Scintigraphic Evaluation of Experimental Colitis in Rabbits

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Scintigraphic techniques are frequently used for evaluation of inflammatory bowel disease. The radiopharmaceutical of choice is labeled leukocytes. In this study, two new agents, 111In-labeled polyethylene glycol-coated liposomes and 111In-labeled human nonspecific gamma globulin (immunoglobulin G; IgG), were compared with 111In-leukocytes in a rabbit model of colitis. Methods: In rabbits, acute colitis was induced by colonic instillation of trinitrobenzene sulfonic acid at 25 cm from the anal sphincter. After 24 hr, 15 MBq of the radiopharmaceuticals was injected intravenously in groups of four rabbits. Twenty-four hours after injection, the animals were killed and macroscopic abnormalities were scored in seven consecutive affected colonic segments of 5 cm each (0 = normal, 1 = inflammation, 2 = ulcers). The ex vivo uptake was measured in the normal ascending colon and the affected colonic segments. The colitis index (CI, affected-to-normal colon-uptake ratio) was calculated. Results: Histologically, an acute, patchy, transmural colitis was observed at the site of instillation and the distal colon. The CI of all agents in colitis lesions correlated with the severity of the abnormalities. With increasing severity, the CI for liposomes was higher. 1.86 ± 0.24, 4.88 ± 0.42 and 7.42 ± 0.54 (p = 0.68, p < 0.001); for leukocytes 1.77 ± 0.32, 3.10 ± 0.58 and 5.54 ± 0.83 (p = 0.31, p < 0.01); for IgG 1.60 ± 0.29, 2.61 ± 0.21 and 2.65 ± 0.21 (p = 0.29, p < 0.02). Conclusions: Indium-111-labeled-leukocytes, -IgG and -liposomes all show increased uptake in inflamed colonic tissue. Indium-111-liposomes showed the highest CI, which correlates best with the morphological abnormalities. Indium-111-leukocytes and 111In-liposomes are superior to 111In-IgG for this indication.

Key Words: radionuclide imaging; diagnostic imaging; gamma globulin; indium-111; scintigraphy; inflammatory bowel disease

Inflammatory bowel disease is a condition with fluctuating episodes of relapses and remissions of acute colitis. In clinical practice, diagnostic procedures are most helpful for evaluating the status of the diseased colon. The major diagnostic tools are endoscopy (allowing direct inspection of the diseased mucosa), radiographic evaluation using barium enemas (providing images of the morphological abnormalities) and scintigraphic modalities (showing functional images of the degree of inflammatory activity in affected areas in the gut). For the latter technique, a variety of radiopharmaceuticals are available.
When scintigraphic evaluation of the abdomen is considered labeled leukocytes are currently the agent of choice, since high sensitivity and specificity is observed, especially in acute colitis (1). Unfortunately, the preparation of radiolabeled autologous leukocytes has several disadvantages that limit its application. In particular, the necessity to draw and handle possibly contaminated blood constitutes an inherent risk to other patients and staff (2, 3). Moreover, isolation and labeling of leukocytes is a relatively complicated and time-consuming procedure that is not possible in every nuclear medicine facility (4). To overcome these difficulties, research has been directed toward developing agents that are as equally effective, but easier to produce from instant, ready-to-use radiolabeling kits.

In this study in a rabbit model of acute colitis, the targeting of $^{111}$In-labeled-leukocytes is compared with the performance of two recently developed radiopharmaceuticals: $^{111}$In-labeled human nonspecific polyclonal gamma globulin (immunglobulin G; IgG) and $^{111}$In-labeled sterically stabilized liposomes. Indium-111-IgG has already been applied in clinical practice for the diagnosis of a wide variety of infectious and inflammatory processes (5). Labeled liposomes have also been investigated in patients (6, 7). However, these conventional liposomes, as used in the past, are rapidly cleared from the circulation by phagocytic cells of the mononuclear phagocyte system (8). The advantage of sterically stabilized liposomes is the prolonged residence time in circulation with consequently higher levels of uptake in inflammatory foci and low liver and spleen uptake (9–11).

**MATERIALS AND METHODS**

**Animal Model**

In female New Zealand white rabbits (weight 2.5–3 kg), acute colitis was induced as described previously with minor modifications (12–14). Experiments were performed in accordance with the local animal welfare committee guidelines. During the experiment, the rabbits were fasted, but had water ad libitum. Animals were anesthetized with an intravenous injection of a 0.7-ml mixture of fentanyl 0.315 mg/ml and fluanisone 10 mg/ml (Hypnorm). After retrograde insertion of a flexible silicone tube, 1 ml of 30 mg trinitrobenzene sulfonic acid in 30% ethanol, followed by 1 ml 50% ethanol flush, was instilled in the colon 25 cm from the anal sphincter. Thereafter, anesthesia was terminated by intravenous injection of 0.2 ml of naloxon hydrochloride 0.4 mg/ml (Narcan). Twenty-four hours after colitis induction, the respective radiopharmaceuticals were injected through the ear vein.

**Radiopharmaceuticals**

**Indium-111-Leukocytes.** One hundred milliliters of blood were drawn carefully from an anesthetized donor rabbit by carotid artery cannulation in 60 ml syringes, each containing 10 ml 0.33% methylcellulose in citric acid dextrose. The total leukocyte count of the donor rabbit was $10 \times 10^9$/liter, with approximately 50% granulocytes. Preparation of the labeled leukocytes was performed as described previously (15, 16). In brief, after sedimentation of the erythrocytes, the supernatant was removed. The remaining cell suspension was centrifuged twice and the cell pellet was washed with phosphate buffered saline (PBS)/1% HSA. Indium-111-oxine (100 MBq) in 0.2 M tris(hydroxymethyl)aminomethane hydrochloride (pH = 8.0) was added to the cell suspension. After a 30-min incubation period, the cells were incubated at room temperature for 30 min, centrifuged and resuspended in PBS/1% human serum albumin. Morphological integrity of the leukocytes was checked by light microscopic examination. Labeling efficiency (cell associated activity/total activity $\times 100\%$) was higher than 95%. Indium-111-leukocytes (15 MBq) were administered intravenously.

**Indium-111-Liposomes.** Partially hydrogenated egg-phosphatidylcholine with an iodine value of 40 was derived (17). The polyethylene glycol 1900 derivative of distearoyl phosphatidylethanolamine, partially hydrogenated egg-phosphatidylcholine and cholesterol was prepared in a molar ratio of 0.15:1.85:1. A lipid film was formed by rotary evaporation (pH = 8.0) was added to the cell suspension. After a 30-min incubation period, the cells were incubated at room temperature for 30 min, centrifuged and resuspended in PBS/1% human serum albumin. Morphological integrity of the leukocytes was checked by light microscopic examination. Labeling efficiency (cell associated activity/total activity $\times 100\%$) was higher than 95%. Indium-111-leukocytes (15 MBq) were administered intravenously.

**Imaging Procedure and Biodistribution**

Twenty-four hours after colitis induction, three groups of four rabbits were intravenously injected through the ear vein with either $^{111}$In-leukocytes, $^{111}$In-liposomes or $^{111}$In-IgG. The rabbits were immobilized in a mold and placed prone on a gamma camera equipped with a parallel-hole medium-energy collimator. Each rabbit was imaged at 5 min, 1 hr, 4 hr, 10 hr and 20 hr after injection. Images (100,000 counts per rabbit) were obtained and stored in a 256 $\times$ 256 matrix.

After acquiring the final images, the rabbits were killed with an overdose of sodium phenobarbital 24 hr after colitis induction. The colon was resected and tissues were fixed in 4% formaldehyde in PBS. Tissue samples were embedded in paraffin and 5-μm sections were stained with hematoxylin-cosin for light-microscopic examination.
The mucosa shows beginning necrosis and ulceration (arrows). The submucosa is edematous (*). Areas of granulocyte infiltration can be identified throughout the colonic wall. Hematoxylin–eosin-stained transverse sections: (A) ×130, (B) ×330.

FIGURE 1. Histology of trinitrobenzene sulfonic acid-induced acute colitis. The mucosa shows beginning necrosis and ulceration (arrows). The submucosa is edematous (*). Areas of granulocyte infiltration can be identified throughout the colonic wall. Hematoxylin–eosin-stained transverse sections: (A) ×130, (B) ×330.

FIGURE 2. Scintigraphic images of rabbits with experimental colitis. (A) Indium-111 leukocytes, 10 hr postinjection, (B) Indium-111 leukocytes, 20 hr postinjection, (C) Indium-111 liposomes, 10 hr postinjection, (D) Indium-111 liposomes, 20 hr postinjection, (E) Indium-111 IgG, 10 hr postinjection, (F) Indium-111 IgG, 20 hr postinjection. Note the physiological uptake in liver, spleen and for 111In-liposomes and 111In-IgG also kidney and blood pool. ✓ = liver, * = spleen, — > = delineation of colitis.
TABLE 1
Tissue Distribution (%ID/g; mean ± s.e.m.) Obtained 48 hr after Colitis Induction and 24 hr after Injection of the Radiopharmaceuticals

<table>
<thead>
<tr>
<th>Tissue</th>
<th>111In-IgG</th>
<th>111In-leukocytes</th>
<th>111In-liposomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood</td>
<td>0.22 ± 0.03</td>
<td>&lt; 0.01</td>
<td>0.13 ± 0.008</td>
</tr>
<tr>
<td>Muscle</td>
<td>0.01 ± 0.001</td>
<td>&lt; 0.01</td>
<td>0.002 ± 0.0002</td>
</tr>
<tr>
<td>Lung</td>
<td>0.06 ± 0.001</td>
<td>&lt; 0.01</td>
<td>0.06 ± 0.002</td>
</tr>
<tr>
<td>Liver</td>
<td>0.20 ± 0.02</td>
<td>&lt; 0.01</td>
<td>0.53 ± 0.04</td>
</tr>
<tr>
<td>Spleen</td>
<td>0.12 ± 0.008</td>
<td>&lt; 0.01</td>
<td>8.08 ± 1.09</td>
</tr>
<tr>
<td>Kidney</td>
<td>0.19 ± 0.02</td>
<td>&lt; 0.01</td>
<td>0.05 ± 0.006</td>
</tr>
<tr>
<td>Ascending colon</td>
<td>0.05 ± 0.002</td>
<td>&lt; 0.01</td>
<td>0.01 ± 0.003</td>
</tr>
<tr>
<td>Descending colon</td>
<td>0.13 ± 0.01</td>
<td>&lt; 0.01</td>
<td>0.03 ± 0.006</td>
</tr>
</tbody>
</table>

IgG = gamma globulin.
*111In-IgG vs. 111In-leukocytes.
**111In-leukocytes vs. 111In-liposomes.
***111In-liposomes vs. 111In-IgG (p < 0.01).

acute trinitrobenzene sulfonic acid-induced colitis in rabbits. In clinical practice, leukocytes are considered the standard technique for scintigraphic evaluation of disease activity in inflammatory bowel disease (1,22). In this study, 111In-liposomes showed higher absolute, as well as uptake, ratios in diseased colonic segments compared with the 111In-leukocytes. Moreover, correlation of the macroscopic abnormalities observed in the affected colon and relative colonic uptake, of 111In-liposomes was better compared with 111In-leukocytes. In addition, hepatosplenic uptake of 111In-liposomes was considerably lower than that of 111In-leukocytes, which is not only important for adequate scintigraphic evaluation of the alimentary tract in the upper abdomen, but also for reduction of the radiation burden to the spleen and to long-living T-lymphocytes, which are also labeled in mixed leukocyte preparations (23). Despite the lower absolute uptake of 111In-leukocytes in colitis lesions, diseased colon segments could be delineated well since uptake in the background tissues (i.e., normal colon and muscle) was extremely low, providing sufficient contrast. Abnormalities were depicted early on the 111In-leukocyte images due to the relatively fast blood clearance. A major advantage of 111In-liposomes is the ease of preparation of a high-quality radiopharmaceutical without the need to isolate and handle blood.

The superiority of 111In-leukocytes over labeled gamma globulin confirms clinical results with labeled gamma globulin (5,24). The abnormalities depicted by the labeled leukocytes scintigraphy were shown to correlate better with disease activity than those observed on labeled gamma globulin images, indicating relatively low sensitivity and specificity of the latter agent (24,25). In this study, this was exemplified by the lower relative uptake of 111In-IgG in affected colon as compared with 111In-leukocytes (and 111In-liposomes). This lower ratio will obviously make it more difficult to differentiate accumulation in inflamed from normal tissue uptake. Moreover, even the limited physiological excretion of labeled gamma globulin in the gut may interfere with adequate evaluation of diseased colon (5).

The mechanism of accumulation in the target area of 111In-leukocytes and the two new radiopharmaceuticals is entirely different (26). Adequate 111In-leukocytes scintigraphy requires viability of the cells with intact chemotactic capacities, since the labeled cells must actively migrate to an inflammatory target similar to unlabeled leukocytes. When damaged, the labeled cells show prolonged margination in the lungs, followed by enhanced clearance by the mononuclear phagocytic system (27). This further emphasizes the need for careful preparation of leukocytes during labeling. Indium-111-liposomes and 111In-IgG both accumulate in inflamed tissue by virtue of increased vascular permeability (26). Thus, prolonged intravascular activity will be beneficial for the degree of uptake in inflammation. This also explains why agents like labeled colloids (also a particulate radiopharmaceutical) do not provide adequate delineation of colitis (28,29). Colloids have a short circulation time and distribute rapidly to liver, spleen and bone marrow without sufficient focal uptake in disease. Similar characteristics can be observed with non-PEGylated larger liposomes (6,7). Whether any specific uptake of labeled liposomes in inflammatory cells plays a role in accumulation of the radiopharmaceutical in inflammatory foci remains to be established.

CONCLUSION

Indium-111-liposomes were superior to 111In-leukocytes for scintigraphic evaluation of acute colitis due to high focal uptake and relatively low accumulation in many organs. In addition, in view of the ease of preparation, this new formulation is particularly attractive for progression to clinical studies. Indium-111n-IgG was not very well suited for imaging colitis, because the uptake in diseased segments was relatively low and