Technetium-99m labelled liposomes to image experimental arthritis

Otto C Boerman, Wim J G Oyen, Gert Storm, M Luisa Corvo, Louis van Bloois, Jos W M van der Meer, Frans H M Corstens

Abstract

Objectives—Liposomes sterically stabilised with polyethylene glycol (PEG) labelled with technetium-99m were tested for their ability to image adjuvant arthritis in a rat model.

Methods—Adjuvant arthritis was induced in the ankle joint of the left hind foot by injection of Mycobacterium butyricum in Freund's incomplete adjuvant in the foot pad. Seven days later animals received the following radiopharmaceuticals labelled with \(^{99m}\)Tc: (a) non-PEG-liposomes, (b) PEG-liposomes, or (c) non-specific human polyclonal IgG. For each of the radiopharmaceuticals the in vivo distribution of the radiolabel was monitored both scintigraphically as well as by counting the dissected tissues at two, eight, and 24 hours after injection.

Results—The pharmacokinetics of the radiopharmaceuticals differed considerably (half life in the blood: PEG-liposomes (18 hours) > \(^{99m}\)Tc-IgG (3 hours) > non-PEG liposomes (1 hour)). The inflamed focus was visualised with each of the agents. The uptake of each of the radiopharmaceuticals in the inflamed ankle region correlated with their residence time in the blood (inflamed joint uptake: PEG liposomes (1.15% injected dose (ID)/g) > \(^{99m}\)Tc-IgG (0.35% ID/g) > non-PEG-liposomes (0.05% ID/g)). Quantitative analysis of the images showed that the inflamed ankle to background ratio was highest with the PEG-liposomes (7.5 at 24 hours after injection), while with the other two agents this ratio did not exceed 4.

Conclusion—This study shows that \(^{99m}\)Tc-labelled PEG-liposomes may be an excellent agent to visualise arthritis. Increased label uptake in the inflamed joint and increased target to background ratios can be obtained with PEG-liposomes because of their long circulating properties. In addition to their use as vehicles for scintigraphic imaging of arthritis PEG-liposomes might also be used for the site specific delivery of antirheumatic drugs.

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arthritis. Moreover, PEG-liposomes can also be 'loaded' with drugs and thus could potentially be used for site directed delivery of antirheumatic drugs.

In this study we compared the imaging potential of \( ^{99m} \)Tc-PEG-liposomes with that of non-PEG-liposomes and the commercially available imaging agent \( ^{99m} \)Tc-IgG, in rats with adjuvant arthritis.

**Methods**

**ANIMAL MODEL**

Adjuvant arthritis was induced in the left foot of randomly bred male Wistar rats (3 month old, body weight 300 g) as described by Weisman. After ether anaesthesia, 0.1 ml of a suspension of M ycobacterium butyricum (Difco Labs, Detroit, MI) in Freund's incomplete adjuvant (Sigma Chemical Co, St Louis, MO) (10 mg/ml) was injected in the foot pad of the left foot. Six days after induction, accumulation of mononuclear cells in the loose connective tissues of the foot can be appreciated at histological examination. Seven days after the inoculation, the respective radiopharmaceuticals were injected via the tail vein.

**PREPARATION OF LIPOSOMES**

Partially hydrogenated egg-phosphatidylcholine with an iodine value of 40 (PHEPC) prepared as described previously was obtained from Asahi Chemical Industry Co (Ibaraki, Japan). Cholesterol and glutathione were obtained from Sigma (St Louis, MO). For the preparation of PEG-liposomes the polyethylene glycol (PEG) 1900 derivative of DSPE (Avanti Polar lipids, Montreal) was used as an ingredient.

A chloroform/methanol mixture (10/1, v/v) containing DSPE, PHEPC, and cholesterol was prepared at a molar ratio of 0.15:1.85:1. A lipid film was formed by rotary evaporation followed by high vacuum to remove residual organic solvent. The lipid film was dispersed at room temperature in 50 mM glutathione in HEPES buffer (10 mM HEPES, 135 mM NaCl, pH 7.5) at a phospholipid concentration of 120 mM. The liposomes were sequentially extruded through polycarbonate filters of 200, 100, 80, and 50 nm pore size (Poretics, Livermore, CA). Unentrapped glutathione was removed by gel filtration on a 10DG column (Bio-Rad) eluted with 5% glucose.

**LABELLING PROCEDURES**

Preformed glutathione containing non-PEG-liposomes or PEG-liposomes were labelled with \( ^{99m} \)Tc essentially as described previously. \( ^{99m} \)Tc was transported by \( \text{d,L-} \)hexamethylene propylene amine oxide (HMPAO) through the bilayer and trapped irreversibly in the internal aqueous phase caused by reduction by the encapsulated glutathione. Briefly, 2.0 ml of liposomes (75 mmol phospholipid/ml) were incubated for 15 minutes at room temperature with 20 mCi \( ^{99m} \)Tc-HMPAO. Removal of unencapsulated \( ^{99m} \)Tc-HMPAO was achieved by gel filtration on a 10DG column (Bio-Rad) eluted with 5% glucose.

A Technescan-HIG vial (Malinckrodt Medical, Petten, the Netherlands) was reconstituted with 20 mCi \( ^{99m} \)Tc-pertechnetate according to the manufacturer's instructions. The resulting \( ^{99m} \)Tc-IgG was used without any further purification.

**BIODISTRIBUTION STUDIES**

Seven days after the inoculation of \( M \) butyricum in the foot pad, 45 rats were divided randomly into three groups of 15 rats. Each group was injected with 100 \( \mu \)Ci of either \( ^{99m} \)Tc-labelled non-PEG-liposomes, PEG-liposomes or \( ^{99m} \)Tc-IgG via the tail vein.

At two, eight, and 24 hours after injection, five rats of each group were killed with 30 mg intraperitoneally injected phenobarbital. Blood was obtained by cardiac puncture. After cervical dislocation, several tissues (inflamed left ankle, right ankle, muscle, liver, spleen, kidney, intestine, right femur, and bone marrow from the right femur) were dissected, weighed, and their activity was measured in a shielded well type gammacounter. To correct for physical decay and to permit calculation of the uptake of the radiopharmaceuticals in each organ as a fraction of the injected dose, aliquots of the injected dose were counted simultaneously. Inflamed ankle to contralateral ankle uptake ratios (IA/CA) were calculated.

**IMAGING PROTOCOL**

Adjuvant arthritis was induced in another nine rats as described above. Seven days later, groups of three rats received 300 \( \mu \)Ci of \( ^{99m} \)Tc-labelled non-PEG-liposomes, PEG-liposomes or \( ^{99m} \)Tc-IgG via the tail vein. Rats were anaesthesised (halothane/nitrous oxide/oxygen) and were placed prone on a single head gammacamera equipped with a parallel hole low energy collimator (Orbiter, Siemens Inc, Hoffman Estates, IL). The three groups of rats were imaged synchronously at five minutes, one, two, four, six, and 24 hours after injection. Symmetric 15% windows were used for the 140 keV energy peak. Images (300 000 counts per image) were obtained and stored in a 256 x 256 matrix.

The scintigraphic results were analysed by drawing regions of interest over the heart region, the inflamed foot, over the normal contralateral foot—used as a background region —and over the whole animal. Inflamed foot to background ratios and percentage residual activity in the inflamed foot (inflamed foot to whole body ratio) were calculated.

**STATISTICAL ANALYSIS**

Values are given as mean (SD). Statistical analysis was performed using the one way analysis of variance test.
Results

LABELLING AND QUALITY CONTROL OF THE RADIOPHARMACEUTICALS

The labelling efficiency of Technescan HIG 10 minutes after reconstitution with 20 mCi of 99mTcO4− was 97% as determined by instant thin layer chromatography (Gelman Labs, Ann Arbor, MI). The non-PEG and the PEG-liposomes were labelled with 99mTc-HMPAO with a labelling efficiency of 73% and 76%, respectively. Analysis of a sample of each of the purified labelled liposome preparations on a BioRad 10DG column indicated that more than 96% of the radioactivity was associated with the liposomes.

BIODISTRIBUTION STUDIES

Table 1 shows the biodistributions of the 99mTc-labelled non-PEG-liposomes, PEG-liposomes, and 99mTc-IgG in rats with adjuvant arthritis induced in the left foot. The non-PEG-liposomal preparation cleared very rapidly from the blood: two hours after injection blood concentrations had fallen to values as low as 0.17 (0.03)% ID/g. These non-PEG-liposomes showed relatively high uptake in liver and spleen early after injection (2.65 (0.20) and 5.10 (1.09)% ID/g, respectively at two hours after injection). In contrast, blood clearance of the PEG-liposomes was much slower (fig 1A). Blood concentrations of the 99mTc-IgG preparation were intermediate between those of the two liposomal preparations at all time points (fig 1A).

The three radiopharmaceuticals also showed considerable differences in uptake in the inflamed ankle (table 1). With the PEG-liposomes this uptake increased over time up to a value of 1.15 (0.18)% ID/g at 24 hours after injection, while the inflamed ankle uptake with the non-PEG-liposomes and the 99mTc-IgG remained almost at the same level throughout the study period (0.1% ID/g and 0.5% ID/g, respectively) as shown in figure 1B. At eight hours and 24 hours after injection the IA/CA ratio obtained with the PEG-liposomes was significantly higher than the ratio obtained with the other two radiopharmaceuticals (p<0.05). The IA/CA ratios obtained with the PEG-liposomes increased in time up to a value of 7.51 (0.91) (fig 2).

Both liposomal formulations showed relatively high uptake of the radiolabel in the spleen. At 24 hours after injection splenic uptake was 4.0 (0.8)% ID/g and 11.1 (1.5)% ID/g for non-PEG and PEG-liposomes, respectively. With the 99mTc-IgG preparation uptake in the spleen was much lower (0.34 (0.04)% ID/g, 24 hours after injection). With this radiopharmaceutical the kidney was the organ with the highest activity (7.62 (1.29)% ID/g, 24 hours after injection).

IMAGING STUDIES

The inflamed foot was visualised with each of the radiopharmaceuticals included in this study. Figure 3 shows the image 24 hours after injection of the rats that received 99mTc-labelled non-PEG-liposomes, PEG-liposomes or 99mTc-IgG.

Table 1  Biodistribution of 99mTc-non-PEG-liposomes, 99mTc-PEG-liposomes, and 99mTc-IgG in rats with adjuvant arthritis on the left ankle. Five rats per group were used. Error bars represent SD.

<table>
<thead>
<tr>
<th>Non-PEG-liposomes</th>
<th>PEG-liposomes</th>
<th>99mTc-IgG</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 hours</td>
<td>8 hours</td>
<td>24 hours</td>
</tr>
<tr>
<td>Blood</td>
<td>0.17 (0.03)</td>
<td>0.07 (0.01)</td>
</tr>
<tr>
<td>Inflamed ankle</td>
<td>0.10 (0.01)</td>
<td>0.11 (0.04)</td>
</tr>
<tr>
<td>Muscule</td>
<td>0.03 (0.00)</td>
<td>0.01 (0.00)</td>
</tr>
<tr>
<td>Bone marrow</td>
<td>0.29 (0.08)</td>
<td>0.25 (0.09)</td>
</tr>
<tr>
<td>Femur</td>
<td>0.08 (0.03)</td>
<td>0.03 (0.01)</td>
</tr>
<tr>
<td>Lung</td>
<td>0.16 (0.05)</td>
<td>0.09 (0.02)</td>
</tr>
<tr>
<td>Spleen</td>
<td>5.01 (1.09)</td>
<td>5.04 (1.21)</td>
</tr>
<tr>
<td>Kidney</td>
<td>3.68 (0.45)</td>
<td>3.56 (0.71)</td>
</tr>
<tr>
<td>Liver</td>
<td>2.65 (0.29)</td>
<td>2.61 (1.13)</td>
</tr>
<tr>
<td>Intestine</td>
<td>0.12 (0.02)</td>
<td>0.05 (0.01)</td>
</tr>
<tr>
<td>IA/UA ratio</td>
<td>2.97 (0.35)</td>
<td>4.97 (2.48)</td>
</tr>
</tbody>
</table>

Data shown as mean (SD).
liposomes, and the $^{99m}$Tc-PEG-liposomes was 18 hours, one hour, and three hours, respectively (data not shown). Furthermore, quantitative analysis of the images confirmed the superiority of the PEG-liposomes: from four hours onwards the uptake in the inflamed foot was significantly higher for the PEG-liposomes as compared with the other preparations ($p < 0.03$) (fig 4). Activity in the contralateral foot was low for each of the radiopharmaceuticals. Consequently, inflamed foot to background ratios were highest for the PEG-liposomes as well (7.4 (1.1) vs 3.6 (1.5), 24 hours after injection).

**Discussion**

This study showed that in a rat model PEG-liposomes preferentially localise to arthritic joints, and thus PEG-liposomes potentially could be used (a) to image rheumatoid arthritis or (b) for the site specific delivery of antirheumatic drugs. The diagnosis of rheumatoid arthritis in patients with typically established disease is relatively easily made, but may be more difficult early in the course of the disease. An accurate clinical and diagnostic evaluation in patients is important because early treatment to suppress the inflammatory process may prevent progressive damage to articular structures. Furthermore, accurate assessment of the status of the disease allows a more objective way to evaluate the efficacy of the therapeutic regimen.

Liposomes, sterically stabilised with PEG, have been shown to preferentially localise to infectious foci. In previous studies we have shown that sterically stabilised liposomes labelled with gamma-emitters can be used to image infectious and inflammatory foci in soft tissue. This study in rats with adjuvant arthritis showed that $^{99m}$Tc-PEG-liposomes are superior to both $^{99m}$Tc-non-PEG-liposomes as well as $^{99m}$Tc-IgG to image experimental arthritis. The PEG-liposomes were superior in terms of both absolute uptake in the target tissue as well as target to background ratios. Several studies in patients with rheumatoid arthritis have shown that $^{99m}$Tc-IgG is a useful imaging agent for the clinical evaluation of rheumatoid arthritis, further supporting the clinical potential of $^{99m}$Tc-labelled PEG-liposomes. In addition, the finding that PEG-liposomes displayed the highest absolute uptake in the inflammatory foci suggests that PEG-liposomes could also be exploited for site specific delivery of antirheumatic drugs. It has been shown in a rat model that liposomal methotrexate is more effective than the free drug in adjuvant arthritis. We have studied the therapeutic potential of using liposomes with encapsulated oxygen derived free radical scavengers in the model used in this study (Corvo et al., unpublished data).

The performance of the non-PEG-liposomes in this study was comparable with the results obtained in previous studies: an optimised formulation of non-PEG-liposomes evaluated in a rat model of adjuvant arthritis revealed an initial half life of one to two hours, with an IA/CA ratio of 4. In clinical studies

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**Figure 2.** Inflamed ankle to unaffected ankle ratio obtained with non-PEG-liposomes, PEG-liposomes, and $^{99m}$Tc-IgG two hours, eight hours, and 24 hours after injection. The biodistribution data of five rats per group were used. Error bars represent SD.

**Figure 3.** Scintigrams of rats with adjuvant arthritis imaged 24 hours after injection of $^{99m}$Tc-labelled PEG-liposomes, non-PEG-liposomes, and $^{99m}$Tc-IgG.

**Figure 4.** Quantitative analysis of the scintigraphic images of rats (three rats per group) injected with $^{99m}$Tc-labelled non-PEG-liposomes, PEG-liposomes, and $^{99m}$Tc-IgG. The activity in the inflamed foot was assessed. The whole body activity at five minutes after injection was set at 100%ID. Error bars represent SD.
Scintigraphic detection of experimental arthritis

The skilled assistance of G Grutters (Central Animal Facility, Hospital Nijmegen) in the preparation of the radiopharmaceuticals is gratefully acknowledged. Koenders (Department of Nuclear Medicine, University Hospital Nijmegen) in the preparation of the radiopharmaceuticals is gratefully acknowledged.

The role of Fc receptor interaction in the accumulation of IgG in inflammatory foci is minimal. Therefore, scintigraphic detection of rheumatoid arthritis with either IgG or liposomes both represent non-specific targeting methods, exploiting the increased capillary permeability in inflammatory foci. Consequently, it is expected that imaging with a liposome based radiopharmaceutical cannot discriminate rheumatoid arthritis from other inflammatory processes in joints. The role of radiolabelled liposomes in the diagnostic investigation of patients with rheumatoid arthritis has to be determined in clinical studies.

In conclusion, this study shows that PEG-liposomes may be powerful vehicles for scintigraphic imaging of the joints affected by rheumatoid arthritis as well as for the targeted delivery of antirheumatic drugs.