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Diagnosing Infection in Febrile Granulocytopenic Patients With Indium-111–Labeled Human Immunoglobulin G

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Purpose: Delineation of focal infection is a major problem in the management of febrile granulocytopenic patients. The utility of indium-111–labeled human nonspecific immunoglobulin G (In-111–IgG), a newly developed radiopharmaceutical for imaging focal inflammation, was investigated in patients with adequate WBC counts. In the present study, we investigated whether In-111–IgG scintigraphy could be used to locate infection in granulocytopenic patients.

Materials and Methods: Granulocytopenic rats with focal infection were imaged after In-111–IgG injection. Thereafter, In-111–IgG scintigraphy was performed in 20 granulocytopenic patients. Images were obtained 4, 24, and 48 hours after injection of 75 mBq In-111–IgG. Scintigraphic findings were compared with clinical, roentgenologic, and ultrasonographic methods and culture results.

Results: In the animal model high In-111–IgG accumulation was observed in the infectious focus. In the patients, 13 proven pulmonary, abdominal, joint, and soft tissue infections of both bacterial and fungal origin were detected adequately. In-111–IgG uptake not due to verified inflammation was observed in the large bowel of two patients. A thoracic wall infiltrate showing only mild inflammatory activity was not detected. Small toxoplasmosis lesions in heart, liver, and kidneys were obscured by physiologic In-111–IgG activity in these organs.

Conclusions: In-111–IgG scintigraphy is a useful technique to delineate focal infection in patients with granulocytopenia. Accumulation of the radiopharmaceutical does not appear to be granulocyte-mediated. In-111–IgG is a safe and convenient radiopharmaceutical that probably contributes to the early diagnosis of focal infection in granulocytopenic patients.


MATERIALS AND METHODS

Human nonspecific, polyclonal IgG (Sandoglobulin; Sandoz AG, Nuremberg, Germany) was conjugated to diethyleneetriaminepentaacetic bicyclic anhydride (bicyclic DTPA) and radiolabeled with In-111 (indium chloride; Amersham International Ltd, Buckinghamshire, United Kingdom) via citrate transchelation: "The labeling efficiency was always higher than 95%.

Imaging Procedures

Scintigraphic images were obtained with a Siemens Orbiter gamma camera connected to a Scintiview image processor (Siemens Inc, Hoffman Estates, IL). All images were collected in a digital format with a 256 x 256 matrix. A medium-energy, parallel-hole collimator was installed. Imaging was performed using both In-111 photopeaks (173 keV peak, 15% symmetric window; 247 keV peak, 15% symmetric window).

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Animal Study

In four young, randomly bred, male Wistar rats (weighing 200 to 220 g), severe granulocytopenia was induced with intraperitoneally injected cyclophosphamide. On days 1, 3, and 6, a dose of 200, 100, and 100 mg cyclophosphamide per kg of body weight was injected, respectively. The granulocyte count was monitored by daily blood samples obtained by orbital puncture. After severe granulocytopenia had been established, an infection was induced on day 6 by inoculating approximately 10⁶ colony-forming units of \textit{Staphylococcus aureus} in the left calf muscle. One day later, when gross swelling was apparent, 6 mBq of In-111 labeled to 100 μg IgG-DTPA conjugate was injected in the tail vein. Scintigraphic images were recorded at 4, 24, and 48 hours postinjection (PI). Regions of interest with a fixed size were drawn over the infectious focus and the contralateral calf muscle. Ratios of In-111—IgG uptake in infectious foci to that in the contralateral muscle were calculated. All mean values are given ± SEM.

Patient Study

Patients with fever and a granulocyte count below 2.0 × 10⁷/L were eligible for the study. The criteria for fever included an oral temperature greater than 38.5°C on one occasion or greater than 38°C on two or more occasions during a 12-hour period, as described by the Consensus Panel of the Immunocompromised Host Society.² Antibiotic treatment was not stopped or altered during the study. The experimental nature of the imaging procedure was explained to the patients. Informed consent was obtained. No patient had a history suggestive of IgA- or IgG-deficiency or adverse reaction to previous IgG administration. Pregnant and lactating females were excluded from the study. The study was approved by the institutional research review board.

Patients received an intravenous (IV) dose of approximately 1 mg of IgG labeled with 75 mBq of In-111. One patient, a 15-year-old female, received only 55 mBq of In-111—IgG for dosimetric reasons. The effective dose equivalent after IV administration of 75 mBq In-111—IgG was calculated to be 15 mSv and was similar to that of leukocyte scintigraphy (18 mSv after IV injection of 30 mBq In-111—labeled leukocytes).³,⁴,⁵

In-111—IgG images were obtained at 4, 24, and 48 hours PI for a preset time of 5, 7.5, and 10 minutes, respectively. Spot views of the total body were obtained at least 24 hours PI.

Images were interpreted independently by three observers blinded to the results of the verification procedures. An In-111—IgG scan was interpreted as positive if focally increasing accumulation of activity could be noted over time.

In-111—IgG scintigraphy results were verified by clinical, roentgenologic, ultrasonographic, and microbiological methods. All mean values are given ± SEM.

RESULTS

Animal Study

On day 6, when calf muscle infection was induced, all animals had severe granulocytopenia. The mean granulocyte count was 0.1 ± 0.02 × 10⁷/L. At all times, infectious foci showed a high degree of In-111—IgG uptake. The ratios of In-111—IgG uptake in the focus relative to that in the noninfected, contralateral muscle steadily increased from 2.6 ± 0.3 (4 hours PI) to 6.0 ± 0.4 (24 hours PI) and finally reached 12.3 ± 1.9 (48 hours PI).

Patient Study

Twenty patients were studied (13 males, seven females; mean age, 36.9 years; range, 15 to 63 years). Sixteen patients suffered from different types of leukemia, three had malignant lymphoma, one had aplastic anemia. Most patients were granulocytopenic due to remission induction chemotherapy or conditioning regimen before bone marrow transplantation. Patient no. 11 had granulocytopenia of unknown origin. All patients were febrile for approximately 1 to 2 weeks.

Individual hematologic diagnoses, granulocyte cell counts, scintigraphic results, and verification procedures are summarized in Table 1. All patients, except patients no. 2 and 11, received antibiotic treatment. The mean granulocyte count was 0.4 ± 0.1 × 10⁷/L; the median granulocyte count, 0.2 × 10⁷/L.

Typical Scintigraphic Findings

After remission reinduction therapy for relapse of acute myelogenous leukemia, patient no. 5 developed a molar root infection, resulting in an infiltrate in the left mandibular region (Fig 1A). This focus was believed to be the cause of her fever. Total-body imaging using In-111—IgG revealed a large zone with increased uptake in the area of the middle lobe of the right lung (Fig 1B). The chest x-ray, made a few days before scintigraphy, was normal (not shown). One week later, only mild abnormalities were seen on the chest x-ray (Fig 1C). At that time, initial clinical symptoms of pulmonary infection were noted. A chest x-ray taken 2 weeks after scintigraphy showed a hyperdense area, matching the area of increased uptake on In-111—IgG scintigraphy (Fig 1D). The patient died 1 week later. Postmortem examination revealed a pulmonary infection caused by \textit{Aspergillus fumigatus}. In this case, In-111—IgG scintigraphy showed a pulmonary infection that preceded clinical symptoms and chest x-ray abnormalities by at least 1 week.

Figure 2 shows the images of patient no. 6, who had aplastic anemia. Despite antibiotic therapy, he developed fever and symptoms of pulmonary infection. Scintigraphy showed multiple coin-shaped lesions in both lungs (Fig 2A) that matched the lesions on the chest.
<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Sex, Age</th>
<th>Medical History</th>
<th>Granulocytes (x 10^9/L)</th>
<th>IgG Scan</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M, 39</td>
<td>ALL, BMT, GVHD</td>
<td>0.4</td>
<td>Negative</td>
<td>Thoracic wall infiltrate after Hickman catheter caused by SA.</td>
</tr>
<tr>
<td>2</td>
<td>M, 45</td>
<td>Hairy cell leukemia</td>
<td>1.0</td>
<td>Negative</td>
<td>No infection proven.</td>
</tr>
<tr>
<td>3</td>
<td>M, 58</td>
<td>B-CLL</td>
<td>0.1</td>
<td>Lungs</td>
<td>Pulmonary infection [BAL: SV, SA, Hi].</td>
</tr>
<tr>
<td>4</td>
<td>M, 54</td>
<td>NHL stage IV-B</td>
<td>1.3</td>
<td>Negative</td>
<td>No infection (autopsy).</td>
</tr>
<tr>
<td>5</td>
<td>F, 43</td>
<td>AML, BMT, relapse AML</td>
<td>0.05</td>
<td>Mandible</td>
<td>Extraction of infected molar tooth.</td>
</tr>
<tr>
<td>6</td>
<td>M, 22</td>
<td>Aplastic anemia</td>
<td>0.1</td>
<td>Lungs</td>
<td>AF infection of the lung, proven at autopsy.</td>
</tr>
<tr>
<td>7</td>
<td>F, 41</td>
<td>AML</td>
<td>0.3</td>
<td>Lungs</td>
<td>Clinical and roentgenologic diagnosis: pulmonary Aspergillus infection.</td>
</tr>
<tr>
<td>8</td>
<td>F, 15</td>
<td>Ileocecal NHL</td>
<td>1.7</td>
<td>Lungs</td>
<td>Pulmonary infection [BAL: CF, HSV].</td>
</tr>
<tr>
<td>9</td>
<td>F, 44</td>
<td>AML, BMT, GVHD</td>
<td>0.5</td>
<td>Lungs</td>
<td>Generalized toxoplasmosis infection (autopsy).</td>
</tr>
<tr>
<td>10</td>
<td>F, 31</td>
<td>Mediastinal NHL, stage I-A</td>
<td>0.6</td>
<td>Thoracic wall</td>
<td>Thoracic wall ulcer after diagnostic parasternal mediastinitomy. Pleural effusion: photopenic on IgG; culture: no infection.</td>
</tr>
<tr>
<td>11</td>
<td>M, 63</td>
<td>CLL</td>
<td>1.0</td>
<td>Right side of lower abdomen</td>
<td>Surgery: perforated appendicitis.</td>
</tr>
<tr>
<td>12</td>
<td>M, 44</td>
<td>ALL, BMT</td>
<td>0.2</td>
<td>Wrist</td>
<td>Septic arthritis with prompt recovery after vancomycin.</td>
</tr>
<tr>
<td>13</td>
<td>M, 43</td>
<td>AML</td>
<td>0.2</td>
<td>Colon</td>
<td>No infection proven.</td>
</tr>
<tr>
<td>14</td>
<td>F, 18</td>
<td>Relapse ALL</td>
<td>0.6</td>
<td>Negative</td>
<td>No infection; skin lesions [IgG negative]: allergic vasculitis.</td>
</tr>
<tr>
<td>15</td>
<td>F, 17</td>
<td>ALL, BMT, GVHD</td>
<td>0.1</td>
<td>Negative</td>
<td>No infection proven.</td>
</tr>
<tr>
<td>16</td>
<td>F, 17</td>
<td>AML</td>
<td>0.06</td>
<td>Right side of lower abdomen</td>
<td>Pain and tenderness in the right side of the abdomen, disappeared in a few days, no microbiologic confirmation.</td>
</tr>
<tr>
<td>17</td>
<td>M, 20</td>
<td>ALL</td>
<td>0.1</td>
<td>Negative</td>
<td>No infection proven.</td>
</tr>
<tr>
<td>18</td>
<td>M, 50</td>
<td>AML</td>
<td>0.01</td>
<td>Distal colon</td>
<td>No infection proven.</td>
</tr>
<tr>
<td>19</td>
<td>M, 34</td>
<td>CML</td>
<td>0.03</td>
<td>Lower left side of abdomen</td>
<td>Unverified. *</td>
</tr>
<tr>
<td>20</td>
<td>M, 40</td>
<td>CML</td>
<td>0.05</td>
<td>Oral cavity</td>
<td>Fulminant oral mucositis.</td>
</tr>
</tbody>
</table>

Abbreviations: BAL, bronchoalveolar lavage; BMT, bone marrow transplant; ALL, acute lymphocytic leukemia; CLL, chronic lymphocytic leukemia; NHL, non-Hodgkin's lymphoma; AF, Aspergillus fumigatus; CF, Citrobacter freundii; Hi, Haemophilus influenzae; GVHD, graft-versus-host disease; AML, acute myelogenous leukemia; CML, chronic myelogenous leukemia; HSV, herpes simplex virus; SA, Staphylococcus aureus; SV, Streptococcus viridans.

*This patient died 1 week after scintigraphy. Permission for autopsy was not given.

x-ray (Fig 2B) but were more distinct. The clinical course was highly suggestive of an Aspergillus infection. Cultural proof could not be obtained despite repeated bronchoalveolar lavages. The patient died 1 month after scintigraphy due to progressive pulmonary infection. Permission for autopsy was not given.

Patient no. 11 with chronic lymphocytic leukemia and high fever had no clinical signs of an infectious focus. On scintigraphy, however, uptake of In-111-IgG was seen in the right side of the lower abdomen (Fig 3). The patient developed abdominal pain 1 week later, and a perforated appendix was surgically removed a few days later.

The scintigraphic results for patient no. 12, a bone marrow transplant recipient who developed fever and mild swelling of the wrist, depict high In-111-IgG uptake in the affected wrist (Fig 4). Puncture did not yield specimens for bacterial culture. After vancomycin had been added to the antibiotic regimen, the patient promptly recovered and the inflammation subsided.

**Overall Results**

**Proven Inflammatory and Infectious Foci Showing Increased In-111-IgG Uptake (True-Positive Studies)**

**Pulmonary lesions.** Two *A fumigatus* infections were proven by culture (patients no. 5 and 8). In one patient (no. 6) the clinical and roentgenologic course was compatible with *aspergillosis*. Two patients (no. 3 and 7) had pulmonary infection caused by bacteria. Patient no. 9 had a toxoplasmosis infection.

**Bone and joint lesions.** Septic arthritis showed increasing In-111-IgG accumulation (patient no. 12). An aseptic, prednisone-induced, femoral head necrosis was also positive on In-111-IgG scintigraphy (patient no. 9).
Fig 1. Patient no. 5. (A) In-111–IgG image of the head (48 hours PI) showing increased uptake in the left mandibular region due to molar root infection (arrow). (B) Anterior In-111–IgG image of the chest (48 hours PI) showing increased uptake in the middle lobe of the right lung (arrow). (C) Chest x-ray 1 week after scintigraphy showing only mild abnormalities in the middle lobe of the right lung. (D) Chest x-ray 2 weeks after scintigraphy showing large hyperdense area, matching the area of increased uptake on In-111–IgG scintigraphy. The patient died in shock 1 week later. Postmortem examination revealed pulmonary infection caused by Aspergillus fumigatus. In-111–IgG scintigraphy depicted pulmonary infection at least 1 week earlier than the chest x-ray.

Abdominal lesions. An appendicular infiltrate that was proven at surgery (patient no. 11) and an infection in the right side of the lower abdomen that was suspected on clinical grounds (patient no. 16) showed increased In-111–IgG uptake.

Soft tissue lesions. A mandibular infiltrate due to a molar root infection (patient no. 5), a postmediastinotomy thoracic wall ulcer (patient no. 10), and a fulminant oral mucositis (patient no. 19) were clearly visualized.

No Infection, Normal In-111–IgG Scintigraphy (True-Negative Studies)

A pleural effusion was photopenic on In-111–IgG scintigraphy. Repeated cultures remained sterile (patient no. 10). Skin lesions showed no increased uptake and were diagnosed as allergic vasculitis rather than septic emboli (patient no. 14). An infectious origin of a right shoulder swelling in patient no. 20 could not be proven by cultures or roentgenologic examination. At a
later date, chloroma was proven by biopsy, histologic examination, and subsequent response to irradiation. In five other patients with normal In-111-IgG scintigraphies, infection could not be proven.

Noninfected Areas With Increased In-111-IgG Uptake (False-Positive Studies)

In two cases (patients no. 13 and 18) infection could not be established. Intense activity was seen in the large bowel. In both patients, no clinical or microbiologic signs of abdominal infection were present. Patient no. 13 remained febrile for approximately 2 weeks. During this
period he was treated with ceftazidime and co-trimoxazole. Normalization of temperature coincided with an increase of the blood granulocyte count. After treatment with ciprofloxacin and co-trimoxazole, patient no. 18 became afebrile within 2 weeks after scintigraphy.

Proven Focal Infections With No Increased In-111-IgG Uptake (False-Negative Studies)

In patient no. 1, a thoracic wall infiltrate caused by \textit{S. aureus} showed no increased In-111-IgG uptake. During scintigraphy, however, the size of the infiltrate and the signs of inflammation had diminished. In the following weeks, an extensive \textit{P. aeruginosa} infection of the chest wall developed.

For patient no. 9 who had toxoplasmosis, proven infection of the heart, kidneys, and liver showed no abnormal uptake.

Unassessable Study

In patient no. 19 a focus in the left side of the lower abdomen could not be verified. The patient died 1 week after scintigraphy. Permission for autopsy was not given.

Calculations for In-111-IgG Scintigraphy

Using the number of evaluated lesions (n = 26) mentioned above, we calculated a sensitivity of 76%, a specificity of 78%, and an accuracy of 77% for In-111-IgG scintigraphy, with a positive predictive value of 87% and negative predictive value of 64%.

DISCUSSION

Results from the animal study showed high In-111-IgG uptake in the infected muscle. Although the number of animals was small and only \textit{S. aureus} infection was studied, the experiment showed that In-111-IgG accumulates in infectious foci, despite low granulocyte counts. In rats without granulocytopenia, the ratio of activity uptake appeared to be lower (between 2.3 and 3.4). Higher uptake in granulocytopenic rats may be explained by greater outgrowth of bacteria in the absence of granulocytes. We chose \textit{S. aureus} infections for these experiments because it is one of the few not rapidly fatal infections in granulocytopenic rats. Data in the literature suggest that the causative microorganism is not a determining factor for accumulation of radiolabeled IgG in infectious foci, even in immunocompromised animals.

Our results in humans indicate that In-111-IgG scintigraphy shows performance characteristics in granulocytopenic patients similar to those in patients with normal or elevated WBC counts. Pulmonary, abdominal, joint, and soft tissue infections were detected. In patients no. 3 and 7 with positive In-111-IgG images of the lungs and clinical and roentgenologic evidence of pulmonary infection, the possibility must be considered that bronchoalveolar lavage might have identified resident oral contamination when the bronchoscope was passed through the nasopharynx rather than recovering the actual pathogenic microbial flora. With In-111-IgG, not only bacterial, but also fungal infections were localized adequately and sometimes in early stages, as demonstrated by patients no. 5 and 11. The diagnosis of infections (especially those caused by fungi) in granulocytopenic patients is notoriously difficult, and the ability to detect such infections holds great promise as it may lead to early microbiologic diagnosis and specific treatment. Even when microbiologic confirmation is not achieved, localization of a focus may give an indication of the causative pathogen.

With regard to our false-positive studies, no infection could be proven in two patients showing marked In-111-IgG uptake in the large bowel. One reason for this accumulation might be significant mucosal barrier damage by cytarabine, given 2 to 3 weeks before imaging. This drug is known to cause extensive desquamation of the intestinal mucosa with exudation and bleeding. Therefore, increased In-111-IgG uptake in the large bowel might have been due to increased protein leakage. Another possible explanation is that local bowel uptake occurred because of a chemotherapy-induced break in the mucosal integrity with local bacterial invasion but negative blood cultures, and the patient's temperature normalized due to empiric antibiotic treatment.

The number of false-negative studies was low. One focal lesion (a thoracic wall infiltrate) was missed. Temporary improvement of the infiltrate in the period of scintigraphic imaging may have accounted for the absence of In-111-IgG accumulation. In a patient with generalized toxoplasmosis, the lungs showed increased In-111-IgG uptake, whereas the heart, kidneys, and liver, containing multiple small lesions, appeared normal on scintigraphy. This is not surprising, as these organs show a relatively high physiologic In-111-IgG uptake in all patients, thereby obscuring possible small lesions in these organs.

If we assume that In-111-IgG scintigraphy is not appropriate for the detection of lesions in organs such as the liver, kidneys, and heart because of high background activity, it is probably justified to delete the missed toxoplasmosis lesions from the calculations. This would
In one patient, an artifact was observed in the subcutaneously tunneled part of the Hickman catheter due to injection of In-111-IgG through the catheter. Since Hickman catheters are known to be the site and source of infection, an optimal scintigraphic image of the tissue around the catheter should be obtained. Therefore, we recommend administering In-111-IgG through direct venipuncture in the contralateral arm.

Despite the use of antibiotics in 18 patients, we obtained high-quality images. It seems unnecessary to stop or alter antibiotic medication for imaging purposes.

Both the animal and patient studies indicate that neutrophils are not a major factor in the uptake of In-111-IgG in infectious foci, making Fc-γ receptor-mediated accumulation an unlikely mechanism. This is in agreement with the hypothesis by Morrel et al, who suggest that In-111-IgG accumulation is caused by enhanced vascular permeability.

Patients with clinically proven infectious foci represent a population different from those with no clinically identifiable focus (eg, with regard to the recommended antibiotic treatment, time course for treatment, and the outcome of the febrile episode). It appears that In-111-IgG scintigraphy will become a valuable additional diagnostic tool for those febrile patients in whom no focus can be identified by conventional techniques or in whom an inflammatory component of known abnormalities is to be evaluated. Further studies are needed to establish whether In-111-IgG scintigraphy can contribute to the improvement of therapy in febrile granulocytopenic patients due to early localization of focal infection, especially in patients with fever of unknown origin who do not respond to antibiotic treatment. Furthermore, the use of follow-up scans during or after adequate treatment of infection warrants further studies.

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