

RFA was used to treat cardiac arrhythmias in the 1980s. In the early 1990s, 2 groups of researchers used modified radiofrequency equipment to create focal thermal injuries deep within the liver. Examination of the ablated livers provided evidence that the process created a well-defined region of heated and necrotic tissue in a zone around the point where the uninsulated needle tip had been placed. Although necrotic lesions were produced in these early experiments, the size of the thermal injuries was small (~1 cm), leading the investigators to propose that radiofrequency waves could be effective at destroying small liver tumors. Modern equipment can create thermal ablation zones of 1 cm to 7 cm in diameter, large enough to be clinically relevant.

Heat is produced when radiofrequency waves, generated by a transducer, travel through a probe directly into the tumor. The alternating currents of radiofrequency waves passing into the tumor tissue from an electrode create ionic movement, which, in turn, generates heat (see Figure 4). This heating of the tissue drives extracellular and intracellular water out of the tissue, which results in coagulation necrosis. Coagulation necrosis occurs when the hyperthermia from the RFA electrode causes alterations in the proteins in liver tissue. The heated tissue dries and becomes mass-like, appearing as an area of hardened hepatic tissue with a white center and red periphery. A central charred line often can be seen, designating the

Figure 4. This computer-generated image depicts the elements of ultrasonographic-guided percutaneous ablation of hepatic tumors, and representative preablation and postablation CT scans. Illustration and caption courtesy of Gerald D Dodd II, MD, University of Colorado Anschutz Medical Campus, Aurora, Colorado.
electrode tract. Tissue coagulation is achieved with temperatures between 60°C and 100°C.

High-precision placement of the RFA electrode is essential to achieving successful tumor ablation and maintaining patient safety. Imprecisely placed electrodes could result in the perforation of the target or surrounding tissue, vessel laceration and bleeding, collateral thermal damage to adjacent organs, or insufficient tumor overlap in the ablation, which could lead to tumor progression. The use of image guidance assists in placing the electrode with high precision.

**Equipment and Methodology**

To generate the alternating electrical current required to induce thermal injury, the RFA system requires a closed-loop circuit consisting of an electrical generator, a needle electrode, a patient (who serves as a resistor), and large dispersive electrodes, which also are known as grounding pads. The radiofrequency current is delivered from a generator through a probe made up of a partially insulated needle with an activated tip that is not insulated. This tip varies in length; the most common size is 3 cm long. Tips typically are either singular and straight or consist of an array of expandable tines that form an umbrella shape and fully encompass the tumor when deployed (see Figure 5).

The success of RFA is highly dependent on tissue temperature and heating duration. Effective ablation can be achieved only through optimization of heat production and loss. Heat loss, or the heat-sink effect, is the result of heat dissipation by blood flowing through adjacent hepatic vessels. Some of the thermal output from the RFA electrode drains away, thereby decreasing the thermal effect for the targeted malignant tissue (see Figure 6). Effective ablation is reduced by heating tissues to greater than 100°C, which produces charred tissue and expands the ablation zone. To ensure destruction of microscopic tumor extensions, the ablation zone should extend approximately 1 cm beyond the tumor margin. This area is referred to as the ablation margin and is crucial in ensuring all components of the lesion are ablated completely, eliminating future lesion extension or growth (see Figure 7).

Many commercially available variations on RFA electrodes and generators are available (see Table 1).
These systems vary in the type of electrodes they deploy. Several systems use deployable tines that expand once inside the tumor or at the tumor edge, and some systems use straight-needle electrodes. Systems also vary in how they measure tissue impedance. Some determine impedance via an electrical measurement to ensure that tissue boiling is occurring. Another system monitors the electrical resistance of tissue during ablation and automatically adjusts the power output to ensure consistent current flow through tissue. Internally cooled electrodes can be used to minimize charring and ensure optimal energy distribution.\(^{26}\)

**Approaches**

For treatment of hepatic tumors, RFA can be performed percutaneously, laparoscopically, or through open surgery. Each approach has distinct advantages, depending on the clinical circumstances (see Table 2).\(^{25}\)

The choice of approach depends on several factors considered collectively, including\(^{43}\):

- The patient’s overall health.
- Tumor attributes such as size, location, and number.
- Physician experience.

Generally, the open surgery approach is reserved for patients who are not candidates for a minimally invasive method.\(^{43}\) The percutaneous approach is used most often for treating hepatic tumors because it is the least invasive.\(^{25}\) Percutaneous RFA leads to the most rapid recovery of the 3 methods.

Percutaneous RFA has proved to be highly effective on hepatic tumors smaller than 3 cm.\(^{25}\) Disadvantages of the percutaneous RFA approach include the lack of visualization of small surface lesions and deep tumors. In addition, percutaneous RFA has shown a higher rate of local recurrence of large tumors and those close to major vessels than have other approaches, which suggests partial or incomplete ablation during the initial procedure.\(^{53}\) When RFA is applied to hepatic tumors adjacent to major vessels, the “heat sink” effect occurs, causing convective heat loss and preventing complete ablation of the tumor.\(^{44}\) In patients with liver cirrhosis...

**Table 1**

<table>
<thead>
<tr>
<th>Company</th>
<th>System Name</th>
<th>Electrode Type</th>
<th>Electrode Mechanism</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>AngioDynamics</td>
<td>StarBurst XL</td>
<td>Deployable tines</td>
<td>Expands once inside tumor or at tumor edge</td>
<td>Distributes energy over a large area</td>
</tr>
<tr>
<td>RadioTherapeutics</td>
<td>RF Ablation System</td>
<td>Deployable tines</td>
<td>Expands once inside tumor or at tumor edge</td>
<td>Distributes energy over a large area</td>
</tr>
<tr>
<td>Radionics</td>
<td>Cool-tip RF System</td>
<td>Straight needle</td>
<td>No expansion</td>
<td>Internally cooled electrodes produce minimal tissue charring</td>
</tr>
<tr>
<td>Berchtold</td>
<td>Elektrotom 106 HFTT</td>
<td>Straight needle</td>
<td>No expansion</td>
<td>Internally cooled electrodes produce minimal tissue charring</td>
</tr>
</tbody>
</table>
and small hepatic lesions, the percutaneous approach is preferred to avoid using general anesthesia during surgery.\textsuperscript{25}

For larger tumors, the surgical approach offers more direct control of hepatic perfusion, which results in more effective ablation.\textsuperscript{25} The open approach allows the physician to better see small surface and deep tumors and facilitates manipulation of adjacent internal structures in a controlled and efficient manner. The use of intraoperative US helps detect occult metastatic disease. The surgeon can occlude portal inflow to reduce heat dissipation from the ablation and increase the amount of tissue treated.\textsuperscript{53} A disadvantage is the potential for complications typically associated with general surgery.

The laparoscopic approach combines benefits from the percutaneous and surgical approaches.\textsuperscript{53} Laparoscopic RFA involves accessing the hepatic lesions via multiple small incisions yet is minimally invasive. Internal structures are seen more easily using a laparoscope than with the percutaneous method, allowing for some internal manipulation and a reduced potential for accidental thermal contact or injury.\textsuperscript{53,54} Clinicians with advanced skills in percutaneous displacement of adjacent structures using fluids, balloon catheters, or carbon dioxide might be able to perform RFA percutaneously instead of laparoscopically.\textsuperscript{54} Incorporation of ultrasonographic guidance into the laparoscopic approach supports detection of lesions smaller than 2 cm.\textsuperscript{54}

A study of 608 patients undergoing percutaneous or open RFA procedures for treatment of both primary and metastatic liver tumors examined early (up to 30 days post-RFA) and late (more than 30 days post-RFA) complication rates.\textsuperscript{57} Patients who underwent open RFA had a higher early complication rate (8.6%) than did patients who had percutaneous RFA (4.4%), but late complication rates were not statistically different between the 2 groups.\textsuperscript{57} Overall, RFA-related mortality was low (0.5%) in both groups.\textsuperscript{57}

**RFA Patient Selection**

The Society of Interventional Radiology assigns potential RFA candidates to 4 categories\textsuperscript{25}:

- Unsuitable for surgery because of inadequate liver function or comorbidities.
- Ineligible for surgical resection because of wide distribution of tumors within the liver.
- Surgical candidates with limited metastasis who might be better served with RFA to limit unnecessary hepatectomies.
- Patients best served by use of RFA to control tumor burden as a bridge to transplantation.
Patients with HCC fall most often into the first category. Patients who have cirrhosis, a previous hepatectomy, or comorbid conditions such as coronary artery disease, chronic obstructive pulmonary disease, or cardiomyopathy might have an unacceptably high risk for surgery and benefit greatly from RFA.\textsuperscript{25}

RFA prevents unnecessary hepatectomies and achieves local control in patients who have limited hepatic lesions. Patients who have 2 or more lesions in different lobes of the liver are at high risk for surgical complications because a large volume of liver tissue must be removed. These patients would likely benefit from a combination of surgical resection and ablation therapy.\textsuperscript{25}

The purported ideal size of metastatic and HCC tumors for RFA varies. It has been suggested that HCC tumors smaller than 5 cm have a higher probability of complete ablation than larger tumors. Specifically, tumors smaller than 3 cm demonstrate superior results from ablation, making them ideal for RFA. Lesions in the 3-cm to 5-cm range show acceptable results, and HCC tumors larger than 5 cm have unfavorable results from ablation. Favorable outcomes typically are observed with ablation of colorectal metastases that are 4 cm or less.\textsuperscript{50}

RFA tends to yield better results when tumors are surrounded by cirrhotic tissue. The cirrhotic tissue insulates the tumor and improves coagulation. Tumors that are close to visceral organs or surrounded by large blood vessels are at risk of partial ablation. If organs or blood vessels are close to the ablation zone, the use of hydrodissection or altered patient positioning might help move the structures away from the tumor.\textsuperscript{50}

Ablation time is based on the thermal output (temperature) used and the tumor volume. Tumor volume directly influences the number of ablations required.\textsuperscript{38} Typically, tumors smaller than 3 cm are treated with one ablation event or electrode sweep. Tumors larger than 3 cm might require multiple electrode placements to completely ablate the tumor. To prevent or minimize local recurrence of ablated tumors, physicians reinsert the electrode along the ablation tract to reduce the possibility of tumor seeding or hemorrhaging. Patients typically receive conscious sedation or general anesthesia during the RFA procedure, which is often completed on an outpatient basis.\textsuperscript{38} In general, RFA of a 4-cm tumor takes approximately 11 minutes to complete.\textsuperscript{46}

Short-term and long-term follow-up is required using imaging indicators, typically acquired through US, CT, or MR scans. Postprocedure imaging is especially critical to identify partial or incomplete tumor ablation.\textsuperscript{38}

**RFA Treatment of Hepatic Lesions**

Optimal tumor size for RFA of hepatic lesions appears to be related to anatomic variables such as the tumor’s proximity to major vessels. The tumor burden of a patient eligible for ablation is unclear because the size and specifics of each tumor play a role in the success of the ablation.\textsuperscript{25} Although no published guidelines concerning RFA and tumor size or quantity exist, current agreement indicates that tumors smaller than 5 cm in diameter present a greater probability of complete ablation compared with those larger than 5 cm in diameter.\textsuperscript{25,55,59}

In up to 98% of cases, RFA can control local metastatic growth of tumors smaller than 5 cm.\textsuperscript{59} Livraghi et al reported excellent ablation results for tumors smaller than 3 cm and moderate results for those in the 3-cm to 5-cm range.\textsuperscript{64} Well-defined encapsulated HCC lesions showed better ablation than nonencapsulated lesions.\textsuperscript{25,58}

Tumor ablation is considered complete and successful if the tumor area is entirely enclosed by the coagulation (the ablation area) because a minimal distance between tumor and coagulation surfaces is required to prevent residual tumor cells.\textsuperscript{60} If residual tumor cells or tissue are present, the ablation has failed.

**Disease-Free Survival**

The Society for Interventional Radiology, through its Interventional Oncology Task Force and the Standards Division, endorses the use of RFA for select patients with HCC and colorectal cancer metastases.\textsuperscript{25} Jasarovic et al analyzed patients with solitary colorectal liver metastases who underwent either hepatic resection or ablation therapy.\textsuperscript{28} The authors’ results showed longer disease-free survival (37.6 months) for the patients who had hepatic resection compared with patients who had RFA only, who had average survival of 22.3 months.\textsuperscript{28}

Patients with hepatic lesions who have contraindications for complete liver resection might achieve prolonged survival when ablation is used in conjunction with partial surgical resection. The combination of
surgery and RFA still offers considerably less long-term survival than resection/transplant alone. Patients treated with RFA might experience some local recurrence of tumor growth, but treatment with curative intent should be the standard. When other options are unavailable, RFA is a treatment option that contributes to lower morbidity from hepatic cancer.

**RFA as a Bridge to Liver Transplantation**

Liver transplantation was considered a primary treatment option for late-stage HCC in the 1980s, but recurrence rates of HCC in transplanted livers was significantly high at 65% to 75%. This high rate of recurrence was likely caused by accelerated tumor regrowth resulting from immunosuppression. A moratorium was placed on liver transplants as a clinical treatment for HCC in 1989. In 1996, interest in transplant for patients with early-stage HCC was renewed with the publication of a study showing that 4-year survival rates for cirrhotic transplant patients with HCC did not differ significantly from those of patients who underwent transplant for reasons other than cancer. This study provided the framework, referred to as the Milan criteria, for transplant within North America and much of the rest of world that is still in use today. The Milan criteria for determining a patient's eligibility for liver transplant are as follows:

- A single HCC lesion smaller than 5 cm, or presence of 2 or 3 lesions smaller than 3 cm.
- Absence of extrahepatic involvement.
- No lymphatic involvement.

A follow-up study retrospectively examined data on more than 30,000 patients who had a liver transplant between 1987 and 2001 through data from the Organ Procurement and Transplant Network. The authors found that survival rates were significantly worse in patients with HCC compared with those having transplants for other indications. However, rates of survival improved over time for patients with HCC who had transplants, increasing from 25% for the 1987 to 1991 study period to 61% for transplants performed between 1996 and 2001. In the late 1990s, patient selection criteria were revised, which likely contributed to the improved patient survival rates in the later study period.

According to the American Liver Foundation, approximately 17,000 people were on the liver transplant wait list in early 2015, and more than 6000 transplants occur each year. In 2002, a set of criteria called the Model for End-Stage Liver Disease (MELD) was implemented for patient wait-list ranking. These criteria provided a method for moving the most severe liver disease cases to the top of the recipient list and refined overall criteria. After implementation of MELD, the number of new patients added to the wait list decreased and the number of transplants increased, as did the number of HCC patients who received transplants shortly after being added to the wait list.

Concerns were raised that MELD was giving HCC patients higher priority over noncancer transplant candidates because more candidates with similar MELD scores who did not have HCC died waiting for transplants than did HCC patients following MELD implementation. Eventually, the concerns resulted in a slight change to the MELD criteria in 2003.

In general, patients eligible for liver transplantation wait several months to more than a year for a donor organ to become available. During this waiting period, additional tumors might appear that render the patient ineligible for transplantation. RFA has been used in some cases to remove these interval lesions. The usefulness of RFA as a bridge to transplantation varies depending on regional wait time for donation and individual patient characteristics.

**Complications of RFA**

As with any therapeutic procedure, careful consideration of the risks and benefits must be weighed before opting to treat a patient with RFA. Even though RFA is considered safe, it is associated with complications (see Table 3), although the incidence rate is low. RFA complications can occur because of:

- Thermal effects.
- Insertion of a foreign surgical instrument through tissue.
- Sedation.
- Embolization or vascular balloon occlusion procedures that decrease perfusion to the tumor and are designed to make RFA more effective.
Complication risk might increase depending on lesion size, site of electrode placement, and RFA operator experience.

Complications resulting from thermal effects of RFA for hepatic tumors have been studied and reported most often in the literature. In general, as the tumor’s distance from the radiofrequency probe increases, the rate of heating decreases. However, even though the targeted lesion receives the focus of energy from the radiofrequency electrode, those structures and tissues immediately adjacent to the lesion could be exposed to increased thermal discharge. Injuries to the gastrointestinal tract, gallbladder, bile ducts, and diaphragm have been reported in patients receiving RFA for liver tumors, and some have resulted in death. Some reported thermal injuries occurred early in the adoption of RFA into clinical practice and are of less concern today. The physician can prevent injury to adjacent structures such as the bowel and diaphragm by closely monitoring the distance between the electrode and the healthy structure or tissue.

Postablation syndrome is a flu-like illness that occurs in approximately one-third of patients after RFA and other ablative procedures. Symptoms appear approximately 3 days after the procedure and last about 5 days. Development of postablation syndrome is significantly correlated to the volume of tissue ablated. Postablation syndrome occurs as a result of the body’s response to inflammation induced by the ablation of tissue.

Ablation procedures in which large volumes of tissue are treated can produce high-grade fever, nausea, vomiting, and lethargy that can persist for several weeks. Ablations of smaller lesions might produce low-grade fever, leukocytosis (increase in white blood cell count), and malaise, with symptoms persisting fewer than 10 days.

Electrode insertion and removal introduces possible complications. The most common complication from RFA is hemorrhage. Although risks of hemorrhage are low, severe hemorrhage following RFA has been reported. Strict screening of patients for coagulation disorders and monitoring of bleeding is important for preventing postablation hemorrhaging complications. Risk of infection at the electrode insertion site is low with RFA. Some practitioners administer prophylactic antibiotics prior to the procedure; however, this is not a universal practice and little evidence supports using prophylactic antibiotics to decrease infection risk from RFA.

Tract seeding, a rare occurrence involving deposits of malignant cells along the tract of a biopsy needle or other surgical instrument, is of moderate concern with RFA. In a study of 200 patients with primary and metastatic liver tumors, tract seeding was found in 4% of patients. Another study of 1314 patients with 2542 HCC lesions reported a rate of 0.9% electrode tract seeding. Tract ablation, a technique whereby the RFA practitioner runs the electrode over tracts produced during the ablation therapy, has been suggested as a method to decrease or prevent both bleeding and tract seeding.

### Imaging With RFA

Imaging is used before, during, and after ablation. Three medical imaging modalities currently are used

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**Table 3**

<table>
<thead>
<tr>
<th>Complication</th>
<th>Source</th>
<th>Mediation or Prevention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal injury to adjacent structures</td>
<td>Thermal energy</td>
<td>Closely monitor the distance between electrode and structure during the RFA procedure.</td>
</tr>
<tr>
<td>Skin burns</td>
<td>Heat from grounding pads</td>
<td>Use larger grounding pads.</td>
</tr>
<tr>
<td>Postablation syndrome</td>
<td>Ablated tissue volume</td>
<td>Ablate the minimum amount of tissue required.</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>Pre-existing coagulation disorder or bleeding during procedure</td>
<td>Screen patients for existing conditions and monitor for bleeding during the procedure.</td>
</tr>
<tr>
<td>Infection</td>
<td>Electrode insertion</td>
<td>Administer prophylactic antibiotics prior to the procedure.</td>
</tr>
<tr>
<td>Tumor (tract) seeding</td>
<td>Electrode</td>
<td>Incorporate tract ablation into the procedure.</td>
</tr>
</tbody>
</table>
in RFA procedures: US, CT, and MR. These guidance systems assist during percutaneous insertion of the RF electrode and help the physician guide the electrode to hepatic lesions. Imaging also assists in monitoring the extent of the ablation zone and residual tumor tissue.

Image-guided tumor ablation is a relatively new branch of interventional oncology. The need to standardize terminology, reporting, and treatment comparisons was recognized by members of the International Working Group on Image-guided Tumor Ablation. In 2003, this group developed the first set of standards for terminology and reporting criteria to improve communication and accuracy of comparison of technologies and results.

**Ultrasoundography**

US provides real-time imaging to the interventional radiologist and no ionizing radiation to patients. The modality is particularly indicated for patients who have back pain or problems with breathing because the patient does not need to be in a fully supine position, as is necessary in CT and MR.

Equipment with optional compound imaging can provide image detail to help better distinguish hepatic lesions. Once the lesion is located, the sonographer measures the lesion. The segment of liver in which the tumor is located is identified and tumor vascularity is assessed. In addition, major hepatic or portal vessels within the immediate area are identified. HCCs and metastases might appear with a hypoechoic halo on sonograms; however, tumors most often treated by RFA are typically echogenic foci within the liver.

Although transabdominal US has been used for RFA, intraoperative and laparoscopic US are considerably more accurate because the transducer directly contacts the liver. Over the past few years, microbubble contrast agents have been introduced into traditional transabdominal US for detection of liver metastases, providing a more specific characterization of hepatic tumors. Detection and delineation of hepatic tumors has improved with the continued development of contrast-enhanced US techniques. Real-time evaluation of blood flow and perfusion of normal and pathological tissue are now possible and are critical in determining RFA procedure variables, such as temperature and ablation time.

The use of contrast-enhanced US for RFA guidance provides real-time evaluation of liver metastases. Wu et al reported on 136 patients with 219 hepatic metastases examined with contrast-enhanced US and compared results of retrospective analysis of 126 patients with 216 lesions who had been treated with RFA using unenhanced US before introduction of contrast-enhancement methods. The authors found that use of contrast-enhanced US before RFA provided valuable clinical information that contributed to a higher survival rate for patients with single tumors and tumors larger than 2 cm compared with patients examined without contrast.

Using contrast-enhanced US also can help practitioners evaluate therapeutic efficacy immediately after ablation, allowing for additional treatment if necessary. A drawback is the appearance of the RFA zone immediately after ablation. For the first 15 minutes and up to 6 hours, the RFA zone appears as an echogenic cloud, and waiting at least 30 minutes is usually necessary to allow for clear delineation of the RFA zone on sonograms.

The sonographer is essential to the success of the RFA procedure maintaining patient cooperation and assisting in establishing the criteria for RFA therapy. Sonography is used to assess the liver to see how easily hepatic lesions can be identified, the size of lesions, and the proximity of lesions to adjacent tissue and organs. In addition, sonography displays optimal RFA access to lesions. If the lesions are not located peripherally in the liver, the patient will be under conscious sedation in most cases and will be able to suspend respiration when requested. However, lesions located peripherally are best treated under general anesthesia because of pain during and after the RFA procedure.

**Computed Tomography**

CT images acquired before and after RFA are used to compare the shape, size, and position of the ablation zone with the tumor. Rieder et al suggest using a tumor map to assess therapeutic efficacy. The proposed tumor map is a 2-D color-coded tool that provides a fast and reliable assessment of the ablation state. The map is meant to help the physician assess therapeutic effectiveness and provide navigation within the 3-D volume rendering of the tumor vicinity. A color scheme
on the tumor map supports accurate visualization of the ablation state on 2-D images and is incorporated onto the tumor’s surface in 3-D volume rendering. This map allows physicians to identify residual tumor tissue without additional follow-up.  

CT-guided stereotactic RFA has been used in some cases to more precisely track the RFA probe in real time. Widmann et al evaluated the use of stereotactic RFA in 20 patients with a total of 35 primary or metastatic liver tumors. They concluded that CT-guided stereotaxis for precise location of hepatic lesions has potential for targeting within arbitrary trajectories in liver segments and locations; however, stereotactic RFA was not evaluated in regard to patient safety, technical success, or effectiveness as an ablative therapy for localized tumor treatment.  

CT scanning is used for staging and follow-up of patients after RFA to assess therapeutic success of the RFA treatment. Triphasic and quadriphasic (precontrast, arterial, portal, and equilibrium) dynamic CT images are useful for evaluating focal liver lesions diagnosed with US and to assess patients who have elevated levels of α-fetoprotein with normal sonograms.  

With CT imaging, the RFA zone is centered at the point of the RFA electrode and appears round or oval. In principle, cross-sectional imaging with CT displays the area of coagulation necrosis as nonenhancing. This nonenhanced area is transient, typically disappearing within a month following ablation. It is important to assess RFA effectiveness one month following ablation because a thin, enhanced hyperemic rim typically surrounds the RFA zone and might obscure residual tumor tissue.  

**Magnetic Resonance Imaging**  
MR imaging is a useful modality for RFA because the high-resolution, multiplanar images can help physicians monitor tumor and tissue perfusion. However, MR has drawbacks when used during RFA procedures, including limited access of personnel to the patient because of the magnet’s structure, the inability to scan patients who have metallic implants or are severely obese, and the requirement that all surgical tools and accessories be MR compatible. MR also is more costly than other imaging modalities available for RFA guidance and has a slower refresh rate. It is recommended that MR be performed in patients whose CT findings are diagnostically inconclusive or those with contraindications to iodinated contrast agents.  

On MR scans taken following ablation, the RFA zone typically is heterogeneous and mixed in signal intensity on T1-weighted images but has low, homogeneous signal intensity on T2-weighted images. The pattern of the zone on T1-weighted MR images varies.  

**RFA Zone Characteristics Following Ablation**  
Typical changes are observed on CT and MR scans acquired immediately following RFA. A high attenuation track appears along the electrode path but disappears with time. The track represents an area of increased cellular disruption. Small attenuation air bubbles resulting from tissue fluid boiling during the RFA procedure also might be observed. The treating physician must ensure that the residual bubbles are not from hepatic abscesses or an infarction. Arterioportal shunting often is observed; it is caused by mechanical or thermal injury to hepatic vessels during the procedure and resolves on its own.  

Occasionally, the RFA zone appears slender or irregular instead of round or oval, most often due to the heat-sink effect. If the RFA zone is adjacent to hepatic vessels, the vessels might indent and deform the zone. This usually can be seen on imaging immediately following the RFA procedure (see Figure 4). If interval enlargement of the RFA zone is observed, the enlargement is the result of an RFA complication such as hepatic abscess or a biloma. A biloma is an unexpected collection of bile that becomes encapsulated and should be investigated completely. Peripheral rim enhancement with or without air bubbles might indicate a hepatic abscess, which also could be indicated by a patient’s clinical features. The RFA zone can have a target-like appearance on CT or MR images caused by differences in tissue properties between the tumor and adjacent ablated parenchyma. The ablation margin should be evaluated if the target-like appearance is observed.  

Rarely, a hepatic arterial pseudoaneurysm occurs within the RFA zone. The pseudoaneurysm appears as an anechoic region with a characteristic arterial waveform pattern on Doppler US. On contrast-enhanced CT or MR images, the complication is displayed as a round or oval lesion within the territory of the RFA zone that
enhances intensely during the hepatic arterial phase. Local tumor progression usually occurs outside the RFA margin, although it might appear similar in shape to a hepatic arterial pseudoaneurysm. The tumor does not enhance as much as the pseudoaneurysm, however. On rare occasions, a calcification is seen within the RFA zone, but this is most often associated with specific types of tumors such as metastatic colon cancer of the mucinous subtype.

Comparing Imaging Modalities for RFA Guidance and Follow-Up

Granata et al compared the diagnostic accuracy of hepatospecific contrast-enhanced MR to triple-phase CT scanning following RFA in HCC patients. The authors evaluated 34 HCC patients with 42 hepatic lesions who were treated with percutaneous RFA under ultrasonographic guidance at one-month and 3-month follow-up intervals. All patients received CT with an iodinated contrast medium injection and MR with a hepatospecific contrast medium injection. Four radiologists evaluated the images for tumor necrosis, residual or recurrent malignancy, and evidence of new lesions. Of the 2 diagnostic modalities, MR proved more effective in post-RFA assessment for HCC patients than did triple-phase CT. The MR scans were more sensitive in detecting residual HCC lesions.

As a guidance tool for RFA, US presents distinct advantages over CT or MR because of its widespread availability, ease of use, lack of radiation exposure, and lower cost. For assessment of ablation success, however, contrast-enhanced CT and MR are preferred (see Figure 8).

MR guidance for ablation is less desirable than ultrasonographic guidance because MR imaging is more expensive, requires dedicated interventional MR equipment, and is not as available for real-time monitoring. CT guidance exposes patients to ionizing radiation, adverse effects from contrast agents, and a maximum of 2 contrast-enhanced scans during the ablation procedure before the upper limit of contrast volume is reached. The sensitivity of dynamic contrast-enhanced MR is greater than that of contrast-enhanced CT, at 84% for MR vs 47% for CT. In addition, MR displays smaller lesions than CT.

Ultrasonographic guidance overcomes several limitations of CT and MR but has its own limitations. Specifically, US cannot help distinguish lesion margins during the RFA procedure because of the formation of gas bubbles during the procedure. This leads to high positive recurrence rates with ultrasonographic guidance. Contrast-enhanced US has been proposed as a means to overcome the limitations of conventional US.
With contrast enhancement, the practitioner can have continuous, dynamic evaluation of tumor microcirculation in situ, which enables detection of residual tumor in the RFA ablation zone.\(^8\)\(^-\)\(^1\)\(^3\)

Wiggermann et al reported a change in therapeutic management in 59% of evaluated cases using contrast-enhanced US compared with conventional US and concluded that contrast-enhanced US provides reliable and immediate assessment of RFA efficacy in treating liver lesions.\(^8\) The authors further reported that when contrast-enhanced US was combined with CT, complete ablation of all liver tumors was achieved in a sample treatment group at 3-month follow-up.\(^8\)

**Efficacy of RFA for Hepatic Tumors**

The use of RFA as a treatment for hepatic tumors is relatively safe and effective.\(^8\)\(^4\) In patients with metastatic hepatic lesions, RFA produces significant survival benefits in tumors less than 3 cm.\(^8\)\(^4\) A systematic review of RFA in colorectal liver metastases by Stang et al identified local tumor recurrence rates for treated patients from 5% to 42% with tumor size larger than or equal to 3 cm being the predominant indicator of localized ablation failure rates.\(^8\)\(^6\)

The success of RFA on HCC and colorectal metastases led to the introduction of RFA to treat liver metastases from other primary cancers.\(^8\)\(^9\) Increasing evidence suggests that RFA is an effective method for treating tumors 3 cm to 5 cm rather than just smaller tumors. A study by Liu and Qian evaluated the effect of RFA on malignant hepatic tumors by comparing its efficacy in primary and metastatic liver cancer.\(^8\)\(^7\) Survival rates at 1, 3, and 5 years for primary liver cancer patients receiving RFA treatment were comparable with those from surgical resection, confirming RFA as an effective treatment of hepatic tumors smaller than 5 cm.\(^8\)\(^7\) Survival rates of patients with metastatic liver cancer were found to be much lower, possibly because of the advanced stage of these malignancies. However, treatment with RFA minimizes the trauma and potential complications from surgery.\(^8\)\(^7\)

**Conclusion**

As cancer rates continue to increase around the world, novel treatment approaches will provide much-needed treatment options for patients. RFA has been proven a safe, effective alternative to surgical treatment for hepatic cancers; however, the technology still is in relative infancy in terms of standards, the precise role of imaging, and optimal practice. The potential of RFA to manage hepatic tumors appears promising, as does the potential expansion of the role of imaging in ablative therapy. This will result in the need for additional training and expertise as a requirement for oncological and interventional radiology practitioners employing these treatment and imaging modalities.

Amy Jacobs, MS, received her bachelor of science degree and master of science degree in biology from the University of West Florida in Pensacola and a bachelor of science degree in psychology from Florida State University in Tallahassee. She manages a large-scale ecological monitoring program in the Western United States and works as a freelance science writer. Amy has been published in numerous scientific journals and has served as a journal manuscript reviewer throughout her career.

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**References**


Radiofrequency Ablation for Liver Cancer


Radiofrequency Ablation for Liver Cancer

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

1. The tripling of adult primary liver cancer cases in the United States from 1975 through 2011 most likely resulted from:
   a. the HIV/AIDS epidemic.
   b. increased hepatitis C infections related to chronic intravenous drug use.
   c. poor control of alcoholism and cirrhosis.
   d. improved detection methods.

2. In the United States, more than one-third of primary liver cancers are attributed to:
   a. hepatitis B and C viruses.
   b. smoking and aflatoxin exposure.
   c. cirrhosis and obesity.
   d. obesity and diabetes.

3. Which is the most common type of hepatic cancer in adults?
   a. hepatoblastoma
   b. hemangiosarcoma
   c. colorectal metastases
   d. hepatocellular carcinoma (HCC)

4. The most common growth pattern for HCC in the United States is a single, invasive tumor.
   a. true
   b. false

5. Which is considered the strongest clinical risk factor in the development of primary liver cancer?
   a. liver cirrhosis
   b. aflatoxin exposure
   c. colorectal cancer
   d. intravenous drug use

6. Which imaging modality often is used for screening or surveillance for people at risk for hepatic tumors?
   a. abdominal ultrasonography (US)
   b. computed tomography (CT)
   c. positron emission tomography (PET)
   d. magnetic resonance (MR) imaging

continued on next page
7. On diagnostic imaging, HCC is suspected when the lesion exhibits which group of features?
   a. pseudocapsule, hepatic septa, microcapsule, and cilia
   b. arterial flow, internal septa, mosaic appearance, pseudocapsule, and hepatic arterial enhancement
   c. arterial flow, pseudocapsule, uniform appearance, and cilia
   d. hepatic arterial enhancement, arterial flow, and extrahepatic calcifications

8. Liver metastasis is most commonly a result of which type of cancer?
   a. breast
   b. melanoma
   c. colorectal
   d. pancreatic

9. Which of the following factors can eliminate a patient from consideration as a candidate for liver resection?
   1. minimal hepatic reserves
   2. comorbidities
   3. multiple lesions
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

10. Radiofrequency ablation (RFA) uses ______ energy to destroy tumors.
    a. thermal
    b. kinesthetic
    c. chemical
    d. microwave

11. Modern RFA equipment can create thermal ablation zones within a range of ______ cm to ______ cm.
    a. 0; 3
    b. 2; 4
    c. 1; 7
    d. 5; 10

12. Coagulation necrosis occurs when the RFA electrode causes:
    a. alterations in mitochondrial cells.
    b. cauterization.
    c. freezing of tissue.
    d. alterations in tissue proteins.

13. During RFA, tissue coagulation is achieved with temperatures between ______ °C to ______ °C.
    a. 40; 60
    b. 65; 85
    c. 60; 100
    d. 80; 115

14. The surgical approach works well for ablation of larger tumors because it offers:
    a. more direct control of hepatic perfusion.
    b. more rapid recovery.
    c. fewer complications.
    d. the “heat sink” effect.

15. Tumors smaller than ______ cm demonstrate superior results from ablation and are ideal for RFA.
    a. 1
    b. 3
    c. 5
    d. 7
16. RFA tends to yield better results when tumors are surrounded by:
   a. an extensive blood vessel supply.
   b. calcified lesions.
   c. cirrhotic tissue.
   d. normal, healthy parenchyma.

17. Which of these factors does not affect the success of RFA in treating hepatic tumors?
   a. tumor encapsulation
   b. tumor location
   c. tumor size
   d. patient size

18. Development of postablation syndrome is significantly correlated to:
   a. the volume of tissue ablated.
   b. the type and stage of cancer treated.
   c. the patient’s overall health and comorbidities.
   d. practitioner skill and experience.

19. Which is the most common complication from RFA?
   a. mortality
   b. tract seeding
   c. infection
   d. hemorrhage

20. Which of the following statements is false regarding use of contrast-enhanced ultrasonography with RFA for hepatic tumors?
   a. It provides real-time evaluation of lesions.
   b. The information provided has contributed to higher survival rates for some patients.
   c. The RFA zone is easily evaluated within less than 5 minutes of the procedure.
   d. Its use to evaluate therapeutic efficacy immediately following RFA can allow for additional treatment.

21. Preinterventional and postinterventional CT images are used to compare which of the following characteristics of the ablation zone to the tumor after an RFA procedure?
   1. shape
   2. size
   3. position
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

22. With CT imaging, the RFA zone is centered at the point of the RFA electrode and appears:
   a. target-like or laminar.
   b. echogenic.
   c. round or oval.
   d. irregular.

23. MR imaging is recommended instead of other imaging modalities when:
   1. there are inconclusive findings on CT.
   2. the patient cannot lie in a supine position.
   3. there are contraindications to iodinated contrast agents.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

24. Small attenuation air bubbles displayed on CT and MR images during post-RFA evaluation are most likely indications of:
   a. hepatic abscess.
   b. boiling fluid in tissues.
   c. coagulation necrosis.
   d. thermal injury.
25. In a review of patients with colorectal liver metastases, which tumor factor was the predominant indicator of localized ablation failure rates?
   a. size
   b. quantity
   c. appearance
   d. density
Directed Reading Evaluation
Radiofrequency Ablation for Liver Cancer

Thank you for taking the time to complete this evaluation. 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. Why did you choose to complete this DR?
   ○ Interested in the topic
   ○ Needed CE credits immediately
   ○ Topic pertained to my area of practice
   ○ Other

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

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

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   ○ Too difficult
   ○ Somewhat difficult
   ○ Just the right level
   ○ Somewhat easy
   ○ Too easy

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

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

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

8. Overall, how valuable are the DRs to you?
   ○ Very valuable
   ○ Valuable
   ○ Somewhat valuable
   ○ Not very valuable

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Radiofrequency Ablation for Liver Cancer

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

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As diagnostic and interventional transcatheter procedures increase in number and complexity, today’s catheterization laboratory–based radiologic technologist is challenged by an ever-expanding body of knowledge. The Cardiac Catheter Book provides a comprehensive review of this rapidly evolving specialty. From the fundamentals to the latest therapeutic advances, this book provides the information needed by today’s cardiovascular invasive specialist.

Written in an easily comprehensible style, this book and supporting online content lead the reader through a practical review of cardiac catheterization basics, with sections about indications, risks and complications, patient preparation, equipment and laboratory setup, contrast media, and interpretation of findings. The authors examine current, evidence-based diagnostic approaches to commonly seen conditions including valvular disease, cardiomyopathies, coronary artery disease, congenital heart disorders, pericardial disease, and aortic dissection. It also covers a range of basic interventional catheter techniques such as percutaneous coronary intervention, coronary stent implantation, rotational atherectomy, and cutting balloon angioplasty.

What distinguishes this book is its focus on new developments in the interdisciplinary treatments of structural and valvular heart disease. It provides valuable insight into emerging procedures such as transcatheter aortic valve implantation, interventions for mitral regurgitation, occlusion of the left atrial appendage, and renal nerve ablation for resistant arterial hypertension. The authors list additional learning opportunities at the conclusion of each chapter.

This hardcover book is printed on high-quality paper that enhances the detail of the images and ensures the text’s durability. Measuring 10 × 8 inches and weighing 3.2 lb, this book is not easily portable. It is, however, a highly visual reference containing 566 illustrations, including coronary angiograms and radiographic images, that clarify concepts and provide additional pathways to learning and understanding.

Recognizing the limitations of print media for the presentation of dynamic imaging studies, the publisher provides access to the Thieme Media Center. The online media center offers more than 350 videos demonstrating step-by-step approaches, case studies, and detailed angiographic sequences. The videos benefit the novice as well as the experienced technologist who might not have the opportunity to see a wide variety of angiograms or interventions in his or her own facility. Because the textbook offers still images and text to
describe a pulmonary embolism, the reader can only imagine the hemodynamics of this life-threatening event. The media center, however, supports deeper learning by providing video of an angiogram demonstrating thrombi in the left and the right pulmonary and segmental arteries and an asystolic heart, allowing the reader to observe the effects of this catastrophic situation. Most of the videos are accompanied by a brief explanation in addition to the fluorographic projection angle, making this online supplement a useful stand-alone resource.

The Cardiac Catheter Book successfully combines a textbook with an online companion Web site to create a complete learning experience. This book is a valuable addition to the radiologic technologist’s professional library.

Christopher Steelman, MS, R.T.(R)(CI), RCIS
The Medical University of South Carolina
Children’s Hospital
Charleston, South Carolina


Radiography in the Digital Age was created to help students learn the complex concepts of physics, exposure technique, and biology as they relate to the world of digital imaging. The book is an invaluable resource for radiography students, but it also benefits radiographers who have transitioned from film-screen to digital imaging.

The information is organized into 5 major sections, allowing the reader to gradually learn and understand the concepts. Also helpful is the presentation of digital concepts alongside conventional ones, demonstrating to the reader how things have changed and how they need to be changed to enhance image production. Current terminology is used throughout, but conventional terminology is referenced to enhance understanding.

The well-written textbook provides a wealth of information on topics from the use of contrast and the effects of kVp to chapters on mobile imaging, fluoroscopy, quality control, radiation biology, and radiation protection. Clear and visually pleasing diagrams, illustrations, and images complement the presented concepts.

The accompanying workbook (sold separately) helps students recall and memorize material. Although the textbook covers much of the American Registry of Radiologic Technologists content specifications for the radiography examination, the workbook questions do not correlate to the style of questions used on the examination. Instructor resources such as question banks, laboratory exercises, and PowerPoint slides are available but were not assessed as part of this review.

Overall, Radiography in the Digital Age is accurate and appropriate for students learning radiography in the modern world of digital imaging, for those educating them on the subject, and for practicing professionals transitioning to digital technology.

Linda DeRenzis, MSEd, R.T.(R)
Program Director
Albert Einstein Medical Center
School of Radiologic Technology
Philadelphia, Pennsylvania


Differential Diagnosis in Ultrasound Imaging is available in hardback and e-book, and
in Italian, Russian, and English. The book’s thorough discussion of body structures, such as vessels, abdominal organs, lymph nodes, and reproductive organs, makes this second edition an essential reference for sonographers, radiologists, radiology interns, and other practicing physicians, and as a textbook for the student sonographer. However, this text is not an ideal reference about sonography during pregnancy, as it features only a small section on pathology in early pregnancy.

This second edition offers more than 2800 high-quality medical images and illustrations, significantly more than the first edition. These images include traditional grayscale, color Doppler, elastography, contrast-enhanced ultrasonography, vessel analysis with Doppler waveforms, and power Doppler images, which are cross-referenced to high-quality radiographs and computed tomography, magnetic resonance, and fluoroscopy images. Many of the anatomy illustrations and sonograms are labeled and are situated side-by-side for easy comparison.

The sections within each chapter are clearly delineated, and the text is logical, easy to understand, and easy to navigate thanks to color-coded page edges. Tables address key highlights including pitfalls of imaging, classifications of normal anatomy and pathology, causative factors, and use of other imaging modalities in conjunction with or instead of sonography. Many of the key highlight boxes are color-coded to specify types of criteria. For example, blue boxes list indications for sonography of an organ system and other basic anatomical knowledge. These concept boxes also provide quick access to key information, which helps readers understand the differential diagnosis process. Topography boxes provide quick reference to echogenicities, sonographic landmarks, and structures’ relation to other organs in the body. The information about the incidence of pathology is useful to the student reviewing for American Registry for Diagnostic Medical Sonography testing.

Differential Diagnosis in Ultrasound Imaging is a valuable resource for departments, staff, radiologists, students, and educators. The e-book option would benefit sonography students and residents and those who work in a mobile setting rather than in a static workspace.

Although the illustrations, updated sonograms, color images of anatomical structures, and key concept boxes make the book a good choice to use in teaching sonography students, it does not include instructor or student resources or testing materials. Regardless, I would highly recommend this book as a reference for those in the medical imaging community.

Jo Gramley, MAHR, R.T.(R)(M)(CT), RDMS
Program Director and Instructor of Radiography
Heartland Community College – Division of Health and Human Services
Normal, Illinois
Spontaneous Hemoperitoneum

LaNae Holman, BS, R.T.(R)(CT), RDMS

The female gonad, the ovary, produces oocytes (eggs) that mature in the inner wall of ovarian follicles, which are sphere-shaped aggregations of cells in the ovary. Each month, a follicle ruptures and releases an oocyte (see Figure 1). Occasionally, the oocyte does not release or the follicle does not rupture. If the follicle continues to grow, it can develop into a fluid-filled sac called an ovarian cyst. Many women will develop ovarian cysts at some point in their lives. Typically these cysts, also known as functional cysts, produce minor to no symptoms, and resolve on their own.¹ Symptoms of ovarian cysts include irregular menses, pain, nausea, vomiting, fullness or heaviness in the abdomen, or pressure in the pelvis²; some cysts bleed inside the ovary.² When pain is sudden or severe or accompanied by fever or signs of shock, immediate medical help is necessary because cysts can be life-threatening.¹ The ovary can become torsed (twisted), or the cyst might rupture, causing hemoperitoneum.²

Case Description

A 33-year-old woman, gravida 4 para 4, presented to the emergency department with acute abdominopelvic pain that she had for 8 hours. She had a history of gallstones with cholecystectomy and endometriosis with vaginal hysterectomy. The patient was evaluated in the emergency department for a possible ovarian cyst.

Laboratory tests showed the patient had leukocytosis. Appendicitis also was suspected, and a computed tomography scan of the abdomen and pelvis with intravenous contrast was ordered.

In the radiology department, 100 mL iopamidol injection 61% was injected in the patient’s intravenous line. The scan revealed hemoperitoneum with the greatest density in the right lower quadrant of the pelvis. A structure believed to be the right ovary contained 2 cysts adjacent to a tubal ligation clip, which seemed to be the epicenter of the hemorrhagic material. The fluid extended superiorly into the abdomen around the liver and spleen (see Figure 2).
Case Summary
Spontaneous Hemoperitoneum

It was believed that the patient had either a hemorrhagic cyst or a ruptured ovarian vessel, and she was taken to surgery. Laparoscopy was performed, and a survey of the abdomen showed a large clot in the pelvis. The left ovary appeared normal; however, omental adhesions obscured the right ovary and were removed with sharp dissection. The right ovary had a large clot at the distal end, which was removed. The opening was consistent with a ruptured ovarian cyst, and the cyst bed was fulgurated (cauterized). Active bleeding was minimal during surgery. The abdomen was irrigated and all clots were removed. Approximately 500 mL of blood were removed from the patient’s abdomen.

Discussion
Although ovarian cysts are common in reproductive-aged women, hemorrhagic cysts are much less common, especially when they bleed to this extreme. In this case, a half-liter of blood leaked into the abdominal cavity in a matter of hours because of the ruptured cyst.

Because appendicitis also was suspected and the patient had sufficient body fat, no oral contrast agent was administered. If an oral contrast agent had been administered, a nonbarium contrast agent would have been used in the event the patient required surgery.

Some differential diagnoses for right lower quadrant pain include:\n
- Appendicitis.
- Ovarian cyst.
- Ovarian torsion.

Figure 2. A. Axial computed tomography (CT) image showing fluid surrounding the liver and spleen. B. Axial CT image showing hemoperitoneum in the right adnexa (arrow). C. Coronal CT image showing hemoperitoneum around the liver and spleen (blue arrows) and also in the right adnexa (white arrow). Images courtesy of the author.
Rupture of an ovarian vessel.
Pelvic inflammatory disease.
Ectopic pregnancy.
Other gynecological disease.
Cystitis.
Bladder stones.
Diverticulitis.
Kidney stones.

Laboratory tests and imaging, such as ultrasonography and computed tomography, can help rule out some of the above (eg, human chorionic gonadotropin for ectopic pregnancy, white blood count for appendicitis, urinalysis for infection or hematuria).\(^1\)

Incidentally, the patient was taking birth control pills—a common treatment for ovarian cysts.\(^1\) She also was not taking any sort of anticoagulant therapy, which is thought to be a risk factor for cyst rupture.\(^2\)

**Conclusion**

This hemoperitoneum was found after an intravenous contrast media−enhanced examination. No oral contrast agent was used because of the patient’s body habitus and the suspicion of appendicitis. The contrast agent enhanced the blood that had leaked into the peritoneal cavity and helped visualize the source of the bleed. Although ultrasonography is more commonly used to image the ovaries, in this case, computed tomography was useful because the cyst was hemorrhaging into the abdominal cavity.

LaNae Holman, BS, R.T.(R)(CT), RDMS, is a staff technologist for Conejos County Hospital in La Jara, Colorado.

**References**

Developing a student learning assessment plan for an imaging, radiation therapy, or medical dosimetry program can be a daunting task. Starting backward from the ideal graduate and deciding what to measure makes the process easier and provides data essential for program improvement. By working backward, assessment becomes an exciting, informative process. Examining the ideal graduate helps identify skills, attitudes, behaviors, and values that are important to measure.

Similar to terminology used in computer technology, the adage of “garbage in, garbage out” also is valid for assessment. If the objectives and student learning outcomes (SLOs) do not measure the skills, attitudes, behaviors, and values of the ideal graduate, no amount of data or analysis will provide the program with information for continuous quality improvement. If the ideal graduate is one who is skilled at producing a PowerPoint (Microsoft) presentation, then that skill should be measured. If that skill is not important for an entry-level radiographer, magnetic resonance technologist, radiation therapist, or medical dosimetrist, then measuring that skill provides meaningless data and will never lead to program improvement. This article provides a different lens through which to view assessment and make the process easier and more useful to the assessment team and the program.

The Joint Review Committee on Education in Radiologic Technology (JRCERT) developed standards for accredited educational programs with input from the medical imaging, radiation therapy, and medical dosimetry communities. The JRCERT Standards require programs to set goals and measure SLOs in 4 areas: clinical competence, critical thinking, professionalism, and communication. When working assessment backward, program faculty should consider these questions:

- What skills, attitudes, and behaviors should our graduates possess in relation to the 4 goal areas?
- How will our graduates be differentiated from graduates of other medical imaging, radiation therapy, and medical dosimetry educational programs?
- How will we know whether our educational program has been successful?

Answering these questions provides a more concrete idea of the assessment data needed to ensure the program reaches its established goals. Each program is unique, so its assessment plan will be unique as well. Although the 4 goal areas might be the same, the objectives and SLOs differ depending on the type of program, its structure, and degree offered. For example, at the certificate and associate degree levels, the program might not require students to write research papers for publication; however, at the baccalaureate and master’s degree levels this might be appropriate. One program might place extra emphasis on communication with patients from diverse populations, while another might focus on adaptability to new technologies. The faculty for each program determine the
unique qualities they desire the program’s graduates to possess. Continuous quality improvement via assessment is the only way to determine whether goals are being met, and if not, what changes should be made to improve the program.

**Desirable Skills, Attitudes, and Behaviors**

Considering the 4 goal areas, there are many desirable skills, attitudes, and behaviors for the graduate. **Box 1** contains possible statements a program might consider depending on its goals. These are not necessarily SLOs, but merely statements a program might make regarding the characteristics graduates could demonstrate in relation to each goal. With further refinement, these statements can become the basis for SLOs.

These statements are absent of any reference to scores or pass rates on the credentialing examination or completion of specific classroom or laboratory assignments. Although all graduates are expected to pass the national credentialing exam, it is a minimum expectation and does not demonstrate a graduate’s ability to function with entry-level skills in the clinical setting. The JRCERT Standards require that programs collect and report credentialing examination pass rates as one measure to assure program effectiveness. With regard to specific classroom or laboratory assignments—unless a program determines, for example, that it is vital the graduate be skilled at presentations using PowerPoint software—developing and gathering data for this attribute provides less than meaningful assessment data for the program.

**Differentiation**

To create differentiation, the program and the respective communities of interest should focus on a unique set of values that is well-integrated into the curriculum. For example, a program might state something similar to the following in reference to its values.

*In addition to meeting the learning outcomes, our students will be identified by their demonstration of excellence in regard to:*

- Competence in addressing cultural diversity.
- Excellence in patient care.
- Technical expertise.

Each value is well-communicated to students because the topic is reinforced in almost every class and evaluated throughout the program.

**Putting It All Together**

Once a program is clear on the skills, attitudes, behaviors, and values associated with the ideal graduate,
it is time to put it all together. Further delineation is needed to hone in on what each statement means in terms of measurable skills, attitudes, and behaviors. Although some statements seem clear, everyone associated with the program must know exactly what the requisite skills, attitudes, behaviors, and values are and how they will be assessed. Consider the statement from the critical thinking example in Box 1: Our graduates adapt to new procedures, technologies, and situations. The specific behaviors, skills, and attitudes associated with the statement must be identified to determine how to use this desired trait in an assessment plan. Skills, attitudes, and behaviors associated with being adaptable need to be determined, and specific new procedures, technologies, or situations of focus for the program specified. Once these steps are completed, SLOs can be developed for a particular goal (see Box 2).

**Measuring Success**

When the program and all of the communities of interest have agreed on the ideal graduate’s skills, behaviors, attitudes, and values and appropriate SLOs have been developed and measured, the final step is to analyze the assessment results to determine program success. If benchmarks are continually being met, it might be time to raise the benchmarks or find another area to examine and assess for program improvement. However, if the established benchmarks are not being met over multiple assessment periods, the program should reassess benchmarks, measurement tools, and perhaps curriculum. It is possible the content area covered by the SLOs needs to be enhanced or the benchmarks might have been set too high.

The program can analyze the data for patterns. Data might show a specific group of students not meeting the benchmark, or it might show all students struggling with the SLOs. Trends leading to decreasing results might be found by studying data over several years. When examining data in relation to the curriculum, any changes in teaching methodology or instructors should be taken into account. Careful analysis of data will show whether the measurement tools really measure the SLOs and should help the program identify opportunities for incremental improvement, which is the purpose of assessment.

**Box 2**

**Sample Student Learning Outcomes**

**Example Goal 1:**

- **Our students/graduates will use critical-thinking skills.**
  - SLO 1.1 – students will analyze pretreatment imaging and make treatment adjustments. A possible measurement tool is an imaging rubric.
  - SLO 1.2 – students will produce treatable plans for areas that have previously received radiation therapy. A possible measurement tool is a treatment plan.
  - SLO 1.3 – students will adjust positioning to accommodate the patient’s condition. Possibilities for measurement tools are clinical evaluations and simulation evaluations.

**Example Goal 2:**

- **Our students/graduates will demonstrate professionalism.**
  - SLO 2.1 – students will demonstrate ethical behaviors. Possibilities for measurement tools are clinical evaluations and employer surveys.
  - SLO 2.2 – students will be prepared for the employment interview process. A possible measurement tool is to produce a professional résumé.
  - SLO 2.3 – students will be able to analyze career opportunities. A possible measurement tool is to develop a career plan.

**Conclusion**

Assessment is the most effective means by which program faculty can make evidence-based decisions for program improvement. Working assessment backward involves the program and communities of interest working together to make the process more meaningful. Asking questions to determine the skills, attitudes, behaviors, and values that are most important to the program and communities of interest provides valuable insight for the program and a roadmap for the assessment process. Once the meaningful traits are identified, determining what to measure is simple. With measurable SLOs, multiple measurement tools can be identified or developed for effective measurement of student learning.

Because communities of interest are involved in the assessment process, there is buy-in from the clinical sites. When program faculty, clinical instructors, and clinical staff have the same expectations for student learning, the evaluations and measurement tools are
more effective and the data more reliable. The collected data are truly meaningful, and when analyzed, the information is a powerful tool for program improvement. No program is perfect, but with incremental changes programs can continue to improve.

Stephanie Eatmon, EdD, R.T. (R)(T), FASRT, is a member of the JRCERT Board of Directors and an advisor for the National University Radiation Therapy Program. She can be contacted at sleatmon15@gmail.com.

References


Stakeholder Engagement Essential to Health Information Technology Project Success

Theresa Gleason Grady, MSM, R.T.(T)

In 2009, the U.S. government mandated that hospitals and clinics implement electronic health records (EHRs) and make meaningful use of the data collected by the end of 2014. Clinics and hospitals enlisted staff from a variety of roles to lead the effort. With the promise of increased reimbursement and the threat of financial penalties, adoption of EHR was a high priority. Project leaders were under intense pressure to succeed by the end of 2014.

Complex information technology (IT) projects such as EHR have high failure rates, and lack of involvement from key stakeholders is often the reason for failure.1,2 Looking at the success rates for these projects, one might wonder whether the health care professionals tasked with implementing EHR systems in radiologic settings understood the value of stakeholder engagement before they started their projects. Furthermore, now that the EHR projects are implemented, would those project leaders look back and realize the value of involving key staff early and keeping them involved throughout the project?

**Stakeholder Engagement**

At a 2006 workshop conducted by the American Medical Informatics Association, participants developed a list of best practices for IT projects. This list included “how to identify all stakeholders and ensure a common vision among them.”1 Stakeholder engagement has been defined as a “process of relationship management that seeks to enhance understanding and alignment between companies and their stakeholders” and as “practices the organization undertakes to involve stakeholders in a positive manner in organizational activities.”3

Stakeholder engagement has value, but it takes work. Identifying stakeholders, defining their roles, communicating with them, and resolving their specialized and conflicting requirements can take just as much effort as evaluating vendors and documenting new workflows. Project managers often do not invest sufficient time and resources, and the results are lacking. For example, one study found that IT implementation projects often are unsuccessful because of problems with cross-team collaboration, which is a form of stakeholder engagement.1 According to the study, at least 40% of all IT projects are abandoned or fail to meet business requirements, with some industries reporting failure rates up to 70%. Although health care IT projects in particular require collaboration, study authors noted “difficulty in translating among specialties, stakeholders, clinicians, and implementers, sometimes to the point of creating a ‘culture clash.’”4

With the amount of energy required, one might wonder whether stakeholder engagement is worth the effort. The U.S. government thinks so, and the high failure rates associated with poor collaboration support the notion. In fact, the U.S. Department of Health & Human Services expressly advised that
stakeholder engagement be integrated into any EHR implementation plan. The department also included several how-to articles about stakeholder engagement on its EHR Web site.

**Attitudes Among Clinicians**

This article’s author polled subscribers of the Society for Radiation Oncology Administrators online listserv about their awareness of and attitudes about stakeholder engagement. Although the federal government’s EHR Web site includes substantial information on the subject, nearly half of respondents did not have a formal stakeholder engagement plan at the start of their EHR implementation.

Although 59% of respondents had a plan at project onset, the remaining 41% represent a lot of ad hoc approaches to a critical issue. Senior management overseeing transformational IT projects might want to require a formal stakeholder engagement plan as part of the overall project plan.

When asked about their attitudes toward the value of stakeholder engagement before starting their projects, 60% of survey respondents reported having positive expectations, stating that they “expected stakeholder engagement to be beneficial to my EHR implementation.” Attitudes toward stakeholder engagement after completing EHR projects were significantly different: Only 41% reported having a positive view of stakeholder engagement once they were done.

The negative attitude shift might be because stakeholder engagement is difficult, and implementing transformational technologies like EHR is already hard enough. To improve IT project success rates, hospitals and clinics should provide the project with resources to facilitate stakeholder engagement.

Although the 2014 deadline for EHR adoption has passed, the future will bring new and challenging IT projects—likely driven by government regulation or competitive pressures. Understanding the value of stakeholders and how to engage them will increase the success rates for these projects.

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*Theresa Gleason Grady, MSM, R.T.(T), has gained insight into why major projects succeed and fail during her 30 years as a radiation therapist, chief therapist, and clinical administrator working in the Greater Boston area. For more information on this topic, contact the author at tgleasongrady@hotmail.com.*

**References**

Providing high-quality patient care is a never-ending goal for radiologic technologists. Because it is a responsibility they take seriously, technologists always look for new strategies and tactics to enhance their patient-care skills. Whether it is staying abreast of the newest advances in medical imaging and radiation therapy technology or improving radiation safety departmental protocols, every step ultimately makes a difference.

One way to make a big difference is to educate patients about the radiologic technologist’s role on the health care team. Because medical imaging and radiation therapy often are unfamiliar to people until they have to undergo an examination or treatment, radiologic equipment and the professionals who perform the procedures can be mysterious to patients and cause unease. This uneasiness is heightened by the ongoing media coverage about radiation dose management in radiologic procedures, so patients naturally look to radiologic technologists for guidance.

To increase the public’s awareness of radiologic science professionals, the American Society of Radiologic Technologists launched the ACE patient awareness campaign in 2013. The campaign is anchored by an easy-to-remember acronym that asks technologists to:
- Announce their name.
- Communicate their credentials.
- Explain what they are going to do.

Applying the steps is a simple way for registered technologists (R.T.s) to make sure their patients know who they are, and it immediately helps build rapport with patients. In addition to the acronym, the campaign features several patient-targeted tactics to enhance patients’ experience during medical imaging or radiation therapy procedures.

To make sure patients know upfront that they are being treated by R.T.s, the campaign materials include a poster designed to be displayed in waiting rooms, dressing rooms, and examination areas. The message on the poster is clear: I am a registered radiologic technologist, and I care about you.

The campaign also offers ACE patient cards. The cards include information about R.T.s and an area for patients to record their medical imaging and radiation therapy examinations. They provide another way for technologists to reinforce to patients that their No. 1 priority is high-quality patient care. For patients, the cards are a takeaway that reminds them that an educated and certified health care professional performed their procedure.

The campaign Web page, www.asrt.org/ace, features information for patients about medical imaging and radiation therapy procedures. The downloadable pages help patients understand what they can expect prior to undergoing a procedure.

The last component of the campaign is the Click To Commit initiative. Click To Commit asks R.T.s to...
incorporate the ACE principles into their daily interactions with patients. It is an easy way for technologists to demonstrate their commitment to top-notch patient care.

All R.T.s are committed to providing the best care possible, and they embrace their responsibilities with passion and dedication. Resources, such as those available through the ACE campaign, ultimately can help R.T.s further enhance patient care.

Jake Buehler, MA, APR, is the director of public relations for the American Society of Radiologic Technologists. He can be reached at jbuehler@asrt.org.

Help Us Raise the Profile of Radiologic Technologists

As health care managers, you play an important role in our efforts to educate patients about the radiologic technologist’s role on the health care team. Now we have the ACE campaign to help us achieve that goal.

ACE is an easy-to-remember acronym to remind radiologic technologists to:

- Announce their name
- Communicate their credentials
- Explain what they’re going to do

Please encourage your staff to embrace the ACE acronym, participate in the Click To Commit pledge and use the materials available at www.asrt.org/ACE.
Critical thinking is fundamental to achieving the primary goals of the radiologic sciences. Critical thinking is not a technique or method to be learned, but rather a process or frame of mind that includes cognitive and affective domains of reasoning. Cognition is the set of all mental abilities and processes such as attention, memory, judgment, evaluation, problem solving, and decision making. The affective domain includes motivations, attitudes, perceptions, and values. Both the cognitive and affective domains can enhance, inhibit, or prevent student learning and critical thinking. However, some prominent theorists view critical thinking as a composite of skills, knowledge, and attitudes, rather than a stand-alone set of cognitive skills. According to Scriven and Paul:

[C]ritical thinking is that mode of thinking about any subject, content or problem in which the thinker improves the quality of his or her thinking by skillfully taking charge of the structures inherent in thinking and imposing intellectual standards upon them.

For radiologic science students, this means they need to develop into well-cultivated thinkers. They need to raise questions, solve problems, gather and interpret relevant patient information, have open minds, and communicate effectively. These are the characteristics of an individual who can think critically.

These goals are tied to improved patient care outcomes and health care reform efforts. They can be attained only through reasoning, problem solving, and reflection. Because radiologic technologists must be able to think critically to provide quality patient care, radiologic technology program faculty must provide their students with opportunities and encouragement to develop this skill. Radiologic science students should learn critical thinking methods and how to apply them in clinical situations. For example, students must develop skills to evaluate a radiograph for exposure factors and anatomical structures to produce quality radiographs. Through this learning process, students increase their technical expertise and critical-thinking skills, which helps them become reliable professionals who can ensure excellent patient care.

Critical thinking has many elements and is difficult to evaluate. Educators often struggle to teach critical-thinking skills because not every individual has them. In addition, many students are challenged by tasks requiring critical thought, even if their educators attempted to teach it. For example, although current models of education encourage standardized practice, problems arise when standardized practices become rote. Students who learn processes by memorization will struggle when expected to use their own judgment or to recognize clinical situations that require them to adapt practice to unique situations.

To prepare students for the field of radiologic technology, faculty must develop students’ critical-thinking skills and close the gap between theory and practice.
Fostering each student’s ability to think critically is essential in the health care environment. With changes in technology and the evolving role of the technologist, radiologic technology is increasingly complex. To provide high-quality medical imaging for diagnostic interpretation, students must sharpen their thinking skills.

**Barriers to Critical Thinking**

Critical thinking is disciplined, clear, and rational. These skills require that individuals conceptualize, analyze, synthesize, evaluate, and apply information to reach accurate conclusions. Obstacles to critical thought result from egocentric and sociocentric ways of thinking. *Egocentric thought* is a preoccupation with one’s own world. Individuals who are egocentric regard themselves and their opinions as being more important than others. *Sociocentric thought* is focused on one’s own social group. Both modes of thought can inhibit a person’s ability to develop clear, rational, and evidence-based thinking.

In addition to personal obstacles, decades of cognitive research suggest that critical thought cannot be taught by traditional methods. Critical-thinking skills cannot be imparted whole, but rather must be exercised and nurtured gradually. Many educators who have sought to teach critical-thinking skills assume that once students learn them, they can apply them in any situation; however, research indicates that critical thought is not that sort of skill. The processes of thinking in the present moment are intertwined with background, or domain, knowledge.

Students can be directed to look at a problem from multiple perspectives, but if they do not know much about a problem, they might be unable to examine it from multiple perspectives. Educators can teach theory, facts, and process, and students can memorize them; however, students need background information about the problems they will face at work as well as experience and practice to think about them critically.

For example, a radiologic science student needs domain knowledge to be able to evaluate the quality of a radiograph. Without being taught to recognize the features of a radiograph, he or she could not apply critical-thinking skills to assess it. Some experts contend that critical thinking improves if it is developed and assessed within the context of a discipline. McPeck asserted that:

> [C]ritical thinkers evaluate information in light of background knowledge, context, and reflective skepticism and postulated that it is impossible and incoherent to attempt to teach critical thinking in isolation from skills being taught to students.

Further, McPeck noted that useful thinking skills “tend to be limited to specific domains,” and that critical thinking is not a “general ability nor is it a specific set of skills.”

**Enhancing Critical Thought**

Although critical-thinking skills cannot be taught, they can be improved. Several techniques can be implemented in a classroom to encourage the development of critical thinking. McCormick and Whittington reported that using problem sets, individual and group written reports, group presentations, and laboratory tests emphasized higher cognitive levels and better critical-thinking skills. These activities also helped students develop the effective communication skills required in the clinical setting. The laboratory allows students to practice positioning skills taught in the classroom. Debates help students view an issue from different perspectives and present their interpretation of a health care issue. Small groups allow the student to develop teamwork and respect for others’ opinions and contributions. All of these activities help develop the cognitive and affective domains of thinking. Meyers suggested that teaching activities such as debates, problems sets, and small-group work improve critical-thinking skills. Instructors can nurture critical thinking using these techniques.

Other activities that stimulate higher-level thinking in students are questioning, role playing, case studies, journaling, and simulations. Education by rote memorization does not cultivate critical thinking or problem solving. However, radiologic science educators can incorporate different teaching strategies into their lectures to promote critical thinking. For example, they can provide students with case scenarios to help them recognize and solve problems they might encounter in the clinical setting. Educators also can have students analyze and evaluate radiographs in the classroom.

Students cannot develop their critical-thinking skills by listening to one lecture or having one clinical
Teaching Techniques

Can Critical-Thinking Skills Be Taught?

Experience. Critical-thinking skills develop over time as a result of varied experiences until they become part of the individual. They are used in all aspects of life, not something saved just for clinical practice.

Although critical-thinking skills are employed in many areas of life, instructors must assess their students’ skills in relation to radiologic technology. Educators can evaluate student progress in critical-thinking skills by observing students’ decision-making and communication skills as well as their performance of radiographic procedures in clinical settings.

Conclusion

Developing critical-thinking skills is a lifelong endeavor for committed students. Critical thinking is self-guided, self-disciplined thinking based upon background information, practical experience, evidence, and reason. People who think critically are more likely to live rationally, reasonably, and empathically. Critical thinkers strive to diminish the effect of their egocentric and sociocentric tendencies. They use the intellectual tools that critical thinking offers to analyze, assess, and improve their own lives and their professional practice.

Regina C Panettieri, MPA, R.T.(R)(CT), is associate professor for the Bronx Community College of the City University of New York.

References


According to the Brookings Institution, patenting by U.S. inventors is at its highest level since the Industrial Revolution. In fact, by 2011 the United States Patent and Trademark Office (USPTO) had issued patent number 8,000,000. The field of radiology is no stranger to patented innovations. According to the Society of Interventional Radiology, more than 2,400 patent applications for drugs and modern medical devices that advance minimally invasive treatments have been filed by its members over the past 40 years. For radiologic technologists with novel ideas, understanding the patent process is essential. For example, inventors must conduct a thorough search and review of existing patents to ensure their idea is in fact new. Those who want to understand the patent process must start with the basics including this USPTO definition:

A patent is a property right granted by the Government of the United States of America to an inventor “to exclude others from making, using, offering for sale, or selling the invention throughout the United States or importing the invention into the United States” for a limited time in exchange for public disclosure of the invention when the patent is granted.

A patent differs from a copyright or trademark. A copyright is a form of protection for “original works of authorship,” and a trademark protects a word, phrase, symbol, or design that identifies and distinguishes the goods of one party from those of others. A patent can be filed for any process, machine, manufactured item, or composition of matter, as well as improvements to patented items. Furthermore, for an invention to be patentable it also must be considered novel, nonobvious, adequately described, and claimed by the inventor in clear and definite terms. Laws of nature, physical phenomena, abstract ideas, and inventions that are offensive or not useful to public morality are not eligible for patent protection.

Examples of Patents in Radiology

Medical patents typically are categorized as pharmaceutical or device related. According to the Institute of Medicine, the primary difference between drug and device patents is that eligible pharmaceutical discoveries might receive “new drug product exclusivity.” In other words, pharmaceutical discoveries can receive exclusive marketing rights for a limited time granted by the U.S. Food and Drug Administration (FDA) upon approval of a drug.

An example of a recently issued radiology-related patented device is the real-time ultrasound probe. This device’s U.S. patent number is 8,945,013, and the patent was issued on February 3, 2015. The device is described as a “probe assembly [that] may be operable to reciprocally pivot the plurality of ultrasonic transducers at a rate sufficient to generate real-time or near real-time three-dimensional images of the image volume.”

Patrick Jones, BS, R.T.(R)

Patents Demystified
The application filing date for this patent was June 1, 2009, which means almost 6 years were required to complete the patent process. According to the World Intellectual Property Organization, it is not uncommon for patent approval to take several years, depending on the invention under question and its field of application. Once a patent is granted, it lasts for 20 years. After the initial patent window expires, an extension must be approved by the USPTO in consultation with the FDA. In the above patent example, understanding the patent verbiage is less important than understanding how technical and descriptive a patent description should be.

In comparison with the real-time ultrasound probe patent, consider the description of a drug patent for materials and methods for magnetic resonance imaging contrast agents and drug delivery. The U.S. patent number for this material is 8 580 230, and the patent was issued on November 12, 2013. The inventors filed 30 claims with this patent. The material is described as follows:

*The present invention relates to compositions of Prussian blue (hereinafter referred to as “PB”) materials as contrast agents for medical imaging or as vehicles for drug delivery, and methods relating to the use thereof. PB belongs to the class of iron hexacyanoferrate (II). PB is known by the chemical formula: Fe.sup.III.sub.4[Fe.sup.II(CN).sub.6].sub.3.nH.sub.2O. In the chemical formula for PB, the value n represents an integer in the range from 1 to about 24. The PB materials according to the invention may have a composition of the chemical compound: A.sub.4xFe.sup.III.sub.4[Fe.sup.II(CN).sub.6].sub.3+x.nH.sub.2O.*

The patent description also discusses variations of this chemical compound and the novel application of its use as a drug delivery platform and contrast agent for magnetic resonance imaging.

This type of general-to-specific description, in which the invention is described broadly first and then discussed with increasingly more specificity with subsequent claims, is promoted by experts in the field and commonly used in patent publications. In the *Intellectual Property & Technology Law Journal*, Valoir and Paradiso explained that if inventors describe an invention in broad terms initially and specify details later, they can secure more rights.

**Patent Oversight**

The granting and enforcement of patents are governed by national laws and international treaties, where those treaties have been given effect in national laws. The USPTO is the federal agency responsible for granting patents and registering trademarks within the United States. It advises the president of the United States, the secretary of commerce, and U.S. government agencies on intellectual property policy, protection, and enforcement, as well as promotes increased effectiveness of intellectual property protection around the world. An example of this involvement of intellectual property protection is the Patent Cooperation Treaty of 1970. The treaty was created to assist applicants seeking international patent protection, to help patent offices with their patent granting decisions, and to facilitate public access to technical information related to those inventions. Currently, 148 countries are included in the treaty.

The World Intellectual Property Organization is a global forum for intellectual property services and is a self-funded agency of the United Nations, with 188 member states. The organization was established in 1967 to develop a balanced and effective international intellectual property system supporting innovation and creativity for the benefit of all.

The World Trade Organization supervises international trade and administers the international agreement on Trade-Related Aspects of Intellectual Property Rights, which establishes minimum standards of property rights protection. In 1994, the agreement introduced intellectual property law into the international trading system; it remains the most comprehensive international agreement on intellectual property to date.

More specific to medical imaging, the Center for Devices and Radiologic Health, a branch of the FDA, ensures that “patients and providers have timely and continued access to safe, effective, and high-quality medical devices and safe radiation-emitting products.” This organization also supports the innovation of medical devices “by advancing regulatory science, providing
The industry with predictable, consistent, transparent, and efficient regulatory pathways. Its mission is to ensure that consumers can be confident in devices marketed in the United States. The USPTO frequently consults with the Center for Devices and Radiologic Health and other branches of the FDA when approving patents and extensions on existing patents.

The Patent Process

Development of any product, regardless of whether it is a device or drug, will pass through 8 stages of development (see Box). Investigation of intellectual property issues and patent database searches are performed during the early stages of idea development and screening. Patent searches involve complex reviews of previous public disclosures of U.S. and foreign patents, and it is common practice for inventors to employ a licensed professional to perform these searches on their behalf.

Six steps are essential to patent an invention. Each step requires researching the competition in the respective industry, explaining the method of developing the invention, and understanding the USPTO patent application requirements.

Step 1: Inventor’s Disclosure

Inventors must use confidentiality agreements when disclosing their invention to other professionals. Although they might work collaboratively with law offices, consultants, and research and development personnel, confidentiality agreements ensure that the inventor retains ownership of his or her invention. Defining ownership of an invention can be complicated, as a variety of scenarios could exist (eg, a single inventor, joint inventors, and employer rights to ownership of an employee’s invention).

Step 2: Patent Search

Patentability searches, also referred to as anticipation searches, help to determine whether an invention is likely to qualify for a patent. More detailed searches are included within the general patent search to detect possible patent infringement. Because of their complexity and legal issues that can result, these searches should be performed by licensed USPTO professionals. The resources for patentability searches are provided by the USPTO at patent and trademark libraries found in most major U.S. cities, as well as online through a variety of Web sites, including www.uspto.gov and the Google patent search engine.

Step 3: Application Preparation

The components to patent application preparation include fees, letters, requests, drawings, specifications, claims, an abstract, exhibits, models, specimens, and other documents. Application fees account for only a small portion of the expenses required to develop and maintain a patented product. The application fees involve filing, search, and examination fees and can vary within a range of several hundred dollars depending on the type of application submitted. In addition, strict attention must be paid to instructions about formatting sections of submissions to ensure a timely review. For example, for submitted drawings, formats for the scale of the drawing, exploded views, and cross-sectional views are enforced. Written submissions also must follow format requirements for numbers, letters, reference characters, and paper margins.

Step 4: Application Examination

During the patent application examination, an assigned patent examiner reviews the application, repeats patentability searches, and drafts an examination report that ensures compliance with legal requirements. The patent examiner issues a formal communication to the applicant that includes research citations and court rulings. The applicant must respond with opposing citations or rulings supporting his or her position.

Box

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<th>Stages of Product Development</th>
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<td>1. Idea generation.</td>
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<td>3. Idea development and testing.</td>
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<td>6. Technical implementation.</td>
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<td>7. Commercialization.</td>
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<td>8. New product pricing.</td>
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**Step 5: Application Amendment**

Applicants can make amendments to patent claims, specifications, and drawings. If a patent application requires amendments, additional rules dictate when and how amendments are made according to USPTO rules. For example, if an amendment is submitted late following a final rejection or an appeal, the applicant is required to submit a sufficient reason for the late submission.14

**Step 6: Patent Filing**

There are 2 methods for filing a patent with the USPTO: provisional and nonprovisional applications. Provisional patent applications provide a method for disclosing the invention and assigning an early priority date. This type of application was established in 1995 to provide opportunities for inventors to document the current use of an invention with the contingency that a nonprovisional patent application be filed within one year of filing the provisional patent application. The filing date of a nonprovisional patent application is then documented as the date on which the USPTO receives a complete and compliant application.14

**Summary**

Product innovation, development, and marketing are at an all-time high in the United States partly because of the ability to patent and protect intellectual property. Radiology professionals interested in product innovation and implementation should understand the factors that make an idea or invention patentable, the patent application process, and the organizations that support and enforce successfully filed patents.

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**References**


Evidence of the radiology physician extender (RPE) dates back to the 1970s.1-9 Since then, the RPE profession has developed multiple ways for medical staff with a variety of educational backgrounds to incorporate radiology-related activities into their scopes of practice that are consistent with activities expected of an RPE. For the purpose of this article, RPE includes the professional branches physician assistant (PA), nurse practitioner, radiology practitioner assistant (RPA), radiologist assistant (RA), and consultant radiographer. Articles detailing the benefits and concerns of employing RPEs are abundant and often highlight issues such as clinical competency, cost effectiveness, education and training, scope of practice issues, and role delineation. As with any topic, information can be contradictory depending on the source; thus, access to all published literature about the RPE profession helps to ensure a comprehensive review of the facts and limit potential bias.

Several groups might have interest in reviewing information related to the RPE profession, including potential students making career decisions; imaging department executives who make hiring decisions; and individuals involved in making regulatory, institutional, or public policy decisions. In each of these scenarios, having an efficient method to connect those who need details about RPEs with those who have written papers on the profession is beneficial. For this purpose, a Web-based bibliographic database was established. In this article, we outline the methods used to create the database, populate the bibliographic content, optimize navigation, and maintain the resource to incorporate future pertinent publications. We share our experience so others can apply a similar strategy for other radiologic issues.

Examples of Bibliographic Databases

A bibliographic database is an organized collection of references to published literature, often including journal and newspaper articles, conference proceedings, reports, government and legal publications, patents, and books. Such a database can be general in scope or cover a specific academic discipline. A significant number of bibliographic databases are proprietary, meaning they are available only through licensing agreements from vendors.10

Many bibliographic databases evolve into digital libraries, providing the full text of the indexed contents, while others converge with nonbibliographic scholarly databases to create more complete discipline-specific search engines.11

Although no known example of a Web-based bibliographic database could be found within the field of radiologic health sciences, the use of such systems in medicine is fairly common. For example, MEDLINE is a bibliographic database of life sciences and biomedical information. Compiled by the U.S. National Library of Medicine, MEDLINE is freely available on the Internet and is better known by its search engine tool, PubMed. More than 5642 biomedical journals, containing more
than 21.6 million records, are indexed in MEDLINE, including bibliographic information for articles covering medicine, nursing, pharmacy, dentistry, veterinary medicine, and health care.12-13 In 2014 alone, PubMed/MEDLINE was searched 2.7 billion times.14

As another example, Omid and Davood Beiki established the ParsMedline database in 2003.15 ParsMedline was designed to organize and archive Iranian medical research and facilitate access to that information for the Iranian scientific community, students, and research centers. The Beikis recognized that researchers in their country had difficulty accessing and disseminating information, and that easy access to reliable information for health workers could be a cost-effective and achievable strategy to improve health care in their country. They established a database with more than 79,000 bibliographic descriptions from 1978 to 2004. The Beikis’ article details their database project experience and demonstrates the opportunity we all have to access and distribute information.

Database Content
A search with the PubMed database engine was performed between June 8 and June 20, 2014, using the medical subject headings (MeSH): radiologist assistant, radiology practitioner assistant, radiology physician assistant, nurse practitioner, consultant radiographer, radiology physician extender, and radiology midlevel provider, each used in combination with the term radiology. The search strategy was limited to peer-reviewed journals in English. The reference lists of qualifying articles were reviewed to identify additional resources. The results were initially filtered by relevance of the titles to the MeSH terms of interest and then further filtered by the relevance of the abstracts to the RPE profession. Articles related to radiographers or nurses with advanced imaging roles who were not specifically physician extenders were omitted, as well as articles related to medical imaging specialties generally managed by nonradiologist physicians (i.e., radiation oncology and interventional oncology/cardiology).

Because the initial search resulted in few articles related to the consultant radiographer profession, an additional search was conducted on this term without combining it with radiology via Google following the same article inclusion and exclusion criteria.

Content Analysis
Articles that were not peer reviewed but still deemed scholarly also were included in the database. For example, the Society of Radiographers journal, Radiography, does not perform peer reviews, but the majority of consultant radiographer articles appear in that journal. Therefore, no articles about consultant radiographer practice show up in PubMed. The consultant radiographer articles were found in a Google Scholar search, and the inclusion rule was softened so they could be included in the database. Their inclusion allows investigators using the database to decide whether they want to limit their search to peer-reviewed articles only, and it enables us to include a majority of the articles on the consultant radiographer, which were not published via a peer-reviewed process even though they are of value to investigators.

Although such articles demonstrate the historic development of the physician extender career paths, including these articles dramatically increases the database content and diminishes its focused objective.

The PubMed search strategy identified 669 potential articles pertaining to the RPE profession. The Google Scholar search pertaining to the consultant radiographer yielded 20,600 potential articles, of which only the first 100 were reviewed. Of the 769 articles reviewed, 152 were marked for potential inclusion using the title alone. This number was reduced to 124 articles following a review of the article abstracts. Four additional articles were identified after reviewing the accepted articles’ reference lists. With 28 articles being identified in multiple MeSH term searches, 100 original articles were initially submitted to the bibliographic database. The Table reports the search results for each of the MeSH terms used.

The analysis of these 100 articles yielded information related to the frequency of article publication by calendar year, journal type, and RPE professional branch. Articles dated as far back as 1970, with the majority (43%) published between 2005 and 2009 (see Figure 1). Twenty-six different journals published at least one article on some aspect of the RPE profession. However, 5 journals published the majority of articles (see Figure 2):

- 20% – Journal of the American College of Radiology (American College of Radiology [ACR]).
Creating a Radiology Physician Extender Web-based Database

Identifying Trends

The peak in RPE articles that occurred between 2005 and 2009 likely is associated with the advent of the RA career pathway. In 2005, the American Registry of Radiologic Technologists first offered a national RA certification exam.

Despite the presence of PAs in the radiology department, which dates back significantly farther than their RPE counterparts, 34% of the available RPE literature is specifically focused on the RA profession. This might be because practice in radiology is only one possible avenue for PAs, who are eligible to practice in all areas of medicine, or it might reflect the low percentage of PAs who pursue a career in radiology.

The decrease in published RPE articles between 2010 and 2014 might be related to issues involving lack of recognition for RAs as nonphysician providers under Medicare law. However, national advocacy efforts are underway and 29 states currently license or recognize the RA designation.16 This challenge to broader acceptance might have been a distraction to continued clinical and professional research initiatives.

Also of interest is that 4 organizations (ACR, SoR, ASRT, and RSNA) published 65% of articles about the RA profession. Authors interested in increasing the public’s recognition and understanding of the RPE

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**Table**

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<td>152</td>
<td>124</td>
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</tr>
</tbody>
</table>

*aGoogle Scholar search results
Abbreviation: MeSH, medical subject headings.

---

**Figure 1.** Frequency of radiology physician extender (RPE)–related article publications.

- 17% – *Radiography* (Society of Radiographers [SoR]).
- 16% – *Radiologic Technology* (American Society of Radiologic Technologists [ASRT]).
- 12% – *Radiology* (Radiological Society of North America [RSNA]).
- 5% – *Radiology Management* (Association for Medical Imaging Management [AHRA]).

Of the 5 recognized RPE professional branches, the majority of articles written were solely related to the practice of RAs (34%, n = 33), followed by PAs in radiology (23%, n = 23), consultant radiographers (15%, n = 16), nurse practitioners in radiology (9%, n = 8), and RPAs (3%, n = 3) (see Figure 3). In addition, 15% of the articles included in the database reported on more than one RPE profession type.
profession might consider publishing in different journals to reach new audiences (eg, referring physicians, hospital administrators, and patient advocacy groups).

Limitations to the Content Search

The authors of this article recognize 3 limitations to this project: First, using Google Scholar, primarily for identifying consultant radiographer-related articles, was suboptimal. Because our search strategy resulted in a large number of results, we were forced to conduct a self-limiting review of the first 100 articles populated. Second is the concern that other scholarly articles about the RPE profession might exist but perhaps did not undergo the peer-review process and might have been missed during our PubMed search. A search via Google Scholar, similar to that performed for the consultant radiographer, could have been performed for each of the other RPE professions to identify missing articles. One final limitation was that full articles could not always be located, which meant we could not review every reference list for other potential articles.

Database Creation

The 100 articles of interest were entered into a Microsoft Excel spreadsheet with categories such as title, author, journal, publication year, issue, volume, and page range. A temporary “article tracking” field used a database key to help the developers follow the progression of article collection, review, and inclusion or exclusion. The key included:

- SS-Hit – article identified via search engine.
- RL-Hit – article identified via reference list review.
- Dup – possible duplicate article.
- ? – question of article relevance.
- No abs – awaiting allocation of article abstract.
- Abs-TBR – abstract to be reviewed for relevance.
- Abs-R – abstract reviewed.
- RL-TBR – reference list to be reviewed.
- RL-R – reference list reviewed.

When duplicate articles were identified, additional research was performed to identify the cause (eg, article editorial or reprint), and if truly a duplicate, the original was incorporated and the duplicate culled.

Web-based Conversion and Site Hosting

When the spreadsheet was complete, ASRT staff members converted it into a searchable Web-based format with added administrative features. They wrote a user interface for the database in the Microsoft.NET Framework, using ASP.NET and C#. SQL Server 2012 was used for the database engine, with the repository supported by a single table. The user interface for the database employed search fields similar to those of the original spreadsheet, excluding “article tracking.” Field searches were set to toggle between ascending or descending alphabetical or numerical values. In addition, when available, hyperlinks were
created for select article titles to provide instant access to article abstracts and, in many cases, to open-source and subscription-based full articles. (Publishers prohibit linking directly to full article text unless the article is available in an open-source format.)

Development time was streamlined because the ASRT Web site already supported user services (ie, login and profile). ASRT designated a page for the database on its Web site.

**Database Management**

An account with the National Center for Biotechnology Information, an institute affiliated with the National Institutes of Health and home of the PubMed database, was established through routine public access and monthly e-mail alerts matching the article search parameters of interest. This was done to ensure relevant items garnered from the alerts were included so the database remained a useful source of current articles. A similar e-mail alert feature was established with Google Scholar for articles pertaining to consultant radiographers. One of the authors was given the role of administrator and provided with unique Web access to add content to the database.

In addition, because every search strategy could miss items, a process was developed to review submissions recommended by individuals for the database. To make a recommendation, users should e-mail article information to rpearticle@asrt.org. The administrator will verify the article’s publication within a scholarly journal and review it for relevance.

**Expanding the Database**

The scope of the database could expand to include articles that pertain to other RPE professionals in development from subspecialty areas such as nuclear medicine and sonography. It also could include regulatory, legislative, and national curriculum documents related to the various branches of the RPE profession. In addition, articles could be categorized according to their focus (clinical competency, cost effectiveness, education and training, scope of practice issues, or role delineation).

Finally, others in the radiologic sciences who are involved with similar medical imaging issues could see this index as an example of how to organize substantial data into one resource that is customized to increase access to the most relevant literature.

**Publicizing and Using the Resource**

The success of an educational resource such as the Radiology Physician Extender Article Database can be realized only if it is widely available via open access and if the community it serves takes ownership of its development. The ASRT-hosted database is fully accessible to the general public (see **Figure 4**).

The index is a useful resource for those in the RPE profession conducting research, and it should help advance the profession. It is a “living project” that requires users to promote the database, develop innovative new applications for the archived content, and provide feedback on additional features that could increase its usefulness.

The index also might help students who are considering an RPE education weigh the benefits and disadvantages of each avenue after reading relevant articles. Similarly, radiology administrators interested in employing an RPE professional to increase the...
efficiency of their department can use the database to identify articles that aid the decision-making process. Finally, advocates involved in lobbying for professional recognition or optimized scopes of practice for RPEs could use this database to find examples of precedence in practice spanning more than 40 years of published literature.

Wesley Shay, MS, R.R.A., R.T.(R), is a radiologist assistant for Memorial Sloan-Kettering Cancer Center in New York, New York. He is also the primary manager of the Radiology Physician Extender Article Database.

Jonathan Mazal, MS, R.R.A., R.T.(R)(MR), served as a board member for the Society of Radiology Physician Extenders Foundation from 2010 to 2011. He has served as vice-chair and chair for the American Society of Radiologic Technologists (ASRT) Radiology Assistant Chapter from 2011 to 2015. He was a 2010 Siemens scholarship recipient and in 2011 was named a Virtual Symposium on Research Advancing Researcher, as well as received an ASRT Foundation Seed Grant for research.

Jeffrey S Legg, PhD, R.T.(R)(CT)(QM), is associate professor and chairman of the department of radiation sciences and director of the radiologist assistant program, School of Allied Health Professions of Virginia Commonwealth University. He also is the associate editor for the Americas of Radiography.

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References
A 60-year-old woman presented to the emergency department for shoulder pain from a recent fall. A full shoulder series was performed, including an axillary projection, on a Carestream computed radiography unit.

Exposure numbers indicate the amount of radiation arriving at the image receptor. An exposure index increase of 300 represents a doubling of exposure. The axillary projection seen in Figure 1 demonstrates poor image quality. The exposure index number for the projection was 3110, which is significantly higher than the institution’s predetermined maximum allowable exposure index of 2000. The exposure index number for the image represents a plate exposure of more than 3 times the acceptable permissible maximum. Such gross overexposures are termed plate saturation. Plate saturation also causes excess radiation exposure to the patient and results in dose creep.

Computed radiography plate saturation causes a rescaling error during image processing, resulting in images with poor contrast and brightness. Another consequence of plate saturation is the reader’s inability to completely erase the image from the plate. Residual signal on the imaging plate can cause ghosting artifacts on subsequent exposures. When computed radiography plates are saturated, the imaging facility where the examination was performed routinely sets aside saturated image receptors for at least 24 hours to allow the residual image to fade. The plates are then erased and reloaded.

Figure 1. This image demonstrates the effects of computed radiography plate saturation. Note the overall dark appearance of the image and loss of contrast. Image courtesy of the author.
Another artifact appears as a light vertical line on the left side of the image (see Figure 2). The line was most likely caused by dust or dirt on the imaging plate or the light guide of the plate reader. When this artifact appears, the imaging plate should be cleaned. If the artifact persists, the reader should be cleaned and serviced.

Thomas G Sandridge, MS, MEd, R.T.(R), is program director for the school of radiography sponsored by Northwestern Memorial Hospital in Chicago, Illinois.

References
More than 100 years have passed since Wilhelm Roentgen’s discovery of x-rays, a form of electromagnetic radiation with wavelengths shorter than visible light. Roentgen’s work was the continuation of other scientists’ study of the properties of light waves. Subsequent research into particle theory by Albert Einstein and others led to the physics principles that not only laid the groundwork for state-of-the-art medical imaging but also changed the understanding of our universe, from atoms to black holes. Because light is the visual medium of radiologic science, technologists must develop an artistic eye. This retrospective pays homage to those who advanced the scientific theory of light and contributed to the foundation of modern medical imaging:

- Wilhelm Roentgen – x-rays (1895).
- Albert Einstein – photoelectric effect (1905).
- Werner Heisenberg – uncertainty principle (1932).
- Christian Doppler – Doppler effect (1842).
- Rembrandt van Rijn and Johannes Vermeer – old masters in painting light (1600s).

**Wilhelm Conrad Roentgen**

Roentgen discovered the rays that behave in ways both similar to and strikingly different from visible light. He coined the term “x-rays” because to him they were a great mystery, and in algebra, “x” represents an unknown quantity that is replaced by the solution. In his seminal 1896 article, he described the unique characteristics of x-rays that are still accurate today, including that they:

- Transmit in complete darkness.
- Are invisible to the human eye.
- Originate from a cathode ray tube.
- Penetrate black paper that blocks visible light.
- Light up barium platinocyanide-coated paper.
- Expose photographic covered plates.
- Diminish at a distance but fluoresce at 2 m.
- Have an intensity that follows an inverse square law.
- Make wood, water, and human flesh appear transparent, but metal and bone remain opaque. The transparency of intervening objects depends on their molecular density and thickness.
- Are not reflected by mirrors nor deflected by glass prisms.
- Travel at a constant speed—the speed of light.
- Share some properties with visible light.

Shortly after Roentgen published his article, x-rays were identified as a continuum of the electromagnetic spectrum of light. In 1901, Roentgen received the first Nobel Prize awarded in physics (see Figure 1). As a tribute to Roentgen’s original description, the high-energy waves still are called x-rays, even though they are no longer mysterious.

**Albert Einstein**

Einstein was preoccupied with the unique qualities of light his entire career. Although he is best known for...
his theories of relativity, his Nobel Prize was awarded primarily for his explanation of the photoelectric effect, which revealed that x-rays were a form of light that traveled in quanta, or packets of energy. Einstein's persistent curiosity about the peculiar nature of light resulted in the special theory of relativity, an idea conceived while riding his bicycle toward a lamp light. He reasoned that unlike moving Newtonian objects whose speeds are summed or subtracted, the speed of light is constant for all observers. Relativity would explain everything, from the tiniest subatomic particles to galaxy-devouring black holes.

**Max Planck’s Light Bulbs**

Planck's scientific work often is described as theoretical studies in black-body radiation, but his commissioned job was finding out how to get the most visible light from light bulbs using the least amount of energy. He used statistical analysis to match observations that atoms do not emit light energy in continuous waves but rather in discrete packets of energy \((E)\) as determined by a discrete integer \((n)\) multiplied by Planck’s constant \((h)\) multiplied by their frequency \((v)\), the equation being \(E = nhv\). This first step led to the quantum theory, and it was the first indication that classical Newtonian physics could no longer explain everything; an altogether new form of physics was required.

The photoelectric effect explained that the incident light that ejects electrons from atoms can be understood only if light consisted of quantized packets of energy \((hv)\), rather than as a continuous wave. Electrons are not ejected until a minimum amount of light energy (threshold frequency) is reached, and the number of electrons ejected depends on how many light photons were involved (intensity). The maximum kinetic energy of the ejected electron \((K_{\text{max}})\) is determined by Planck’s constant \((h)\) multiplied by the frequency of the incident photon \((v)\) minus the threshold frequency \((v_0)\), that is, \(K_{\text{max}} = h(v - v_0)\).

The photoelectric effect explains one way x-rays interact with human tissue and how technical radiographic settings work. When preparing to take a radiograph, setting the kilovoltage potential determines the energy of the x-ray beam and penetration, and setting the milliamperes determines exposure and exposure time. Both kilovoltage and milliamperes contribute to image quality and contrast. Therefore, understanding the nature of light is key to producing radiographs of diagnostic quality.

**The Speed of Light**

Other types of waves require a static medium. Sonar, for example, requires water, and sound requires air. It was once believed that light waves required a medium of “ether,” which was invisible and undetectable. The concept of ether was highly problematic because it meant there was an absolute reference in the universe: an invisible “stage” for all interaction. This concept of absolute reference was rejected long ago by Galileo and later by Ernst Mach; both said that all motion is relative and...
cannot be detected unless referenced by an outside point of view. In a break from classic Newtonian physics in which velocities are summed or subtracted, Einstein theorized that light coming from (or observed by) a moving traveler has the same velocity from any reference point, an idea confirmed by the Michelson-Morley experiment in 1887. Einstein once said, “For the rest of my life I will reflect on what light is” (see Figure 2).

The constant speed of light changed the way the universe was perceived. Not only could the all-permeating ether finally be discarded, but the measurements once thought to be the concrete foundations of Newtonian physics (time, distance, and mass) were now subject to change. Einstein’s relativity makes the science fiction adventures of galaxy-hopping space travel in Star Trek and Star Wars a mere fantasy. The vast distances and the universal speed limit of light make intergalactic travel too impractical. If a hypothetical space craft approaches the speed of light, time slows, length compresses, the mass of the space craft increases, and impossibly high amounts of energy are required. At a certain point, the space craft stops accelerating, despite greater energy input.

A result of Einstein’s special theory of relativity has been called the most famous equation in all of science: energy (E) equals mass (m) multiplied by the speed of light squared (c^2), that is E = mc^2. This simple equation, which states that energy and mass are interchangeable quantities, often is misinterpreted as the formula of the atomic bomb. The principle of the atomic bomb is bombardment of a uranium atom with a neutron that splits the uranium atom into 2 smaller atoms and more neutrons that trigger a fission chain reaction. Although tremendous energy is released, it is the energy of internuclear binding forces, and there is no appreciable change in mass.

A much better demonstration of E = mc^2 is in explaining the physics of the positron emission tomography scanner, in which a positron and electron annihilate each other and convert their masses into pure light energy, consisting of photons traveling in opposite directions. This light is detected and calculated as a 3-D image of the patient. Although most radiologic technologists do not think about the relativity theory in their daily practice, it is the foundation of some radiologic images.

Einstein expanded his ideas with his general theory of relativity, which explained the phenomenon of gravity as a distortion of the space-time continuum and predicted monstrous black holes where gravity is so great even light cannot escape. Relativity explains the tiniest and the most immense objects in the universe.

**Niels Bohr**

The model of the atom proposed by Bohr explained Planck’s quanta of energy emission and Einstein’s photoelectric effect but, in doing so, rejected the Newtonian model of the atom. The Rutherford model of electrons orbiting the central nucleus was inadequate because a charged particle changing direction in an orbit would lose energy and fall into the nucleus. Bohr’s model had to explain atomic light interaction, chemical reactions, and the inherent stability of atoms. A carbon atom can undergo countless chemical reactions yet remains a
carbon atom. As Bohr further investigated the atom, the idea of separate properties of light being a wave and electrons being particles was no longer valid. With the photoelectric effect, Einstein showed that light could be a photon particle. Louis de Broglie then showed that particles could be waves. Both photons and electrons had a particle-wave duality. The electron therefore could exist as a standing wave around the nucleus, absorb and emit quanta of light energy, and yet remain stable. The paradoxes that resulted from Bohr’s quantum theory altered the foundations of science.

The archetypical test of the quantum theory is a simple demonstration with light. According to Feynman, the classic double-slit experiment:

\[
\text{has in it the heart of quantum mechanics. In reality, it contains the only mystery. We cannot make the mystery go away by 'explaining' how it works...In telling you how it works we will have told you about the basic peculiarities of all quantum mechanics.}
\]

With the double-slit experiment, if photons are shot through a single slit toward a screen, they create an expected diffraction pattern. If the photons are then shot through 2 parallel slits, they create an interference pattern as the peaks and troughs of the light waves cancel or build on each other. However, if the photons are shot only one at a time, they create an interference pattern as if the one photon simultaneously went through both slits.

The same experiment can be performed by shooting electrons (or other particles). With one slit open, a line of particles is detected on the screen. With two slits open, the electrons show an interference pattern. If both slits are kept open and a detector that can see which slit the electron passes through is introduced, the interference wave pattern collapses and 2 lines appear on the screen. The mere act of observation somehow alters the experiment.

Instead of fighting the contradictions that arose in his work, Bohr embraced them as an indication that he was getting closer to the truth. His atomic model has since been superseded by more refined theories based on his ideas of complementarity. When he was to be rewarded the Order of the Elephant by the Danish king, Niels Bohr designed his own coat of arms that included the yin-yang symbol and the Latin motto, *contraria sunt complemerta*, which means “opposites are complementary.”

**Figure 3.** Artist’s conception of atomic probability waves. At the subatomic level, measurements become fuzzy and experiment design changes the results. Fractal art by Eric A Gehlin of Schaumburg, IL. Reprinted with permission from the artist.

**Werner Heisenberg**

Heisenberg found that the method of investigation alters the result of an experiment. He explained this idea mathematically in his *uncertainty principle*, which remains a major tenet of quantum mechanics. The light used to measure particles imparts energy, altering the momentum or location of the particles, thus changing the results by the mere act of observation. An experiment can be designed to measure momentum or location precisely, but not both (the experimenter has to choose). Although this finding was unsettling for physicists who strive for precise measurements, at the atomic and subatomic levels, precision was impossible (see Figure 3). According to Heisenberg:

\[
The violent reaction on the recent development of modern physics can only be understood when one realizes that here the foundations of physics have started moving; and that this motion has caused the feeling that the ground would be cut from science.\]
Einstein could not accept the imprecision of quantum mechanics for philosophical reasons, believing that it had to be incomplete. He spent many of his later years trying to find a grand unification theory that would improve upon quantum mechanics. Max Planck also had doubts about quantum theory, even though his work started the quantum revolution in physics.

Although we should not infer the uncertainty principle to hedge on macroscopic radiologic findings, radiologic technologists often must trade between image resolution and patient dose, thereby affecting the observed results. In the practice of screening for early cancer and disease, the x-rays and injected contrast media might “alter the experiment,” thereby imparting their own health risks.

**Christian Doppler**

Doppler was a professor who studied mathematics, physics, and astronomy. He published a paper on spinning binary star systems, noting that starlight shifts to the violet spectrum when a star is moving toward an observer on Earth, and that starlight shifts to the red when a star is moving away. The explanation was that the wavelength of the light wave was compressed or elongated depending on the motion of the source relative to the observer. He applied this concept to sound waves and proved the same Doppler effect with a passing train that had on board a musical band playing a precise note. When the Doppler effect is applied to sound, it explains the tone of an approaching and departing train whistle; when applied to radar it predicts violent weather; when applied to ultrasound it determines the direction and velocity of blood flow; and when applied to distant starlight it explains our expanding (red shifted) universe (see Figure 4).

In radiology, the common use for the Doppler effect is with vascular ultrasonography. Using the Doppler effect, an ultrasonographer can evaluate and screen for the risk of stroke from carotid artery stenosis, renal arterial causes of hypertension, abdominal aortic aneurysms, peripheral vascular disease, deep vein thrombosis, portal vein thrombosis and varices, and postcatheterization pseudoaneurysms. Countless lives have been saved or improved because of a phenomenon originally seen in starlight.

A legacy from Doppler’s work is the continued use of red and blue to show direction, but common ultrasonography convention has the colors reversed, with red indicating blood flowing toward the transducer and blue indicating blood flowing away. That is probably because we associate red with being more immediate, when in fact light from a source going away is red shifted, with a longer wavelength and lower frequency.

Doppler’s idea extends well beyond the sonography suite and even tells us about the origins of our universe. Edwin Hubble demonstrated that all objects observed in deep space are found to have Doppler red-shifted velocity relative to Earth and to each other. This Doppler red-shifted velocity is proportional to the object’s distance from the Earth and all other interstellar bodies. This tells us that our universe is expanding and supports the theory that the universe was created by the Big Bang, which occurred about 13.7 billion years ago.

**Old Master Painters**

Artists such as Rembrandt and Vermeer were adept at depicting light to create realistic 3-D images on 2-D canvases. These artists studied the interaction of light with their models and understood the human perception of subtle shading and light to make their artwork dramatic and convincing. Rembrandt’s famous portraits and self-portraits displayed skill with light source
placement, later duplicated by movie director Cecil B DeMille who coined the term “Rembrandt lighting.” A primary light source was placed high at a 45° angle to the face to best show high-contrast lighting and facial geometry. A second half-dimmed light was placed at mid-height and at 45° on the opposite side to reveal subtle tones on the less-well-lit side of the face. If the lighting was placed successfully, the less-well-lit cheek and area under the eye would show interesting half tones. This lighting technique still is used today by portrait photographers (see Figure 5).

Vermeer was skilled at depicting subjects in naturally lit interiors with a subtle photorealistic style that is considered uncanny even today. Some believe Vermeer used special optics and mirrors because much of his lighting was too subtle for the naked eye to detect. For example, scientific analysis showed that his backgrounds depicted the inverse square law, with an exponential diffusion of light, which is difficult to capture when using only the artistic eye.

Experienced technologists use artistic vision when they create radiographs. By positioning and framing their subjects and by adjusting contrast and exposure, each image can be a work of art that not only is pleasing to the eye but also contains a wealth of diagnostic information (see Figure 6).

Light, as visual information, is portrayed in art. Light also is the medium for medical imaging, whether in the form of a backlit film, cathode ray tube monitor, liquid crystal display screen, or plasma monitor. The eye is our most complex and highly evolved sense organ, capable of detecting subtle changes in light and color, and transferring this information (via the optic nerves and optic tracts) to the visual cortex of our occipital lobes. However, what distinguishes artists and seasoned radiology professionals from other people is postprocessing (ie, the thinking that occurs after perceiving that visual data). Much of science and medicine is about logic, language, analysis, and categorization (left brain functions). However, visual processing (the artistic eye) is about conceptualization, spatial orientation, and pattern recognition (right brain functions). These

Figure 5. Self-Portrait (1669) is an oil on canvas by Rembrandt, on display at the Mauritshuis museum in The Hague. Rembrandt was a master of lighting, shadow, color, and form. Public domain image.

Figure 6. The Art of Painting (1668) is an oil on canvas by Vermeer, on display at the Kunsthistorisches Museum in Vienna, Austria. The background wall demonstrates the inverse square law of light diffusion. This painting had special meaning to the artist and remained in his personal collection. Public domain image.
right-brain skills are hard to teach and measure but are important in radiology.

With the rapid increases in digital image resolution and in the number of multiplanar images involved with each case, developing the right brain is crucial to make sense of this visual information overload, especially when the radiologist formulates an educated opinion on volumes of visual data. Knowingly or unknowingly, a seasoned radiologist develops the right brain through the experience of viewing thousands of medical images. This “artistic eye” can be further enhanced in radiologists and radiologic technologists who study and can appreciate the techniques used by great artists. Or better yet, they can train their right brains by creating original art themselves.\(^{13}\)

**Conclusion**

Radiologists and radiologic technologists use light and artistic vision in their daily work. They sense subtle shades, recognize patterns, and use symmetry and balance to detect abnormalities. When this artistic skill is applied in combination with an appreciation for the underlying physics that creates the images, a thorough knowledge of human anatomy, and an understanding of the pathophysiology of disease, we can serve our patients by providing timely diagnoses and excellent medical care (see **Figure 7**).

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**Mark Hom, MD,** is assistant professor of radiology affiliated with the Virginia Commonwealth University Health System. He also practices interventional radiology at the Veterans Affairs Medical Center in Richmond. He earned his medical degree from the University of North Carolina at Chapel Hill where he illustrated the anatomy lab manual. Hom completed his residency in diagnostic radiology at the Medical College of Virginia in Richmond. More of Hom’s illustrations and theories appear in his book *The Science of Fitness: Power, Performance, and Endurance,* which he coauthored with Tour de France champion Greg LeMond.

**References**

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www.asrt.org/asrtatrsna
essential education
Case Study: Neuroglial Cyst

This axial T1-weighted magnetic resonance image shows a benign ependymal neuroglial cyst located along the left temporal lobe, medial to the temporal horn of the lateral ventricle. The patient presented with hemifacial spasm (facial tic). Although hemifacial spasm usually is caused by vascular compression of the root exit zone of a facial nerve, it also can be caused by compression from a cyst such as this one. This image appears in MR Basics: Module 11 – Pathology Part 1. Visit the ASRT Store, www.asrt.org/store, for more information.

Archive

Atomic Battery. The X-Ray Technician, September 1957.

An atomic battery the size of a cough drop has been developed which uses as its power source Promethium 147, a radioactive substance which will produce energy over a long period, at the same time requiring minimum shielding.

You Might Have Missed…

[Technologists] should not perpetuate the myth that seafood allergy correlates with iodine or radiopaque contrast allergy.

Turn to Page 623 for the full story.

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