**Intratesticular Transplantation of Testicular Cells from Leukemic Rats Causes Transmission of Leukemia**

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**ABSTRACT**

A rat T-cell leukemia model was used to study the safety of germ cell transplantation as a mean of preventing infertility in males undergoing gonadotoxic cancer treatment. Donor germ cells were harvested from the testes of terminally ill leukemic rats and were either used directly or cryopreserved and thawed before transplantation by rete testis microinjection. All rats transplanted with testicular cells from leukemic donors developed signs of terminal rat T-cell leukemia, whereas control animals remained healthy. Cryopreservation of the donor germ cells caused a 3- to 6-day delay in the terminal phase of leukemia. When a known number of leukemic cells were mixed with germ cells and microinjected into the testis, the rate of appearance of terminal leukemia was directly related to the number of transferred leukemic lymphoblasts. As few as 20 leukemic cells were able to cause a cancer relapse resulting in terminal leukemia 21 days after transplantation in three of five transplanted animals. Our results demonstrate that germ cell transplantation with the presently used techniques is not safe enough for clinical use. Improved methods for purging testicular specimens of cancer cells or totally new approaches with transient xenogenetic host models to detect contamination of malignant cells must be developed before this technique can be offered to patients without fear of disease relapse.

**INTRODUCTION**

There are numerous clinical reports describing adverse effects of cytostatic agents on future fertility of childhood cancer patients (1–4). Severe testicular damage has been observed among patients who have received treatment according to LSA,M protocol (5) and after chemotherapy with alkylating agents (6). The pretreatment conditioning for bone marrow transplantation including cytostatic drugs and total body irradiation causes gonadal damage and infertility (7). Major intensification of therapy, which has led to better survival during recent decades, will most probably increase the gonadal damage and infertility in the future (8).

No clinically useful methods for protecting spermatogenetic cells from chemotherapy-induced damage have been introduced thus far. Endocrine therapy with the aim of turning off testicular activity by using agonists or antagonists to gonadotrophin-releasing hormone does not seem to be clinically useful as a protective means (9, 10). Most pediatric cancer patients are too young for pretreatment sperm banking, and poor semen quality attributable to malnutrition and the cancer disease itself may decrease the clinical application of this method even among pubertal boys (11).

Transplantation of germ cells to mouse testes made sterile by cytostatic drug treatment has been reported by Brinster and Zimmermann (12) and, recently, successful germ cell transplantation to pri-

**MATERIALS AND METHODS**

**Host Animals.** Male piebald variegated (PVG) rats at the age of 25 days were treated with one dose of busulfan (10 mg/kg) administered i.p. to destroy the stem spermatogonia in the seminiferous tubules. Animals were maintained in the institute animal house under standard conditions. Animal ethics committee approval for all experiments was given by the Northern Stockholm Animal Ethics Committee No. N169/97.

**Preparation of Donor Animals with Rat T-cell Leukemia.** The rat T-cell leukemia cell line has been isolated from spontaneously leukemic rats of the Oxford hooded (syngenic with piebald variegated/c, PVG) inbred strain. The leukemic cells have been shown to express the rat T-cell marker (PVG) receptor (18). The leukemia is maintained by serial i.p. passage every 17th day (19).

Leukemic rats were killed by CO₂ inhalation when approaching the terminal phase (characterized by continuous piloerection, weight loss, and cervical lymph node enlargement; Ref. 18). A leukemic cell suspension (concentration: 1 × 10⁷ cell/ml) was prepared from five enlarged cervical lymph nodes as described earlier (19). Transmission was made by i.p. inoculation with 1000 cells/g body weight to three rats aged 25 days. Age-matched controls received saline. When the signs of spreading leukemia were seen 14 days after inoculation (19), treated animals and controls were sacrificed for donor cell harvest (leukemic donors: body weights, 75 ± 13 g; spleen weights, 1.1 ± 0.1 g; control donors: body weights, 96 ± 4 g; spleen weights, 0.3 ± 0.0 g).

**Harvest of Donor Germ Cells.** One-half of one testis from each leukemic and control donor was carefully separated with a knife and immersion-fixed in Bouin’s fixative. The samples were embedded in paraffin and prepared for light-microscopic examination of testicular morphology. The other half and the second testis of the same animal was decapsulated, minced into smaller pieces in Eagle’s MEM with Eagle’s salts (Life Technologies, Inc., Paisley, United Kingdom) supplemented with sodium bicarbonate (15 mM), glutamine (4 mM), HEPES (15 mM), nonessential amino acids, penicillin (100 units/ml), and gentamicin (40 µg/ml). This medium (MEM) was used for all procedures during cell preparation, injection, and freezing. Testis tissue was placed in medium containing 0.5 mg/ml collagenase/dispace (digestion I: Boehringer Mannheim Biochemicals, Mannheim, Germany) and 0.03 mg/ml DNase (Boehringer Mannheim Biochemicals) and incubated in a shaking water bath at 32°C for 10 min to separate interstitial cells. After centrifugation at low

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TESTICULAR CELL TRANSPLANTATION AND LEUKEMIA

Table 1  Leukemia transmission, final body, spleen, seminal vesicle, and testicular weight after intratubular and interstitial injection with fresh and cryopreserved testicular germ cells

<table>
<thead>
<tr>
<th>Donor cells/ testis (10⁶)</th>
<th>Donor</th>
<th>Injection route</th>
<th>No. of rats developing leukemic total injected</th>
<th>Time to terminal stage (days)³</th>
<th>Body weight (g)⁴</th>
<th>Spleen weight (g)⁴</th>
<th>Seminal vesicle weight (g)⁴</th>
<th>Injected testes weight (g)⁴</th>
<th>Contralateral testes weight (g)⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh tubular</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Healthy 1 and 2</td>
<td>Rete</td>
<td>0/6</td>
<td>No symptoms</td>
<td>170 ± 18</td>
<td>0.52 ± 0.04</td>
<td>0.18 ± 0.03⁵</td>
<td>0.65 ± 0.07</td>
<td>0.57 ± 0.05</td>
</tr>
<tr>
<td>1.5</td>
<td>Leukemic 1 and 2</td>
<td>Rete</td>
<td>7/7</td>
<td>14 ± 0</td>
<td>140 ± 10</td>
<td>2.66 ± 0.22⁶</td>
<td>0.05 ± 0.01</td>
<td>1.23 ± 0.31</td>
<td>0.52 ± 0.05</td>
</tr>
<tr>
<td>Cryopreserved tubular</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>Leukemic</td>
<td>Rete</td>
<td>2/2</td>
<td>17 ± 0</td>
<td>192 ± 26</td>
<td>2.62 ± 0.23⁷</td>
<td>0.11 ± 0.01</td>
<td>1.11 ± 0.31</td>
<td>0.55 ± 0.03</td>
</tr>
<tr>
<td>0.1</td>
<td>Leukemic</td>
<td>Interstitial</td>
<td>3/3</td>
<td>19 ± 0</td>
<td>168 ± 1</td>
<td>2.97 ± 0.09</td>
<td>0.11 ± 0.00</td>
<td>1.71 ± 0.11</td>
<td>0.59 ± 0.03</td>
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<tr>
<td>0.2</td>
<td>Leukemic</td>
<td>Rete</td>
<td>4/4</td>
<td>20 ± 0</td>
<td>170 ± 3</td>
<td>1.95 ± 0.27</td>
<td>0.11 ± 0.01</td>
<td>0.84 ± 0.21</td>
<td>0.51 ± 0.02</td>
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<tr>
<td>Cryopreserved interstitial</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>Leukemic</td>
<td>Rete</td>
<td>3/3</td>
<td>17 ± 0</td>
<td>176 ± 9</td>
<td>2.65 ± 0.14⁸</td>
<td>0.12 ± 0.01</td>
<td>1.43 ± 0.36</td>
<td>0.62 ± 0.04</td>
</tr>
</tbody>
</table>

³ Values are given as mean ± SE.
⁴ P < 0.05 compared with seminal vesicle weight after intratubular or interstitial injection of freshly isolated leukemic donor cells.
⁵ P < 0.05 compared with spleen weight after intratubular or interstitial injection of healthy donor cells.
⁶ P < 0.05 compared with testis weight after intratubular injection of healthy donor cells.

RESULTS

Testicular Morphology of Leukemic and Healthy Donors. Histological sections of leukemic donor testes showed blood vessels filled with leukemic cells. Some interstitial infiltrates of leukemic cells were also seen (Fig. 2A). The morphology of control testes was normal (Fig. 2B).

Transmission of Leukemia after Spermatogonial Transplantation. Fourteen days after intratubular or interstitial injection, all hosts receiving fresh testicular cells from a leukemic donor developed typical signs of terminal rat T-cell leukemia, whereas control animals remained healthy (Table 1). Injection with cryopreserved germ cells caused a 3- to 6-day delay in the terminal phase of leukemia (Table 1).

³ B. P. Seitchell, unpublished observations.
injection with cryopreserved cells caused a tumor-like infiltration of
the interstitial tissue. All leukemic animals showed very similar spleen enlargements compared with controls (Table 1), and they also had smaller seminal vesicular glands (Table 1), which is a good indicator of lower androgen levels. The injection site in either the intratubular compartment or the interstitial compartment had no effect on terminal phase timing or on terminal body weights (Table 1).

**Testicular Morphology after Transplantation of Freshly Isolated Donor Cells.** Testes of the animals microinjected with freshly isolated cells from leukemic donors were markedly enlarged compared with contralateral control testis or the testes of the animals injected with healthy donor cells (Table 1). No statistically significant difference was seen in the size of the testes after intratubular or interstitial injection of fresh cells from leukemic donors (Table 1), and the injection site of cells from leukemic donors did not affect the histological morphology. The interstitial tissue was filled with leukemic cells, and malignant lymphocytes with active cell division were seen (Fig. 2C). The seminiferous tubules showed degenerating germ cells, and occasionally empty tubules without Sertoli or germ cells were seen (Fig. 2C). The contralateral untouched testis showed Sertoli cells-only tubules with and without degenerating spermatogenetic cells as a result of the busulfan treatment. This histological picture was very similar to that in microinjected (Fig. 2D) and un.injected testes of control animals. However, in the un injected testes of the leukemic recipient animals, some few leukemic infiltrates were seen in the interstitium just beneath the capsule.

**Testicular Morphology after Transplantation of Cryopreserved Donor Cells.** After transplantation of cryopreserved testicular cells from leukemic donors, testicular enlargement appeared more slowly. The testicular size was significantly ($P < 0.05$) smaller after intratubular injection (0.92 ± 0.51 g) than after interstitial injection (1.62 ± 0.17 g) of cryopreserved cells in experiment 3. Interstitial injections caused marked enlargement of the testes (Table 1) and destruction of the morphology of testicular tubules by dividing leukemic cells to an extent comparable with the finding after intratubular injection with freshly isolated testicular cells (Fig. 2C). Intratubular injection with cryopreserved cells caused a tumor-like infiltration of the caput epididymidis, which adhered firmly to the testicular capsule, with a shorter interval in the animal group that received cells from the sample showing the best viability after thawing. The terminal phase was reached after 17 days also in the animal group that received cells from the interstitial tissue. The contralateral uninjected testis had a morphology of leukemic donor testes suggests that most leukemic cells originate as few as 20 leukemic cells are able to cause a relapse of the malignant disease when injected into the testis.

**DISCUSSION**

This study shows that germ cell transplantation with fresh and frozen testicular cells from leukemic donor rats transmits acute leukemia to healthy recipients. An immediate conclusion from our findings is that spermatogonial transplantation with unpurged testicular samples should not be used for any leukemic patient to restore their fertility. Even patients with lymphoma or metastasising cancers might incur a risk of recurrence, because cancer cells circulating in blood vessels may contaminate testicular biopsies. Our data also shows that as few as 20 leukemic cells are able to cause a relapse of the malignant disease when injected into the testis.

Manipulation of the testicular samples might change the risk of recurrence after spermatogonial transplantation, because cryopreservation of the donor cell population was able to change the aggressive course of the leukemia and the testicular infiltration. Cryopreservation most probably decreased the number of viable leukemic cells in the samples, inasmuch as the speed of appearance of terminal leukemia was directly related to the number of leukemic lymphoblasts injected. The histological morphology of leukemic donor testes suggests that most leukemic cells originate from the interstitial tissue (Fig. 2A). Accordingly, the more aggressive course of the leukemia seen after injection of interstitial cells instead of
tubular cells also supports the finding that the leukemic cell content of the donor sample is related to the timing of terminal leukemia.

The small sample size of the testicular biopsies will present problems in purging the cancer cells from the spermatogenetic stem cells. The cell contents of testicular biopsies would constitute only a small proportion of the cell number transplanted in the present study, and orchiectomy for sample collection would not be acceptable in clinical practice. One possibility to circumvent this problem would be in vitro maintenance of testicular stem cells. Reinitiation of spermatogenesis after culture of spermatogonia for several months has shown to be successful in mice (20). Such in vitro culture of testicular tissue might also deplete malignant cells before autologous retransplantation. Another possibility could be to use xenologous immunodeficient hosts such as severe combined immunodeficiency mice to preassess testicular samples for cancer-cell contamination and engraftment capacity of the stem cells. Xenologous transplantation might be useful also to maintain and grow the stem cell population. The observation that rabbit and dog germ cells colonize the seminiferous tubules of immunodeficient mice, but show no differentiation, suggests that initiation of complete spermatogenesis may occur only between closely related species (21).

The present results show that spermatogenic donor cells can be harvested from terminally ill leukemic animals, although their functional capacity to reconstitute spermatogenesis was not investigated. The cells can be cryopreserved and thawed like spermatogenic cells from healthy donors. This may differ from earlier observations that sperm collection and sperm cryopreservation are difficult after malignant disease (11). In line with this observation is the previous finding that the spreading leukemia disturbs especially the later differentiation steps of spermatogenesis, which involves haploid cell types, whereas more immature germ cell types are preserved (17). However, because of the short observation time and early occurring leukemic symptoms, the ability of stem cells obtained from leukemic donors to initiate spermatogenesis could not be evaluated in the present study.

It is remarkable that when freshly isolated samples were injected intratubularly, the leukemic cells showed the capacity to invade the testicular interstitium. The histological morphology of these testes was comparable with that of interstitially injected testes or to the testicular morphology after intratesticular transplantation with rat leukemic T-cells (19) that was reported previously. This may indicate that a bigger number of more invasive and proliferative leukemic cells

Fig. 2. Testicular morphology of germ cells in donor and recipient testes (bar, 40 μm). A, testis of leukemic donor. Testicular blood vessels are filled with leukemic cells, and there are also some interstitial infiltrates of leukemic cells (arrow). B, testicular tissue of healthy control donor. C, testis microinjected intratubularly 14 days earlier with testicular cells from leukemic donor. Interstitial infiltration with leukemic cells and seminiferous tubules (**) mainly empty of cells are found. D, testis microinjected intratubularly 14 days earlier with testicular cells from a healthy donor, showing germ cell-depleted, Sertoli cell-only tubules after the sterilizing busulfan treatment. It is too early to evaluate any recovery of spermatogenesis by the grafted germ cells.
in freshly isolated testicular samples are able to penetrate the seminiferous tubule wall and cause a direct infiltration into the interstitium. The present results confirm the earlier observation that the testis has barriers decreasing the leukemic cell infiltration into the interstitium (19, 22). The vascular endothelium of intact testis has previously been shown to restrict the penetration of the leukemic cells from the circulation into the testis (19, 22). The present results support the earlier observations that similar barriers may exist also between the tubular and the interstitial compartment (19, 22).

In conclusion, this study shows that, with the harvest and transplantation techniques used presently by us and others, spermatogonial transplantation is not safe enough for clinical use. Improved methods for the purging of testicular samples of cancer cells and the enrichment of spermatogonial stem cells, or totally new approaches with passage through xenogenic host models, must be developed before this technique can be offered as a means to rescue, without the fear of disease relapse, the future fertility of male cancer patients.

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REFERENCES


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