Damage to endothelial cells is the common feature of vascular disorders associated with hematopoietic stem cell transplantation (HSCT). Elevated numbers of circulating endothelial cells reflect the extent of endothelial damage in a variety of disorders but their use in HSCT has not been investigated so far. We studied 39 patients undergoing allogeneic HSCT with different conditioning regimens and 22 healthy controls. Circulating endothelial cells were enumerated with immunomagnetic isolation during the course of HSCT. After conditioning, cell numbers were significantly elevated (median 44 cells/mL) compared with baseline (median 16 cells/mL) and controls (median 8 cells/mL). Patients who received radiation had an earlier peak when compared with patients who received chemotherapy. Patients who received reduced-intensity conditioning had significantly lower cell numbers (median 24 cells/mL) than those who received standard conditioning. These observations provide a novel marker to investigate microvascular endothelial damage and the effects of different conditioning regimens in patients undergoing HSCT. (Blood. 2004;103:3603-3605)

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negative (Figure 1). Likewise, stains for alpha smooth-muscle actin were carried out to exclude pericytes. Specifically, cells were stained with murine anti-human alpha smooth-muscle actin antibody (Cymbus Biotechnology, Chandlers Ford, United Kingdom) and APAAP technique (Dako) with human aortic smooth muscle cells as positive controls (donated by Dr I. Dumler, Hannover, Germany). These stains were also negative (data not shown).

Cell numbers were compared with the Mann-Whitney U test, paired Wilcoxon test, and the Friedman test for comparison of cell numbers at different points in time, respectively.

**Results and discussion**

Low numbers of circulating endothelial cells were observed in healthy controls (range, 4-24 cells/mL; median, 8 cells/mL). In contrast, cell numbers were significantly elevated at baseline, that is, before the conditioning regimen (median, 16 cells/mL, \( P < 0.0001 \) when compared with healthy controls). Cells had the characteristic morphology of circulating endothelial cells (Figure 2) as described elsewhere. Briefly, they were oval-shaped, between 10 \( \mu \)m and 100 \( \mu \)m in length, and had a well-delineated cytoplasm. There was a significant increase in cell numbers after conditioning (maximum increase: range, 16-424 cells/mL; median, 44 cells/mL, \( P < 0.0001 \) when compared with baseline). Patients who received total body irradiation had similar cell numbers (maximum increase: range, 16-424 cells/mL; median, 58 cells/mL; not significant). Patients who received reduced-intensity conditioning had significantly lower cell numbers (maximum increase: range, 20-52 cells/mL; median, 24 cells/mL) than their counterparts who underwent conventional conditioning with total body irradiation and cyclophosphamide (\( P < 0.05 \)) or chemotherapy only with busulfan/cyclophosphamide (\( P < 0.01 \); Figure 3A). However, patients who received total body irradiation had an early peak of elevated cell numbers, whereas patients who received chemotherapy had a more protean elevation of cell numbers (Figure 3B).

Damage to microvascular endothelial cells is a well-recognized complication of HSCT. Mechanisms of this disorder remain poorly understood, although both radiation and myeloablative chemotherapy have been implicated. Graft-versus-host prophylaxis with calcineurine inhibitors may also be involved, more so since these drugs have a propensity to damage endothelial cells. Elevation of soluble markers, such as sVWF and thrombomodulin, has been described during HSCT. Nurnberger and colleagues demonstrated an increase of thrombomodulin and plasminogen activator inhibitor type-1 (PAI-1) with the number of vascular complications (VOD, GVHD, CLS, sepsis) after bone marrow transplantation. Finally, endothelial damage has recently been linked to chronic GVHD.

Here, we have demonstrated an increase in circulating endothelial cells as new markers of endothelial damage in conjunction with the conditioning phase of HSCT. Our findings also suggest the presence of a dose effect on the account that patients who...
underwent reduced-intensity conditioning had lower cell numbers than those who received conventional conditioning. We postulate that considerable endothelial damage occurs during the conditioning phase of HSCT. Surprisingly, patients already had slightly elevated cell numbers before conditioning. It is tempting to speculate that this finding may reflect prior chemotherapy. Alternatively, elevated cell numbers may also reflect the underlying disease, tissue repair, or ongoing angiogenesis. Significant differences between patients with CML and acute leukemia before disease, tissue repair, or ongoing angiogenesis. Significant differences between patients with CML and acute leukemia before conditioning had a shorter time from the end of the conditioning phase to their peak in cell numbers than those who received myeloablative chemotherapy alone. Much has been learned about the effects of ionizing radiation of vascular endothelial cells; induction of apoptosis is well documented. Moreover, endothelial damage is an important pathway for the development of radiation-related endothelial progenitor cells been documented extensively after HSCT, however, has not been investigated so far. Neither have endothelial progenitor cells been documented extensively after HSCT, although recent evidence suggests that endothelial cells of donor origin occur at a later stage.

In summary, circulating endothelial cells are a promising new marker to monitor microvascular endothelial damage in patients undergoing HSCT. Further studies should now corroborate our findings in larger numbers of patients, provide longer follow-up, and evaluate whether higher numbers of circulating endothelial cells indicate the development of vascular complications or GVHD.

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References
10. Dignat-George F, Sampol J. Circulating endothelial cells: life, death and detachment of the endothelial cell basement membrane. The fate of these endothelial cells in blood is still unclear. It is conceivable that circulating endothelial cells may interact with other cell populations and initiate inflammatory mechanisms. Moreover, it is reasonable to assume extensive repair mechanisms as a sequel to widespread endothelial damage in these patients. The time frame of these events, however, has not been investigated so far. Neither have endothelial progenitor cells been documented extensively after HSCT, although recent evidence suggests that endothelial cells of donor origin occur at a later stage.

In summary, circulating endothelial cells are a promising new marker to monitor microvascular endothelial damage in patients undergoing HSCT. Further studies should now corroborate our findings in larger numbers of patients, provide longer follow-up, and evaluate whether higher numbers of circulating endothelial cells indicate the development of vascular complications or GVHD.
Circulating endothelial cells as a marker of endothelial damage in allogeneic hematopoietic stem cell transplantation

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