**Title: Comparison of HLA-matched sibling and unrelated donor transplantation in adult patients with acquired severe aplastic anemia**

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**Running title:** Comparable outcomes of MSD-SCT and URD-SCT for SAA

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**ABSTRACT**

Recently improved survival of severe aplastic anemia (SAA) patients who received allogeneic stem cell transplantation (SCT) from unrelated donors (URD) suggests that its role can be further extended as a first-line treatment. To address this issue, the outcomes of adult SAA patients receiving SCT were compared according to the following three donor-type groups: 8/8–matched sibling (MSD; n=153), 8/8 well-matched unrelated (WM-URD; n=72), and 6–7/8 partially-matched unrelated (PM-URD; n=33). The proportion of patients experiencing immunosuppressive treatment failures was significantly higher in the URD groups (*P* < 0.01) than in the MSD group. Graft failure incidences, transplant-related mortality incidences, and graft-versus-host disease-free, failure-free survival rates of the MSD, WM-URD, and PM-URD groups were 14.6%, 0%, and 0% (*P* < 0.01); 6.1%, 13.8%, and 21.7% (*P* = 0.03); and 76.7%, 55.5% and 51.5% (*P* < 0.01), respectively. The overall survival (OS) rate of the MSD group (93.9%) was significantly higher than that of the PM-URD (78.3%; *P* < 0.01) group, but not to that of the WM-URD (86.2%; *P* = 0.18) group. Our study showed comparable OS rates between the MSD and WM-URD groups, which suggests the extending role of URD-SCT as a first-line treatment option for adult SAA patients with WM-URD.

**Keywords;** allogeneic stem cell transplantation; severe aplastic anemia; matched sibling donor; unrelated donor

**INTRODUCTION**

Aplastic anemia is a rare disease characterized by pancytopenia in the peripheral blood (PB) followed by bone marrow (BM) hypoplasia due to an immune-mediated destruction of hematopoietic precursors [1]. Patients with a severe form of the disease (severe aplastic anemia [SAA]) are significantly at higher risk of death due to its severe complications, such as fatal infection and/or hemorrhage, if they do not receive optimal therapeutic interventions. According to several guidelines, allogeneic stem cell transplantation (SCT) from human leukocyte antigen (HLA)-matched sibling donors (MSD-SCT) and immunosuppressive treatment (IST) have been considered as a first-line treatment for younger (≤ 50 years old) and older (> 50 years old) adult SAA patients, respectively [2, 3]. Allogeneic SCT from HLA-matched unrelated donors (URD-SCT) has been considered as a second-line treatment option for patients who experienced IST failures, according to previous studies showing relatively poorer outcomes compared to that of MSD-SCT [4-6]. However, although patients who received IST as a first-line treatment can achieve long-term overall survival (OS) of 80–90%, a significant proportion of those patients suffer from a high treatment failure rate, including lack of response with transfusion-dependency, disease relapse, and clonal evolution [7]. Additionally, because of a frequently observed partial response after IST, achieving complete recovery of the quality of life seems to be difficult, followed by restrictions to daily activities due to subnormal hemoglobin and/or platelet counts or increased risk of infections due to subnormal neutrophil count and long-standing cyclosporin (CsA) exposure [8].

Over the last two decades, high-resolution HLA typing with more optimized transplant-related techniques and better supportive care have improved the outcomes of URD-SCT for pediatric and adult SAA patients [9, 10]. Recent studies showed that the outcomes of children and adolescent patients who received URD-SCT as a first-line treatment were not significantly different to those of patients who received MSD-SCT [11, 12]. Reflecting these results, an updated guideline recommends that URD-SCT may be considered as a first-line treatment for pediatric patients without suitable MSD [3, 13]. However, comparative studies regarding the outcomes of adult SAA patients who received MSD-SCT and URD-SCT are very rare. To address this issue, major long-term outcomes of consecutive adult SAA patients who received MSD-SCT and URD-SCT at our institution were comparatively analyzed, including propensity score matching sub-cohort analysis.

**PATIENTS AND METHODS**

**Patients and treatment strategies**

We analyzed the outcomes of 257 consecutive adult (≥ 18 years old) SAA patients who received MSD-SCT or URD-SCT between March 2002 to May 2018 at the Seoul St. Mary’s Hospital, Seoul, Korea. According to conventional therapeutic schemes [2, 3], younger (≤ 40–50 years old) patients with appropriate MSD received MSD-SCT as a first-line treatment. Patients who were not considered as candidates of MSD-SCT received IST, consisting of horse or rabbit anti-thymocyte globulin (ATG) plus CsA, as a first-line treatment. However, patients who immediately required treatment, per physicians’ discretion, received URD-SCT as a first-line treatment [7]. On the contrary, patients experiencing IST failures received URD-SCT as a second-line treatment. In searching for the appropriate MSD (8 of 8 allele-matched) and/or URD (≥ 6 of 8 allele-matched) by screening for HLA–A, HLA–B, HLA–C, and HLA–DRB1 alleles, the high-resolution (DNA sequencing) molecular typing method was performed. All patients were ≤ 65 years old with adequate organ function and performance status at the time of transplantation. This study was approved by the institutional review board of the Seoul St. Mary’s Hospital.

**Transplant-related procedures**

Patients received a conditioning of fludarabine (Flu, 30 mg/m2 intravenously [IV] for 6 days) and cyclophosphamide (Cy, 50 mg/kg IV for 2 days) plus rabbit ATG (ThymoglobulinⓇ, 2.5 mg/kg IV for 4 days) for MSD-SCT or fractionated total body irradiation (TBI, 400–800 cGy) plus Cy (50–60 mg/kg IV for 2 days) for URD-SCT. If potential candidates for MSD-SCT experienced severe infection with/without significant co-morbidities, they received a conditioning of total nodal irradiation (750 cGy for 1 day) plus rabbit ATG (1.25 mg IV for 3 days or 2.5 mg IV for 2 days). Although we have requested BM harvest to all potential donors, the choice of BM and PB stem cells were determined according to their preferences. After the infusion of BM stem cells or granulocyte-colony stimulating factor-mobilized PB stem cells, the prophylaxis for graft-versus-host disease (GVHD) was as follows: short-course methotrexate (10 mg/m2 for MSD-SCT or 5 mg/m2 for URD-SCT at day 1, 3, 6, and 11) plus CsA (target through level of 150–300 ng/mL) for MSD-SCT or FK506 (target through level of 10–15 ng/mL) for URD-SCT. Since August 2009, low-dose rabbit ATG (1.25 mg/kg IV for 2 days) has been administered to patients who received URD-SCT from HLA-mismatched donor and/or PB stem cells [14]. Thereafter, the protocol was amended so that all patients, who have received URD-SCT since December 2016, received rabbit ATG (2.5 mg/kg for 2 days). Other detailed transplant-related procedures, including supportive care strategies, were described in our previous reports [14, 15].

**Definitions**

The diagnosis of the disease and categorization of the severity were performed according to the criteria proposed by Camitta et al [16]. Patients’ pre-transplant comorbidities were assessed according to the Hematopoietic Cell Transplantation-Specific Comorbidity index [17]. Neutrophil and platelet engraftment were defined as an absolute neutrophil (ANC) count ≥ 0.5 × 109/L for at least 3 consecutive days and a platelet count ≥ 20 × 109/L for at least 7 consecutive days without transfusion support. Primary and secondary graft failure (GF) were characterized by a failure of neutrophil engraftment at days 28 with either irreversible ANC < 0.5 × 109/L or platelet count < 20 × 109/L, with or without evidence of previous donor engraftment, respectively. Post-transplant complications of acute GVHD and chronic GVHD, grade ≥ 3 infectious complications, sinusoidal obstruction syndrome, and hemorrhagic cystitis were evaluated according to the previous published criteria [18]. Additionally, we defined a composite end-point of GVHD-free, failure-free survival (GFFS) based on the following: being alive without experiencing grade III-IV acute GVHD, chronic GVHD requiring systemic therapy and primary or secondary GF [15, 19].

**Statistical analysis**

This study aimed to compare the major outcomes, including GF incidence, transplant-related mortality (TRM) incidence, GFFS rate, and OS rate, of adult SAA patients who received allogeneic SCT from the following donor-type groups: MSD (the MSD group), well-matched URD (8/8 allele-matched; the WM-URD group), and partially-matched URD (6–7/8 allele-matched; the PM-URD group). All time-dependent parameters were measured from the first day of stem cell infusion. Continuous and categorical variable were described by median with ranges and count with relative frequency, respectively. Comparisons between the baseline and transplant-related characteristics according to donor-type groups were performed by using the independent two-sample t-test, the χ2 test, and Fisher’s exact test. GFFS and OS rates were calculated using Kaplan–Meier estimates and compared using the log-rank test. The neutrophil and platelet engraftment, primary and secondary GF, acute GVHD and chronic GVHD, and TRM were described as the cumulative incidence estimate and compared using the Grey’s test. The prognostic significance of covariates was determined using the Cox proportional hazards model for GFFS and OS and the proportional hazards model for the sub-distribution of a competing risk for acute GVHD and chronic GVHD, primary and secondary GF, and TRM. Furthermore, we compared the major outcomes between the MSD and the URD (WM-URD plus PM-URD) groups for the propensity score-matching sub-cohort of patients receiving allogeneic SCT as a first-line treatment, considering the limited number of patients of the URD group. The propensity score-matching sub-cohort was established by propensity score calculated by using a logistic regression model for each individual patient [20], fitted for a donor-type group according to the following variables: age, interval from diagnosis to transplant, and stem cell source, which significantly affected transplant-related outcomes in a previous study [21]. Subsequently, one-to-three matched groups were created by nearest neighbor matching without replacement. Factors were considered significant if they had an associated *P* <0.05 as determined by the likelihood ratio test, using two-tailed significance testing. Data were analyzed in December 2018 using R version 3.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

**RESULTS**

**Baseline and transplant-related characteristics**

The median age of our patients was 34 (range, 15–64) years at transplantation, with 167 (64.7%) aged ≤ 40 years. The etiologies of the disease were categorized as follows: idiopathic in 234 (90.7%), pregnancy-associated in 9 (3.5%), hepatitis-related in 7 (2.7%), drug-induced in 5 (1.9%), and others in 3 (1.2%) patients. At the transplantation, 133 (51.6%) patients experienced failures for one or more courses of IST, with the proportions significantly higher in the WM-URD (*P* < 0.01) and the PM-URD (*P* < 0.01) groups compared to that of the MSD group, which contributed to relatively higher proportions of patients who had longer (> 12 months) interval from diagnosis to transplantation (*P* < 0.01 and *P* = 0.02, respectively) and heavily (> 100 units) transfusion history (*P* = 0.01 and *P* = 0.05, respectively) of the WM-URD and the PM-URD groups compared to that of the MSD group. With the discriminable transplantation processes according to donor-type groups, the MSD group had relatively higher proportions of patients who were older (> 40 years) (*P* < 0.01 in both), using BM stem cells (*P* = 0.01 and *P* = 0.09, respectively), and using ABO blood type-matched donor (*P* = 0.01 and *P* < 0.01, respectively) compared to that of the WM-URD and PM-URD groups. More detailed baseline and transplant-related characteristics according to donor-type groups are described in Table 1. Infused CD34+ and CD3+ cell doses of patients who received BM and PB stem cells were 3.01 × 106/kg (range, 0.25–14.37) and 4.92 × 106/kg (range, 1.81–17.03), and 38.79 × 106/kg (range, 1.70–463.68) and 329.64 × 106/kg (range, 1.34–1234.70), respectively.

**Engraftment**

Except two (0.8%) patients who died of infectious complication at day 7 (in the PM-URD group) and cerebrovascular event at day 10 (in the MSD group), all patients achieved neutrophil engraftment at a median 12 (range, 5–26) days. Neutrophil engraftment incidences of the MSD, the WM-URD, and the PM-URD groups were 99.3% (95% confidence interval [CI], 95.4–99.9), 100%, and 97.0% (95% CI, 59.8–99.8) at day 28, respectively (*P* = 0.79). Excluding three (1.2%) patients who did not experience platelet count nadir (in the MSD group), 230 (95.0%) patients achieved platelet engraftment at a median 17 (range, 7–433) days. Platelet engraftment incidences in the MSD, the WM-URD, and the PM-URD groups were 88.0% (95% CI, 81.5–92.3), 81.9% (95% CI, 70.7–89.2), and 75.8% (95% CI, 56.4–87.4) at day 28, respectively (*P* = 0.48). More detailed incidences of neutrophil and platelet engraftments are described in Table 2.

**GVHD and other post-transplant complications**

At a median 29 (range, 9–162) days, 68 (26.4%) patients experienced grades II-IV acute GVHD, including grade II in 53 (20.5%), grade III in 10 (3.9%), and grade IV in 5 (1.9%) patients. Grades II-IV acute GVHD incidences of the MSD, the WM-URD, and the PM-URD groups were 8.5% (95% CI, 4.8–13.6), 36.1% (95% CI, 25.1–47.2), and 57.6% (95% CI, 38.6–72.6) at day 100, respectively (*P* < 0.01). At a median 7.3 (range, 0.9–131.9) months, 57 (22.1%) patients developed mild-to-severe chronic GVHD, including mild in 23 (8.9%), moderate in 21 (8.1%), severe in 15 (5.8%) patients. Mild-to-severe chronic GVHD incidences of the MSD, the WM-URD, and the PM-URD groups were 8.6% (95% CI, 4.8–13.8), 43.4% (95% CI, 31.6–54.6), and 36.6% (95% CI, 20.3–53.0) at 6 years, respectively (*P* < 0.01). More detailed incidences of acute (including grades III-IV) GVHD and chronic (including moderate-to-severe and severe) GVHD according to donor-type groups are presented in Table 2.

At a median 2.1 (range, 0.2–114.4) months, 86 (33.3%) patients experienced grade ≥ 3 infectious complications. Grade ≥ 3 infectious complications incidences of the MSD, the WM-URD, and the PM-URD groups were 26.1% (95% CI, 19.3–33.5), 35.2% (95% CI, 24.2–46.4), and 57.6% (95% CI, 38.6–72.6) at 6 years, respectively (*P* < 0.01). There were no significant differences of other post-transplant complications incidences according to donor-type groups (*P* > 0.10). More detailed post-transplant complications incidences according to donor-type groups are described in Table 3.

**Graft failure and transplant-related mortality**

Although primary GF was not observed in any patient, 23 (8.9%) patients (only in the MSD group) experienced secondary GF at a median 14.1 (range, 0.9–97.2) months. Secondary GF incidences of the MSD, the WM-URD, and the PM-URD groups were 14.6% (95% CI, 9.3–20.9), 0%, and 0% at 6 years, respectively (*P* < 0.01). The secondary GF incidence of the MSD group was significantly higher compared to that of the WM-URD (*P* < 0.01) and the PM-URD (*P* < 0.01) groups (Fig. 1A). Of those who experienced secondary GF, 19 (86.4%) patients received second allogeneic SCT, followed by achieving sustained engraftment without mortality. Three (13.6%) who only received supportive care patients remained alive at the last follow-up.

At a median 2.1 (range, 0.2–9) months, 23 (8.9%) patients died without experiencing GF due to the following causes: acute GVHD in 8 (3.1%), infectious complications in 8 (3.1%), secondary malignancies in 4 (1.6%), chronic GVHD in 2 (0.8%), and cerebrovascular hemorrhage in one (0.4%) patients. TRM incidences of the MSD, the WM-URD, and the PM-URD groups were 6.1% (95% CI, 3.0–10.8), 13.8% (95% CI, 5.8–25.0), and 21.7% (95% CI, 9.4–37.4) at 6 years, respectively (*P* = 0.03). The TRM incidence of the PM-URD group was significantly higher than that of the MSD group (*P* = 0.01). There were no significant differences of TRM incidences between the MSD and the WM-URD groups (*P* = 0.21), and the WM-URD and the PM-URD groups (*P* = 0.19) (Fig. 1B). Other baseline and transplant-related characteristics did not affect the TRM incidence (*P* > 0.20).

**GFFS and OS**

With a median survivor’s follow-up duration of 79.1 (range, 6.1–177.6) months, 175 (67.8%) patients were alive without experiencing GF and grades III-IV acute GVHD, and chronic GVHD requiring systemic therapy. The GFFS rates of the MSD, the WM-URD, and the PM-URD groups were 76.7% (95% CI, 63.2–80.2), 55.5% (95% CI, 41.3–67.5), and 51.5% (95% CI, 33.5–66.9) at 6 years, respectively (*P* < 0.01). The GFFS rate of the MSD group was significantly higher compared to that of the WM-URD (*P* < 0.01) and the PM-URD (*P* < 0.01) groups. There was no significant difference of the GFFS rates between the WM-URD and the PM-URD groups (*P* = 0.22) (Fig. 1C). Patients’ age (≤ 40 years vs. > 40 years; 76.8% vs. 64.3% at 6 years, *P* = 0.06) and preceding IST history (yes vs. no; 61.3% vs. 76.7% at 6 years, *P* = 0.01) were also potential candidates affecting GFFS rate. However, donor-type group (WM-URD vs. MSD; hazard ratio [HR] 1.78, 95% CI 1.02–3.13, *P* = 0.04 and PM-URD vs. MSD; HR 2.44, 95% CI 1.25–4.76, *P* < 0.01) was the only significant factor affecting GFFS rate in multivariate analysis (*P* < 0.01) (Table 4).

At the time of analysis, 234 (90.7%) patients were alive. The OS rates of the MSD, the WM-URD, and PM-URD groups were 93.9% (95% CI, 88.6–96.8), 86.2% (95% CI, 72.9–93.3), and 78.3% (95% CI, 59.6–89.0) at 6 years, respectively (*P* = 0.02). The OS rate of the MSD group was significantly higher than that of the PM-URD (*P* < 0.01), but not to that of the WM-URD (*P* = 0.18) group (Fig. 1D). There was no significant difference in OS rates between the WM-URD and the PM-URD groups (*P* = 0.18). Heavily transfusion history (≤ 100 units vs. > 100 units; 97.7% vs. 89.3%, *P* = 0.09) was another potential candidate affecting OS rate. However, donor group (WM-URD vs. MSD, HR 1.69, 95% CI 0.65–4.40; *P* = 0.28 and PM-URD vs. MSD; HR 3.27, 95% CI 1.21–8.85; *P* = 0.02) was only significant factor affecting OS rate in multivariate analysis (*P* = 0.04) (Table 4).

**Subgroup analysis for the propensity-score matching cohort of patients receiving allogeneic stem cell transplant as a first-line treatment**

We compared the major post-transplant outcomes between the MSD and the URD groups for the propensity score matching cohort of patients who received allogeneic SCT as a first-line treatment (one-to-three matching; 54 and 18 patients of the MSD and URD groups, respectively). The patients’ baseline and transplant-related characteristics were not significantly different between the MSD and the URD groups, except significantly higher proportion of patients who had male sex (*P* = 0.03), long interval from diagnosis to transplant (P < 0.01), and used PB stem cells (*P* < 0.01) in the URD group (Table S1). Grades II–IV acute (5.6% vs. 50.0% at day 100; *P* < 0.01) and grades III–IV acute GVHD (0% vs. 16.7% at day 100; *P* < 0.01) and mild-to-severe chronic (12.0% vs. 38.7% at 6 years; *P* < 0.01), moderate-to-severe chronic (19% vs. 22.2% at 6 years; *P* < 0.01), and severe chronic (0% vs. 16.7% at 6 years; *P* < 0.01) GVHD incidences were significantly higher in the URD group compared to that of the MSD group. There were no significant differences of GF incidence (15.9% vs. 0%; *P* = 0.06), TRM incidence (3.7% vs. 11.8% at 6 years; *P* = 0.25), GFFS rate (78.5% vs. 66.7% at 6 years; *P* = 0.21), and OS rate (96.3% vs. 88.9% at 6 years; *P* = 0.24) between the MDS and the URD groups. (Fig. 2).

**DISCUSSION**

In our current study, which compared the long-term outcomes of adult SAA patients who received allogeneic SCT according to donor-type groups, there was no significant difference of the OS rates between the MSD and the WM-URD groups. However, the OS rate of the PM-URD group was significantly lower compared to that of the MSD group, although it was acceptable to be used in the clinical practice. These results suggest the possibility of URD-SCT, especially using WM-URD, as a first-line treatment option for adult SAA patients, at least in terms of OS rate. Nevertheless, there are several considerations that should be taken with caution.

The most evident limitation of this study is the unbalanced distribution of the clinical and transplant-related characteristics of the donor-type groups. According to our therapeutic scheme, the proportion of older (> 40 years) patients was significantly higher in the MSD group compared to that of URD groups. Conversely, the proportions of those who had longer interval from diagnosis to transplant (> 12 months) and heavily transfusion history (> 100 units) were significantly higher in the URD groups, since most patients in the URD groups experienced previous IST failures, compared to that of the MSD group. Additionally, PB stem cells were more frequently used in the URD groups due to donors’ preferences than in the MSD group. The unequally distributed characteristics might suggest that most of the results from our current study can be depreciated. However, most of these factors were associated with poor post-transplant outcomes [21-24], except a significantly higher proportion of patients having older age (> 40 years) that was more frequently observed in the MSD group than in the URD groups. It might more negatively attribute post-transplant outcomes of the URD groups than the MSD group. Consequently, an unbalanced distribution of the clinical and transplant-related characteristics of the donor-type groups cannot significantly affect our major conclusion of the comparable OS rates between the MSD and the WM-URD groups. Certainly, this observed limitation of this study should be validated by further well-designed prospective cohorts with well-balanced groups.

A substantially high secondary GF incidence only in the MSD group may be an additional limitation in our study. GF incidences of the previously published studies using Flu-based conditioning were commonly low (from 0% to 13.9%) [25-27], supporting the hypothesis that a high secondary GF incidence of the MSD group was not only due to the low intensity of conditioning regimen. When we compared the clinical and transplant-related characteristics of the current study and other previous studies’ cohorts, the proportion of patients who had heavily transfusion history was relatively higher in our cohort (77.1%) than that in the previous studies’ cohort. Consequently, it suggests that a Flu-based conditioning might be insufficient to overcome the possible occurrence of GF in these high-risk patients of the MSD-SCT group. In contrast, despite the fact that a substantial proportion of patients in the URD groups also had a heavily transfusion history and some of them with 1–2 allele mismatched donor, secondary GF was not observed in any of them. Previous studies investigating the factors affecting GF incidence for SAA patients who received allogeneic SCT showed that irradiation-based conditioning might facilitate sustained engraftment [28, 29]. Therefore, a very low GF incidence of the URD groups might be due to the potent immunosuppression of the TBI-based conditioning sufficient to overcome a possible occurrence in high-risk patients of the URD groups [30]. Furthermore, whether this limitation of Flu-based conditioning can be solved by the intensification of conditioning in high risk patients should be investigated by further studies.

Yagasaki et al. analyzed the outcomes of children and adolescent SAA patients who received allogeneic SCT, which showed no significant difference of OS rates between the MSD and the URD groups (100% vs. 93.8% at 10 years; *P* = 0.25) [11]. Dufour et al. also showed comparable OS rates of pediatric SAA patients who received allogeneic SCT as a first-line treatment between the MSD and the URD groups (91% vs. 96% at 2 years; *P* = 0.30) [12]. They also compared the outcomes of those who received IST and URD-SCT as a first-line treatment, which showed a significantly higher event-free survival rate of the latter group than that of the former group (40% vs. 92% at 2 years; *P* < 0.01). These above-mentioned studies suggest an extending role of URD-SCT as a considerable first-line treatment option for children and adolescent SAA patients, which have changed the treatment scheme for these patients [3]. However, comparative studies that analyzed the outcomes of adult SAA patients who received MSD-SCT and the URD-SCT are insufficient. A large European Group for Blood and Marrow Transplantation registry-based study by Bacigalupo et al. showed insignificantly different OS rates between the MSD and the URD groups (HR 1.20; 95% CI 0.93–1.55; *P* = 0.16) [21]. However, this study has difficulty in representing the comparable OS rates of adult SAA patients who received MSD-SCT and URD-SCT, considering the proportion of patients aged of ≤ 20 years approaching to approximately 50%. Our study showed insignificantly different OS rates between the MSD and WM-URD groups in adult SAA patients along with the clinically acceptable outcomes of the PM-URD group. This supports a considerable role of URD-SCT as a first-line treatment option in adult SAA patients. Furthermore, our additional propensity score matching sub-cohort analysis showing a comparable OS rate of SAA patients who received MSD-SCT and URD-SCT as a first-line treatment might make our results more evident, although a very limited number of patients of this cohort result in a difficulty in drawing conclusive results.

The incidences of acute and chronic GVHD of the URD groups were significantly higher than those of the MSD group. Additionally, we showed the GFFS was significantly higher in the MSD group than that of the URD group. Considering relatively high morbidity and mortality of patients experiencing acute and chronic GVHD [31, 32], these results should be a major consideration when performing URD-SCT as a first-line treatment for adult SAA patients. Therefore, all possible efforts to ameliorate the incidences of acute and chronic GVHD for patients to achieve long-term survival with an adequate quality of life are essential. Our recently published report for adult SAA patients who received URD-SCT using PM-URD or PB stem cells may provide with a possible solution for this issue [14]. It showed significantly lower acute grades II–IV and chronic GVHD incidences (31.2% vs. 61.5% at day 100; *P* < 0.01 and 21.9% vs. 65.4% at 3 years; *P* < 0.01, respectively) of patients who received low-dose ATG (2.5 mg/kg) compared to patients who did not receive low-dose ATG. Furthermore, emerging prophylactic approaches with an improved understanding of GVHD pathophysiology will lead us to overcome this challenging area of allogeneic SCT. Consequently, these may support the extended role of URD-SCT as a first-line treatment in the near future.

In conclusion, our current study showed that OS rates between the MSD and the WM-URD groups of adult SAA patients who received allogeneic SCT along with the clinically acceptable outcomes of PM-URD group were insignificantly different, which suggests the possibility for the role of URD-SCT as a first-line treatment option. The strength of our study is as follows: this is a unique comparative analysis including only adult SAA patients who received allogeneic SCT between the MSD and the URD groups. However, because this is a retrospective study with a limited number of patients who received allogeneic SCT as a first-line treatment, future well-designed prospective studies are required to confirm our results.

Supplementary information is available at Bone marrow transplantation’s website

**REFERENCES**

1. Shin SH, Lee SE, Lee JW. Recent advances in treatment of aplastic anemia. Korean J Intern Med.2014;6**:**713-26.

2. Scheinberg P, Young NS. How I treat acquired aplastic anemia. Blood.2012;6**:**1185-96.

3. Killick SB, Bown N, Cavenagh J, Dokal I, Foukaneli T, Hill A *et al.* Guidelines for the diagnosis and management of adult aplastic anaemia. Br J Haematol.2016;2**:**187-207.

4. Deeg HJ, O'Donnell M, Tolar J, Agarwal R, Harris RE, Feig SA *et al.* Optimization of conditioning for marrow transplantation from unrelated donors for patients with aplastic anemia after failure of immunosuppressive therapy. Blood.2006;5**:**1485-91.

5. Kojima S, Matsuyama T, Kato S, Kigasawa H, Kobayashi R, Kikuta A *et al.* Outcome of 154 patients with severe aplastic anemia who received transplants from unrelated donors: the Japan Marrow Donor Program. Blood.2002;3**:**799-803.

6. Passweg JR, Perez WS, Eapen M, Camitta BM, Gluckman E, Hinterberger W *et al.* Bone marrow transplants from mismatched related and unrelated donors for severe aplastic anemia. Bone Marrow Transplant.2006;7**:**641-9.

7. Shin SH, Lee JW. The optimal immunosuppressive therapy for aplastic anemia. Int J Hematol.2013;5**:**564-72.

8. Viollier R, Passweg J, Gregor M, Favre G, Kuhne T, Nissen C *et al.* Quality-adjusted survival analysis shows differences in outcome after immunosuppression or bone marrow transplantation in aplastic anemia. Ann Hematol.2005;1**:**47-55.

9. Maury S, Balere-Appert ML, Chir Z, Boiron JM, Galambrun C, Yakouben K *et al.* Unrelated stem cell transplantation for severe acquired aplastic anemia: improved outcome in the era of high-resolution HLA matching between donor and recipient. Haematologica.2007;5**:**589-96.

10. Viollier R, Socie G, Tichelli A, Bacigalupo A, Korthof ET, Marsh J *et al.* Recent improvement in outcome of unrelated donor transplantation for aplastic anemia. Bone Marrow Transplant.2008;1**:**45-50.

11. Yagasaki H, Takahashi Y, Hama A, Kudo K, Nishio N, Muramatsu H *et al.* Comparison of matched-sibling donor BMT and unrelated donor BMT in children and adolescent with acquired severe aplastic anemia. Bone Marrow Transplant.2010;10**:**1508-13.

12. Dufour C, Veys P, Carraro E, Bhatnagar N, Pillon M, Wynn R *et al.* Similar outcome of upfront-unrelated and matched sibling stem cell transplantation in idiopathic paediatric aplastic anaemia. A study on behalf of the UK Paediatric BMT Working Party, Paediatric Diseases Working Party and Severe Aplastic Anaemia Working Party of EBMT. Br J Haematol.2015;4**:**585-94.

13. Marsh JCW, Risitano AM, Mufti GJ. The Case for Upfront HLA-Matched Unrelated Donor Hematopoietic Stem Cell Transplantation as a Curative Option for Adult Acquired Severe Aplastic Anemia. Biol Blood Marrow Transplant.2019; e-pub ahead of print 24 May 2019; doi: 10.1016/j.bbmt.2019.05.012.

14. Park SS, Kwak DH, Jeon YW, Yoon JH, Lee SE, Cho BS *et al.* Beneficial Role of Low-Dose Antithymocyte Globulin in Unrelated Stem Cell Transplantation for Adult Patients with Acquired Severe Aplastic Anemia: Reduction of Graft-versus-Host Disease and Improvement of Graft-versus-Host Disease-Free, Failure-Free Survival Rate. Biol Blood Marrow Transplant.2017;9**:**1498-508.

15. Shin SH, Jeon YW, Yoon JH, Yahng SA, Lee SE, Cho BS *et al.* Comparable outcomes between younger (40 years) and older (>40 years) adult patients with severe aplastic anemia after HLA-matched sibling stem cell transplantation using fludarabine-based conditioning. Bone Marrow Transplant.2016;11**:**1456-63.

16. Camitta BM, Storb R, Thomas ED. Aplastic anemia (first of two parts): pathogenesis, diagnosis, treatment, and prognosis. N Engl J Med.1982;11**:**645-52.

17. Sorror ML, Maris MB, Storb R, Baron F, Sandmaier BM, Maloney DG *et al.* Hematopoietic cell transplantation (HCT)-specific comorbidity index: a new tool for risk assessment before allogeneic HCT. Blood.2005;8**:**2912-9.

18. Champlin RE, Perez WS, Passweg JR, Klein JP, Camitta BM, Gluckman E *et al.* Bone marrow transplantation for severe aplastic anemia: a randomized controlled study of conditioning regimens. Blood.2007;10**:**4582-5.

19. Holtan SG, DeFor TE, Lazaryan A, Bejanyan N, Arora M, Brunstein CG *et al.* Composite end point of graft-versus-host disease-free, relapse-free survival after allogeneic hematopoietic cell transplantation. Blood.2015;8**:**1333-8.

20. Austin PC. An Introduction to Propensity Score Methods for Reducing the Effects of Confounding in Observational Studies. Multivariate Behav Res.2011;3**:**399-424.

21. Bacigalupo A, Socie G, Hamladji RM, Aljurf M, Maschan A, Kyrcz-Krzemien S *et al.* Current outcome of HLA identical sibling versus unrelated donor transplants in severe aplastic anemia: an EBMT analysis. Haematologica.2015;5**:**696-702.

22. Bacigalupo A, Socie G, Schrezenmeier H, Tichelli A, Locasciulli A, Fuehrer M *et al.* Bone marrow versus peripheral blood as the stem cell source for sibling transplants in acquired aplastic anemia: survival advantage for bone marrow in all age groups. Haematologica.2012;8**:**1142-8.

23. Schrezenmeier H, Passweg JR, Marsh JC, Bacigalupo A, Bredeson CN, Bullorsky E *et al.* Worse outcome and more chronic GVHD with peripheral blood progenitor cells than bone marrow in HLA-matched sibling donor transplants for young patients with severe acquired aplastic anemia. Blood.2007;4**:**1397-400.

24. Eapen M, Le Rademacher J, Antin JH, Champlin RE, Carreras J, Fay J *et al.* Effect of stem cell source on outcomes after unrelated donor transplantation in severe aplastic anemia. Blood.2011;9**:**2618-21.

25. George B, Mathews V, Viswabandya A, Kavitha ML, Srivastava A, Chandy M. Fludarabine and cyclophosphamide based reduced intensity conditioning (RIC) regimens reduce rejection and improve outcome in Indian patients undergoing allogeneic stem cell transplantation for severe aplastic anemia. Bone Marrow Transplant.2007;1**:**13-8.

26. Kim H, Lee JH, Joo YD, Bae SH, Hyun MS, Lee JH *et al.* A randomized comparison of cyclophosphamide vs. reduced dose cyclophosphamide plus fludarabine for allogeneic hematopoietic cell transplantation in patients with aplastic anemia and hypoplastic myelodysplastic syndrome. Ann Hematol.2012;9**:**1459-69.

27. Srinivasan R, Takahashi Y, McCoy JP, Espinoza-Delgado I, Dorrance C, Igarashi T *et al.* Overcoming graft rejection in heavily transfused and allo-immunised patients with bone marrow failure syndromes using fludarabine-based haematopoietic cell transplantation. Br J Haematol.2006;3**:**305-14.

28. Champlin RE, Horowitz MM, van Bekkum DW, Camitta BM, Elfenbein GE, Gale RP *et al.* Graft failure following bone marrow transplantation for severe aplastic anemia: risk factors and treatment results. Blood.1989;2**:**606-13.

29. Gluckman E, Horowitz MM, Champlin RE, Hows JM, Bacigalupo A, Biggs JC *et al.* Bone marrow transplantation for severe aplastic anemia: influence of conditioning and graft-versus-host disease prophylaxis regimens on outcome. Blood.1992;1**:**269-75.

30. Umeda K, Yabe H, Kato K, Imai K, Kobayashi M, Takahashi Y *et al.* Impact of low-dose irradiation and in vivo T-cell depletion on hematopoietic stem cell transplantation for non-malignant diseases using fludarabine-based reduced-intensity conditioning. Bone Marrow Transplant.2019;8**:**1227-36.

31. MacMillan ML, Robin M, Harris AC, DeFor TE, Martin PJ, Alousi A *et al.* A refined risk score for acute graft-versus-host disease that predicts response to initial therapy, survival, and transplant-related mortality. Biol Blood Marrow Transplant.2015;4**:**761-7.

32. Fiuza-Luces C, Simpson RJ, Ramirez M, Lucia A, Berger NA. Physical function and quality of life in patients with chronic GvHD: a summary of preclinical and clinical studies and a call for exercise intervention trials in patients. Bone Marrow Transplant.2016;1**:**13-26.

**FIGURE LEGEND**

Fig. 1 **a** Graft failure incidence, **b** transplant-related mortality incidence, **c** GFFS rate, and **d** OS rate according to donor-type groups.

Fig. 2 **a** Graft failure incidence, **b** transplant-related mortality incidence, **c** GFFS rate, and **d** OS rate according to donor-type groups for the propensity-score matching cohort of patients receiving SCT as a first-line treatment.