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ORIGINAL ARTICLE

Allogeneic hematopoietic stem cell transplantation for intermediate-risk acute myeloid leukemia in the first remission: outcomes using haploidentical donors are similar to those using matched siblings

Yan-Ru Ma[1] · Lan-Ping Xu[1] · Xiao-Hui Zhang[1] · Kai-Yan Liu[1] · Ying-Jun Chang[1] · Meng Lv[1] · Chen-Hua Yan[1] · Yu-Hong Chen[1] · Wei Han[1] · Feng-Rong Wang[1] · Xiao-Dong Mo[1] · Xiao-Jun Huang[1,2] · Yu Wang[1]

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Abstract

Allogeneic hematopoietic stem cell transplantation (allo-HSCT) is an effective and curative treatment for acute myeloid leukemia (AML). We explored the outcome of haploidentical donor (HID) transplantation for intermediate-risk AML and compared to that of matched sibling donor (MSD) transplants. One hundred twenty-seven consecutive patients with intermediate-risk AML in the first complete remission (CR1) who underwent allo-HSCT between January 1, 2015, and August 1, 2016, were enrolled. Thirty-seven patients received MSD grafts, and 90 received HID grafts. The 2-year leukemia-free survival (LFS) of the HID group was comparable to that of the MSD group: 82.0% ± 4.1% versus 82.7% ± 6.4%, $P = 0.457$. The 2-year cumulative incidences of relapse and transplantation-related mortality (TRM) were comparable between the HID and MSD groups (relapse, 4.5% ± 0.1%, versus 11.5% ± 0.3%, $P = 0.550$; TRM, 13.4% ± 0.1% vs. 5.8% ± 0.2%, $P = 0.154$). The HID recipients had a trend of a lower 2-year cumulative incidence of positive posttransplant flow cytometry (FCM+) and relapse than the MSD recipients (5.6% ± 0.1% vs. 19.9% ± 0.5%, $P = 0.092$). These results suggest that the outcomes of allo-HSCT with HIDs are comparable to those with MSDs in terms of LFS, TRM, and relapse for intermediate-risk AML in CR1. HIDs could be an alternative to MSDs for intermediate-risk AML.

Keywords Haploidentical donor · Matched sibling donor · Intermediate-risk · Acute myeloid leukemia

Introduction

Acute myeloid leukemia (AML) remains the most frequent indication for allogeneic hematopoietic stem cell transplantation (allo-HSCT) [1–3]. AML patients with unfavorable cytogenetics are recommended to undergo HSCT in the first complete remission (CR1) due to their high risk of relapse. However, the recommendations for HSCT in intermediate-risk AML were less clear. The risk-benefit ratio in regard to patient fitness, donor source, minimal residual disease (MRD) status, and transplant center experience must be evaluated when making a decision on HSCT. The 2017 European LeukemiaNet (ELN) recommendations and the 2018 National Comprehensive Cancer Network (NCCN) Guidelines recommended that allo-HSCT could be used as postremission therapy for intermediate-risk AML patients [4, 5]. An increasing number of studies have suggested that adults with intermediate-risk AML in CR1 could benefit from allo-HSCT [6–10]. However, the lack of a matched sibling donor (MSD) and the difficulty in finding a matched unrelated donor (MUD) limited the application of allo-HSCT.

For patients who lack an MSD, a haploidentical donor (HID) could be an option. A multicenter, prospective study in China demonstrated similar survival after HID-HSCT and MSD-HSCT for patients with intermediate- or high-risk AML in CR1 [11]. The haploidentical group had a 3-year overall

✉ Yu Wang
ywyw3172@sina.com

[1] Peking University People's Hospital, Peking University Institute of Hematology, National Clinical Research Center for Hematologic Disease, Research Unit of Key Technique for Diagnosis and Treatments of Hematologic Malignancies, Beijing Key Laboratory of Hematopoietic Stem Cell Transplantation, Collaborative Innovation Center of Hematology, Peking University, No 11 Xizhimen South Street, Beijing 100044, China

[2] Peking-Tsinghua Center for Life Sciences, Beijing, China

survival (OS) of 79%, which was comparable to the 82% 3-year OS in the HLA-identical group ($P = 0.36$). A publication on intermediate- and high-risk AML by Yoon et al. reported a 5-year leukemia-free survival (LFS) of 65.9% for MSD and 68.5% for HID in intermediate-risk AML; however, in the posttransplant cyclophosphamide (PT-CY) setting, a worse LFS was observed by Salvatore et al. in HID-HSCT than in MSD-HSCT for intermediate-risk AML (56% versus 70%, respectively, $P < 0.01$) [12]. In recent years, more safety and efficacy data were obtained on HID transplants than on MSD/MUD transplants [5, 13–17]. While remarkable improvements have been made in HID-HSCT, the role of HID-HSCT for intermediate-risk AML is somewhat controversial. The NCCN guidelines suggested that patients with intermediate-risk AML could receive alternative donor transplantation in the absence of matched donors [5], while haploidentical allo-HSCT is not listed as a consolidation option in the ELN recommendations [4]. Our previous study reported that HID-HSCT was superior to chemotherapy alone as a postremission treatment for intermediate-risk AML [7, 8]. As published data on HID-HSCT for intermediate-risk AML are limited, whether transplantation from an HID is equivalent to that from an MSD for intermediate-risk AML is still a matter of debate.

Here, we report the results of the comparison of HID transplants and MSD transplants for homogeneous patients with intermediate-risk AML in CR1.

Patients and methods

Patients

Between January 1, 2015, and August 1, 2016, 127 consecutive patients aged ≥ 15 years with intermediate-risk AML in CR1 received HID ($N = 90$) or MSD ($N = 37$) allo-HSCT according to donor availability at the Peking University Institute of Hematology. Fourteen patients who received a haplo-HCT from maternal donors or collateral relatives with low-dose posttransplant cyclophosphamide (PT-CY) [18] were excluded. The study protocol was approved by the Institutional Review Board of Peking University. All patients provided their written informed consent for this procedure.

Risk status

Patients were stratified as intermediate-risk AML based on the NCCN guidelines [5]. Included criteria are (1) wild-type NPM1 without FLT3-ITD mutation; (2) t(9;11); and (3) cytogenetic abnormalities not classified as favorable or adverse. Excluded criteria are (1) the favorable-risk cytogenetics t(8;21), t(15;17), inv(16), or t(16;16); (2) mutated NPM1 without FLT3-ITD mutation; (3) the poor-risk cytogenetics including complex karyotypes (≥ 3 clonal chromosomal abnormalities), monosomal karyotypes, − 5, 5q-, − 7, 7q-, 11q23-non t(9;11), inv(3), t(3;3), t(6;9), and t(9;22); and (4) wild-type NPM1 and mutated FLT3-ITD.

Transplant protocols

The transplantation procedure was described in previous studies [11, 19, 20]. For HID transplants, the busulfan (BU)-based conditioning regimen consisted of cytarabine (Ara-C; 4 g/m^2/day, intravenous, days − 10 and − 9), BU (3.2 mg/kg/day, intravenous, days − 8 to − 6), cyclophosphamide (CY; 1.8 g/m^2/day, days − 5 and − 4), rabbit antithymoglobulin (ATG; 2.5 mg/kg/day, days − 5 to − 2), and semustine (Me-CCNU; 250 mg/m^2, oral, day − 3). For MSD transplants, patients received hydroxyurea (Hu; 40 mg/kg, two doses, oral, day − 10), a lower dose of Ara-C (2 g/m^2/day, intravenous, day − 9), and no ATG; otherwise, the regimen was identical to that of haploidentical patients. Bone marrow (BM) cells and/or peripheral blood (PB) cells were collected after G-CSF mobilization. Day 1 was the first day of donor cell infusion. All transplantation recipients received cyclosporine A (CsA), mycophenolate mofetil (MMF), and short-term methotrexate (MTX) as graft-versus-host disease (GVHD) prophylaxis. The haploidentical graft recipients received G-CSF (5 μg/kg, subcutaneously, daily) from day + 6 until myeloid recovery [21, 22].

Monitoring of MRD

BM assessments were performed to assay for MRD before transplantation. After transplantation, BM samples were examined at + 1, + 2, + 3, + 4.5, + 6, + 9, + 12, + 18, and + 24 months, as well as once a year thereafter. More frequent analyses were performed if the MRD status became positive. Eight-color multiparameter FCM was used to detect leukemia-associated antigen phenotypes (LAIPs). More than 0.01% of previously identified LAIPs were defined as FCM-positive (FCM+) [23–25].

Definitions

Neutrophil recovery was defined as the first day of 3 consecutive days when an absolute neutrophil count (ANC) ≥ 0.5 × 10^9/L was achieved, and platelet recovery was defined as the first day of 7 consecutive days when a platelet count ≥ 20 × 10^9/L was achieved without transfusion. Relapse was defined as hematological relapse or extramedullary relapse [5]. TRM was defined as death due to any cause other than relapse. OS was calculated from the date of HSCT to the date of death from any cause. LFS was calculated from the date of HSCT to the date of relapse or death. GVHD-free/relapse-free survival (GRFS) was calculated from the date of HSCT to the date of events that included grades III–IV aGVHD, cGVHD requiring systemic therapy, relapse, or death [26].

Statistical analysis

The last follow-up date was March 1, 2019. The primary endpoint for the study was OS, and secondary endpoints included LFS, relapse, and TRM. The Mann-Whitney *U* rank sum test was used for continuous variables, and a chi-square test or Fisher's exact test was used for categorical variables. All tests were two-sided. Kaplan-Meier outcome curves were constructed for the OS and LFS of patients. The log-rank test was used to identify prognostic factors, and a Cox proportional hazards regression model was used to assess the relative impact of previously defined risk factors with multivariate analysis. The cumulative incidences of relapse and GVHD were calculated with a completing-risk model, with TRM as the competing event. The forced factor (haploidentical vs. HLA-identical) and all factors with $P < 0.20$ in the univariate analysis were included in a multivariate regression. $P < 0.05$ was considered significant. Data analyses were primarily conducted with SPSS software (SPSS, Chicago, IL) and R software (version 2.6.1) (http://www.r-project.org).

Results

Patient characteristics

Baseline characteristics for the subjects are summarized in Table 1. In comparison to MSD recipients, the HID recipients were younger ($P = 0.011$). The median time from the diagnosis of AML to transplantation in the HID group was longer than that in the MSD group ($P = 0.003$).

Engraftment

All patients achieved neutrophil recovery. The median time to neutrophil recovery was 16 days (range, 12–27 days) in the MSD group and was 13 days (range, 9–25 days) in the HID group ($P = 0.000$). Platelet engraftment was observed in 126 cases, at a median of 13 days (range, 8–43 days) in the MSD group and 15 days (range, 9–784 days) in the HID group ($P = 0.032$). One HID recipient had persistent thrombocytopenia and died of severe pneumonia at 38 days posttransplant. All patients exhibited complete donor chimerism at 1 month after transplantation.

Relapse

Of the 127 patients, 11 patients (8.7%) relapsed, with a median time of 355 days after transplantation (range, 50–969 days). The median time to relapse was 254.5 days (range, 126–727 days) for the MSD group and 473 days (range, 50–969 days) for the HID group. In the competing-risk model, the 2-year rate of relapse in the HID group was not significantly different from that in the MSD group (4.5% ± 0.1%, versus 11.5% ± 0.3%, $P = 0.550$) (Fig. 1). If either a positive posttransplant FCM status or a morphological relapse was considered relapse at the MRD level, the HID group had a tendency to have a lower relapse rate than the MSD group (5.6% ± 0.1% vs. 19.9% ± 0.5%, $P = 0.092$). Fifteen patients were posttransplant MRD+ or experienced disease recurrence. Of them, one received palliative care, and 14 received interventions. Of them, 4 patients in the MSD group and 5 patients in the HID group received a preemptive/therapeutic donor lymphocyte infusion (DLI) at a median time of 295 days (range, 70–1070 days) posttransplant. At last follow-up, 9 (60%) patients died of relapse.

As shown in Table 1, 5 MSD patients and 12 HID patients had positive pre-MRD status. Two MSD patients and three HID patients experienced MRD reactivation after transplantation.

In the multivariable analysis, a WBC count at diagnosis ≥ 100×10^9/L remained the only independent risk factor for higher risk of relapse (Table 2). Other variables including the donor type, recipient age, and cycles of induction to achieve CR1 (1 cycle vs. ≥ 2 cycles) were not significantly associated with the risk of relapse.

TRM

At the last follow-up, 6 MSD recipients and 18 HID recipients died. The causes of death included relapse ($n = 9$) and TRM ($n = 15$). The leading cause of death after transplantation was severe pneumonia ($n = 10$), accounting for the cause of death in 8 HID recipients and in two MSD recipients. The cumulative incidence of TRM at 2 years was not significantly different between HID and MSD transplants (13.4% ± 0.1% vs. 5.8% ± 0.2%, $P = 0.154$). The 2-year probability of TRM was significantly higher for recipients > 50 years than those ≤ 50 years (29.3% ± 1.7% vs. 9.0% ± 0.1%, $P = 0.005$). In the multivariate analysis, recipient age > 50 years was confirmed as the only independent prognostic factor for TRM (Table 2).

GVHD

The cumulative incidence of grades II-IV aGVHD at 100 days posttransplant was 30.0% after HID-HSCT and 5.4% after MSD-HSCT ($P = 0.002$). Severe aGVHD tended to occur more frequently in HID-HSCT than in MSD-HSCT (8.9% vs. 0%, $P = 0.062$). Other factors including female donor to male recipient (F-M) were not associated with the development of aGVHD.

The 2-year rate of cGVHD was lower in the HID-HSCT group than in the MSD-HSCT group (25.1% ± 0.2% vs. 45.6% ± 0.7%, $P = 0.007$), and the 2-year incidence of extensive cGVHD was not significantly different between the HID- and MSD-HSCT groups (10.3% ± 0.1% vs. 22.6% ± 0.5%, $P = 0.068$). In the multivariable analysis, the following factors

Table 1 Patient characteristics

Characteristics	MSD	HID	*P*
Total patients, *n*	37	90	
Median age, y (range)	43 (15–62)	33 (15–57)	0.011
Gender			0.126
Male, *n*(%)	24 (64.9%)	45 (50.0%)	
Female, *n*(%)	13 (35.1%)	45 (50.0%)	
Donor-recipient gender match			0.001
Female→male, *n*(%)	15 (40.5%)	12 (13.3%)	
Others, *n*(%)	22 (59.5%)	78 (86.7%)	
Conditioning regimen			–
BU/CY, n(%)	35(94.6%)	–	
BU/CY + ATG, n(%)	–	90 (100%)	
TBI/CY, *n*(%)	1 (2.7%)	–	
BU/Flu, *n*(%)	1 (2.7%)	–	
Graft source			0.083
BM + PB, *n*(%)	35 (94.6%)	90 (100%)	
PB, *n*(%)	2 (5.4%)	0 (0%)	
Median MNC, $\times 10^8$/L (range)	7.75 (4.20–11.89)	8.35 (5.00–12.35)	0.113
Median CD34, $\times 10^6$/L (range)	2.66 (0.61–6.40)	2.46 (0.50–7.52)	0.760
Median follow-up of survivors, *d* (range)	1011 (100–1479)	1065(184–1476)	0.690
WBC at diagnosis			0.020
$\leq 100 \times 10^9$/L, *n*(%)	27 (77.1%)	78 (94.0%)	
$> 100 \times 10^9$/L, *n*(%)	8 (22.9%)	5 (6.0%)	
Median, $\times 10^9$/L (range)	27.69 (0.4–379.18)	5.23 (0.14–294.44)	0.008
Cycles of induction			0.344
1 cycle, *n*(%)	23 (62.2%)	66 (73.3%)	
2 cycles, *n*(%)	11 (29.7%)	19 (21.1%)	
3 cycles, *n*(%)	3 (8.1%)	3 (3.3%)	
4 cycles, *n*(%)	0 (0%)	2 (2.2%)	
Time from diagnosis to transplantation			
Median, mo (range)	6 (4–9)	7 (2–21)	0.003
Pre-MRD status			1.000
Positive, *n*(%)	5 (13.5%)	12 (13.5%)	
Negative, *n*(%)	32 (86.5%)	77 (86.5%)	

ATG anti-thymocyte globulin, *BM* bone marrow, *BU* busulfan, *CY* cyclophosphamide, *Flu* fludarabine, *HID* haploidentical donor, *MNC* mononuclear cell, *MRD* minimal residual disease, *MSD* matched sibling donor, *PB* peripheral blood, *TBI* total body irradiation, *WBC* white blood cell

were associated with the development of cGVHD: cycles of induction to achieve CR1 ≥ 2 (≥ 2 cycles vs. 1 cycle, HR = 2.175, 95% CI 1.040–4.547, $P = 0.039$), and HLA matching (matched vs. mismatched, HR = 2.408, 95% CI 1.316–4.408, $P = 0.004$). Female donor/male recipient was not a risk factor for cGVHD (F-M vs. others, HR = 1.260, 95% CI 0.620–2.562, $P = 0.523$). No risk factors for the occurrence of extensive cGVHD were found.

Survival after transplantation

The 2-year OS after transplantation was 83.1% ± 4.0% in the HID group and 88.5% ± 5.4% in the MSD group ($P = 0.623$) (Fig. 2a). The 2-year LFS of the HID group was comparable to that of the MSD group (82.0% ± 4.1% versus 82.7% ± 6.4%, respectively, $P = 0.457$) (Fig. 2b). Furthermore, the 2-year GRFS was not significantly different between the HID and MSD groups (71.8% ± 4.8% vs. 65.9% ± 8.0%, $P = 0.769$) (Fig. 2c).

The survival was significantly different between patients who were > 50 years old and younger patients (OS, $P = 0.011$; and LFS, $P = 0.018$). In the subgroup analysis, worse outcomes for patients > 50 years old were seen in MSD transplants (OS, $P = 0.032$; and LFS, $P = 0.009$) but not in HID transplants (OS, $P = 0.195$; and LFS, $P = 0.297$). Patients who had positive pretransplant MRD (pre-MRD+) had

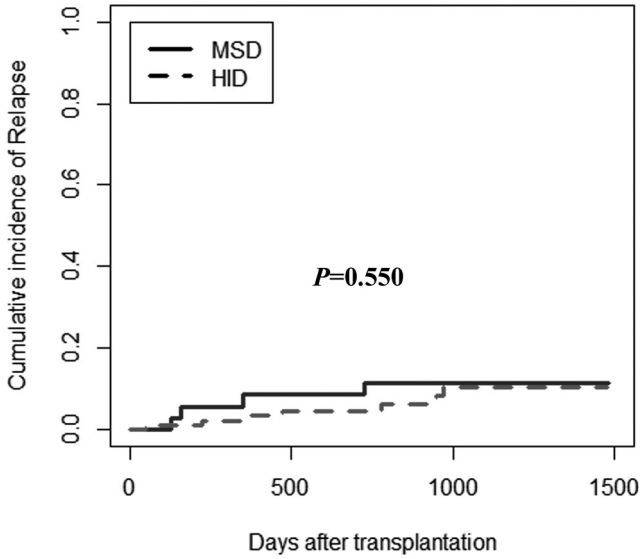

Fig. 1 Cumulative incidence of relapse. HID, haploidentical donor; MSD, matched sibling donor

significantly worse OS and LFS than the negative pre-MRD (pre-MRD−) group (OS, $P = 0.002$; and LFS, $P = 0.012$), but the GRFS was not significantly different between these two groups ($P = 0.153$).

In the Cox regression, pre-MRD+ status and recipient age > 50 years were independent risk factors of OS and LFS. For GRFS, recipient age > 50 years remained the only adverse factor for GRFS in the multivariable analysis (Table 2).

Discussion

HID-HSCT has been established as an alternative for patients who lack an HLA-identical donor. Several studies have described HID transplants for AML patients and have compared HID transplants with MUD or MSD transplants [11, 13, 27, 28]. However, most of these studies examined AML patients as a whole population without stratifying by cytogenetics, and other studies focused on HID transplants for high-risk AML. In this study, we compared the outcomes of HID transplants with that of MSD transplants for homogeneous intermediate-risk AML patients in CR1. Our data demonstrated similar LFS and OS with HID and MSD, which is consistent with a report from Korean researchers and with our previous study on intermediate-risk and high-risk AML [11, 29].

Notably, HID transplants had a trend of decreased relapse probability at the MRD level, suggesting a potential graft-versus-leukemia (GVL) effect of HID. There are conflicting data on whether HID-HSCT might have a superior GVL effect than MSD or MUD-HSCT [13, 27, 29–32]. While no superior GVL effect of HID-HSCT has been confirmed in a large population [30], there has been some evidence that

Table 2 Cox proportional hazards models for survival

Factors	Relative risk	95% CI	*P*
Overall survival			
HID vs. MSD	1.341	0.523–3.438	0.542
Age > 50 years vs. ≤ 50 years	3.307	1.280–8.547	0.014
Positive pre-MRD vs. negative	3.611	1.463–8.912	0.005
Leukemia-free survival			
HID vs. MSD	1.583	0.622–4.029	0.335
Age > 50 years vs. ≤ 50 years	2.950	1.152–7.551	0.024
Positive pre-MRD vs. negative	2.770	1.153–6.655	0.023
GVHD, relapse-free survival			
HID vs. MSD	1.072	0.515–2.233	0.852
Age > 50 years vs. ≤ 50 years	2.429	1.047–5.636	0.039
Positive pre-MRD vs. negative	1.922	0.835–4.425	0.125
WBC ≥ 100×10^9/L at diagnosis vs. < 100×10^9/L	2.277	0.939–5.524	0.069
Relapse			
HID vs. MSD	0.881	0.208–3.735	0.864
Positive pre-MRD vs. negative	2.417	0.496–11.789	0.275
WBC ≥ 100×10^9/L at diagnosis vs. < 100×10^9/L	4.825	1.204–19.346	0.026
TRM			
HID vs. MSD	2.817	0.627–12.657	0.177
Age > 50 years vs. ≤ 50 years	4.756	1.579–14.321	0.006
Positive pre-MRD vs. negative	2.590	0.805–8.328	0.110

GVHD graft-versus-host disease, *HID* haploidentical donor, *MRD* minimal residual disease, *MSD* matched sibling donor, *TRM* transplant-related mortality, *WBC* white blood cell

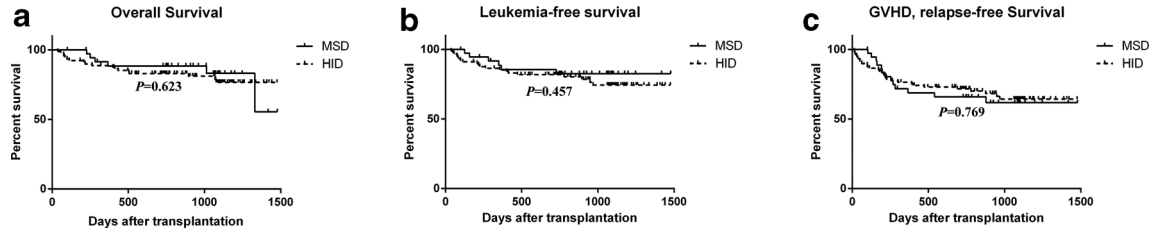

Fig. 2 Survival. **a** Overall survival. The 2-year OS after transplantation was 83.1% ± 4.0% in the HID group and 88.5% ± 5.4% in the MSD group. **b** Leukemia-free survival. The 2-year LFS was 82.0% ± 4.1% in the HID group and 82.7% ± 6.4% in the MSD group. **c** GVHD, relapse-free survival. The 2-year GRFS was 71.8% ± 4.8% in the HID group and 65.9% ± 8.0% in the MSD group. GVHD, graft-versus-host disease; HID, haploidentical donor; MSD, matched sibling donor

HID grafts might yield better GVL effects in some specific populations [30, 31]. Ringden et al. reported a lower relapse rate in the HID group for acute leukemia (AL) in CR2/3 than that in the MSD group [30]. Wang et al. showed that the cumulative incidence of relapse was 26% after HID transplants for relapsed/refractory AL, which was lower than that after MSD transplants (49%, $P = 0.008$) [31]. Yoon et al. also observed a lower relapse rate (18.5%) in HID than in MSD transplants (23.5%) for intermediate-to-poor risk AML in CR1 [29]. Our findings showed that HID grafts seemed to have a stronger GVL effect in this intermediate-risk population, although we found no significant difference in relapse rates between HID- and MSD-HSCT, probably due to the small sample size. In addition, it is worth noting that MSD recipients exhibited an increased risk of a positive FCM status posttransplant. Preemptive interventions for patients who are MRD+ might reduce relapse after transplantation and reduce the difference in relapse rates between MSD- and HID-HSCT [23, 33]. It could be argued that there were some unbalanced baseline factors, including patient age, and WBC count at diagnosis, which might also have influenced the risk of relapse. However, among patients with a WBC count at diagnosis $\geq 100 \times 10^9$/L, three of the eight MSD patients relapsed, and none of the five HID recipients experienced recurrence; however, the sample size was not large enough to draw a valid conclusion. These observations confirmed that HID-HSCT might have better protection against relapse than MSD-HSCT in this population.

With regard to GVHD, our data suggested that there was a higher incidence of aGVHD in the HID cohort than in the MSD cohort, as reported in our previous studies comparing MSD- and HID-HSCT [11, 34]. However, the MSD group showed a relatively higher cumulative incidence of cGVHD than the HID group. A higher proportion of cGVHD was also observed after MSD transplants than after HID transplants in our previous study on myelodysplastic syndrome (MDS) [35], which is in agreement with results from PT-CY-based transplantation [27]. The reason for the higher rate of cGVHD in MSD transplants is unclear, but there are some possible explanations. In the present study, we noted that male recipients with female grafts were significantly more common in the MSD group than in the HID group. The combination of female donors and male recipients was associated with an increased risk of GVHD, which was supported by studies from Randolph et al. and was observed by our group in haploidentical transplant settings [36–38].

While a higher frequency of aGVHD may theoretically lead to a high risk of TRM following HSCT, the analyses from Yoon et al. and those from our center failed to show a higher TRM among HID transplants than among MSD recipients [29], although Salvatore and colleagues previously conducted a pair-matched analysis of recipients from the European Society for Blood and Marrow Transplantation (EBMT) and found that HID-HSCT resulted in more TRM than MSD [12]. Notably, the aforementioned EBMT results were mainly based on the PT-CY protocol for GVHD prophylaxis, and this distinction might have partially contributed to the differences among these results. Although there were more F-M transplants in the MSD group, F-M was not associated with aGVHD, cGVHD, or TRM in this population.

In accordance with our previous reports, no correlations between donor type and survival were found in the multivariable analysis for OS, LFS, and GRFS, and older age (> 50 years old) was an adverse factor for OS, LFS, and GRFS. Previous reports showed that patients > 50 years old had a worse survival than other patients because of their increased TRM [11, 39]. In the current study, patients > 50 years had a higher TRM rate than younger recipients. Nevertheless, the disadvantage of old age was obvious for only the MSD recipients, which is in line with our previous reports that age > 50 years old had no influence on survival and TRM among HID recipients [40]. Increasing experience has demonstrated that these patients might benefit from HID-HSCT [8], and our results suggest that when an MSD is not available for adults with intermediate-risk AML, HID may be used in both in young and older patients.

For ethical and practical reasons, the patients were not randomized to receive HID or MSD grafts. Although homogeneous patients received HID- or MSD-HSCT transplants according to donor availability, there were still some unbalanced factors. The patients in the HID cohort were younger and had

a longer time to transplant than those in the MSD cohort. However, the median interval from diagnosis to transplant was 7 versus 6 months between the two cohorts. Despite these limitations, our data supported HID-HSCT as a postremission strategy for intermediate-risk AML in CR1.

In summary, haploidentical and HLA-identical donor transplantation have similar survival for patients with intermediate-risk AML in CR1. These results showed that haploidentical donors could be an alternative for AML patients who lack an HLA-identical donor.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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