Direct Intralymphatic Injection of Radiolabeled $^{111}$In-T101 in Patients with Cutaneous T-Cell Lymphoma

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ABSTRACT

Direct intralymphatic administration of radiolabeled monoclonal antibody in targeting antigen-bearing lymphoma cells in regional lymph nodes of patients with cutaneous T-cell lymphoma was evaluated. Seven consecutive patients undergoing staging lymphangiography received intralymphatic infusions of $^{111}$In-T101 to evaluate lymph node involvement. This procedure was accomplished without significant complication. The $^{111}$In-T101 rapidly distributed throughout the regional lymphatic compartment and passed into the systemic circulation. Tumor-bearing sites in the inguinal-femoral lymph nodes retained from 0.42 to 4.8% of the injected dose of radiolabeled antibody. Three patients were upstaged to Stage IV A based on tumor involvement found after radiolymphoscintigraphy-directed biopsy of groin lymph nodes, selected because of intense radioactivity by gamma camera imaging. Compared with previously reported s.c. antibody administration, there was a marked reduction in the radioactive exposure of normal tissues at the injection sites in the lower extremities. Direct intralymphatic delivery of $^{111}$In-T101 appears to be a feasible, efficient method for delivering therapeutic doses of radiolabeled antibody.

INTRODUCTION

CTCL* is a distinctive subtype of lymphoma, possibly of reticular etiology (1), which is rarely cured by existing therapies (2). T101 is a murine monoclonal antibody which binds to CD5, an M, 65,000 antigen, expressed on normal T-cells as well as on malignant T- and B-cells (3). Administration of the radiolabeled $^{111}$In-T101 i.v. for radioimmunoscintigraphy of both CTCL and chronic lymphocytic leukemia patients has resulted in reproducible imaging of tumor-involved sites (4–7). Biopsy of involved lymph nodes in patients with CTCL showed recovery of only a very small fraction of the injected dose (<0.02%,g), but this was approximately 10–100 times greater than previously reported delivery of radiolabeled monoclonal antibodies in solid tumors (4–8). Delivery of $^{111}$In-T101 i.v. also resulted in >50% of the injected dose localizing in the liver and spleen.

In a therapeutic trial, administration of large doses of unlabeled T101 did not result in significant clinical benefit despite a transient lowering of circulating tumor cell number (9, 10). To enhance the therapeutic effect, Rosen et al. (11) coupled iodine-131 to T101 for administration to patients with refractory CTCL. The five patients with CTCL treated with $^{111}$In-T101 experienced brief objective and subjective improvements, but bone marrow toxicity was dose limiting.

One way to decrease nonspecific reticuloendothelial uptake, to improve the efficiency of lymph node imaging, and to reduce toxicity in therapeutic trials is to administer antibody s.c. for regional lymphatic uptake. Extensive animal studies have shown that s.c. delivery of monoclonal antibody results in highly efficient delivery to lymphoid target cells in the regional lymphatics with much less systemic uptake than is seen with i.v. injection (12–16).

Delivery of $^{111}$In-T101 s.c., into the web spaces of the foot of patients with CTCL also resulted in efficient delivery of the labeled antibody to normal and tumor-involved lymph nodes along the draining regional lymphatic vessels (17, 18). Comparison of biopsy data from patients receiving $^{111}$In-T101 by s.c. administration showed a much greater percentage of injected dose recovered from cancerous lymph nodes than previously reported with i.v. radiolabeled T101 administration (18). Since regional lymph nodes are thought to be an important proliferative compartment for malignant cells in CTCL (19, 20), this is a potentially important target for radiolabeled T101 therapy. After s.c. $^{111}$In-T101 antibody administration, a large fraction of the injected radioactive dose remained at the injection sites, which cleared with a half-life of 14–29 h. This local retention resulted in 136–280 rads/mCi, or a total of 34–70 rads, to each foot per study (17, 18). This radiation dose exposure did not result in clinical toxicity. However, the α- and β-emitting isotopes required for therapeutic purposes would exceed limits of local tissue tolerance if delivered s.c. (21).

In the present study, we infused radiolabeled monoclonal antibody directly into cannulated lymphatic vessels of the foot at the time of routine diagnostic lymphangiography. The technique of direct antibody injection in the lymphatics was pioneered by Order et al. (22) using heteroantibody preparations directed against tumor-associated antigens. Further work with regional delivery of radiolabeled antibody in patients with carcinoma was reported by DeLand et al. (23). The goal of this approach would be to preserve the efficiency of tumor tissue
targeting reported with the s.c. lower extremity monoclonal antibody injections and to ameliorate the problem of retention of radiolabeled monoclonal antibody at the injection site.

MATERIALS AND METHODS

Patients. Seven patients with histologically confirmed CTCL were studied (Table 1). These investigations were done under a protocol approved by a National Cancer Institute-Institutional Review Board, and all patients gave informed consent. Patients being evaluated for this study were also being evaluated for an ongoing National Cancer Institute-Navy Medical Oncology Branch therapy protocol for treatment of CTCL that entailed an extensive staging evaluation of lymph nodes, peripheral blood, skin, and visceral for evidence of disseminated disease. The details and rationale for this staging approach have been previously published, and this evaluation includes standard lymphangiography (24-27). The median age was 45 years and 5 of the 7 patients were males. In all of the patients in this study the sites of documented tumor involvement were restricted to skin and lymph nodes. Three patients had T1 skin involvement (<10% of their total skin area was involved with lesions) suggestive of CTCL. Three patients had T2 skin involvement (>10% of their total skin clinically involved with CTCL plaques). The final patient had extensive CTCL tumors of the skin. Two patients had palpable inguinal lymphadenopathy, and the 5 remaining patients had no evidence of nodal involvement.

No patient had visceral involvement. Although one lymphangiogram was abnormal, it was classified for staging as not being diagnostic of lymphoma. All but one patient had clinical stage IA disease, considering the result of the routine staging evaluation.

Monoclonal Antibody Characteristics. The T101 monoclonal antibody has been the subject of numerous previous publications (3-11,17,18, 28). It is a murine IgC2a that recognizes the CD5 cell surface antigen, which is known to modulate (29). The monoclonal antibody 9.2.27 (IgC2a), which binds to a high molecular weight proteoglycan antigen expressed on melanoma but not CTCL cells, was used as an isotypically matched control (30). Although not previously reported, studies with s.c. administered 125I-9.2.27 showed preferential binding to normal lymph nodes when compared to 125I-BL-3 and IgC1 antiidiotypic monoclonal antibody (30). The 9.2.27 and the T101 used for these studies were prepared and labeled as previously reported (6, 31).

As summarized in Table 2 quality control analysis revealed an incorporation of 92-99% of the indium-111 onto the antibody, and the final immunoreactivity ranged from 61-87% (mean, 76.8%) as determined in a cell-binding assay (4-6) (Table 2). The final antibody conjugate preparations were sterile and pyrogen free.

Study Methods. A total of six patients were studied on the day of the lymphangiography by intralymphatic injection of T101 in dosages including 0.1, 0.5, and 1 mg (Table 2). Five patients received bilateral intralymphatic 111In-T101 antibody, with one-half of the injectate infused into the cannulated lymphatic of the dorsum of each foot. One patient, because of severe chronic obstructive pulmonary disease, received an ipsilateral contrast pedal lymphangiogram with direct intralymphatic administration of 111In-T101 (500 µCi/5 ml) and a contralateral s.c. injection of the radiolabeled T101. The previously reported s.c. injection technique was used, and the radionuclide conjugate was injected into the web spaces of the foot using a 25-gauge needle (17).

The seventh patient underwent a similar study to evaluate the specificity of the imaging. First, he received bilateral intralymphatic injections of the isotypically matched control antibody, 111In-9.2.27. Twelve days later, he received bilateral injections of 111In-T101 in the web spaces of the feet.

The direct intralymphatic injections were performed in the course of standard diagnostic lymphangiography. A small volume of Evans blue dye with 1% xylocaine was injected into the web spaces of the foot to facilitate localization of the lymphatic vessels. A lymphatic vessel was then cannulated with a 30-gauge lymphangiography needle. Patency was established by infusing normal saline with a Hobb's pressure-sensitive pump. For patients in whom adequate cannulation of the lymphatic vessel was in question, a small amount of radiodense lymphangiogram contrast agent (ethiodol) was injected to determine patency. For the direct intralymphatic antibody delivery, the total activity of the indium-111 injected was 500 µCi. The radioisotope was chelated to approximately 0.1 mg of T101, and additional unlabeled T101 was added when necessary to obtain the final antibody mass (up to 1 mg). The preparation was then diluted to a volume of 10 ml and divided in half. Five-ml portions were then infused intermittently into the cannulated lymphatic vessels by the pressure-sensitive pumps over approximately 30 min. Immediately after infusion of the radiolabeled T101, ethiodol lymphangiographic dye for the diagnostic lymphangiogram was injected, typically over a 2-h period.

Upon completion of infusion, patients were scanned using a large field-of-view gamma camera equipped with a medium-energy collimator. Twenty % windows were centered over the 173- and 247-keV photopeaks of indium-111. Serial 10-min spot images of the feet, pelvis, abdomen, and chest were obtained on a nuclear medicine computer at intervals starting within 4 h of injection and continued up to 4 days thereafter. Anterior whole body images were also obtained 2-4 days after injection. The images were analyzed by drawing regions of interest over the liver, spleen, lymph nodes, and lymphatics of the lower extremities. The total counts administered were calculated from the region of interest analysis of a previously studied group of patients who received identical amounts of the labeled antibody via a s.c. injection (17, 18).

Decay-corrected data were used for calculating the uptake and clearance of radioactivity in lymph nodes and other organs. Activity in inguinal-femoral nodes, iliac nodes, and injection site on each side was expressed as a percentage of initial activity injected on that side. Activity in paraaortic nodes, liver, and spleen was expressed as a fraction of total initial administered activity, (i.e., amount of activity injected in both feet). Because of their relatively superficial location, counts in the lymphatics and inguinal-femoral and iliac nodes were not corrected for attenuation. Liver, spleen, and paraaortic nodes were assumed to be underestimated by a factor of 2 because of tissue attenuation based on the half-value layer of approximately 15 cm in water for the γ-photon

<table>
<thead>
<tr>
<th>Patient</th>
<th>Antibody (IgC2a)</th>
<th>Route of delivery</th>
<th>111In activity (µCi)</th>
<th>111In-protein incorporation (%)</th>
<th>Antibody immunoreactivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>i.l.*</td>
<td>500</td>
<td>95</td>
<td>70</td>
</tr>
<tr>
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<td>0.1</td>
<td>i.I.</td>
<td>500</td>
<td>95</td>
<td>84</td>
</tr>
<tr>
<td>3</td>
<td>0.2*</td>
<td>i.I./s.c.</td>
<td>1000</td>
<td>94</td>
<td>72</td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
<td>i.I.</td>
<td>500</td>
<td>99</td>
<td>87</td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>i.I.</td>
<td>500</td>
<td>97</td>
<td>83</td>
</tr>
<tr>
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<td>500</td>
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<td>81</td>
</tr>
<tr>
<td>7A</td>
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<td>i.I.</td>
<td>500</td>
<td>95*</td>
<td>65*</td>
</tr>
<tr>
<td>7B</td>
<td>0.5</td>
<td>s.c.</td>
<td>500</td>
<td>92</td>
<td>61</td>
</tr>
</tbody>
</table>

| Mean    | 95.7            | 76.8             |

* i.l., intralymphatic.

* A final T101 dose of 0.1 mg was administered to both of the lower extremity by either s.c. or direct intralymphatic injection as described in "Study Methods."

* Data from administration of 111In-9.2.27 conjugated (patient 7A) were not included in calculation of the mean.
of indium-111 (17, 18). The activity in the lymphatics was expressed as a percentage of total activity in the whole body at the time of evaluation. While these calculations are inexact because of variable attenuation of radioactivity from the study subject, the quantitation is valid to permit approximate comparison with other published reports (17, 18, 31). Vital signs were monitored. Serial blood and plasma samples were obtained at 5 and 30 min; 1, 2, 24, 48, and 72 h; and later time points when feasible. Serial 24-h urine collections were performed up to 3 days.

Plasma volume was determined from nomograms using the patient’s body surface area. The total circulating plasma activity was calculated based on the concentration of indium-111 in plasma and the plasma volume. Liver and renal function were monitored at the time of the study and 1 week after infusion. Five of 7 patients underwent lymph node biopsies at 1–10 days after the labeled antibody administration. For each patient the surgeon was directed to biopsy a lymph node from a site of the inguinal chain which was marked and corresponded to the highest tracer uptake on the gamma camera images. The biopsy sample was weighed and counted in a gamma counter along with a standard, and the percentage of the injected dose/g was calculated. Since only one-half of the total injected dose was available for binding to these ipsilateral inguinal-femoral lymph nodes, the percentage of injected dose/g was doubled to allow relevant comparisons to other organs.

Patients were evaluated for development of a human anti-mouse antibody response. Baseline and serial post-antibody infusion sera were tested as previously described (5, 32). Briefly, 1 μl of patient serum was incubated with 0.5–1 ng (10,000 cpm) of iodine-125-labeled B7.2.3, an IgCl anti-carcinoma monoclonal antibody. The total reaction volume was 110 μl and the incubation was for 20 h at 40°C. Then, 20 mg of formalin-fixed staphylococcal A cells (Immunoprecipitin; Bethesda Research Laboratories, Bethesda, MD) was added for 15 min at 40°C. The immunoglobulins were then precipitated by centrifugation at 3000 rpm. Human anti-murine antibody level was calculated as a percentage of the total counts in each assay tube that bound to protein A after correcting for nonspecific binding. To determine nonspecific binding, a control using normal serum was used. Generally, the activity bound by protein A in these tubes was the same as, or 1–2% lower than, the activity bound by protein A when no serum was added. The variance of the nonspecific tubes was used to determine the significance of a human anti-mouse antibody level, which had to be >3 SD above the average nonspecific binding value to be considered positive. The mean SD over a 6-month period of performing this assay was 2.2%. To validate this assay a high-performance liquid chromatography-based technique of assaying for specific immune complexes indicative of a host immune response was also performed as previously reported (32).

RESULTS

All three concentrations of T101 used in this study resulted in good visualization of lower trunk and paraaortic lymph nodes, even at the earliest imaging time points (17, 18). A representative scintigraphic image, obtained 48 h after infusion of the monoclonal antibody, is shown in Fig. 1. At the time of the initial imaging inguinal, iliac, and paraaortic nodes could be visualized. Liver and spleen were also visualized, although to a lesser degree (liver and spleen not included in the field of view in Fig. 1). In all patients, there was irregular uptake along the length of the lower extremity lymphatic channel after intralymphatic delivery of radiolabeled antibody (Fig. 2) (ranging from 6 to 26% of the retained dose/extremity, as determined from the whole body scan). Radionuclide uptake in the lymphatic channels decreased >50% within 48 h (Fig. 2, right). Residual activity at 4 h in the injection site ranged from 0.2 to 14.2% (3.8 ± 4.7%, mean ± SD) of the ipsilateral injected dose as determined by a large-field region of interest quantitation, which counted the entire foot.

In Table 3 data obtained from the in vitro analysis of lymph node biopsies are summarized. The five lymph nodes evaluated had a mean weight of 2.9 g (range, 0.8–6.2 g). The percentages of total injected dose/g of tissue were 0.22 and 0.42% for the two histologically benign nodes (LN-2) and ranged from 0.28 to 4.4% for the three histologically malignant nodes (LN-3). The total percentage of injected dose counted in the resected lymph nodes ranged from 0.384 to 4.8. A mean of 0.87% of injected dose was recovered from the two biopsied lymph nodes with only mild dermatopathic changes and a mean of 2.89% of injected dose was recovered from the three pathologically involved lymph nodes. Fig. 1 shows representative scan findings with region of interest analysis of the whole body scanning of patient 4. It shows that 16.6%, 13.5, and 3.8% of total injected radioactivity were retained in the right groin, left groin, and paraaortic lymph nodes, respectively.

In four patients, the inguinal lymph node biopsies were performed in the area of most intense radioactivity after infusion of the radiolabeled antibody. None of these sites were suspected clinically to be involved with tumor. Three of these four scan-directed biopsies revealed tumor involvement (extensive dermatopathic changes with large clusters of convoluted cells or a totally effaced lymph node) (27). The fifth biopsied patient was the one who first received radiolabeled 9.2.27. The node biopsy was performed on a clinically suspicious node, but no pathological evidence of tumor was seen. This biopsy was performed on a lymph node region thought to be part of the most intense area of radioactivity after the s.c. injection of radiolabeled T101. Although a 1.8-g lymph node was removed, follow-up scanning revealed little decrease in the original radioactivity of the targeted nodal cluster (in contrast to what was observed for all of the other post-biopsy scans). At completion of pathological staging, including the results of the scan-directed lymph node biopsies, four patients were considered to have disseminated (IVA) disease (19). Three of the five patients who had a T101-directed lymph node biopsy were upstaged from stage I to stage IV, in the absence of any other clinical tests demonstrating advanced disease.

Table 4 summarizes the region of interest analysis from whole body scans. Intralymphatic delivery of labeled T101 in five patients is compared with intralymphatic delivery of 111In-9.2.27 in the control patient. A greater mean percentage of radioactivity was counted in lymph nodes after infusion of T101 conjugate than after infusion of 9.2.27 conjugate (31 versus 19%). In contrast, a greater amount of 9.2.27 remained in the lower extremity (45 versus 32%). A modestly higher percentage of injected dose (36 versus 24%) of 9.2.27 was found in liver and spleen as compared with T101.

One patient received an initial injection of isotypic control antibody 9.2.27 into the lymphatics of the feet. After it was documented that he had no evidence of human anti-mouse antibody response from the initial antibody administration, this patient also had a follow-up s.c. 111In-T101 scan 12 days later. Representative images from the two different antibody studies are shown in Fig. 3. Considerably more radiolabeled antibody was retained in the feet after s.c. antibody injection than after direct intralymphatic antibody infusion. The concentration of radioactivity was quantitated from the whole body scan. The concentration in regional inguinal-femoral lymphatics after intralymphatic delivery of 111In-9.2.27 was less than that seen with 111In-T101. The percentages of injected dose retained at 48 h in subdiaphragmatic nodal areas for T101 and 9.2.27 were 43 and 19%, respectively. Administration of radiolabeled 9.2.27 resulted in a different pattern of biodistribution, with less
Fig. 1. Representative immunoscintigram (right) and lymphangiogram (left). Patient 3 underwent imaging approximately 48 h after intralymphatic delivery of 111In-T101 (0.5 mg, 500 μCi). Half of the amount was delivered into the pedal lymphatic chain of each foot. The anterior view of the pelvis shows focal accumulation of indium-111 in the inguinal lymph nodes (arrows) and to a lesser extent in the next nodes in the chain, the iliacs (arrowheads) and paraaortics (open arrows). There is also some accumulation in the lymphatic channels (curved arrows). The corresponding lymphangiogram (left) shows normal-appearing lymph nodes. Biopsy of a left inguinal lymph node (with the greatest uptake of indium-111) showed lymphoma.

Fig. 2. Clearance from the injection site after s.c. and intralymphatic injection. Images of the lower extremity were obtained on patient 5 at approximately 2 h following direct intralymphatic administration of 111In-T101 in the left foot (DILA) and s.c. administration of an equal dose in the right foot (s.c.) (right). Left, clearance of radioactivity from the foot after intralymphatic and s.c. injection. The cumulative radiation exposure to the foot was greater after s.c. administration.

In one patient, the intralymphatic and s.c. injection routes were compared directly. Fig. 4 shows the difference in dose retention for the intralymphatically delivered and s.c. T101. Initially, direct intralymphatic administration was associated with higher concentrations of radioactivity in the regional lymphatics, absence of uptake in distant nodal sites, and minimal accumulation in soft tissue tumor in the left breast. In contrast, axillary nodes were seen after radiolabeled T101 administration. Clearance of 111In-9.2.27 from the injection site and serum kinetics after intralymphatic administration were similar to those of 111In-T101. This pattern of 9.2.27 biodistribution after intralymphatic delivery is similar to that seen in two other CTCL patients who received 111In-9.2.27 after s.c. pedal injections (18), and the pattern of 111In-T101 biodistribution is similar to that previously reported for >0.1 mg of s.c. 111In-T101 (18).

In one patient, the intralymphatic and s.c. injection routes were compared directly. Fig. 4 shows the difference in dose retention for the intralymphatically delivered and s.c. T101. Initially, direct intralymphatic administration was associated with higher concentrations of radioactivity in the regional in-
Table 3 Summary of outcome of scan-directed inguinal lymph node biopsy after intralymphatic administration of $^{111}$In-T101

<table>
<thead>
<tr>
<th>Patient</th>
<th>Weight of lymph node (g)</th>
<th>Injected dose/g of tissue*</th>
<th>Total % of injected dose</th>
<th>Lymph node status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.5</td>
<td>0.22</td>
<td>0.980</td>
<td>Negative</td>
</tr>
<tr>
<td>2</td>
<td>0.8</td>
<td>4.4</td>
<td>3.47</td>
<td>Positive</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>0.28</td>
<td>0.42</td>
<td>Positive</td>
</tr>
<tr>
<td>5</td>
<td>6.2</td>
<td>0.78</td>
<td>4.8</td>
<td>Positive</td>
</tr>
<tr>
<td>7*</td>
<td>1.8</td>
<td>0.42</td>
<td>0.76</td>
<td>Negative</td>
</tr>
</tbody>
</table>

*Data was multiplied by 2 to reflect that only one-half of the total injected dose could target the lymph nodes.

* Received s.c. injection of $^{111}$In-T101.

Table 4 Mean percentage of organ retention of radioactivity after intralymphatic injection

Data from anterior whole body scans 24–96 h after radiolabeled antibody administration. Corrected for isotope decay and expressed as percentage of total injected dose.

<table>
<thead>
<tr>
<th>Lymph nodes</th>
<th>T101 (N = 5)</th>
<th>9.2.27 (N = 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower extremities</td>
<td>31 (23–48)*</td>
<td>19</td>
</tr>
<tr>
<td>Liver</td>
<td>32 (14–47)</td>
<td>45</td>
</tr>
<tr>
<td>Spleen</td>
<td>18 (8–38)</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>7 (3–16)</td>
<td>19</td>
</tr>
</tbody>
</table>

* Numbers in parentheses, range.

Fig. 3. Intralymphatic control antibody versus s.c. T101 48 h after injection. Patient 7 underwent an initial intralymphatic injection of $^{111}$In-9.2.27 control anti-melanoma antibody (top). Twelve days later the same patient was given an equal dose of $^{111}$In-T101 s.c. (bottom). The $^{111}$In-T101 shows greater and more discrete localization in the inguinal-femoral lymph nodes than does the $^{111}$In-9.2.27 (at comparable early time points). In addition the T101 images show a higher concentration in the involved skin tumors of the left breast (closed arrows) and localization in the left axillary node (arrowhead). Radioactivity in the lymphatics persists following intralymphatic injection of 9.2.27 but not of T101 (open arrows). Both preparations show uptake of radioactivity in the liver and spleen.

guinal-femoral and iliac lymph nodes. By 24 h, delivery from the s.c. site to the inguinal-femoral and iliac nodes had increased to 56% and was slightly higher than the intralymphatically delivered dose (40%) on the other side (Fig. 4). Injection s.c. resulted in a greater retention on the other side (confined to the anterior foot), whereas direct intralymphatic injection resulted in tracer accumulation distributed along the length of the lower extremity lymphatic channel. At 24 h, 12% of the dose was retained at the injection site for intralymphatic, and 29% for s.c., administration (Fig. 2).

Fig. 4. Comparison of intralymphatic and s.c. delivery. Top, patient 5 received concurrent injections of $^{111}$In-T101 via the intralymphatic route in the left foot (open arrows) and the s.c. route in the right foot. Images obtained approximately 2 h postinfusion show faster cross-over delivery to right inguinal-femoral nodes from the left intralymphatic injection (closed arrows). Bottom, images obtained at 72 h demonstrate that the right inguinal-femoral nodes (closed arrows) have a higher concentration than the left (open arrows), indicating that s.c. delivery, although slower, was also capable of efficient delivery. In addition, the delayed views show targeting to distal lymphatic sites including axillary, hilar, supraclavicular, and cervical nodes (closed arrowheads).

Fig. 5. Blood kinetics of $^{111}$In-T101. The kinetics of $^{111}$In-T101 in the blood is plotted following intralymphatic (ILAG) administration. For the sake of comparison blood clearance data from a previous study of s.c. $^{111}$In-T101 was included (18). Points, means; bars, ±1 SD.

The maximum dose in the blood pool peaked at 12% (range, 2.5–12%) with a median of 24 h (3–96 h). As shown in Fig. 5, in 6 of the patients blood levels of $^{111}$In-T101 after 5 h were always <6% of injected dose. At 1 h 24–54% of the radioactivity recovered in blood was bound to circulating cells and not free in the plasma. The analysis of liver-spleen uptake demonstrates that radiolabeled antibody gains access to the systemic circulation even at the earliest imaging times, with persistence until 96 h. Access of the radioconjugate to the liver is presumably through systemic delivery. Urinary excretion of radioactivity was <7% of the injected dose/24 h, with a cumulative urinary excretion of 12–32% of the injected activity by 72 h.
Table 5. Sites of increased radioactivity on immunoscintigraphic imaging with intralymphatically administered \(^{111}\)In-T101

<table>
<thead>
<tr>
<th>Regional lymph nodes</th>
<th>Patient</th>
<th>Cervical</th>
<th>Supraclavicular</th>
<th>Axillary</th>
<th>Hilar</th>
<th>Other</th>
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<tbody>
<tr>
<td>1</td>
<td>+</td>
<td>+</td>
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<td>+</td>
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<td>+</td>
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<td>+</td>
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<td>+</td>
<td>+</td>
<td>+</td>
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DISCUSSION

Seven patients were treated with \(^{111}\)In-radiolabeled T101 monoclonal antibody during the course of contrast lymphangiography. We observed efficient delivery of labeled antibody to regional lymph nodes. The quality of images with intralymphatic \(^{111}\)In-T101 was very similar to that reported for s.c. administration of this antibody. Both routes of administration resulted in rapid and efficient delivery to regional lymph nodes, but intralymphatic delivery resulted in a much more rapid clearance from the injection site. Injection s.c. showed approximately 80% of the dose at the injection site 4 h (18) after injection, whereas direct intralymphatic injection showed only an average of 3.8% of injected dose at the initial imaging time (<4 h). This faster clearance resulted in an average of 13 rads of absorbed dose in the foot, compared with the previously published range of 34–70 rads after s.c. administration of \(^{111}\)In-T101 (18). The concentrations measured in biopsied nodes were similar to those seen after s.c. administration of T101, and they were 10–100 times higher than those observed after i.v. administration of the radiolabeled antibody (6, 18). Injections s.c. showed approximately 80% of injected radioactivity in the injection site at 4 h (18), whereas intralymphatic infusion resulted in only 3.8% of the injected dose localized to the foot 4 h postinjection. Lymph node biopsy specimens with only mild dermatomic changes contained lower mean percentages of injected dose than did cancerous lymph nodes. A clear resolution of this point is difficult as no definitive histological marker of a malignant T-cell exists.

A large number of lymph node biopsies in CTCL patients would be required to establish whether the reported increased expression of CD5 in malignant T-cells (compared with normal T-cells) was sufficiently pronounced to permit a diagnostic or therapeutic advantage.

In contrast to the experience with the s.c. administration of \(^{111}\)In-T101, no dose dependence of targeting was observed for the limited range of antibody concentrations tested. All three concentrations of T101 resulted in rapid delivery of radioactivity to systemic sites at the earliest imaging time point (18). This observation may be explained by the larger effective dose administered via the intralymphatic route, since less of the injected dose than did cancerous lymph nodes. A clear resolution of this point is difficult as no definitive histological marker of a malignant T-cell exists.

Comparison with the indium-111 isotypic control antibody 9.2.27 showed that mobilization of an irrelevant antibody out of the extremity is also rapid and efficient after direct intralymphatic injection. Localization of T101 in lymphatic tissue exceeded that of 9.2.27, indicating that at least a portion of the T101 targeting resulted from specific antigen binding. Quantitation of antigen-specific node uptake may be underestimated by comparing T101 with 9.2.27 since subsequent studies have shown a preferential concentration of 9.2.27 in lymph nodes when compared with that of a nonspecific immunoglobulin. Radioactivity accumulates in liver and spleen after injection of both \(^{111}\)In-T101 and \(^{111}\)In-9.2.27. This accumulation is related in part to the technique of \(^{111}\)In-diethylenetriamine pentaacetic acid conjugation (33) and in part to other, undefined factors (34).

This study did not include evaluation of the nature of reticuloendothelial uptake, so the radioactivity in the liver could be free isotope, free radiolabeled antibody, radiolabeled antigen-antibody complexes, or radiolabeled antibody bound to T65-positive cells. However, in organs other than liver and spleen the differences in biodistribution of the two antibodies after...
reaching the systemic circulation [in both this and a previous study (18)] suggest that an element of T101 localization is due to antibody specificity.

This was a nonselected group of patients requiring lymphangiography as part of their initial staging for entry into a therapy protocol for CTCL. Even after a very extensive conventional staging workup, biopsies guided by $^{111}$In-T101 led to upstaging of three of five patients. In addition to the biopsy-proven site, there were multiple other hot spots on the scans from this group of clinically early-stage patients. These T101 images may reflect very extensive CD5-positive cell trafficking as well as a significant systemic dissemination, even with early disease. If $^{111}$In-T101 imaging helps define more accurately the extent of disease, available treatments (especially potentially curative total body electron beam therapy) may be applied with a better therapeutic index to appropriately staged patients.

The use of $^{111}$In-T101 as a diagnostic staging tool in T-cell lymphoma patients may be limited by the frequent incidence of human anti-mouse antibody formation. In this report of 5 of 7 patients developed serological evidence of an immune response to the mouse antibody. These findings are in the range reported for other trials with monoclonals (35, 36). A variety of prospects to decrease the frequency of human anti-mouse antibody response exist, including improved formulation of the antibody to exclude antibody aggregates, techniques to increase tolerance of the host to the mouse protein including the use of immunosuppressive agents, and development of “humanized” or human-derived antibodies.

We are currently conducting a clinical trial to evaluate the therapeutic benefit of $^{90}$Y-T101 conjugates of T101, given via either the i.v. or intralymphatic route, to patients with cutaneous T-cell lymphoma. Delivery of tumoricidal radioactivity to regional lymph nodes in selected cases may be a useful adjunct to systemic therapy, especially if tumor cell trafficking through the lymphatic compartment is a major part of this disease process. The critical organ limiting the highest dose of radiolabeled monoclonal antibody would be dependent on the route of administration. Bone marrow stem cell toxicity, as with the $^{131}$I-T101 experience (11), presumably will limit systemic therapy. This myelotoxicity may occur at doses that do not have tumoricidal activity in nodal sites of involvement. Endothelial cells and other normal cell populations in the lymphatic system may limit the dose for direct intralymphatic injection, but injection site toxicity would more severely restrict the maximal dose that could be delivered via s.c. injection. The comparison of lower extremity clearance between s.c. and direct intralymphatic injection favors the latter as the preferred route for delivery of a therapeutic dose of radiolabeled antibody. The therapeutic index for such an infusion could be further improved with a more precisely calibrated pressure-sensitive pump to maintain lower pressure during antibody infusion to minimize extravasation from the lymphatic channels. Retention of labeled antibody in lymphatic channels might perhaps be further diminished if cold antibody were infused prior to labeled antibody. Information from the ongoing Phase I $^{90}$Y-T101 trial may resolve some of these issues.

One additionally speculative possibility deserves brief mention. Since T101 is directed at a pan T-cell antigen present in normal nodes, it may be possible to deliver larger doses of radiation selectively via the lymphatics to treat other, non-T-cell malignancies which localize in regional lymph nodes. One can envision settings in which diseases which extend to the regional nodes (e.g., with early-stage melanoma of the extremities, testicular cancer, or breast cancer) might be better candidates for such an approach than cutaneous T-cell lymphoma.

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Direct Intralymphatic Injection of Radiolabeled $^{111}$In-T101 in Patients with Cutaneous T-Cell Lymphoma

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