Imaging for Infection: From Visualization of Inflammation to Visualization of Microbes

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Abstract

Background: With the development of high-resolution cross-sectional imaging, anatomic identification of most areas of infection has become routine. Imaging a site of infection allows for diagnosis and treatment. In the past, molecular imaging for infection involved mainly the use of radiolabeled leukocytes for functional targeting at infection sites. With the recent development of functional nuclear imaging, bacterial and viral metabolism can also be imaged directly for potential identification of early infection.

Methods: Review of pertinent English-language literature.

Results: Cross-sectional imaging is used routinely to identify and treat sources of infection in patients with fever, leukocytosis, or unexplained hemodynamic instability. Although ultrasound is preferred for the identification of biliary or hepatic sepsis, computed tomography (CT) has proved to be accurate for the identification and treatment of intra-abdominal fluid collections and abscesses. Biologic imaging is a non-invasive technique that identifies sites of infection in cases in which no definite abnormality is identified via cross-sectional imaging. This is made possible by imaging the accumulation of radioisotopes that have been attached to white blood cells or glucose. Biologic imaging is useful for the identification of anatomic sites where there is inflammation or high metabolic demand. However, a drawback of biologic imaging is that it is not specific for infection. Techniques that image microbes directly increase the specificity of imaging results significantly and can be used to quantify and track infectious processes. For example, radiolabeling of antimicrobial proteins and antibiotics is one technique that has been demonstrated to identify areas of infection accurately in animals but is not currently being used clinically in humans. With the advent of gene therapy, many researchers are inserting the herpes viral thymidine kinase gene into both viruses and bacteria. This allows for tracking of the infectious process by imaging the accumulation of radiolabeled thymidine analogues.

Conclusion: This review summarizes standard imaging for infection as it is currently practiced clinically. We will also explore the promising new methods of microbial imaging that are likely to become standards in clinical care in the near future.

ACCURATE DIAGNOSIS OF INFECTION is a key component in effective treatment using antiviral agents or antibiotics. Anatomic identification of established sites of infection can allow for sampling of abscesses. Such collections, in turn, can be used to determine antibiotic susceptibilities of microbes for optimum treatment. Anatomic identification of abscesses can also facilitate procedures such as surgical and interventional drainage that are essential for eradication of major infections.

The last three decades have observed major advances in clinical imaging. Cross-sectional imaging has become indispensable in diagnosing infections and guiding interven-

tional therapies. Advances in cross-sectional imaging have changed the diagnosis and management of infections greatly in the last two decades. The combination of ultrasonography and computed tomography (CT) now allows identification of anatomic areas of infection, as identified by radiologic signs of consolidation or abscess formation. Localization of abscesses by cross-sectional imaging can help direct surgical intervention and also allows percutaneous treatment by needle aspiration or catheter drainage. One of the most important discoveries in infection is the realization that the interaction of the microbe with native immune cells is the basis

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of the sepsis syndrome [1]. This interaction is the basis of a wide variety of functional imaging modalities that aim to localize infection via immune cell trafficking and metabolism. Recent research has demonstrated success in direct imaging of viral and bacterial metabolism. Advances such as these are likely to result in molecular imaging tools that will become part of standard clinical care.

Cross-Sectional Imaging

For the patient with fever, leukocytosis, or unexplained hemodynamic instability, cross-sectional imaging is now a routine part of the work-up for unidentified infection sites and sources of sepsis.

Ultrasound

If an abdominal cause is suspected in a patient with unexplained sepsis, ultrasound remains a valuable tool. It is a portable scanning technique and can be performed in the intensive care unit (ICU) if the patient is too unstable for transport. It is one of the best methods for identification of biliary or hepatic sepsis. Dilation of the gallbladder or biliary tree is a clear sign of pathology. Thickened gallbladder wall is invaluable in diagnosis of cholecystitis, with or without associated gallstone disease. Identification of intra-hepatic fluid collections, particularly with thickened wall, with complexity or with gas is highly indicative of hepatic abscesses.

Ultrasound is also valuable in the identification and localization of intra-abdominal fluid collections [2–4]. Fluid collections in the subphrenic space, the pericolic gutters, or in the pelvis are well visualized with ultrasound. Post-operative perihepatic collections are particularly well visualized. Many of these collections can also be targeted by ultrasound for percutaneous drainage. This technique can even be performed at bedside in the ICU for patients who are too sick to leave the well-monitored setting.

The major obstacle to ultrasound visualization is interference by air. Loops of intestines with intra-luminal gas obscure ultrasound detection. Thus, interloop abscesses, or peri-pancreatic collections are difficult to visualize via ultrasound. Distended loops of bowel may also obscure visualization by ultrasound in patients with ileus due to sepsis or due to recent intra-abdominal surgery [5].

Computed Tomography

With its wide availability, CT has become the most common test used in the diagnosis and detection of intra-abdominal abscesses [5–7]. The availability of multidetector CT scanners allows rapid acquisition of images. Thus, high-quality images can be obtained even in sick patients who have difficulty holding their breath. In particular, CT is better than ultrasonography in obese patients and in patients with abdominal or thoracic dressing, where body habitus or physical surface obstacles obscure the view. Additionally, in the thoracic cavity, CT scanning is highly sensitive for diagnosis of pneumonias, pleural effusion, and loculated collections [4,6–7].

Contemporary contrast protocols allow for identification of even small infected collections. Oral contrast allows for differentiation of bowel lumen with air and a gas-containing abscess cavity. Intravenous contrast allows visualization of

FIG. 1. Intramuscular abscess in patient with unexplained fever and leukocytosis. Computed tomography (CT) demonstrated psoas abscess (arrow).

collections with peripheral contrast enhancement that would be highly suspicious for abscess (Fig. 1). Thus, the identification of collections, particularly complex collections, with internal gas, debris, and peripheral enhancement would be indicative of abscesses.

Using these criteria as hallmarks for infected collection, CT proved to be highly accurate for intra-abdominal fluid collections and abscesses. For example, sensitivity of 90%–100% has been reported in various studies [6,8–10]. Comparatively, ultrasound identification of abscess, even in the best of hands, has a lesser sensitivity of 80%–85% [8,11]. In particular, interloop pathologies, which are obscured by bowel gas from ultrasound evaluation, can be diagnosed successfully with CT. Computed tomography is also useful for retroperitoneal pathology, including retroperitoneal abscesses or pancreatitis or intra-biliary stones. These are areas also difficult to evaluate with ultrasound [12].

Percutaneous Abscess Drainage

Another reason that cross-section imaging has become invaluable for the care of the with sepsis patient is that abscesses identified by scanning can be treated percutaneously. Minimally invasive techniques utilize CT guidance to place needles and catheter into abscess cavities (Fig. 2) [13]. The result is that most patients who previously required surgical drainage and debridement for life-threatening infections can have these sources of infection drained with minimally invasive techniques. For nearly 90% of such patients, the needle- or catheter-based intervention will be the only treatment necessary [14,15]. Uniloculated collections with no fistulous connection to the gastrointestinal tract or bronchial tract are likely to be resolved by percutaneous drainage. Complex collections, particularly those complicated by tissue liquefaction or local hematoma are more likely to require surgical intervention [16–18].

Biologic Scanning

In addition to ultrasound and CT scanning, biologic radionuclide imaging has also been developed for the imaging of infection. Initially developed as a means of scanning for inflammation, and more recently as scanning for microbes, the

FIG. 2. This panel demonstrates the same abscess in Figure 1 successfully treated by percutaneous drainage. Contrast within the intestines (arrows) verify that the abscess was not a loop of intestines with stool.

original goal of biologic scanning was to develop a non-invasive test that identifies sites of infection in cases in which no definite abnormality is identified via cross-sectional imaging. Imaging for microbes is also now being developed to quantify infectious organisms in order to determine load and response to therapy. In the following paragraphs, we will summarize these visualization methods as well as extrapolate the investigative use of imaging for molecules produced at sites of infections, including histamine, serotonin, cytokines, adhesion molecules, complement, and other chemotactic factors. These new imaging techniques and methods are all attempts to detect occult infections and to improve upon the specificity of cross-sectional imaging in the diagnosis of infection.

Methods for Imaging of White Blood Cell Accumulation and Inflammation

Autologous radiolabelled white blood cell scanning

In practice, the scans used most commonly exploit white blood cells that have been labeled with radionuclides (Table 1). Because leukocytes traffic to sites of infection, reinfused labeled leukocytes may allow non-invasive imaging of areas of occult infection, such as osteomyelitis, orthopedic prosthesis, endocarditis, or inflammatory bowel disease. Use of combined nuclear medicine and cross sectional scans such as single-photon emission computed tomography (SPECT)/CT allows for subsequent anatomic localization. Standard imaging of inflammation include indium and gallium scanning.

For indium scanning [19,20], leukocytes are labeled with ^{111}In ex vivo and reinjected. Alternatively, white blood cells (WBC) can be labeled ex vivo with $^{99\text{m}}\text{Tc}$ -sulfur colloids or $^{99\text{m}}\text{Tc}$ -exametazine (HMPAO). Reinfusion of such radiolabeled WBC allows for non-invasive imaging of infections [20]. Local presence of radiolabeled WBC with increasing accumulation over time is highly specific for infection [20,21]. Leukocytes labeled with $^{99\text{m}}\text{Tc}$ are the most commonly used radiolabeled WBC because $^{99\text{m}}\text{Tc}$ has a short half-life (6 h) and favorable gamma radiation energy of 140 keV. However, use of $^{99\text{m}}\text{Tc}$ -labeled leukocytes causes non-specific accumulation in kidneys and intestines released by $^{99\text{m}}\text{Tc}$ -exametazine.

TABLE 1. NUCLEAR MEDICINE TECHNIQUES FOR IMAGING INFLAMMATION

Radiolabeled leukocytes
$^{99\text{m}}\text{Tc}/^{99\text{m}}\text{Tc-SnF}_2/^{111}\text{In}/^{18}\text{F-FDG}/^{64}\text{Cu-labeled WBC}$
Radiolabeled anti-CD4 mAb
Imaging for local glucose metabolism
$^{18}\text{F-FDG}$
Radiolabeled antigranulocyte mAbs
$^{99\text{m}}\text{Tc-human neutrophil peptide 1-3}$
Radiolabeled immunoglobulin
$^{99\text{m}}\text{Tc}/^{111}\text{In-HIG}$
Radiolabeled cytokines
Radiolabeled anti-TNF- α mAbs
Radiolabeled IL-2
$^{123}\text{I-IL-1ra}$
$^{99\text{m}}\text{Tc-IL-8}$
Other markers of inflammation
$^{99\text{m}}\text{Tc-a-E-selectin}$
$^{99\text{m}}\text{Tc}/^{18}\text{F-ubiquitin 29-41}$

$^{99\text{m}}\text{Tc}$, technetium-99m; SnF_2 , stannous fluoride; ^{111}In , indium-111; $^{18}\text{F-FDG}$, ^{18}F -fluorodeoxyglucose; ^{64}Cu , copper-64; WBC, white blood cells; mAb, monoclonal antibodies; HIG, human polyclonal immunoglobulin-G; TNF- α , tumor necrosis factor- α ; IL-2, interleukin-2; $^{123}\text{I-IL-1ra}$, interleukin-1 receptor antagonist; IL-8, interleukin-8

Leukocytes labeled with ^{111}In are preferred for evaluation of the kidneys, bladder, gallbladder, and intestines because there is no major kidney, bladder, or bowel excretion.

More recently, ex vivo radiolabeling of WBCs for positron emission tomography (PET) imaging has been attempted using ^{18}F -fluorodeoxyglucose ($^{18}\text{F-FDG}$) [22,23] and ^{64}Cu [22,23]. However, because of the short half-life of ^{18}F (110 min), delayed imaging that is necessary to observe leukocyte trafficking is not possible. Thus, ^{64}Cu -WBCs are more likely to be useful because the long half-life of ^{64}Cu (12.7 h) allows for imaging up to 18–24 h after reinjection in patients.

Although cross-sectional imaging allows for detection of infection when anatomic changes are apparent, imaging for inflammation allows detection of early pathophysiologic changes before anatomic changes occur. These tests are therefore used principally in patients for whom cross-sectional imaging is negative, but in whom infection or abscess is highly suspected. Thus, utilizing the trafficking of labeled leukocytes allows for visualization of occult sites of infection.

Alternatively, scans that utilize in vivo labeling of leukocytes or other cells in areas of inflammation are also being used to detect occult infection. In these cases, gallium scanning has traditionally been utilized, but more recently has included use of $^{18}\text{F-FDG-PET}$.

The above ex vivo techniques for labeling WBC are accurate, however, the process involved in radiolabeling WBCs is tedious and requires strict sterile conditions. Additionally, the handling of patient blood exposes health care personnel to the many hazards of blood-borne pathogens. As a result, imaging tests that utilize agents that allow for in vivo labeling of WBCs have been developed and are in general use.

Imaging using in vivo agents

Gallium scanning involves injecting ^{67}Ga into the blood stream where it binds to circulating transferrin, lactoferrin,

and leukocytes in vivo [24]. Subsequently, transferrin- and lactoferrin-bound ^{67}Ga particles concentrate in areas of infection by an assortment of mechanisms including hyperperfusion and increased vascular permeability. Certain bacteria also bind directly ^{67}Ga via mechanisms involving high-affinity siderophores and low-molecular weight chelates [4]. However, the long half-life (78 h) and wide organ distribution of ^{67}Ga results in a late time point (48–72 h) for optimum target-to-background ratio [25]. Additionally, the high-energy gamma emissions of ^{67}Ga result in a high radiation dose for the patients and health care workers [25]. Generally, this radiopharmaceutical is used for work-up of chronic osteomyelitis, in detection of opportunistic respiratory tract infections [26], and for fever of unknown origin (FUO) [27]. More recently, ^{68}Ga -citrate has been developed for PET scanning that exploits the same biologic basis for scanning described above, but with the advantage of an earlier optimal scanning time and better anatomic detail [28].

^{18}F -fluorodeoxyglucose

^{18}F -fluorodeoxyglucose (^{18}F -FDG) was developed originally as an imaging tool for staging of cancer [29]. It was soon noted that FDG also accumulates in areas of infection due to high glucose uptake and utilization by leukocytes. The glucose analogue FDG is transported into activated leukocytes by the same glucose transporters used by glucose, where it undergoes phosphorylation by hexokinase to become ^{18}F -FDG-6-phosphate. This molecule is trapped inside the cell because it cannot proceed down the glycolytic pathway nor can it exit the cell via the usual glucose transport proteins. Thus, it may be reliably imageable. In particular, FDG-PET has proved especially useful in the workup for FUO [30–32]. It is also favored for workup in chronic osteomyelitis [31], infectious spondylitis [33], and infected liver cysts [34,35].

Although FDG-PET is now also used commonly for imaging of infection, the test clearly suffers from a lack of specificity because FDG-PET highlights any area of high glycolytic activity including trauma, wound, cancer, and muscle exertion. An additional challenge related to FDG-PET imaging is its high cost and lack of availability in many countries.

Other experimental methods for imaging infection

Three other classes of agents have been tested for imaging of WBC accumulation at sites of infection. Investigators have attempted to image using anti-granulocyte monoclonal antibodies labeled with $^{99\text{m}}\text{Tc}$, but with limited clinical translation [36]. Cytokines and chemokines are found at high concentrations at sites of infection. Thus, many attempts have been made to use labeled cytokines and cytokine receptors for imaging of infection. Strategies investigated have included the use of ^{123}I -interleukin (IL)-1 [37], radiolabeled IL-1 receptor antagonist (IL-1ra) [38], ^{123}I or $^{99\text{m}}\text{Tc}$ -labeled IL-8 [39,40] without major clinical success. Methods of exploiting the increased vascular permeability of sites of infection including the use of $^{99\text{m}}\text{Tc}$ - or ^{111}In -labeled human polyclonal immunoglobulin-G (HIG) [41], or $^{99\text{m}}\text{Tc}$ -albumin nanocolloids have shown biologic activity but not clinical usefulness.

Current clinical indications

Radiolabeled leukocytes are considered the gold standard method for nuclear imaging for occult infections [42]. These scans are used in work-up of inflammatory bowel diseases, acute osteomyelitis [43], soft-tissue infections, and suspected infections of vascular [41,44] and orthopedic prostheses [45].

In work-up of FUO, ^{18}F -FDG-PET/CT has emerged as a test of choice, especially with the anatomic details afforded by the accompanying cross-sectional imaging [30]. Gallium scanning remains favored for imaging of chronic osteomyelitis, spondylitis, and spondylodiscitis [46].

Direct Imaging for Microbes

Attempts have also been made to directly image the microbes responsible for the infection. Two techniques currently under investigation radiolabeled antimicrobial peptides and the radiolabeling of antibiotics and antimicrobials.

Imaging using radiolabeled antimicrobial peptides

In the innate response to infection, many cells of the immune system including phagocytes, endothelial cells produce antimicrobial peptides that protect against microbial infection. These peptides bind to microbes and produce electrostatic and hydrophobic antimicrobial actions [47]. These peptides include human lactoferrin (hLF) [48], ubiquicidin 29–41 peptide fragment (UBI 29–41) [49], and human neutrophil peptide 1–3 (HNP 1–3) [50]. Radiolabeled versions of these peptides or analogues have been used in attempt to image infections (Table 1). Within this strategy, $^{99\text{m}}\text{Tc}$ -UBI 29–41 [49,50] and $^{99\text{m}}\text{Tc}$ -hLF peptide [48] have each shown promise in animal studies. None of these proteins have moved into clinical practice.

Antibiotics and antimicrobials

Antibiotics are designed to specifically target invasive microbes. Active research is directed at using radiolabeled antibiotics to visualize sites of infection (Table 2). One of the most studied agent is $^{99\text{m}}\text{Tc}$ -ciprofloxacin [51]. This agent can label gram-positive and gram-negative bacteria, and exhibits little liver or bowel uptake. Other antibiotics tested in a similar strategy include $^{99\text{m}}\text{Tc}$ - and ^{18}F -labeled ceftizoxime, ceftriaxone, cefuroxime, kanamycin, isoniazid, lomefloxacin, ofloxacin, and rifampicin. Similarly, antifungal agents have also been radiolabeled for visualization fungal infections. In this way, $^{99\text{m}}\text{Tc}$ -labeled fluconazole is being investigated for imaging of occult infection by *Candida albicans* [52]. Studies using radiolabeled antibiotics and

TABLE 2. AVAILABLE RADIOLABELED ANTIMICROBIALS FOR IMAGING INFECTION WITH BACTERIAL AND FUNGAL ORGANISMS

$^{99\text{m}}\text{Tc}$ -fluconazole
$^{99\text{m}}\text{Tc}/^{18}\text{F}$ -ciprofloxacin (Infecton [®] , Draximage, Quebec, Canada)
$^{99\text{m}}\text{Tc}$ -ceftriaxone
$^{99\text{m}}\text{Tc}$ -kanamycin
$^{99\text{m}}\text{Tc}$ -rifampicin

$^{99\text{m}}\text{Tc}$, technetium-99m.

FIG. 3. Imaging of *Escherichia coli* bacterial infection by FDG-PET (left) and FEAU-PET (right). Two subcutaneous deposits of infected tissue were imaged at 12 (middle), and 72 hours (bottom). Uninfected tissue was imaged as a control (top). Note the high background of the FDG-PET, in particular the background in the heart (arrow). FDG-PET, fluorine-18 2-fluoro-2-deoxy-D-flucose-positron emission tomography; FEAU, 2-fluoro-2-deoxy-1-h-D-arabionofuranosyl-5-ethyl-uracil.

antifungals are still in the early stages. Although preclinical data are promising, the clinical data are either early or conflicting. Thus, this promising strategy has not yet been translated to clinical care.

Direct Imaging of Microbial Metabolism

Bacterial imaging

In recent years, attempts have been made to image bacteria directly through pathways that are intrinsic to the specific microbe. A big part of the impetus for achieving such imaging is due to attempts to target cancers using tumor-targeting bacteria as cancer-killing agents. Studies in this field of novel cancer-killing bacteria have used diverse bacteria such as *Bifidobacterium* spp. [53], *Listeria monocytogenes* [54], [55], *Clostridium* spp. [56], *Salmonella* spp. [57–59], *Shigella flexneri* [57], *Vibrio cholerae* [60], and *Escherichia coli* [57]. Investigators in this novel field therefore want the ability to non-invasively track bacteria to correlate with cancer colonization, killing, and toxicity. They also want the ability to image repeatedly and to assess for proliferation of bacteria. These are all goals shared by infectious disease experts tracking natural infections.

Previously, investigators have attempted to image therapeutic bacteria by labeling bacteria such as the *Salmonella* strain VPN20009 with the thymidine kinase gene from the herpes simplex virus. Such HSV1-TK-expressing *Salmonella* VNP20009 have been shown to be imageable by ^{124}I -labeled

thymidine analogue [^{124}I]-2-fluoro-1-h-D-arabino-furanosyl-5-iodo-uracil ([^{124}I] FIAU) [61]. A recent major advancement in this area is the discovery that endogenous bacterial thymidine kinase can be imaged by similar radiolabeled thymidine analogues in the assessment of bacterial distribution and proliferation [62]. In this regard, both [^{18}F]-2-fluoro-2-deoxy-1-h-D-arabionofuranosyl-5-ethyl-uracil ([^{18}F] FEAU) and [^{124}I]-2-fluoro-1-h-D-arabino-furanosyl-5-iodo-uracil ([^{124}I] FIAU) can be used [63].

Figure 3 shows a comparison of imaging for the *E. coli* strain Nissle 1917 (EcN) by [^{18}F]-FDG compared with [^{18}F]-FEAU using non-invasive PET imaging. The radiolabeled thymidine analogues demonstrated specific imaging of *E. coli*, with best bacteria to background contrast at 1 h after injection of tracer for [^{18}F]-FDG and 2 h after injection of tracer [^{18}F]-FEAU. In addition, the non-specific imaging of the heart, brain, and kidneys by FDG-PET is not observed by FEAU-PET [62]. Thymidine imaging can clearly be performed for *E. coli*, and may be a useful test for identification of occult infections, and evaluation of response to antibacterial treatment.

Viral imaging

There is also clear need for a non-invasive imaging test for identification of presence and distribution of viral infection, and assessment of response to treatment. Viral infection generally does not produce anatomic changes such as those observed in bacterial abscesses. Verification of presence and

FIG. 4. Schema for imaging thymidine kinase activity. Radiolabeled FIAU is phosphorylated and trapped within the microbe for imaging. FIAU, 2-fluoro-1-h-D-arabino-furanosyl-5-iodo-uracil.

sites of infection often are hard even when the infection is severe. In addition, when treating acute (e.g., viral meningitis) or chronic infections (e.g., hepatitis C), a non-invasive test that allows quantification of virus will allow for assessment of success in treatment. For these reasons, much attention has been focused on development of such non-invasive imaging.

In this regard, much credit for the major advancements should be given to the field of gene therapy. Because viral vectors are a popular tool for *in vivo* gene transfer, gene therapists have been working on methods for tracking therapeutic viral vectors *in vivo* [64]. The technologies developed are also promising methods for tracking natural viral infections.

The most promising data in imaging of viruses also involve the use of the enzyme thymidine kinase [65]. This enzyme is pivotal in viral incorporation of thymidine into viral DNA. Radiolabeled thymidine analogues such as [^{124}I] FIAU [66,67], and radiolabeled guanosine analogues such as fluor-

oganciclovir [68] or 9-[(3-18F-fluoro-1-hydroxy-2-propoxyl)methyl]guanine([18F] FHPG) [69] are also substrates for the phosphorylation catalyzed by viral thymidine kinase (Fig. 4). These phosphorylated nucleoside analogues are trapped within the tumor cell and accumulate to concentrations that are measurable by current imaging techniques.

In vivo studies have clearly demonstrated that live replication-competent herpes viruses can be imaged with [^{124}I] FIAU using positron emission tomography (PET) [65]. Figure 5 demonstrates that as few as 1×10^7 viral particles in a 0.5-cm diameter tumor can be detected by [^{124}I] FIAU-PET imaging. Furthermore, PET signal intensity is significantly greater at 48 h compared with that at 8 h after viral injection, demonstrating that PET scanning can detect changes in thymidine kinase activity resulting from local viral proliferation. Thus, changes of viral concentration can be detected reliably and sensitively.

Conclusion

Improvements in cross-sectional and biologic imaging have provided the modern clinician with sensitive and accurate identification of sites of disease with great anatomic localization. The armamentarium of tests for diagnosis, surveillance, and targeting treatment for infection is growing. Proving clinical utility of many scans should involve evaluation of accuracy, improvement over existing tests, as well as cost effectiveness.

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FIG. 5. Imaging for herpes simplex infection using FIAU-PET. Small (0.5 cm tumor; left) infected with virus is imaged at 8 h (middle) and 48 h (right). Note the increasing intensity of imaging indicating ability for FIAU-PET to identify proliferation of virus. FIAU-PET, 2-fluoro-1-h-D-arabino-furanosyl-5-iodo-uracil-positron emission tomography.

Author Disclosure Statement

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