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ORIGINAL REPORT

T-Cell–Replete HLA-Haploidentical Hematopoietic Transplantation for Hematologic Malignancies Using Post-Transplantation Cyclophosphamide Results in Outcomes Equivalent to Those of Contemporaneous HLA-Matched Related and Unrelated Donor Transplantation

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ABSTRACT

Purpose
T-cell–replete grafts from haploidentical donors using post-transplantation cyclophosphamide may represent a solution for patients who require allogeneic hematopoietic cell transplantation (alloHCT) but lack a conventional donor. We compared outcomes of alloHCT using haploidentical donors with those of transplantation using conventional HLA-matched sibling donors (MRDs) and HLA-matched unrelated donors (MUDs).

Patients and Methods
Outcomes of 271 consecutive patients undergoing T-cell–replete first alloHCT for hematologic malignancies performed contemporaneously at a single center (53 using haploidentical donors; 117, MRDs; 101, MUDs) were compared. Overall and disease-free survival (DFS) were adjusted for effects of significant patient-, disease-, and transplantation-related covariates using a stratified Cox model.

Results
Patient characteristics were similar between the three donor groups. For patients undergoing MRD, MUD, and haploidentical transplantation, 24-month cumulative incidences of nonrelapse mortality were 13%, 16%, and 7% and of relapse were 34%, 34%, and 33%, respectively (P not significant [NS]). Cumulative incidences of grades 3 to 4 acute graft-versus-host disease (GVHD) at 6 months were 8%, 11%, and 11%, respectively (P NS); extensive chronic GVHD occurred in 54%, 54%, and 38% of patients, respectively ($P < .05$ for those undergoing haploidentical donor *v* MRD or MUD transplantation). Adjusted 24-month probabilities of survival were 76%, 67%, and 64% and of DFS were 53%, 52%, and 60%, respectively; these were not significantly different among the three donor groups.

Conclusion
Haploidentical transplantation performed using T-cell–replete grafts and post-transplantation cyclophosphamide achieves outcomes equivalent to those of contemporaneous transplantation performed using MRDs and MUDs. Such transplantation represents a valid alternative for patients who lack a conventional donor.

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INTRODUCTION

For patients with hematologic malignancies who may benefit from allogeneic hematopoietic cell transplantation (alloHCT), HLA-matched siblings (MRDs) or HLA-matched unrelated donors (MUDs) are considered optimal donors. However, many patients, particularly those from ethnic minority and mixed-race backgrounds, lack such donors. Almost all patients have an available related donor with whom they share a single HLA haplotype (ie, haploidentical donor). Early attempts to use T-cell–replete grafts from haploidentical donors using conventional preparative regimens were associated with unacceptable rates of graft-versus-host disease (GVHD) and graft rejection.[1] Prior attempts to overcome these obstacles to haploidentical alloHCT entailed stringent ex vivo T-cell depletion of the graft, often combined with intense preparative regimens. Although such transplantation has been

demonstrated as feasible, it is associated with slow immune reconstitution and a high rate of nonrelapse mortality (NRM).[2,3] Recently, an alternative approach to haploidentical alloHCT was developed, which uses T-cell–replete bone marrow grafts in combination with post-transplantation cyclophosphamide to prevent GVHD and graft rejection.[4] This approach has demonstrated promising results, including acceptable rates of NRM and severe GVHD in single- and multi-institution phase II trials.[5-7] However, the results from such haploidentical alloHCT have not formally been compared with those of alloHCT using MRDs and MUDs. In particular, it remains unclear whether the greater level of HLA mismatch associated with such haploidentical transplantation results in higher NRM and poorer survival when compared with transplantation performed using optimally HLA-matched conventional donors. To address this question, we compared outcomes of consecutive patients undergoing T-cell–replete haploidentical alloHCT performed at our center with all contemporaneous T-cell–replete alloHCT using MRDs and MUDs.

PATIENTS AND METHODS

Patients

All consecutive patients undergoing first alloHCT for a hematologic malignancy between February 2005 and October 2010 at our center using haploidentical donors (n = 53), MRDs (n = 117), or MUDs (n = 101) were included in this retrospective comparison. A patient underwent transplantation using a haploidentical donor at our center if there was no available MRD or MUD or if a suitable MRD or MUD was unavailable within the timeframe appropriate for the patient's malignancy and clinical circumstances. The time period was chosen to ensure that all living patients had a minimum follow-up of 1 year at the time of analysis. Median follow-up for surviving patients was 36 months (range, 12 to 79.5 months) at the time of analysis. Regimens were classified as myeloablative transplantation versus reduced-intensity conditioning transplantation (RICT)/nonmyeloablative stem-cell transplantation (NST) based on previously defined guidelines.[8,9] For purposes of statistical analysis, RICT regimens were combined with NST regimens and compared with myeloablative conditioning. MRD and MUD transplantations were performed using a variety of preparative regimens (RICT/NST regimens used for MRD and MUD transplantations are listed in Appendix Table A1, online only). No graft was subjected to ex vivo T-cell depletion. Supportive-care algorithms were identical for patients in the three donor groups. All patients were similarly managed in the outpatient setting, with admission reserved for complications or symptoms that could not be adequately managed without inpatient admission.

Haploidentical Donor Transplantation Regimens

Patients underwent alloHCT using haploidentical donors with one of two regimens. Thirty-five patients received a nonmyeloablative regimen that has previously been described,[5-7] consisting of fludarabine 30 mg/m^2 intravenously (IV) once per day on days −6 to −2; total-body irradiation (TBI) 2 Gy on day −1, and cyclophosphamide 14.5 mg/kg IV once per day on days −6 and −5 and 50 mg/kg once per day on days 3 and 4 with a bone marrow graft. Eighteen patients were treated on an institutionally developed myeloablative protocol using fludarabine 25 mg/m^2 IV once per day on days −6 to −2, busulfan 110 to 130 mg/m^2 IV once per day on days −7 to −4, and cyclophosphamide 14.5 mg/kg IV once per day on days −3 and −2 and 50 mg/kg once per day on days 3 and 4, with granulocyte colony-stimulating factor–mobilized peripheral blood stem cells (PBSCs; target CD34+ cell count, 5×10^6/kg) as the graft. No pharmacokinetic adjustment of busulfan dose was performed. All patients received tacrolimus from days 5 to 180, with a target level of 5 to 15 ng/mL, and mycophenolate mofetil (maximum dose, 3 g per day in divided doses) on days 5 to 35. Filgrastim 5 μg/kg was administered from day 5 until neutrophil recovery. Human investigations were performed after approval by the local human investigations committee and in accordance with an assurance filed with and approved by the US Department of Health and Human Services.

End Points

Primary outcomes analyzed were overall survival, disease-free survival (DFS; survival without evidence of active malignancy after transplantation), relapse of malignancy, NRM, acute GVHD, and chronic GVHD. Acute GVHD was classified as clinically significant (grades 2 to 4) or severe (grades 3 to 4). Because of the possibility of delayed onset of clinical acute GVHD after transplantation performed using RICT/NST regimens, cumulative incidence of acute GVHD was assessed at 6 months after transplantation. Chronic GVHD was classified as limited or extensive and also classified as mild, moderate, or severe by National Institutes of Health consensus criteria.[10] Acute and chronic GVHD were evaluated and graded by a single practitioner within the program. NRM and relapse were treated as competing risks. Graft failure was described as absolute neutrophil count $< 0.5 \times 10^9$/L in the presence of poor donor myeloid chimerism (CD33+ cells < 5% donor).

Statistical Methods

Comparisons of patient characteristics between transplantation groups were performed using the Kruskal-Wallis test for age and χ^2 test for categorical data. Cumulative incidences of NRM, relapse, acute GVHD, and chronic GVHD were computed to account for presence of competing risks.[11] Variables considered in multivariate analyses of overall survival and DFS included age, sex, diagnosis, regimen type (myeloablative *v* NST/RICT), graft type (PBSC *v* marrow), Karnofsky performance score, Center for International Blood and Marrow Transplant Research (CIBMTR) disease risk category, and Hematopoietic Cell Transplantation–Specific Comorbidity Index score.[12] Effects of these variables were assessed in Cox models with transplantation groups as strata to allow the baseline hazard functions to vary by type of transplantation. A backward stepwise selection procedure was performed on both overall survival and DFS, with a significance level of 0.1. On the basis of the significant variables, time-dependent variables were created and temporarily included in Cox models to test the proportional hazards assumption. Interactions between the main effects were examined at the same significance level of 0.1, but no interaction effect was significant. The adjusted overall survival and DFS of different types of transplantation were computed as average survival estimates of the pooled sample, weighted by the proportions of the significant variables in the Cox models.[13,14] Postrelapse/progression survival (PRS) was evaluated based on survival times of patients who experienced relapse or progression of their malignancy; the time origin was date of relapse. The follow-up time for PRS was obtained by subtracting the time to relapse from the total follow-up time. PRS can be confounded by the problem of dependent censoring. Specifically, the length of follow-up after relapse depends on the time to relapse and can distort the accurate measurement of PRS. To correct for this phenomenon and adjust for dependent censoring, the inverse probability censoring weighted method[15] was used for estimation of PRS. Outcome comparisons between transplantation using haploidentical donors and MRDs as well as between haploidentical donors and MUDs were of primary study interest. Significance was assessed using the Wald test and was conducted on NRM, relapse, acute GVHD, chronic GVHD, adjusted overall survival, adjusted DFS, and PRS at the fixed time points.[11] In one outcome, a comparison associated with $P < .05$ was identified as significant based on Bonferroni adjustment to control the overall type I error rate at a level of 0.1.

Global tests were also conducted to compare survival outcomes between transplantation using haploidentical donors and MRDs as well as between haploidentical donors and MUDs over the entire study period. 95% confidence bands for differences in adjusted overall survival and DFS between transplantation using haploidentical donors and MRDs and between those using haploidentical donors and MUDs were constructed through simulation.[13,15,16] Adjusted overall survival and DFS were not considered significantly different between two types of transplantation if the horizontal zero line was contained within the confidence band. Gray's tests[17] were conducted to compare cumulative incidences of a competing-risk end point between transplantation using haploidentical donors and MRDs and between transplantation using haploidentical donors and MUDs. Gray's global tests were evaluated, respectively, on NRM, relapse, acute GVHD, and chronic GVHD.

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RESULTS

Patient Characteristics

Characteristics of patients studied in this analysis are listed in Table 1. The groups were well matched, except that patients undergoing alloHCT using haploidentical donors were significantly more likely to receive bone marrow grafts and an RICT/NST regimen. Patients undergoing alloHCT using haploidentical donors were mismatched at a median of five of 10 HLA-A, -B, -C, -DRB1, and -DQB1 loci by high-resolution molecular typing (range, two to five). MRDs were HLA identical to recipients in 114 patient cases (97.5%) and mismatched at a single HLA locus (nine of 10 HLA-A, -B, -C, -DRB1, and -DQB1 loci match) in three patients (2.5%; HLA-A locus mismatch in all patient cases). MUDs were matched at 10 of 10 loci in 87 patients (86%) and nine of 10 loci in 14 patients (14%; mismatched locus: HLA-A, n = 3; HLA-B, n = 2; HLA-C, n = 4; HLA-DQ, n = 5). Donor-cell engraftment occurred in 114 transplantations using MRDs (97.5%), 99 using MUDs (98%) and 52 using haploidentical donors (98%).

Table 1. Patient Demographics and Clinical Characteristics

Characteristic	MRD (n = 117) No.	%	MUD (n = 101) No.	%	Haploidentical (n = 53) No.	%	*P*
Median age, years	50		51		46		
Sex							.286
Male	75	64	55	54	29	55	
Female	42	36	46	46	24	45	
KPS							.319
< 90	32	27	35	35	20	38	
≥ 90	85	73	66	65	33	62	
Prior autotransplantation							.647
Yes	19	16	12	12	9	17	
No	98	84	89	88	44	83	
HCTCI score							.807
0 or 1	44	64	69	68	30	68	
≥ 2	25	36	32	32	14	32	
CIBMTR risk							.593
Low	37	32	27	27	18	34	
Intermediate	16	13	21	21	10	19	
High	64	55	53	52	25	47	
Diagnosis							.253
ALL	12	10	19	19	10	19	
AML	37	32	37	36	17	32	
NHL	25	21	14	14	5	9	
HL	7	6	4	4	6	11	
CLL	3	2.5	5	5	7	13	
CML/MPS	11	9.5	11	11	4	7.5	
MDS	11	9.5	7	7	4	7.5	
MM	9	7.5	4	4	0	0	
Other	2	1.5	0	0	0	0	
Regimen type							< .001
Myeloablative	70	60	47	46	18	34	
RICT/NST	47	40	54	54	35	66	
Cell source							< .001
PBSC	108	92	95	94	21	40	
BM	7	6	6	6	32	60	
PB + BM	2	2	0	0	0	0	

Abbreviations: ALL, acute lymphoblastic leukemia; AML, acute myeloid leukemia; BM, bone marrow; CIBMTR, Center for International Blood and Marrow Transplant Research; CLL, chronic lymphocytic leukemia; CML, chronic myeloid leukemia; HCTCI, Hematopoietic Cell Transplantation–Specific Comorbidity Index; HL, Hodgkin lymphoma; KPS, Karnofsky performance score; MDS, myelodysplastic syndrome; MM, multiple myeloma; MPS, myeloproliferative syndrome; MRD, matched related donor; MUD, matched unrelated donor; NHL, non-Hodgkin lymphoma; NST, nonmyeloablative stem-cell transplantation; PB, peripheral blood; PBSC, peripheral blood stem cell; RICT, reduced-intensity conditioning transplantation.

GVHD

Rates of acute GVHD did not significantly differ by donor type (Figs 1A, 1B). Cumulative incidences of grades 2 to 4 acute GVHD at 6 months were 27%, 39%, and 30% for patients undergoing transplantation using MRDs, MUDs, and haploidentical donors, respectively; cumulative incidence rates for severe (grades 3 to 4) acute GVHD at 6 months were 8%, 11%, and 11%, respectively.

Chronic GVHD was significantly less frequent and less severe in patients undergoing transplantation using haploidentical donors than those undergoing transplantation using conventional donors on point-wise comparison (Figs 1C, 1D). Cumulative incidences of clinically extensive chronic GVHD at 24 months were 54%, 54%, and 38% for patients undergoing transplantation using MRDs, MUDs, and haploidentical donors, respectively ($P < .05$ for those undergoing haploidentical donor *v* MRD and MUD transplantation); cumulative rates of severe chronic GVHD at 24 months were 11%, 12%, and 4%, respectively ($P < .05$ for those undergoing haploidentical donor *v* MUD and .062 for haploidentical donor *v* MRD transplantation).

NRM

Cumulative incidences of NRM are shown in Figure 2A. The respective rates of NRM for patients undergoing transplantation using MRDs, MUDs, and haploidentical donors were not significantly different at 12 (10%, 10%, and 4%, respectively) or 24 months (13%, 16%, and 7%, respectively).

Relapse of Malignancy

Cumulative incidences of relapse of malignancy were not significantly different among patients undergoing transplantation using the three donor groups (Fig 2B). For transplantation using MRDs, MUDs, and haploidentical donors, 24-month cumulative rates of relapse were 34%, 34%, and 33%, respectively.

Overall Survival and DFS

In the Cox analysis performed, transplantation groups were used as strata to allow for time-varying effects between any two types of transplantation. Age, diagnosis, Hematopoietic Cell Transplantation–Specific Comorbidity Index score, and CIBMTR disease-risk category were found to have a significant impact on survival (Table 2). For DFS, age, and CIBMTR disease-risk category were the only significant variables. Adjusted estimates of overall survival and DFS computed as average survival estimates of the pooled sample, weighted by the proportions of the significant variables in the Cox models, are shown in Figure 3. Survival was not significantly different for patients undergoing transplantation using the three types of donors. Adjusted 24-month estimated survival rates were 76%, 67%, and 64% for MRD, MUD, and haploidentical donor transplantation, respectively; adjusted rates of DFS were also similar between the three donor types (53%, 52%, and 60%, respectively, at 24 months). Similarly, global

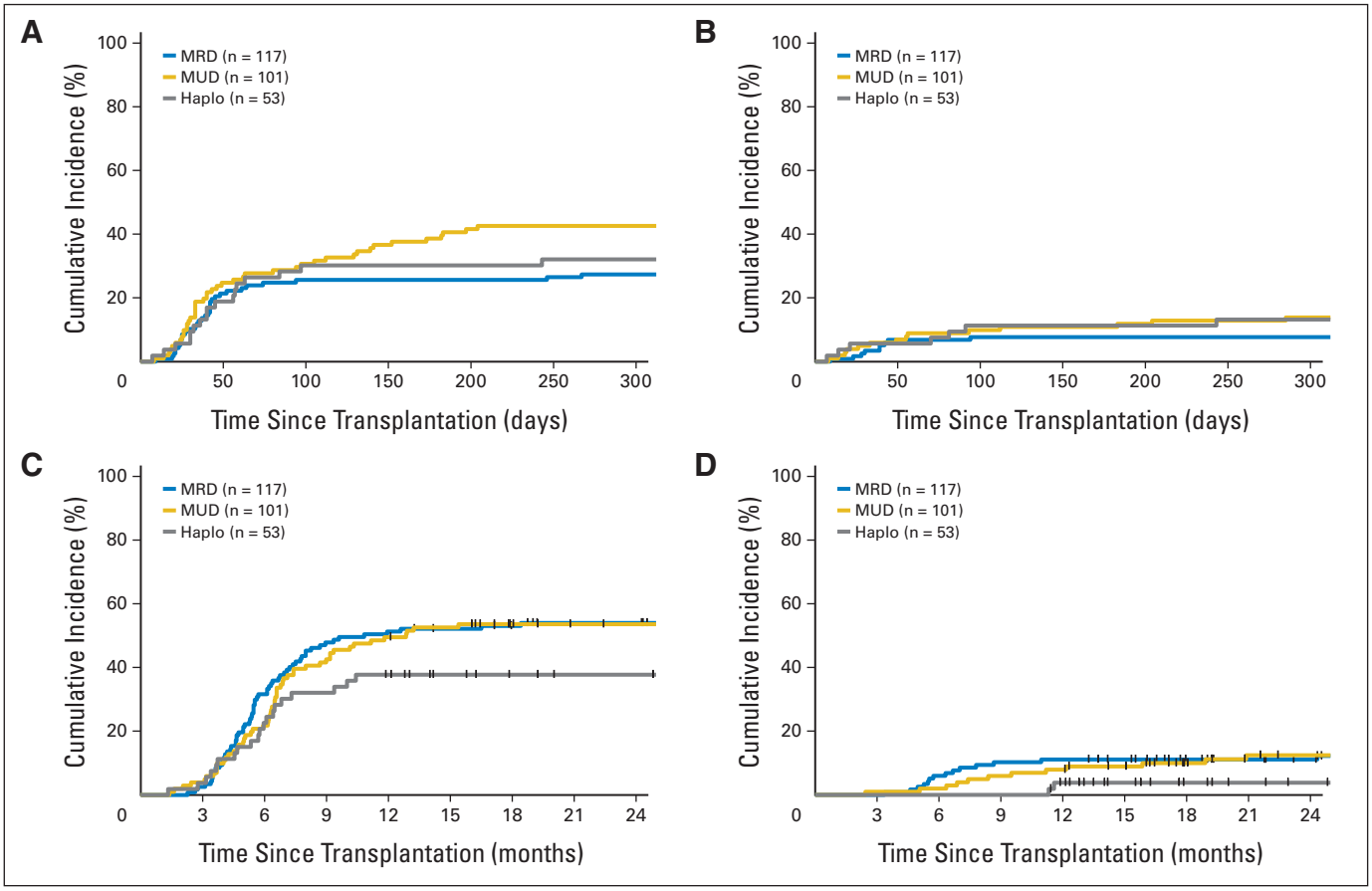

Fig 1. Cumulative incidence of graft-versus-host disease (GVHD) by donor type: (A) grades 2 to 4 acute GVHD, (B) grades 3 to 4 acute GVHD, (C) clinically extensive chronic GVHD, and (D) severe chronic GVHD by National Institutes of Health consensus criteria. Haplo, haploidentical donor; MRD, matched related donor; MUD, matched unrelated donor.

comparisons of overall survival and DFS also demonstrated no significant difference between the adjusted curves for transplantation performed using the different types of donors. Unadjusted curves for overall survival and DFS by donor group are provided in the Appendix for all patients (Appendix Fig A1, online only) and for specific diagnostic categories (Appendix Fig A2, online only).

PRS and Donor Lymphocyte Infusion

Ninety-four patients (35%) suffered relapse or progression of their malignancy at a median of 154 days after transplantation (range, 12 to 1,445 days; 40 patients undergoing MRD transplantation; 37, MUD; 17, haploidentical donor). Estimated PRS, assessed using the inverse probability of censoring weighted method, is shown in Figure

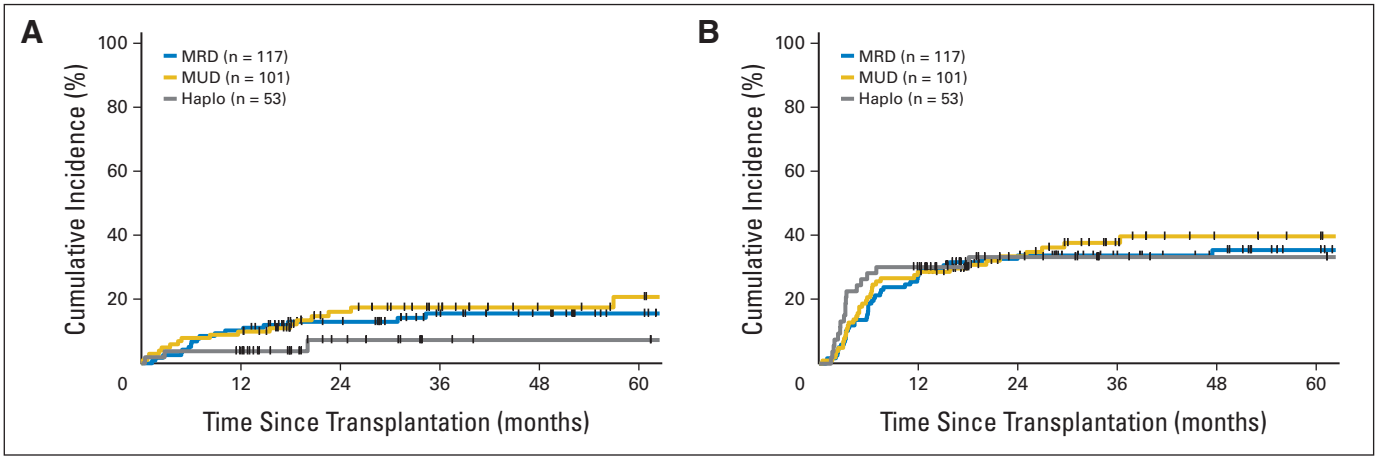

Fig 2. Cumulative incidence of nonrelapse mortality (NRM) and relapse of malignancy by donor type: (A) NRM and (B) relapse; both were analyzed as competing risks. Haplo, haploidentical donor; MRD, matched related donor; MUD, matched unrelated donor.

Table 2. Covariates With Significant Impact in Cox Analysis of OS and DFS

Covariate	HR	90% CI	*P*
OS			
HCTCI score (≥ 2 *v* 0 or 1)	1.74	1.18 to 2.54	.018
CIBMTR risk (high or intermediate *v* low)	1.84	1.17 to 2.88	.026
Diagnosis (ALL *v* other)	1.74	1.07 to 2.80	.059
Age	1.02	1.00 to 1.03	.087
DFS			
CIBMTR risk (intermediate or high *v* low)	1.50	1.07 to 2.11	.047
Diagnosis (ALL *v* other)	1.37	1.01 to 1.84	.086

NOTE. Significant impact defined as $P < .1$.
Abbreviations: ALL, acute lymphoblastic leukemia; CIBMTR, Center for International Blood and Marrow Transplant Research; DFS, disease-free survival; HCTCI, Hematopoietic Cell Transplantation–Specific Comorbidity Index; HR, hazard ratio; OS, overall survival.

4. PRS was significantly inferior for patients who experienced relapse after transplantation using a haploidentical donor than for those undergoing transplantation using other donor types. Estimated rates of PRS at 12 months were 67%, 63%, and 17% for MRD, MUD, and haploidentical donor transplantation ($P < .001$ for those undergoing haploidentical donor *v* MRD and MUD transplantation).

Six of 40 patients undergoing transplantation using MRDs, six of 37 patients undergoing transplantation using MUDs, and none of 17 patients undergoing transplantation using haploidentical donors who experienced relapse were treated with donor lymphocyte infusion (DLI; median initial CD3+ cell dose, 1×10^7/kg). PRS remained significantly different between the three donor groups, even if patients receiving DLI were excluded from analysis (2-month PRS: 64%, 76%, and 17% for MRD, MUD, and haploidentical donor transplantation, respectively; $P < .001$ for those undergoing haploidentical donor *v* MRD and MUD transplantation; Appendix Fig A3, online only).

DISCUSSION

To our knowledge, our study represents the first formal comparison of haploidentical donor transplantation with alloHCT using conventional MRDs and MUDs in an unselected population of patients undergoing first alloHCT for all hematologic malignancies. Although retrospective, strengths of this analysis include the contemporaneous population of patients studied, use of identical supportive care measures, and treatment within a single transplantation program. Furthermore, the primary outcome parameters—overall survival and DFS—were adjusted for potentially confounding patient-, disease-, and transplantation-related variables using a Cox proportional hazards analysis.

Our analysis suggests that incidence of NRM is not higher after haploidentical donor transplantation than after transplantation performed using conventional MRDs and MUDs. Indeed, a long-term NRM rate < 10% was achieved in the haploidentical donor patients (7% at 36 months). This finding is consistent with the low NRM seen in studies of nonmyeloablative T-cell–replete haploidentical donor transplantation performed using post-transplantation cyclophosphamide in multicenter settings.[5,7,18] Our analysis demonstrates that similar low rates of NRM can be achieved in an unselected population of patients undergoing both myeloablative and nonmyeloablative haploidentical donor transplantation performed using post-transplantation cyclophosphamide in a single institution.

The incidence and severity of clinical acute GVHD were not significantly different in patients undergoing transplantation using haploidentical donors when compared with patients undergoing transplantation using conventional donors. However, the incidence of extensive and severe chronic GVHD was significantly lower for haploidentical donor transplantation patients. The rates of acute and chronic GVHD observed after haploidentical donor transplantation in our unselected population were similar to those described in a series of 210 nonmyeloablative haploidentical donor transplantations reported by the Johns Hopkins group.[19] Bone marrow grafts have been demonstrated to cause less chronic GVHD than mobilized PBSC grafts in some randomized clinical trials[20,21] but not in others.[22,23] One meta-analysis in patients undergoing transplantation using MRDs showed a significantly higher incidence of both overall and extensive chronic GVHD in patients receiving PBSC grafts.[24] It is possible that the lower rate of chronic GVHD in the haploidentical donor transplantation patients may be explained by the greater use of bone marrow rather than PBSC grafts in this population. However, a direct relationship with use of T-cell–replete haploidentical donor grafts and post-transplantation cyclophosphamide cannot be excluded.

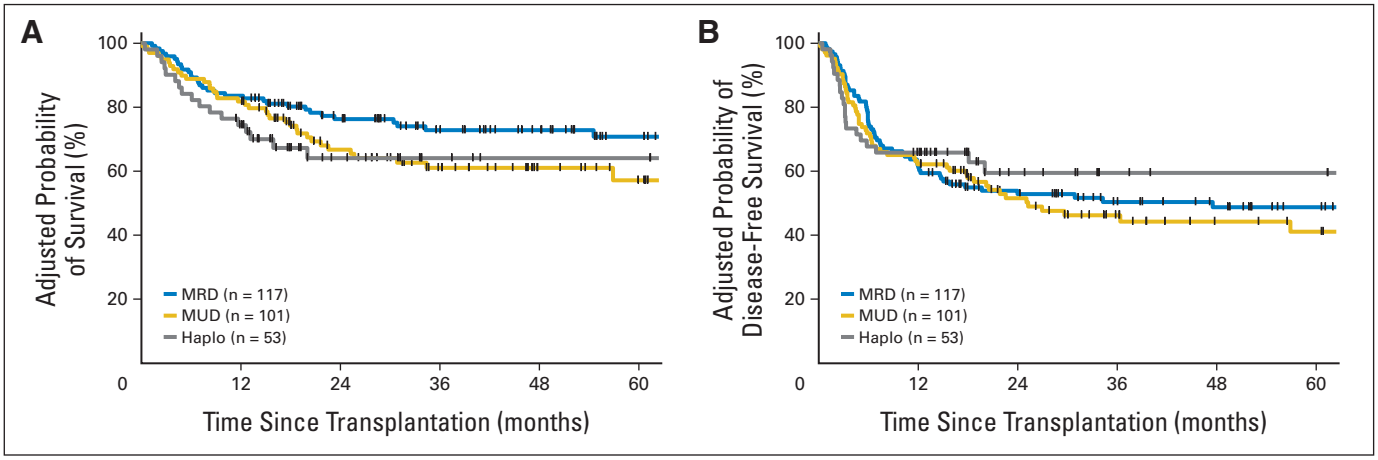

Fig 3. Adjusted estimated probabilities of (A) overall and (B) disease-free survival by donor type. Haplo, haploidentical donor; MRD, matched related donor; MUD, matched unrelated donor.

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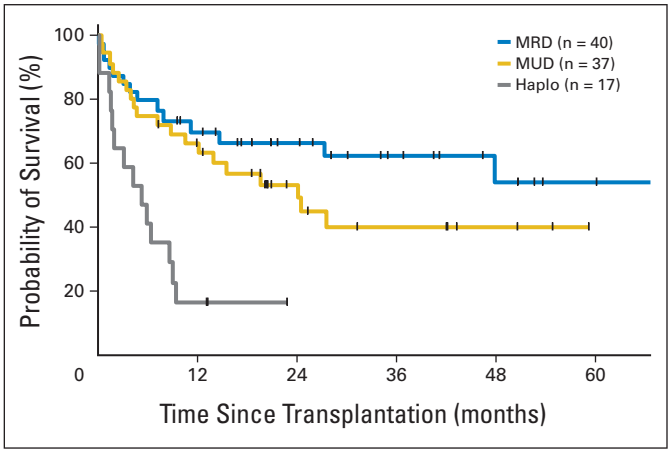

Fig 4. Estimated postrelapse survival assessed by the inverse probability of censoring weighted method. Haplo, haploidentical donor; MRD, matched related donor; MUD, matched unrelated donor.

Despite the less frequent use of myeloablative conditioning and PBSC grafts in the haploidentical donor transplantation patients, cumulative incidence of relapse of malignancy was not higher than cumulative incidence after conventional donor transplantation. Thus, adjusted DFS was not inferior in the haploidentical donor transplantation patients, with 60% of patients being alive and free of active malignancy at 2 years after haploidentical donor transplantation. Similarly, adjusted overall survival was not significantly different when haploidentical donor transplantation was compared with transplantation using conventional donors. T-cell–replete haploidentical donor transplantation has not previously been extensively compared with transplantation using conventional or alternative donor sources. In a comparison of nonmyeloablative transplantation performed for Hodgkin lymphoma in a multicenter setting, T-cell–replete haploidentical donor transplantation (n = 28) was found to have significantly lower NRM, equivalent overall survival, and improved PFS when compared with MRD (n = 38) and MUD (n = 24) transplantation.[18] Additionally, in two prospective parallel phase II trials conducted by the Blood and Marrow Transplant Clinical Trials Network, nonmyeloablative T-cell–replete haploidentical donor transplantation performed using post-transplantation cyclophosphamide was found to produce rates of overall and event-free survival similar to those achieved with nonmyeloablative double umbilical cord blood transplantation, with an NRM of 7% versus 24%, respectively.[5] Our study demonstrates that in an unselected population of patients undergoing transplantation contemporaneously for a variety of hematologic malignancies, including patients treated with myeloablative conditioning, T-cell–replete haploidentical donor transplantation with post-transplantation cyclophosphamide can produce long-term outcomes similar to those achieved with T-cell–replete transplantation using HLA-identical or well-matched MUD donors with conventional GVHD prophylaxis.

An unexpected finding from our study was that that survival after relapse of malignancy (ie, PRS) was inferior in patients undergoing transplantation using haploidentical donors compared with patients undergoing transplantation using MRDs or MUDs (12-month PRS, 17% *v* 67% and 63%, respectively). The factors underlying this finding are unclear. Because only 17 patients who underwent haploidentical donor transplantation experienced relapse, this finding should be approached with caution and needs to be confirmed in larger numbers of relapsing patients. This finding seems unrelated to the difficulty in administering DLI after relapse in patients who have undergone haploidentical donor transplantation. Administration of HLA-haploidentical DLI without post-transplantation cyclophosphamide may result in severe GVHD. Thus, no patient who relapsed after haploidentical donor transplantation received DLI, whereas DLI was administered in six patients who relapsed after MRD transplantation and six who relapsed after MUD transplantation. However, PRS remained inferior in the haploidentical donor transplantation patients, even when patients who received DLI were excluded from analysis (estimated 12-month survival, 64%, 76%, and 17% for MRD, MUD, and haploidentical donor transplantations, respectively; $P < .001$). It is also feasible that the inferior PRS observed in the haploidentical donor transplantation patients may be accounted for by a higher incidence of other risk features among these patients. However, the proportion of relapsing patients who underwent auto-transplantation before alloHCT was not significantly different among the three groups (seven [17.5%] of 40 patients undergoing MRD transplantation; eight [21.6%] of 37, MUD; three [17.5%] of 17, haploidentical donor).

In summary, this comparison suggests that outcomes after transplantation using haploidentical donors with post-transplantation cyclophosphamide are not inferior to those after conventional MRD and MUD transplantation. Transplantation using haploidentical donors with post-transplantation cyclophosphamide should be considered a valid alternative option for patients who need an alloHCT for whom no conventional donor is available.

AUTHORS' DISCLOSURES OF POTENTIAL CONFLICTS OF INTEREST

The author(s) indicated no potential conflicts of interest.

AUTHOR CONTRIBUTIONS

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Data analysis and interpretation: Asad Bashey, Xu Zhang, Connie A. Sizemore, Stacey Brown, H. Kent Holland, Scott R. Solomon
Manuscript writing: All authors
Final approval of manuscript: All authors

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