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The *Journal of the American Osteopathic College of Radiology (JAOCR)* is designed to provide practical up-to-date reviews of critical topics in radiology for practicing radiologists and radiology trainees. Each quarterly issue covers a particular radiology subspecialty and is composed of high quality review articles and case reports that highlight differential diagnoses and important teaching points.

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I am pleased to introduce the Interventional Radiology edition of JAOCR. This issue was only possible due to the tireless dedication and mentorship of Dr. William O’Brien and the outstanding staff of the JAOCR. I hope the readers enjoy the issue as much as I do!

Interventional Radiology (IR) has grown exponentially over the last three decades. Interest in Interventional Radiology fellowships is at an all-time high. This is true despite the loss of many peripheral vascular disease procedures at most centers. A review of the recent IR literature suggests the increased interest in IR is in the treatment of patients with cancer and in those procedures related to Interventional Oncology. However, Interventional Radiologists have continued to forge important alliances with many other specialties including, but not limited to, Internal Medicine, Medical Oncology, Surgical Oncology, Radiation Oncology, Urology and Nephrology. The increasing multidisciplinary approach to patient care requires timely and crucial Radiology input. Expertise provided by both the Interventional and the Diagnostic Radiologist concerning Radiation Safety, Radiation Biology, and Radiation Protection ensures accurate and safe care for a vulnerable patient population.

Interventional Radiology continues to make significant advances in minimally invasive image-guided treatment of patients. Training in IR includes learning these new techniques as well as learning the peri-procedural management of patients. Even with these advances, considerable risk remains in regard to exposure to ionizing radiation for both the patient and the operator. This is particularly true in cases that require Interventional fluoroscopy. In this issue, Dr. Gary Arbique and his colleagues share an insightful article that will help all radiologists understand and manage the radiologic Sentinel Event as defined by The Joint Commission.

The role of the Diagnostic Radiologist in making the rapid and accurate diagnosis of venous thromboembolic disease (VTE) is critical in treatment planning for this potentially life-threatening disease. Included in this issue is an excellent review article on VTE presented by Dr. Jessica Weber.

Additionally, a case report of post-chemoembolization hemorrhage discovered on routine surveillance imaging is presented by Dr. Stephen Reis and Dr. Takeshi Yokoo. This article includes an important review of various potential complications encountered after trans-arterial chemoembolization that the Diagnostic Radiologist may need to resolve.

Finally, Dr. Timothy Morgan and Dr. Lee Pride as well as Dr. Benjamin Atchie submit two pertinent Viewbox cases in the field of Interventional Neuroradiology. The Interventional techniques presented include catheter-based coil embolization of a carotid-cavernous fistula and treatment of refractory epistaxis with a liquid embolic agent.

Many thanks again to Dr. William O’Brien and the JAOCR staff for making this issue a reality.
Introduction

Venous thromboembolic disease is a major cause of morbidity and mortality worldwide and is comprised of two main conditions: deep vein thrombosis (DVT) and pulmonary embolism (PE). Its exact incidence is uncertain, but the incidence of first time venous thromboembolism (VTE) in the United States is estimated at approximately 100 persons per 100,000 each year.\(^1\) Multiple factors result in increased incidence of VTE, including advanced age, race (higher prevalence in Caucasians and African Americans), and presence of risk factors, such as cancer, surgery, trauma, inherited thrombophilic states, and immobilization. Approximately 25-50\% of cases are considered idiopathic, 15-25\% are associated with cancer, and approximately 20\% occur after surgery. The 30-day incidence of death after treated VTE is approximately 6\% for DVT and 12\% for PE.\(^1\) Pulmonary embolism can occur in 50\% to 60\% of patients with untreated DVT with an associated mortality rate of 25\% to 30\%.\(^2\) Clinical diagnosis of VTE can be difficult and unreliable as presenting symptoms can be caused by a multitude of other etiologies. Once diagnosed, treatment decisions are based on the location and extent of disease, severity of symptoms, physiologic sequelae, and underlying risk factors. Diagnostic and interventional radiologists play crucial roles in the diagnosis and management of VTE.

Diagnosis

Appropriate clinical and laboratory evaluations, including physical examination with pretest probability scoring systems such as Wells/Modified Wells Criteria (Table 1) and D-dimer assay, before imaging evaluation can help reduce the number of negative imaging studies.\(^2,3\)

The historic gold standard for imaging diagnosis of both lower and upper extremity deep vein thrombosis is contrast venography. However, this modality has been replaced with other modalities and is now primarily reserved for instances where non-invasive studies are inconclusive, for patients with more complex presentations (e.g., patients with suspected acute on chronic DVT), and for patients undergoing endovascular intervention. Ultrasound is the modality of choice for the imaging diagnosis of both proximal upper and lower extremity deep vein thrombosis.\(^2,4\) (Fig. 1). Advantages of ultrasound include a high sensitivity and specificity for diagnosing proximal DVT, reliability for serial evaluation, ability to be performed bedside, cost effectiveness, and lack of exposure to ionizing radiation. Ultrasound has been found to have lower sensitivity for diagnosing calf vein/distal DVT in the extremities, however.\(^2\)

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<td>Tachycardia</td>
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<td>Immobilization (&gt;3days) or surgery in the last 4 weeks</td>
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Diagnostic criteria for direct evidence of thrombus are loss of compression and visualization of intraluminal filling defect on gray scale imaging, which is usually expansile and may be hypoechoic or echogenic (Fig. 1). These primary findings are combined with color Doppler imaging and augmentation with duplex (if no thrombus is visualized), which provide indirect evidence of thrombus. In the upper extremity, compression can be used for the jugular, axillary, basilic, cephalic, and brachial veins. Although Doppler interrogation of the subclavian vein can be performed, the examination is limited due to osseous structures obscuring the vasculature and preventing use of compression.

Computed tomography venography (CTV) is another noninvasive alternative to diagnose DVT. A main advantage of CTV is the ability to perform a comprehensive evaluation of proximal lower extremity DVT, as well as PE when combined with CT pulmonary angiography (CTPA). Both CTPA and CTV can be accomplished with the same bolus of contrast agent, first by imaging the opacified pulmonary arteries 20-25 seconds after contrast injection, followed by venous imaging from the knees to the diaphragm 2-4 minutes later (Fig. 2). Additional advantages include the ability to identify sources of extrinsic venous compression as an underlying cause of DVT (Fig. 3) and to evaluate for extravascular causes of the patient’s symptoms which may mimic VTE. CTV disadvantages include patient exposure to ionizing radiation and iodinated contrast media. Recent literature indicates that CTV has a sensitivity and specificity similar to Doppler ultrasound; however, there is little evidence to support the routine use of CTV outside of a work-up for PE and proximal DVT.

Magnetic resonance venography can also be used for evaluation of the central veins of the chest, the pelvic veins, and veins of the thigh when ultrasound is non-diagnostic. Approaches included black-blood and flow-based or contrast-enhanced bright blood techniques.

Although catheter angiography is considered the gold standard for diagnosis of pulmonary embolism, it has been replaced by CTPA as the test of choice and standard of care for the diagnosis of PE. Detection of pulmonary emboli to the level of the subsegmental arteries using thin-slice multidetector CTPA has been found in recent studies to have a sensitivity of 96%-100% and a specificity of 89%-98%. Emboli present as filling defects within the pulmonary arterial system when an adequate contrast bolus is achieved (Fig. 4). Radionuclide ventilation/perfusion scans are an alternative if CTPA is contraindicated or results are inconclusive. Posterior-anterior (PA) and lateral chest
radiographs are an important component of the study to exclude other causes of chest pain or shortness of breath and is required for accurate interpretation of abnormal radionuclide ventilation/perfusion scans.

Special attention should be given to assess for VTE on routine oncologic staging CT examinations, since there is a higher incidence and prevalence of VTE in this patient population. Prevalence of unsuspected VTE in oncology patients has been found to be 6.3% and is more common in inpatients and those with advanced disease. Many cases of VTE are unfortunately not diagnosed in oncology patients, despite the known increase risk, which can prove fatal. Staging CT can provide an important diagnostic opportunity to evaluate the pulmonary arteries and/or deep venous structures for VTE (Fig. 5).

Management

The medical treatment of choice for non-life-threatening PE and proximal lower and upper extremity DVT is anticoagulation. Treatment of DVT reduces the risk of extension, PE and recurrent DVT. Anticoagulation is administered for a minimum of 3 months. The role of anticoagulation in DVT isolated to the deep calf veins (below the knees) remains controversial, as distal DVT rarely results in PE. Approximately one-sixth of patients with distal DVT will experience extension of thrombus above the knee; therefore, serial imaging assessment at 1 week is recommended to exclude proximal DVT extension if anticoagulation is not initiated.

Inferior vena cava (IVC) filters also play a role in the management of VTE in certain settings. In patients with VTE and contraindications to anticoagulation,
those who experienced a complication of anticoagulation, cases where adequate anticoagulation could not be achieved, or patients with recurrent embolus despite anticoagulation, IVC filters are considered an absolute indication. Proposed relative indications for IVC filters include prophylactic use in patients with major trauma; those undergoing hip or knee replacement with compromised cardiopulmonary reserve; pregnant women with DVT; burn patients; patients undergoing thrombectomy, embolectomy, or thrombolysis; and in patients with free-floating iliofemoral thrombus. Other prophylactic use is considered controversial.

Suprarenal IVC filter placement may be considered in the setting of an absolute indication for filter placement and thrombus extending above a previously placed infrarenal filter (Fig. 6), when thrombus in the infrarenal IVC precludes normal filter placement, during pregnancy, in cases of gonadal vein thrombus, and in the presence of certain anatomic variants. Filters can be placed in the superior vena cava (SVC), but there are no filters specifically designed or approved for this location; therefore, use of current filters in the SVC is considered off-label. Retrieval filters should be removed when initial indications no longer exist or contraindications to anticoagulation have resolved.

Anticoagulation is effective in decreasing the risk of PE and propagation of DVT but has no direct effect on lysis of thrombus. Venous valves can become damaged by the presence of thrombus in as little as a few weeks, thereby rendering them dysfunctional. This can lead to recurrent VTE and post-thrombotic syndrome (PTS). PTS is characterized by edema, heaviness, stasis dermatitis, hyperpigmentation, chronic leg pain, and ulceration, which can result in decreased quality of life, disability, and even limb loss. Severe PTS is reported in 50% of cases of proximal DVT, and leg ulceration can occur in up to 10%. An uncommon but serious complication of DVT is phlegmasia cerulea dolens. This entity is characterized by extensive DVT that results in massive swelling and cyanosis of the limb. Limb loss is a common consequence of phlegmasia cerulea dolens and associated mortality is high.

Primary treatment of acute proximal DVT for threatened limbs or to prevent the development of PTS include endovascular interventions performed by interventional radiologists and surgical thrombectomy. Surgical thrombectomy is not widely performed due to the availability and success of nonsurgical options. Current endovascular options are catheter-directed thrombolysis (CDT), percutaneous mechanical thrombectomy (PMT), and pharmacomechanical thrombolysis (a combination pharmacologic thrombolysis and PMT). For CDT, an infusion catheter and/or wire are placed through the thrombosed vein and a pharmacologic thrombolytic
VTE, Weber

agent is delivered into the thrombus for a period of 8-24 hours. The patient then returns for follow-up venography, which can be followed by additional CDT (sometimes up to 72 hours), PMT, angioplasty, and/or stent placement depending on angiographic findings and underlying cause for thrombosis. PMT refers to the use of percutaneous catheter-based devices, which mechanically remove thrombus by microscopic fragmentation, maceration, and/or aspiration. The American Heart Association recommends CDT as first-line therapy to reduce PTS in patients with low bleeding risk (level IIA/B). The Society of Interventional Radiology considers the following as indications for CDT in appropriately selected patients: phlegmasia cerulea dolens with low to moderate bleeding risk and any life expectancy, acute/subacute IVC thrombosis in patients with low to moderate bleeding risk and any life expectancy, and acute/subacute/chronic proximal DVT in patients with low bleeding risk and long life expectancy. General contraindications to CDT include any patient with a hemorrhagic disorder, an anatomic lesion that is prone to bleeding, or an absolute contraindication to anticoagulation therapy. Risk of major bleeding with CDT is approximately 8%. With regards to PTS, conclusive evidence for the use of catheter based techniques has not been established despite multiple studies that support the benefit of adding CDT to anticoagulation for treatment of proximal DVT. However, data from the ATTRACT study, an ongoing multicenter, randomized, controlled clinical trial designed to determine if the use of pharmacomechanical catheter-directed thrombolysis reduces the occurrence of PTS over the 2-year follow-up period, will help clarify its role. For now, use of CDT has been shown to significantly reduce pain and swelling and promotes a higher rate of restored venous function. Addition of graduated compression stockings for 2 years has been shown to significantly reduce the incidence of PTS.

Treatment of PE is based on risk stratification. Patients with acute PE with sustained systemic hypotension (systolic blood pressure < 90 mmHg), cardiogenic shock, or need for cardiopulmonary resuscitation are defined as high risk of having massive PE. Intermediate risk or submassive PE is defined as evidence of right ventricular dysfunction on echocardiography or elevated cardiac biomarkers, but with preserved systolic pressure. Patients with acute PE whose systolic pressure is preserved and echocardiography and cardiac biomarkers are negative are considered to have low risk PE; these patients are treated with anticoagulation. Current recommendations by the American Heart Association (AHA) suggest systemic fibrinolysis in massive PE and in submassive PE if bleeding risk is low. The AHA recommendations suggest surgical embolectomy or catheter-based intervention if systemic fibrinolysis is contraindicated or if urgent recanalization is indicated at an experienced center. The American College of Chest Physicians Evidence-Based Clinical Practice Guidelines state similar recommendations. Catheter-based treatment includes CDT and/or mechanical techniques, such as mechanical thrombus fragmentation and rheolytic, suction, or rotational thrombectomy. Ultrasound accelerated thrombolysis can be used in conjunction with CDT and aids in fibrinolysis and increased penetration of the thrombolytic agent in the thrombus.

Conclusion

Interventional and diagnostic radiologists play key roles in the diagnosis and management of VTE. Multiple imaging modalities are available for the diagnosis of VTE, but ultrasound and CT pulmonary angiography are the standards of care for imaging diagnosis of proximal DVT and PE, respectively. Accurate diagnosis of VTE is critical in treatment planning. The treatment of choice for non-life-threatening PE and proximal extremity DVT is anticoagulation. Catheter-directed therapy for DVT and PE is employed for mechanical and/or pharmacologic thrombolysis in specified clinical settings.
References


Introduction

In 2005, the Joint Commission established a new reviewable sentinel event tied to radiation exposure. This event targets both radiotherapy and fluoroscopy doses that can result in serious patient injury. The fluoroscopic component addresses prolonged fluoroscopy procedures that result in peak skin doses greater than 15 Gy. This new event requires institutions to identify and investigate patient radiation exposures that potentially meet this criterion. Currently, fluoroscopic equipment offers no direct measure of peak skin dose; thus, an investigation is required to collect the necessary information for a dose calculation. This calculation is neither trivial nor straightforward and can require significant effort by the medical physicist. The purpose of this article is to provide a framework for detecting potential fluoroscopic sentinel events and calculating the associated patient skin dose.

Sentinel Events

What is a Joint Commission Sentinel Event?

The Joint Commission considers a sentinel event to be an unexpected occurrence involving the risk or actuality of death or serious injury to a patient. The Joint Commission employs sentinel events to signal the need for immediate investigation and response by the accredited health organization. Sentinel events and medical errors are not the same; a sentinel event may not be the result of an error, and an error may not cause a sentinel event.

Although each hospital is expected to identify and define sentinel events pertinent to its particular environment, the Joint Commission specifically defines 10 types of events to be reviewable. Examples include incidents in which patients suffer abduction, rape, suicide, surgery on the wrong body part, or incompatible blood transfusions. The fluoroscopic event discussed here is the newest reviewable event.

What is the Fluoroscopic Sentinel Event?

In 2005, the Joint Commission added the following reviewable sentinel event:

“Prolonged fluoroscopy with cumulative dose >1500 rads to a single field or any delivery of radiotherapy to the wrong body region or >25% above the planned radiotherapy dose.”

The 15 Gy (i.e., 1500 rad) fluoroscopic aspect of this sentinel event is intended to address skin injuries, such as serious burns or necrosis resulting from high levels of radiation delivered during fluoroscopy procedures.

The term “cumulative dose” used by the Joint Commission in reference to fluoroscopy differs from the standard usage in clinical medical physics. Technically, cumulative dose refers to the integrated reference-point air-kerma that must be displayed by modern fluoroscopy devices during a procedure. In reference to the fluoroscopic sentinel event (FSE), the Joint Commission has provided guidance for their meaning of cumulative dose in an on-line set of frequently asked questions. Cumulative dose as used by the Joint Commission is the peak radiation dose delivered to the patient’s skin. Furthermore, it is made clear that cumulative dose to the Joint Commission refers neither to a single procedure nor to a lifetime acquired dose, but that "monitoring cumulative dose over a period of six months to a year would be reasonable." The selection of the specific monitoring time window is left up to the institution.

There are practical consequences of the Joint Commission definition of cumulative dose. Direct measurements of skin dose are not normally available. Therefore, a medical physicist must estimate the cumulative peak skin dose (PSD) using exam data, such as operating parameters, procedure notes, and recorded images. These calculations must assess the
highest dose delivered to any part of the patient’s skin over all the fluoroscopic procedures performed within the institution’s selected time window. Monitoring dose over a time window raises questions on how to deal with multiple procedures within a single institution or across multiple institutions. Obtaining information from outside institutions is very problematic, particularly if several months have elapsed. Solution of this problem awaits widespread implementation of portable electronic records.

Rationale for a Fluoroscopic Sentinel Event.

Radiation injuries to living organisms are related to dose and can be divided into two broad classes: deterministic and stochastic. The fluoroscopic sentinel event addresses deterministic injuries, in particular cutaneous radiation injury (CRI). Deterministic radiation injuries occur above a threshold dose level, and the severity of the injury worsens as dose is increased above that level. CRI effects such as erythema and epilation can be observed when x-ray skin doses exceed 2 Gy, and severe wounds can be expected for dose levels above 10 Gy. However, there is wide variability in the occurrence, progression, and severity of CRI from patient to patient.

Most diagnostic fluoroscopy procedures are of short duration, and the skin doses received by patients are well below CRI threshold levels. However, fluoroscopically-guided interventional (FGI) procedures may require the prolonged use of fluoroscopy. Complex FGI procedures can result in PSD levels high enough to cause CRI.

Responding to a Sentinel Event.

When a sentinel event has occurred, the Joint Commission requires an institution to conduct a timely and thorough root cause analysis (RCA). The RCA must occur within 45 days of the event or the date at which the institution became aware of the event. An RCA focuses on hospital processes, not on assigning blame or assessing individual performance. The aim of an RCA is to identify strategies to prevent similar sentinel events from occurring in the future. The institution must implement and monitor the effectiveness of improvements specified during the RCA.

Reporting Sentinel Events.

The Joint Commission encourages, but does not require, that an institution notify the Joint Commission when a sentinel event occurs and an RCA has been held. If the institution does not notify the Joint Commission, then it must be prepared to provide the RCA report at any time the Commission requests it (e.g., at the next Joint Commission inspection). Failure to pursue an adequate and timely RCA and produce an action plan could result in loss of accreditation.

Strategies for Detecting Sentinel Events

Direct and comprehensive skin dose measurements are rarely available real-time in the clinical setting. Therefore, the cumulative PSD of interest to the Joint Commission is not available to physicians or technologists at the completion of a procedure. Currently, PSD evaluations require investigation and calculation by a medical physicist on a case-by-case basis, and they cannot be performed for every procedure. To efficiently identify potential FSEs requiring detailed evaluation, it is necessary to establish monitoring procedures using PSD indicators that the technical staff can directly access or record at the time of the procedure.

Available Fluoroscopy System Dose Indicators.

The most common dose indicators found on fluoroscopic equipment are reference point air-kerma \( (K_{a,r}) \), air-kerma area product \( (P_{KA}) \), fluoroscopy time, and number of angiographic frames. As illustrated in Fig. 1, \( K_{a,r} \) and \( P_{KA} \) are measures of radiation output. \( K_{a,r} \) is air-kerma at a reference point along the beam axis of a fluoroscope. \( P_{KA} \) is a less direct dose indicator, since it must be divided by beam area to yield air-kerma at a position on the beam axis. Fluoroscopy times and angiographic frame counts are the least useful dose indicators, since they do not account for variations in output radiation that occur with different operating factors and patient size. On older machines, fluoroscopy time may be the only available indicator.

Displays of the \( K_{a,r} \) delivery rate and the cumulative \( K_{a,r} \) value have been an FDA requirement on fluoroscopy equipment since 2006. \( K_{a,r} \) reference points are defined depending on the fluoroscope type.
and are intended to reflect the incident air-kerma at the patient under typical operating conditions. Fluoroscopy systems designed for FGI procedures feature isocentric c-arm gantries. This design facilitates changing view angles without having to adjust table position for anatomy positioned at isocenter. As illustrated in Fig. 2, the FDA recommended reference point on isocentric c-arm systems is 15 cm toward the focal spot from isocenter, a position commonly known as the interventional reference point (IRP). It is important to note that cumulative $K_{a,r}$ is not the patient PSD. $K_{a,r}$ does not account for the actual position of the patient’s skin with respect to the IRP, for dose spreading on the patient due to changes in geometry (i.e., view angle and table position), for attenuation by patient support fixtures, or for correction factors required to convert air-kerma to skin tissue dose. Nevertheless, of the commonly available dose indicators, cumulative $K_{a,r}$ exhibits the best correlation with PSD, and the NCRP recommends using it for monitoring deterministic CRI effects.

Selecting Investigative Thresholds.

Each institution must select threshold levels for dose indicators at which investigations will be triggered. The number of threshold indicators will depend on the quality of dose information available from the fluoroscopy systems in use. If cumulative $K_{a,r}$ is available, it should be used as the investigation trigger; if older fluoroscopy systems are used, a fluoroscopy time trigger may also be necessary. Regardless, trigger thresholds should be low enough to catch all real events but high enough to avoid unnecessary physics evaluations.

Published data from the RAD-IR study of interventional procedures can be used to establish trigger levels. In Part 2 of the study, PSDs estimated with a commercial software application were compared to cumulative $K_{a,r}$ and a mean ratio of PSD to cumulative $K_{a,r}$ of about 0.4 was found. However, ratios up to 2.8 were observed for some types of procedures, suggesting that a threshold value of about 6000 mGy for cumulative $K_{a,r}$ could capture all
Alternatively, NRCP Report 168 recommends the use of substantial radiation dose levels (SRDL) for the purposes of overall procedure dose monitoring and post-procedure patient management. SRDL values for $K_{a,r}$, $P_{K_A}$, and fluoroscopy time of 5000 mGy, 500 Gy-cm², and 60 minutes, respectively, are given as levels at which substantial risk of cutaneous injury may exist. If trigger levels are required for $P_{K_A}$ or fluoroscopy time, ratios between the SRDL values can be used to calculate thresholds consistent with the chosen cumulative $K_{a,r}$. Site experience and additional sources of published literature may allow refinement of the initial values, depending on the nature of the practice and procedure types performed.

Special considerations may be required on biplane fluoroscopes to account for possible overlap of the frontal and lateral radiation fields. A simple, conservative remedy for the purpose of triggering a dose investigation is to add dose indicator values from each plane for comparison with the corresponding threshold.

**Tracking Multiple Procedures.**

Tracking of multiple procedures over time requires that a cumulative record of patient dose indicators be maintained. Most current radiology information systems do not yet offer this capability, so a custom database solution may be necessary. Additionally, not all fluoroscopic procedures have a significant potential for large skin doses and may not need to be tracked. A practical approach is to track cases in areas that have significant potential for large skin doses, such as FGI procedures performed in neuro-angio, cardiac catheterization, and electrophysiology labs.

**Policies.**

An overall policy for detecting and investigating fluoroscopic sentinel events should be developed and implemented by each institution. One possible scheme is shown in Fig. 3. If information on prior exposures is available from the tracking database, the technologists or nursing staff should notify the physician of previous fluoroscopy time or cumulative $K_{a,r}$ for the patient before beginning the procedure. Once the fluoroscopic procedure has started, the physician should be appraised of dose indicator levels during the case. The physician may then choose to implement extra dose control actions, such as using lower dose modes and changing c-arm angle. In teaching hospitals, the attending may need to take direct control of the procedure if the threshold is approached.

After the procedure, the dose tracking database is updated and the cumulative record of dose indicators is evaluated to determine if an investigative threshold were passed. If a threshold limit is exceeded, the
Radiation Safety Officer (RSO) should be notified and an entry made in the hospital event recording system. A defined staff member should be made responsible for all these notifications. All original data for the case should be write-protected on the modality console and preserved until the physics investigation is complete. In the example policy, the RSO notifies the medical physicist that a dose evaluation is required. The results of the investigation are reported back to hospital administration through a defined path. If the physicist determines that the Joint Commission limit on cumulative PSD (15 Gy) has been exceeded, an RCA is held.

**Evaluating Patient Peak Skin Dose**

In an FSE investigation, the organ of interest is the skin, and the dose quantity of interest is the PSD. PSD can be estimated from dose indicators using published regression formulas for similar FGI procedures. However, this method is not patient specific and does not account for circumstances which may contribute to higher than expected doses. A patient specific PSD should be estimated by a medical physicist using information for each procedure involved in the investigation.

**Fig. 4** shows the general steps involved in producing a patient-specific PSD for an FSE investigation. A dose delivery timeline detailing c-arm orientation, table positioning, and operating factors is assembled to allow a skin dose map for each procedure to be constructed. A cumulative skin dose map is made by summing the dose distributions from all procedures. Currently, the primary recorded information available for producing skin dose maps is limited to cumulative air kerma indicators and a set of recorded acquisitions (e.g., DA, DSA, or rotational “runs”) with their associated technical factors available.
in DICOM format. The challenge for the physicist is to reconstruct skin dose maps from this limited information.

**Collecting Information.**

The information required for a PSD calculation is usually incomplete and must be collected from different sources (Fig. 5). The best source of electronically recorded information is most often the modality device, where dose indicator information, logged notes, original images, and other critical information can be accessed. Since storage capacity is usually limited on modality devices, staff should be advised to protect any information associated with an investigation.

Currently, the most important information for a PSD calculation in conjunction with $K_{a,r}$ is the set of acquired images in DICOM format.\(^{14}\) On interventional systems, angiographic acquisitions (e.g., DA, DSA, or rotational “runs”) are automatically saved.\(^6\) Modern systems also provide the ability to store fluoroscopy images; however, storage space restrictions limit the number of images that can be saved. At a minimum, saved images will show patient position, anatomy imaged, and field size. In addition, DICOM image files contain useful dose and geometry related information (Fig. 6). The best source for DICOM images is on the modality itself, since not all acquisitions may be sent to a PACS for long-term storage and some PACS exclude or modify DICOM information. However, the PACS should always be checked for previous procedures. The DICOM standard also supports structured dose reports.\(^{15}\) If available, these reports are another valuable source of information for fluoroscopic and angiographic doses.

A physical inspection of the fluoroscopic equipment should be performed. The inspection should verify the $K_{a,r}$ calibrations, associated reference location, and other pertinent operating parameters. Phantom-based dosimetry may be necessary to construct a dose-

**Figure 5.** A variety of information is required for a fluoroscopy procedure PSD evaluation. Sources of information include the modality, PACS, staff interviews, procedure notes (in either written or electronic form), and procedure image sets.
images provide the most information and require the least number of calculations and assumptions. In the best case scenario, the DICOM dose information associated with a run includes the preceding fluoroscopy dose, and the timeline is directly available. In cases where run dose does not include fluoroscopy, the total fluoroscopy dose can be calculated from the difference of the cumulative dose and the summed run doses. If the run DICOM dose is not available, it can be calculated based on DICOM technique factors, number of frames, and tube output measurements. In the worst case scenario, fluoroscopy dose must be estimated based on fluoroscopy time and phantom measurements using typical dose modes after the run doses have been calculated.

Regardless of the information available, assumptions must be made to assign fluoroscopy dose to the timeline. In all cases, an inherent assumption is that fluoroscopy was performed at the same c-arm angles and beam sizing as angiographic runs. Absent any specific timing information of fluoroscopy dose, additional assumptions to apportion the cumulative fluoroscopy dose along the timeline are required. A

**Dose Delivery Timeline.**

As shown in Fig. 7, the methodology for reconstructing a dose delivery timeline at a reference position varies depending upon the available information. Systems with a dose meter and saved run

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**DICOM Tag Data Sample**

<table>
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<tr>
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</tbody>
</table>
reasonable approach could divide the fluoroscopy dose between runs with weighting determined by the dose-rate for each associated run. The weighting scheme could also be refined to limit fluoroscopy dose between runs to that possible given the calculated fluoroscopy-rate and the time between runs.

Patient Skin Dose Map.

Standard organ dose calculations estimate tissue dose based on kerma in free-air at a reference location relative to the tissue. If available, $K_{a,r}$ can be used as the basis of calculation; otherwise, phantom measurements are required to determine air-kerma levels. The calculation of skin dose from $K_{a,r}$ requires consideration of several factors:

1. **Geometry:**
   Reference positions are defined relative to the fluoroscope, not the patient. Projection to the exposed skin surface using inverse square law $(1/r^2)$ distance scaling, along with proper consideration of beam size and the orientation of the beam axis relative to the patient is required to calculate air-kerma at the patient’s skin.

2. **Dose conversion factors:**
   Correction factors for air-to-tissue dose conversion (f-factor) and a “backscatter factor” to account for scattered radiations from deeper in the body are required to convert air-kerma to tissue dose. Depending on beam size and beam quality, conversion corrections increase skin dose ~30-50% over free-air kerma at the skin surface.

3. **Attenuation:**
   The fluoroscopy table and padding attenuate the radiation beam. As illustrated in Fig. 8, attenuation corrections can be large enough to counterbalance dose conversion factors.

4. **Dose indicator error:**
   The FDA allowance for $K_{a,r}$ accuracy is +/- 35%. However, $K_{a,r}$ displays may be within 10% accuracy over a wide range of operating parameters.

   Consideration of these factors may be approached with varying degrees of sophistication ranging from a rough triage calculation to a complete skin dose map. For example, a triage may consist of an upper-limit calculation based on conservative assumptions that ignore dose spreading due to angulations (or separate beam angles on biplane...
systems). This simplified approach can save effort if the resulting conservative estimate is less than the sentinel event dose level.

Given that dose conversion factors and attenuation partially cancel one another, and that imaging geometries vary during procedures, a calibrated cumulative $K_{a,r}$ dose indicator on a isocentric c-arm system (Fig. 2) might be expected to be nearly equal to or overestimate PSD. However, abnormal circumstances during a procedure or improper operating practices can lead to PSDs larger than the cumulative $K_{a,r}$. Therefore, the cumulative $K_{a,r}$ must not be used as the sole indicator to rule out an FSE.

PSD Estimation and Uncertainty.

The uncertainty of a PSD calculation is difficult to quantify and can be large due to a number of compounding factors. Mapping fluoroscopy dose, in particular, is subject to large uncertainty because there are often no images to indicate where the dose was deposited. Varying the assumptions chosen regarding the fluoroscopy dose timeline can demonstrate this uncertainty range. Where possible, self-consistency checks should be applied to test the validity of fluoroscopy assumptions. For example, the time between runs will be well defined from the DICOM information and the fluoroscopic dose delivered in this time must be consistent with the dose rates expected for the equipment. Other factors which may not be well characterized—such as table movement, beam attenuation, or beam shaping filters—may also require multiple assumptions. Error contributions from machine-reported parameters can be relatively small (<10%), provided that the equipment is well characterized and that operational modes are known. Other small sources of uncertainty include the influence of beam quality, beam geometry, and body part shape on tissue and attenuation corrections.

If assumptions are consistently conservative, the net result will be to bias the PSD to higher values. In some cases, it may be possible to validate methods by the use of radiochromic film. In the absence of such validating data, the physicist must assign uncertainty to PSD estimates based on experience, particularly when near to the sentinel event threshold. Regardless, when fluoroscopic dose contributions predominate, the PSD estimate becomes more speculative in nature.

PSD Estimate Calculation Examples

To demonstrate calculation methodologies, three cases involving varying degrees of information are presented.

Case 1: Bi-Plane C-arm With Run Images and Fluoroscopy Time Available

An older man with a partially thrombosed giant anterior communicating artery aneurysm presented for endovascular treatment. A diagnostic cerebral angiogram and interventional coiling procedure was performed on a bi-plane c-arm system not equipped with a dose monitor. The procedure was complicated

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Figure 8. Broad-beam (10 cm x 10 cm) x-ray transmission at the patient support surface (table or pad as indicated) of an interventional fluoroscope as a function of tube voltage.

Patient table, padding, and c-arm orientation (Posterior-Anterior versus a 45° oblique c-arm orientation) strongly affect transmission. Transmission may also be affected by beam size and beam quality. Attenuation factors should be measured on the actual equipment used for a procedure.
by an arterial perforation, resulting in a cumulative fluoroscopy time of 154 minutes, which exceeded the investigational limit. Angiography comprised 22 frontal and lateral DSA runs (3 fps, ~20 frames each), and 1 rotational DSA run.

**Information Collection Highlights.**

Staff interviews revealed that not all images were sent to PACS. Therefore, run images were obtained directly from the modality. DICOM information provided technique factors and patient-to-source distance for each run. Visual inspection of the image sets provided table translation and patient positioning information. Since the cumulative fluoroscopy time reported was the total for the frontal and lateral C-arm planes, the interviews also provided the fluoroscopy time split between the frontal and lateral arms, as well as details of the procedure timeline. An inspection of the modality verified the operating modes and display parameter calibrations.

**Output Calibration.**

Measurements using an anatomical phantom (Fig. 9) were performed to obtain output exposure and technique factors for fluoroscopy and angiographic acquisitions. Air kerma at the phantom surface was determined for the frontal and lateral planes with the phantom positioned at isocenter for a range of operating parameters. Measurements included the effects of attenuation through the table and padding.

**Calculation Highlights.**

Based on the information collected, a simplified approach was used to estimate PSD:

C-arm angle variations were minor and imaging planes were close to perpendicular; therefore, maximum doses were calculated for the frontal and lateral fields instead of producing a dose map. Fluoroscopy time was split equally between the frontal and lateral planes and proportioned according to relative time gaps between runs. Fluoroscopy preceding each run was assumed to use the same positioning, geometry, magnification and collimation as the following DSA run. The DSA and rotational run air kerma measurements were scaled for patient position (1/r²) and technique factors (kVp², mAs). Fluoroscopy exposures were corrected for SID and positioning. A conservative dose correction factor was applied.

**Results.**

The sum of the PSD for frontal and lateral fields did not exceed 15 Gy (Table 1); therefore, a detailed consideration of frontal-lateral field overlap was not required to rule out the occurrence of an FSE.

**Recommendations.**

Fluoroscopy was performed at a default rate of 15 pulses per second (pps), so a recommendation was...
made to lower the default rate to 7.5 pps. Consistent with the National Council on Radiation Protection (NCRP) Report 168 recommendation that potentially high dose procedures be performed only on fluoroscopy systems equipped with K\textsubscript{a,r} monitors, a recommendation was made to upgrade the system with dose monitors.

**Case 2: Single-Plane C-arm Equipped With an Air-Kerma Monitor**

A middle-aged man with hyperlipidemia presented with exertional chest pain and a positive exercise tolerance test. A coronary angiogram and percutaneous revascularization procedure was performed using single plane fluoroscopy. The procedure was complicated by difficult catheterization and subsequent intracoronary thrombosis, resulting in complete occlusion of the left anterior descending (LAD) coronary artery and severe sustained coronary ischemia, which necessitated intubation with mechanical ventilation. The case cumulative K\textsubscript{a,r} was 16 Gy from 168 minutes of fluoroscopy and 53 angiographic run acquisitions (15 fps, ~38 frames each), which triggered a PSD investigation.

**Information Collection Highlights.**

Staff interviews provided information regarding fluoroscopy operation and timeline of the case. A modality inspection verified operating modes, air kerma meter calibration, and system geometry parameters. Public DICOM tag information for the runs included the kVp technique factors and image acquisition times. Because the contents of the tube current and dose-area-product tags were blank, x-ray output could not be calculated. Proprietary DICOM tags provided three dimensional table position.

**Output Calibration.**

Since only the run kVp technique factors were known, acrylic phantom measurements were performed to measure output air kerma for angiographic runs. Phantom thickness was varied to obtain dose dependence versus kVp for various magnification modes.

**Calculation Highlights.**

Assumptions and details of the calculation for this procedure included:

A complete skin dose map was generated for a plane corresponding to the posterior surface of a supine patient lying on the table pad. K\textsubscript{a,r} for each run was calculated based on phantom measurements. The total fluoroscopy dose was obtained by subtracting the sum of all run doses from the cumulative K\textsubscript{a,r}. Fluoroscopy K\textsubscript{a,r} was apportioned according to the relative time gaps between runs with consideration of the time spent intubating the patient. Fluoroscopy preceding each run was assumed to use the same positioning, geometry, magnification, and collimation as the following angiographic run. C-arm angulations and table position were included in the calculation on a frame-by-frame basis using DICOM information. Dose conversion and beam attenuation corrections were applied consistent with system geometry during each run.

**Results.**

Fig. 10 shows a map of the calculated skin dose at the patient’s back with a PSD of 9 Gy. In this case, the use of oblique views resulted in increased attenuation through the table and pad that numerically cancelled the increase in skin dose over K\textsubscript{a,r} due to the
backscatter and tissue conversion factors. Furthermore, using multiple angles spread the dose over non-overlapping entrance fields, and raising the table above the IRP decreased dose through $1/r^2$ reduction. The net result was a PSD estimate that was significantly lower than the $K_{a,r}$ value. The uncertainty in this estimate was high because fluoroscopy comprised ~70% of the dose, but the use of consistently conservative assumptions throughout the calculation provided a reasonable degree of confidence that the true PSD was less than 15 Gy.

**Recommendation.**

No operational recommendations were necessary, since best practice was used in a complicated case.

**Case 3: Multiple Studies on a Bi-plane C-Arm Equipped with Air-Kerma Monitors**

A middle-aged man with history of dural arteriovenous fistula underwent transvenous embolization of the fistula on a bi-plane c-arm system equipped with air-kerma monitors. The procedure was complicated by the tortuous and complex nature of the fistula. Fluoroscopy time and cumulative $K_{a,r}$ for the case exceeded the investigational limits, and a dose estimate calculation was performed.

**Information Collection Highlights.**

Cumulative $K_{a,r}$, $P_{Ka}$, and fluoroscopy time were available in the patient file on the modality. DICOM image sets provided run-by-run $P_{Ka}$ that included preceding fluoroscopic dose and patient-to-source distance information. Staff interviews provided information regarding fluoroscopy operation and supported timeline details deduced from the DICOM information.

**Output Calibration.**

The accuracies of the dose monitor and the patient-to-source distance DICOM parameter were verified.

**Calculation Highlights.**

DICOM dose information was given in the form of $P_{Ka}$; however, DICOM collimator setting information was not available. Visual verification of run images was used to determine the area factor for air-kerma calculations. It was assumed that fluoroscopy was delivered with the same geometry as the angiographic run that followed it.

**Results.**

Similar to Case 1, the PSD for the case did not exceed 15 Gy for the summed frontal and lateral planes. A more detailed modeling was performed to determine if frontal and lateral field overlap was a factor; the results indicated significant overlap due to the c-arm angles used during the procedure.

**Multiple Visits.**

Two months later, the patient returned for a second embolization procedure for the same fistula. Although the cumulative $K_{a,r}$ and fluoroscopy time for the second procedure did not exceed the institutional threshold, an investigation was triggered on the basis of the sum of the two exam cumulative $K_{a,r}$ values since the exams occurred within a 6 month window. The dose estimate indicated a cumulative PSD close to 15 Gy.

**Recommendation.**

None, best practice was used in a complicated case. This patient did not exhibit signs of CRI. The two-month staging of the procedures may have decreased the potential for injury, but the case still fell within the 6-12 month Joint Commission time window. This example points out the need for a monitoring system to keep track of all procedures.

**Conclusions**

The fluoroscopic sentinel event is defined to be "prolonged fluoroscopy with a cumulative dose >1500 rads (15 Gy) to a single field". The definition of fluoroscopic sentinel event given by the Joint Commission employs the term "cumulative dose" in a
different way than standard radiological physics usage. In the Joint Commission's meaning, this term refers to the PSD accumulated over a 6-12 month interval, not the cumulative reference point air-kerma (K_{a,r}) for a single-procedure that is required by the FDA on modern fluoroscopic equipment. An overall policy for detecting and investigating fluoroscopic sentinel events should be developed by each institution. In the event of a sentinel event, an institution must conduct a timely and thorough root cause analysis.

Substantial time and effort are required by the physicist to convert directly monitored parameters, such as fluoroscopy time or K_{a,r}, into estimated skin doses. Care should be given to the calculation, because overly conservative approaches will lead to an unnecessary and inappropriate root cause analysis. Even if the physicist has the best information regarding the procedure, significant errors can be associated with the dose estimate.

References


Hemorrhage Following Drug-Eluting Bead Transarterial Chemoembolization of Hepatocellular Carcinoma

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Case Presentation

We report the case of a 78-year-old woman with hepatocellular carcinoma who underwent drug-eluting bead transarterial chemoembolization (DEB-TACE). On the first routine follow-up CT six-weeks post procedure, the patient was found to have residual enhancing tumor and active intra-tumoral hemorrhage (Fig 1A). Follow-up laboratory values demonstrated a decrease in hemoglobin. Subsequent catheter arteriogram confirmed active arterial hemorrhage as well as enhancement along the periphery, suggestive of residual tumor, which was treated with repeat embolization (Fig. 1B). Several arteries supplying the residual tumor were embolized using drug eluting bead transcatheter chemoembolization (DEB-TACE). Additionally, the active arterial extravasation was treated with 0.018” coil embolization using platinum microcoils achieving post-embolization hemostasis (Fig. 1C). Nine-month follow up imaging demonstrated no residual enhancing tumor or evidence of active extravasation of contrast material (Fig. 1D).

Figure 1. Early (A) arterial phase CT imaging demonstrates active arterial intra-tumoral hemorrhage in the segment IVB hepatocellular carcinoma, as well as residual enhancement along the periphery of the treated tumor bed, six weeks following initial DEB-TACE. Digital subtraction angiography (DSA) of the right hepatic artery following repeat DEB-TACE and placement of 3mm .018” VortX microcoils (Boston Scientific, Quincy, MA, USA) into two arteries supplying the segment V hepatocellular carcinoma (B) demonstrates no further extravasation of contrast (C). 9 month follow up CT (D) demonstrates no residual enhancing tumor or extravasation of contrast, compatible with successfully treated hepatocellular carcinoma.
Key Imaging Findings

Active intra-tumoral contrast extravasation
Successful transarterial hemostasis and TACE

Diagnoses

Active intra-tumoral hemorrhage following TACE with subsequent transarterial embolization

Discussion

Background.

Complications of TACE are well described in the literature and include liver failure (2.3%), post-embolization syndrome, tumor lysis syndrome (4.6%), abscess (1-2%), non-target embolization, gastrointestinal bleeding, and arterial access site complications. While arterial hemorrhagic complication in the setting of percutaneous intervention has been well documented, intra-tumoral hemorrhage in the setting of transcatheter intervention is rare and hemorrhagic necrosis in the setting of hepatocellular carcinoma as a complication following TACE has not been commonly described in the literature. We report a case of clinically significant hemorrhage within hepatocellular carcinoma (HCC) after drug eluting bead transcatheter chemoembolization (DEB-TACE).

Clinical Course.

A 78-year-old woman with significant medical history, including congestive heart failure, anemia, chronic obstructive pulmonary disease, and coronary artery disease (recently treated with drug eluting coronary artery stents mandating long-term systemic anticoagulation) was diagnosed with a solitary 5.1 cm HCC in segment IVb of the liver on multiphasic dynamic contrast-enhanced (DCE) abdominal computed tomography (CT). The patient had no evidence of positive hepatitis B or C serology or excessive alcohol intake but had insulin dependent diabetes mellitus, morbid obesity, and hypercholesterolemia, consistent with metabolic syndrome and non-alcoholic steatohepatitis. Due to multiple co-morbidities and poor functional status, the patient was deemed a poor surgical candidate for curative resection. Pre-procedure hemoglobin and hematocrit values were 12.2 g/dL and 35.9%, respectively. Her warfarin was held prior to the procedure and her pre-procedure INR was 1.2. The patient subsequently underwent uneventful drug-eluting bead transarterial chemoembolization of the right hepatic lobe. Two vials of drug eluting beads (LC Bead™) 100-300 microns, (Biocompatibles, Inc., Oxford, CT, USA) loaded with 75 milligrams of doxorubicin were diluted with 16 mL of contrast material for a total volume of 20 mL. A total dose of 150 milligrams of doxorubicin was administered to the right hepatic lobe. Chemoembolization was carried to near stasis, and subsequent bland particle embolization was not required. Post-procedure admission was unremarkable, and the patient was discharged home on post-procedure day 1 with minimal pain. Anticoagulation was restarted 5 days following chemoembolization.

Six week follow-up multiphasic DCE-CT demonstrated residual nodular enhancement in the periphery of the treated tumor and extravasation of intravenous contrast material into the central necrotic portion of the tumor in the arterial and subsequent phases (Fig. 1A), compatible with residual viable tumor, as well as active intra-tumoral hemorrhage. The patient had poor appetite and increased fatigue following the original TACE procedure and had persistent abdominal tenderness in the midepigastrium on physical examination. Her INR was found to be 2.6 and her hemoglobin was 9.9 g/dL. The patient’s warfarin was stopped and her coagulation status was corrected with fresh frozen plasma. Despite correction of her INR to 1.7, her hemoglobin level continued to drop to 8.7 g/dL.

Emergent hepatic arteriogram was performed and active extravasation of contrast from multiple branches of the right hepatic artery supplying the tumor was demonstrated. Multiple small arteries supplying the tumor were subselectively catheterized with a Renegade™ Hi-flo™ microcatheter system (Boston Scientific, Quincy, MA, USA), and a small dose of drug eluting beads loaded with 75 milligrams of doxorubicin was administered into each feeding vessel. In addition, two arteries supplying the tumor that demonstrated active extravasation were then coiled using 3mm - VortX 0.018” platinum microcoils (Boston Scientific, Quincy, MA, USA). Post-
embolization angiogram demonstrated improved angiographic appearance with no further active extravasation of contrast and no further tumoral enhancement (Fig. 1B and C).

The patient was observed in the hospital and then discharged on post-embolization day three. The patient’s hemoglobin remained stable throughout the hospital stay. At her one month follow-up visit, the patient denied pain and had improved significantly with stable laboratory values. Follow-up multiphasic DCE-CT at nine months demonstrated no residual enhancing tumor or evidence of active extravasation of contrast material.

**Topic Review.**

TACE involves the regional injection of chemotherapeutic agents followed by an embolic agent. TACE is considered the mainstay of therapy for unresectable HCC, achieving a median survival benefit of more than two years in patients when compared to optimal medical management alone. Reported complications of TACE include liver failure (2.3%), post embolization syndrome, tumor lysis syndrome (4.6%), abscess formation (1-2%), non-target embolization, gastrointestinal bleeding, and arterial access site complications.

Drug eluting beads, which can be loaded with doxorubicin or irinotecan are delivered by transcatheter arterial embolization (DEB-TACE). DEB-TACE has been shown to be safe and effective by Varela, et al., and Poon, et al. However, patients in each of these studies developed severe complications. Six serious complications occurred in 35 patients treated with DEB-TACE (17.1%) in the Poon study, including hepatic rupture, hepatic failure, spontaneous bacterial peritonitis, bleeding ulcers, and bleeding esophageal varices. The patient who developed hepatic rupture had a 10 centimeter subcapsular HCC. Both studies demonstrated significantly less systemic effects of doxorubicin than in patients treated with intravenous doxorubicin chemotherapy.

DEB-TACE has been shown to be as safe and as effective as conventional TACE for the treatment of HCC lesions which are smaller than 5 cm. Lammer, et al. demonstrated no statistically significant difference in the number of serious adverse events in the Precision V trial. Another small study has demonstrated a significant survival benefit in patients treated with DEB-TACE compared with those treated with conventional TACE. More studies are probably needed to confirm the survival benefit of DEB-TACE over conventional TACE. Regardless of the technique used, it is critical for the interventional radiologist and the treatment team to recognize and appropriately treat these complications. We report an interesting case of active extravasation into a treated lesion presumably from intra-tumoral necrosis.

Close follow-up is vital to detection of complications following TACE. All TACE patients at our institution are admitted for overnight pain management and observation for potential life threatening complications of TACE. Most patients are discharged on post TACE day 1. TACE patients are followed with multiphase CT or MR imaging 6 weeks following their procedure. This patient’s intra-tumoral hemorrhage and residual tumor were found at her initial routine 6 week follow-up visit.

Hepatic rupture is a known but not well documented complication in patients who undergo TACE for the treatment of large HCC. Hepatic rupture is thought to result from intra-tumoral hemorrhage into treated necrotic HCC. Most cases of hepatic rupture occur within the first few days after TACE, but hepatic rupture has been reported up to 45 days following TACE. Our case of intra-tumoral hemorrhage was detected 46 days after DEB-TACE without hepatic rupture. This case may represent a rare incident of impending hepatic rupture imaged prior to rupture. Hepatic rupture following TACE is most commonly seen in larger tumors. The late presentation in this case may be due to the smaller size and/or the intraparenchymal location of the tumor.

Intra-tumoral hemorrhage during TACE has only been reported once by Choi, et al. In the only previously reported case of intra-tumoral hemorrhage, active extravasation of contrast was visualized during the TACE procedure. Choi, et al. speculated the hemorrhage in their case was due to angiitis caused by gelfoam, lipiodol, or mitomycin or while they used careful technique, trauma from manipulation of wires or catheters may have contributed.

The treatment of active intra-tumoral hemorrhage in the setting of recurrent or residual tumor requires thoughtful planning. First and foremost
is the problem of treating the potentially life-threatening hepatic hemorrhage. Hepatic arterial hemorrhage can be treated with temporary embolic agents such as gelfoam pledget or gelfoam slurry or permanent embolic agents such as glue, a covered stent, or platinum coils.\textsuperscript{11,12} Second is the problem of treating any residual tumor enhancement and leaving open the option of retreat treating residual or recurrent tumor in the future.

In this case, we embolized the small arteries supplying the residual tumor with drug eluting beads (LC Bead\textsuperscript{™} 100-300 microns) loaded with 75 milligrams of doxorubicin to treat the residual tumor. Repeat angiography demonstrated persistent hemorrhage into the necrotic cavity. Because hemorrhage persisted despite embolization with 100 to 300 micron LC Bead\textsuperscript{™}, a permanent embolic agent was required to treat the hemorrhage. Multiple platinum coils were then used to embolize the bleeding arteries. Using coils precludes future chemoembolization of those vessels. At the time, the risks of continued bleeding and potential hepatic rupture outweighed the benefits of future TACE in this patient.

\textbf{Conclusion}

Clinically significant intra-tumoral hemorrhage is a rarely documented complication of DEB-TACE as most patients may present with frank hepatic rupture. The risk for hepatic rupture increases in large HCC and may increase in patients on systemic anticoagulation and systemic chemotherapy. Repeat chemoembolization with subsequent coil embolization may be an effective treatment option in the rare event of hemorrhagic complications of TACE, such as in impending hepatic rupture.

\textbf{Acknowledgments}

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\textbf{References}

Bilateral Indirect Carotid-Cavernous Fistulas.

A 75-year-old woman presented with long-standing mild proptosis and acute-onset dysphasia. A brain MRI was performed, demonstrating a left temporal lobe hemorrhage with surrounding edema and mass effect (not shown). Digital subtraction angiogram (DSA) revealed Type D bilateral carotid-cavernous fistulas (CCFs). Lateral DSA from a left common carotid artery (CCA) injection (A) shows abnormal communication between the cavernous sinus and branches from the external carotid artery (ECA, black arrow) and internal carotid artery (ICA, white arrow). Frontal DSA from a right CCA injection (B) shows left hemispheric cortical venous drainage (black arrow), likely explaining the patient’s left hemispheric hemorrhage. Bilateral CCA injections (right CCA image shown, C) depicts successful fistula occlusion by transvenous coil embolization (black arrow) across the intercavernous sinus from a left inferior petrosal sinus (white arrow) approach.

A CCF represents an abnormal communication between the cavernous sinus and the carotid circulation, either indirectly from ECA and/or ICA branches or directly from the cavernous ICA. Indirect CCFs tend to present insidiously in post-menopausal women and are commonly misdiagnosed, thus delaying treatment. Direct CCFs most often result from head trauma and are more common in young men. CCFs can be classified into four types: Type A, direct fistula from ICA; Type B, indirect fistula from branches of the ICA; Type C, indirect fistula from branches of the ECA; and Type D, indirect fistula from branches of both the ICA and ECA. Diagnosis is often made by MRI/MRA or CTA and confirmed with DSA. Treatment consists of transarterial and/or transvenous embolization; surgical ligation is also an option. Spontaneous occlusion has been reported in low-flow indirect fistulas supportive.
Hereditary Hemorrhagic Telangiectasia with Embolization for Uncontrolled Epistaxis.

Hereditary hemorrhagic telangiectasia (HHT), also known as Osler-Weber-Rendu disease, is an autosomal dominant disorder which predisposes patients to various vascular abnormalities. These vascular abnormalities classically include telangiectasias involving the mucosal membranes of the nose and gastrointestinal tract. Other common manifestations include arteriovenous malformations (AVMs) of the pulmonary, hepatic, and central nervous system (CNS) vasculature.

Epistaxis secondary to the telangiectasias involving the nasal mucosa is the most common clinical presentation of HHT and can often be challenging to manage. The lateral digital subtraction angiographic images (A and B) presented above, acquired from bilateral common carotid artery injections, demonstrate the patchy nasal mucosal blushing characteristic of telangiectasias. The coned down image (C) is from selective microcatheter injection into the distal internal maxillary artery, obtained during Onyx® embolization for recurrent epistaxis in a 67-year-old man with HHT requiring multiple transfusions.

Endovascular embolization for epistaxis is a reasonable option for patients who fail more conservative management with nasal packing and endoscopic cautery. Multiple techniques with various types of embolic material have been described, perhaps the most common of which is embolization with polyvinyl alcohol (PVA) particles. However, other options include microspheres, gelfoam, coils, and liquid embolics such as Onyx® (EV3 Irvine, California, USA).