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Impact of CD34 Positive Cell Dose on Engraftment in Patients with Acute Leukemias receiving Allogeneic Stem Cell Transplant

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Abstract

Objective: To evaluate the impact of CD34+ cell dosing and transplant type on engraftment measures, complications, and survival in a resource-limited setting.
Methodology: A retrospective cross-sectional study was conducted on 70 patients (Matched: 61.4%; Haploidentical: 38.6%) diagnosed with acute leukemia at a tertiary care center in Pakistan (2016–2023). Variables included CD34+ dose, engraftment timing, GVHD incidence, and 5-year survival, reported as per STROBE guidelines.
Results: The mean CD34+ dose was 8.8*10^6/kg. Neutrophil engraftment was faster in matched transplants (13.7 vs. 16.1 days), though haploidentical grafts showed a higher cumulative success rate (92.6%). Pediatric patients received the highest CD34+ doses and achieved the fastest platelet recovery (9.7 days). At Day 100, successful neutrophil recovery was higher in the matched group (62.7% vs. 48.1%). Acute GVHD and graft failure were more frequent in the haploidentical cohort (37.0% and 25.9%, respectively), while chronic GVHD was higher in matched recipients (18.6%). The 5-year survival was 30.2% for matched and 14.8% for haploidentical transplants, significantly perplexed by high attrition rates (20.9% and 37% lost to follow-up).
Conclusion: Higher CD34+ dosing correlates with enhanced hematopoietic recovery, particularly in pediatric cohorts. While haploidentical transplants are worthwhile alternatives, they face higher rates of acute complications and attrition. Optimizing transplant outcomes in resource-limited settings requires both personalized clinical protocols and resilient longitudinal patient-tracking infrastructure.
Keywords: Acute Leukemia, CD34+ Cell Dose, Engraftment, GVHD, Haploidentical Transplant.

Introduction

Allogeneic hematopoietic stem cell transplant (HCT) has significantly improved the outcome of high-risk acute leukemia. Neutrophil engraftment typically observed between 10 to 28 days post-transplant, while platelet engraftment generally takes place between 14 to 42 days. This duration may vary depending on factors like transplant type and patient-specific characteristics (age, gender or WBC counts)[1], requiring close monitoring for signs of engraftment and potential complications during this period.

CD34 serves as a marker of hematopoietic stem cells, supporting in their quantification and extraction from peripheral blood.[2] Leukapheresis is the method employed to isolate CD34+ cells from blood and bone marrow using targeted antibodies. Modifying the optimal CD34+ cell dose, one should consider factors like patient age, disease severity, prior therapies, and transplant protocols to enhance engraftment and treatment efficacy.[3]

The dose of CD34 counts impacting allogeneic transplant varies internationally and within Asia. There is less published information, as there are variations in practice and outcomes among different countries and regions.

The CD34+ cell dose required for allogeneic HCT depends on histocompatibility levels for HLA-matched donors.[4] An adequate dose ranges from 2 to 5 x 10^6 CD34+ cells/kg, whether from a matched sibling donor (MSD) or matched unrelated donor (MUD). In HLA-mismatched or haploidentical transplantation, a higher dosage of 10 to 20 x 10^6 CD34+ cells/kg is typically administered.[5,6] The graft source can be taken either through peripheral blood stem cells or from bone marrow. [7]

Higher amounts of CD34 counts are associated with better engraftment and reduced risk of graft failure, however it can increase the risk of GVHD. This

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complexity is influenced by various factors, including transplant protocol, patient's age, underlying disease, conditioning regimen intensity and donor recipient compatibility.[8,9]

Prior investigations on the association between CD34 cell dose and long-term survival outcomes have shown variation. The purpose of this study is to evaluate the impact of optimal CD34+ cell dosing on engraftment measures and the incidence of Graft-versus-Host Disease (GVHD) in acute leukemia patients, highlighting how conditioning regimen and prophylaxis protocols can align outcomes in resource-limited settings with those of matched and haplo identical transplants.

To assess long-term survival and relapse incidence while identifying the influence of conditioning regimens and patient-specific variables (age, gender, and diagnosis) on transplant efficacy in a resource-limited setting.

Methodology

A retrospective cross sectional study was conducted at Aga Khan University Hospital, Karachi, Pakistan, from 1st January 2016 till 31st December 2023. The study received approval from the Ethical Review Committee (ERC) of Aga Khan University (ERC #: 2024-9971-29837) and the College of Physicians and Surgeons of Pakistan (CPSP). The patient data was extracted using the electronic medical record numbers of the institute, ensuring patient confidentiality.

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Study variables included patients' demographic characteristics (age, gender); transplant-related factors such as donor type (matched or haploidentical transplant), CD34-positive cell dose and its impact on engraftment, immunosuppressive therapy, and GVHD prophylaxis; post-transplant complications; and clinical outcomes, including overall survival.

Sample size was calculated using the Openepi software and the non-probability consecutive sampling technique was used. To conduct statistical analysis for CD34 positive cell dose using SPSS and descriptive statistics such as means, standard deviations, frequencies, and percentages. The study reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

Inclusion criteria: The study included patients of all age groups who underwent allogeneic hematopoietic stem cell transplant with HLA-matched or haplo-identical donor in acute leukemia, stem cells acquired either from peripheral blood or bone marrow or both, and a myeloablative conditioning regimen along with specific protocols used for haplo-identical.

Exclusion criteria: Patients who underwent allogeneic stem cell transplant for benign disorders.

The primary objective of the study to evaluate the impact of CD34+ cell dosing and transplant type on engraftment measures in patients with acute leukemia undergoing allogeneic hematopoietic stem cell transplantation (allo-HSCT). The secondary objective of the study to compare clinical outcomes, including the incidence of acute and chronic Graft-versus-Host Disease (GVHD), infectious complications (CMV/BK virus), and graft failure between matched and haploidentical transplant modalities.

Engraftment: Defined as the first of 3 consecutive days of an absolute neutrophil count of ≥0.5. Platelet recovery was recorded as the first of 7 consecutive days with a platelet count ≥20 K/μL without transfusion.

Results

The study included 70 patients with acute leukemia, comprising acute myeloid leukemia (AML; n = 27), B-cell acute lymphoblastic leukemia (B-ALL; n = 36)—including Philadelphia chromosome–positive (n = 24) and Philadelphia chromosome–negative (n = 12) cases—and T-cell acute lymphoblastic leukemia (T-ALL; n = 6). The cohort consisted predominantly of male patients (62.3%), with females accounting for 37.7%, and a mean age of 26.3 years.

Haploidentical hematopoietic stem cell transplantation was performed in 27 patients (38.6%), while 43 patients (61.4%) underwent fully matched transplantation. Patients receiving haploidentical transplants were

younger, with a mean age of 23.3 years, compared with 28.2 years in the fully matched transplant group.

Neutrophil engraftment was achieved faster in the fully matched cohort (13.7 vs. 16.1 days); however, a higher cumulative success rate was noted in the haploidentical group (92.6% vs. 86.0%). Platelet engraftment time were similar between transplant types 13.5 vs. 11.9 days (88.9 vs. 88.4%), though pediatric patients showed the fastest recovery overall (9.7 days). Males had slightly longer engraftment times in the haplo-identical group. CD34+ cell doses were comparable across both groups (Haplo: 9.1, Full: 8.7 × 10^6/kg). (Table)

Diagnosis influenced engraftment patterns; Ph+ B-ALL and AML cohorts demonstrated faster recovery (13.6 and 14.4 days; 92% success) compared to Ph- B-ALL and T-ALL cohorts, which showed slower kinetics (14.7 and 15.7 days) and reduced success rates (88% and 83%). The patients were classified into 3 groups based on the CD34+ cell dose received: low, 2-5 × 106 cells/kg; moderate 5-8 × 106 cells/kg; and high, >8 × 106 cells/kg. Mean CD34+ dose: 8.8 ± 4.0 × 10^6/kg (range: 1.14-24.5). Most patients received very high CD34+ doses i.e. 60% of patients, with only a small proportion receiving low to moderate doses. Pediatric patients received highest CD34+ dosing (10.0 ± 3.2 × 10^6/kg) while adolescents the lowest (6.8 ± 3.0 × 10^6/kg). Minimal dose variation observed in gender based CD34+ cell dose yield.

The CY/TBI regimen was the most frequently used conditioning protocol; however, BU/CY was associated with the fastest engraftment, with a mean time of 12.6 ± 2.6 days. Age-stratified analysis demonstrated no statistically significant correlation between age and engraftment time, although a stronger negative trend was observed among adolescent patients.

Regarding GVHD prophylaxis, cyclosporine plus methotrexate was the most commonly employed regimen (64.3%) and was associated with a mean engraftment time of 14.3 days and the lowest complication rate (24.4%). Alternative prophylactic strategies used primarily in haploidentical transplantation, including tacrolimus/mycophenolate mofetil and cyclosporine/mycophenolate mofetil combined with post-transplant cyclophosphamide (PTCy), demonstrated comparable engraftment times but were associated with higher complication rates (44.4% and 57.1%, respectively).

Overall, these findings indicate that while engraftment measures were similar across prophylactic regimen, cyclosporine/methotrexate was associated with a more favorable safety profile.

The complication rates demonstrated discrete patterns based on donor type. Chronic Graft-Versus-Host Disease (cGVHD) was significantly more prevalent in the fully matched cohort (n=8, 18.6%) compared to the haploidentical group (n=2, 7.4%). Conversely, the incidence of acute GVHD (aGVHD) and graft failure was higher in the haploidentical cohort, though these differences did not reach statistical significance (aGVHD: 37.0% vs. 23.2%; Graft failure: 25.9% vs. 13.9%, respectively).

Table I: Correlation of CD34+ Cell Dose with Hematopoietic Recovery.

Transplant Type	CD34+ Dose (×106/kg)	Neutrophil Engraftment (Days)	Neutrophil Success (%)	Platelet Engraftment (Days)	Platelet Success (%)
Fully Matched (n=43)	8.7	13.7	86.0%	11.9	88.4%
Haploidentical (n=27)	9.1	16.1	92.6%	13.5	88.9%

Table II: Comparative Analysis of Post-Transplant Complications.

Complication	Fully Matched (n=43)	Haploidentical (n=27)	Overall (N=70)
Graft-Versus-Host Disease			
Acute GVHD	10 (23.2%)	10 (37.0%)	20 (28.6%)
Chronic GVHD	8 (18.6%)	2 (7.4%)	10 (14.3%)
Graft Outcomes			
Graft Failure	6 (13.9%)	7 (25.9%)	13 (18.6%)
Infectious Complications			
CMV Reactivation	9 (20.9%)	10 (37.0%)	19 (27.1%)
BK Virus	1 (2.3%)	2 (7.4%)	3 (4.3%)
Infection-Free	33 (76.7%)	15 (55.6%)	48 (68.6%)

Table III: Long-term Survival, Relapse Incidence, and Day 100 Chimerism.		
Outcome Measure	Matched Transplant (N=43)	Haploidentical Transplant (N=27)
8-Year Relapse Incidence	7 (16.2%)	5 (18.5%)
Survival Status (Final Follow-up)		
Alive	13 (30.2%)	4 (14.8%)
Deceased	21 (48.8%)	13 (48.1%)
Lost to Follow-up	9 (20.9%)	10 (37.0%)
Day 100 Chimerism (>95% Donor)		
Achieved	23 (53.4%)	16 (59.2%)
Not Assessed / Missing	20 (46.6%)*	11 (40.8%)*

Majority (68.6%) of cohort maintained an infection-free post-transplant course, however affected 31.4% of the total study population. Viral reactivations were the predominant infectious concern, with a higher burden observed in haploidentical recipients. Specifically, Cytomegalovirus (CMV) reactivation was noted in 37% of haploidentical patients compared to 20.9% of matched recipients. Similarly, BK virus incidence was higher in the haploidentical group (7.4% vs. 2.3%). (Table II)

The 8-year relapse incidence was 16.2% (n=7) in the matched transplant group and 18.5% (n=5) in the haploidentical group. Regarding long-term survival, 30.2% (n =13) in the fully matched group were alive at the end of the follow-up period, while 48.8% (n =21) deaths were recorded and 20.9% (n =9) patients were lost to follow-up. In the haploidentical cohort, 14.8% (n =4) remained alive, 48.1% (n =13) died, and 37.0% (n = 10) were lost to follow-up. Full-match transplants had slightly better survival (20.9%) compared to haplo-identical transplants (15.4%), though both had similar mortality rates. By Day 100, chimerism assessed showed >95% in 23 patients of matched transplant (53.4%) while haploidentical 16 patients (59.2%), however 44.3% (n =31) had no chimerism assessment. (Table III)

At the Day 100 landmark assessment, successful neutrophil engraftment (ANC >0.5*10^9/L) was observed in 62.7% (n=27) of the matched transplant cohort, compared to 48.1% (n=13) in the haploidentical group. Conversely, delayed or incomplete neutrophil recovery was noted in 16.2% (n=7) and 18.5% (n=5) of the matched and haploidentical groups, respectively. Regarding megakaryocytic recovery, matched transplants demonstrated a higher rate of platelet engraftment above the clinical threshold at day 100 (41.8%, n=18) compared to the haploidentical cohort (18.5%, n=5). Notably, a higher proportion of haploidentical patients (48.1%, n=13) remained below the platelet threshold at Day 100, highlighting a potential delay in platelet engraftment within this subgroup. (Table)

Table IV: Comparative Engraftment Status at Day 100 Post-HSCT.		
Parameter	Matched Transplant (N=43)	Haploidentical Transplant (N=27)
Neutrophil Recovery (ANC > 0.5*10^9/L)		
Above Threshold	27 (62.7%)	13 (48.1%)
Below Threshold	7 (16.2%)	5 (18.5%)
Not Assessed / Missing	9 (20.9%)	9 (33.3%)
Platelet Recovery (> 100*10^9/L)		
Above Threshold	18 (41.8%)	5 (18.5%)
Below Threshold	16 (37.2%)	13 (48.1%)
Not Assessed / Missing	9 (20.9%)	9 (33.3%)

Discussion

The study consisting of 70 patients who underwent allogeneic hematopoietic stem cell transplantation (allo-HSCT) diagnosed with acute leukemia, provides a profound understanding of the impact of transplant types, CD34+ cell dose, conditioning regimens, and prophylactic approaches on engraftment phase, complications, and post-transplant survival outcomes. The findings highlight the variation in treatment outcomes based on patient-specific factors and underscore the appropriateness of personalized transplant strategies.

Neutrophil engraftment was slower in haplo-identical transplants compared to full-match, yet showed a higher overall success rate. This supports evidence that, with proper immunosuppression, haplo-identical transplants can be effective alternatives when matched donors are unavailable.[13,14] A similar pattern was seen for platelet engraftment outcomes, with slightly longer time in haplo-identical transplants compared to full-match transplants but almost identical success rates, as reported by another study.[15]

Engraftment outcomes were found to be remarkably influenced by age. The fastest platelet recovery was achieved by the pediatric patients; on the contrary, the slowest platelet recovery was seen in the adolescents. This could be the result of the highest CD34+ dosing in pediatric patients, which potentially favored their improved outcomes, as also shown by an earlier study.[16,17] In contrast, literature has shown delayed

platelet engraftment at the lowest doses, which was the case in our adolescent cohort.[18] Given these age-specific outcomes, CD34+ dose needs to be taken into consideration when developing treatment protocols, which should be planned differently based on the age groups to optimize transplant outcomes, as backed by a recent study finding.[19]

The impact of increasing age on neutrophil engraftment was inversely related in our study, even though several studies have not found any significant difference in engraftment rates by age groups.[20,21] Similarly, a negative correlation was observed between the dose of CD34+ cells and platelet engraftment, suggesting that more stem cell input enhances hematopoietic recovery, confirming prior reports linking higher CD34+ doses with faster platelet recovery.[22,23] The positive correlation between absolute neutrophil count (ANC) and platelet engraftment further supports a shared biological trajectory during hematopoietic recovery. The majority of our cohort received very high CD34+ doses and achieved a high success rate for engraftment. Gender-based dosing showed no significant differences, which could be related to the notion that males and females have similar yields of CD34+ cells.[24]

Engraftment in B-ALL shows more adequate results with CD34+ doses of >8 × 10^6/kg, while T-ALL may benefit from customized conditioning regimens and enhanced GVHD prophylaxis.[25,26] AML patients had stable outcomes, supporting current transplant practices with recommended CD34+ doses of 8 × 10^6/kg.[27] The engraftment success rate continued to be high for most of these subtypes, reinforcing the significance of focusing on disease biology and modifiable patient-dependent factors for optimization of CD34+ dose after a certain threshold.[28]

Conditioning regimens significantly impacted engraftment and GVHD rates; although CY/TBI was more commonly used, BU/CY showed faster engraftment but both had the high GVHD incidence as consistent with previous study.[29] In contrast, FLU/MEL and ATG-containing or PTCY (post-transplant cyclophosphamide) regimens yielded optimal outcomes with low GVHD rate, supporting evidence that T cell depletion reduces GVHD and enhances early engraftment.[30-32]

While all GVHD prophylaxis strategies had similar engraftment times, Cyclosporine/Methotrexate showed the lowest complication rates and remains the gold standard[33,34], whereas PTcy/Cyclosporine/MMF demonstrates higher, comparable to that seen in a large retrospective study.[35] Additionally, high CMV-related infection rates, especially in full-match transplants, emphasize the need for targeted prophylaxis in immunosuppressed, CMV-positive patients.

Major complications observed in our study included acute GVHD grade II-IV and chronic GVHD, graft failure, and disease relapse. Acute GVHD and graft failure were more frequent in the haploidentical cohort (37.0% and 25.9%, respectively), while chronic GVHD was higher in matched recipients (18.6%), aligning with globally reported data [36,37], followed by chronic GVHD, while graft failure and relapse occurred at similarly lower rates, indicating acceptable long-term morbidity for the cohort. Overall, these observations reinforce the essential role of preemptive measures to curb post-transplant complications and improve survival outcomes.

Our study shows a 48.6% mortality rate, reflecting the aggressive nature of acute leukemia, with In this study, the observed 5-year survival rates of 30.2% for matched and 14.8% for haploidentical transplants are significantly confounded by high attrition rates of 20.9% and 37%, respectively. This significant loss to follow-up introduces potential predisposition, limiting the reliability of long-term survival interpretations and highlighting a critical need for improved patient assessment system. Ultimately, these findings emphasize that in resource-limited settings, enhancing registry infrastructure is as vital to optimizing allo-HSCT outcomes as refining clinical dosing protocols.[38] Day 100 recovery rates for neutrophils and platelets were lower than early engraftment rates, and incomplete chimerism data revealed gaps in long-term monitoring, stressing the importance of stronger post-transplant follow-up systems.

Our study has limited by its retrospective design, small sample size, single-center data, and incomplete long-term follow-up, emphasizing the need for future studies with vigorous design and follow-up to better assess allogeneic HSCT outcomes in acute leukemia.

Conclusion

The results of our study highlight the decisive role of CD34+ dosing in optimizing engraftment outcomes and

post-transplant usefulness in acute leukemia patients. Modifying transplant types and conditioning regimens based on patient-specific factors along with enhanced prophylactic strategies to limit post-transplantation complications helps in improving disease outcomes. This study represents a comprehensive regional evaluation of allo-HSCT in acute leukemia and provides clinically actionable understandings for enlightening transplant protocols.

References

1. Kayser S, Schlenk RF, Steiner M, Klüter H, Wuchter P. Predicting successful hematopoietic stem cell collection in healthy allogeneic donors. Transfus Med Hemother. 2023;50(5):396-402. doi:10.1159/000531236
2. Davis E, Feuer E, Rapoport C, Lobaugh S, Devlin SM, Archer A, et al. TNC/Kg and CD34+/Kg cell dose impact on patient engraftment after allogeneic transplant with conventional bone marrow; better predictability of graft content needed. Blood. 2023;142(Suppl 1):1013. doi:10.1182/blood-2023-190940
3. Abraham L, JP. Effect of CD34+ cell dose on neutrophil and platelet engraftment kinetics in haematopoietic stem cell transplantation - a single-centre experience. Indian J Physiol Pharmacol. 2021. doi:10.25259/IJPP_138_2020
4. Tiwari AK, Luthra AS, Arora D, Mehta SP, Aggarwal G, Sood N, et al. Correlation of various methods of hematopoietic progenitor cell estimation with standard flowcytometric CD34 enumeration. Asian J Transfus Sci. 2023. doi:10.4103/ajts.ajts_33_21
5. Chen J, Gale RP, Feng Y, Hu Y, Qi S, Liu X, et al. Are haematopoietic stem cell transplants stem cell transplants, is there a threshold dose of CD34-positive cells and how many are needed for rapid posttransplant granulocyte recovery? Leukemia. 2023;37(10):1963-8. doi:10.1038/s41375-023-01973-2
6. Jacob RP, et al. Universal engraftment after allogeneic hematopoietic cell transplantation using cryopreserved CD34-selected grafts. Transplant Cell Ther. 2021;27(8). doi:10.1016/j.jtct.2021.04.026
7. Dalva K, Haskologlu S, Dalva-Aydemir S, Oz MD, Ozturk A, Ipek S, et al. Effect of $CD34^+$ total/myeloid $CD34^+$ cell progenitors and B-lymphoid progenitors within the bone marrow grafts on the hematopoietic recovery after hematopoietic stem cell transplantation. Exp Clin Transplant.2022;20(10):937-44. doi:10.6002/ect.2022.0210
8. Sun YQ, Wang Y, Wang FR, Yan CH, Cheng YF, Chen YH, et al. Graft failure in patients with hematological malignancies: a successful salvage with a second transplantation from a different haploidentical donor. Front Med (Lausanne). 2021;8:604085. doi:10.3389/fmed.2021.604085
9. Remberger M, Grønvold B, Ali M, Mattsson J, Egeland T, Lundin KU, et al. The CD34(+) cell dose matters in hematopoietic stem cell transplantation with peripheral blood stem cells from sibling donors. Clin Hematol Int. 2020;2(2):74-81. doi:10.2991/chi.d.200221.001
10. Gauntner TD, Brunstein CG, Cao Q, Weisdorf D, Warlick ED, Jurdi NE, et al. Association of CD34 cell dose with 5-year overall survival after peripheral blood allogeneic hematopoietic cell transplantation in adults with hematologic malignancies. Transplant Cell Ther. 2022;28(2):88-95. doi:10.1016/j.jtct.2021.11.004
11. Czerw T, Iacobelli S, Malpassuti V, Koster L, Kröger N, Robin M, et al. Impact of donor-derived CD34+ infused cell dose on outcomes of patients undergoing allo-HCT following reduced intensity regimen for myelofibrosis: a study from the Chronic Malignancies Working Party of the EBMT. Bone Marrow Transplant. 2022;57(2):261-70. doi:10.1038/s41409-021-01540-2
12. Pedraza A, Salas MQ, Rodríguez-Lobato LG, Charry P, Suárez-Lledo M, Martínez-Cibrian N, et al. Effect of CD34+ cell dose on the outcomes of allogeneic stem cell transplantation with post-transplantation cyclophosphamide. Transplant Cell Ther. 2023;29(3):181.e1-181.e10. doi:10.1016/j.jtct.2022.12.005
13. Huynh MV, Nguyen QT, Huynh PDV, Hoang ND, Nguyen TH, Phu DC. Haploidentical hematopoietic stem cell transplant using post-transplant cyclophosphamide: a single-center initial experience in Vietnam. Blood Cell Ther. 2021;4(4):75-83. doi:10.31547/bct-2021-002
14. Castagna L, Crocchiolo R, Furst S, Bramanti S, El Cheikh J, Sarina B, et al. Bone marrow compared with peripheral blood stem cells for haploidentical transplantation with a nonmyeloablative conditioning regimen and post-transplantation cyclophosphamide. Biol Blood Marrow Transplant.2014;20(5):724-9. doi:10.1016/j.bbmt.2014.02.001
15. Mussetti A, Kanate AS, Wang T, He M, Hamadani M, Finel H, et al. Haploidentical versus matched unrelated donor transplants using post-transplantation cyclophosphamide for lymphomas. Transplant Cell Ther. 2023;29(3):184.e1-184.e9. doi:10.1016/j.jtct.2022.11.028
16. Gunn N, Damon L, Varosy P, Navarro W, Martin T, Ries C, et al. High CD34+ cell dose promotes faster platelet recovery after autologous stem cell transplantation for acute myeloid leukemia. Biol Blood Marrow Transplant. 2003;9(10):643-8. doi:10.1016/S1083-8791(03)00232-5
17. Furey A, Rastogi S, Prince R, Jin Z, Smilow E, Briamonte C, et al. Bone marrow harvest in pediatric sibling donors: role of granulocyte colony-stimulating factor priming and CD34+ cell dose. Biol Blood Marrow Transplant. 2018;24(2):324-9. doi:10.1016/j.bbmt.2017.10.031
18. Chang YJ, Xu LP, Liu DH, Liu KY, Han W, Chen YH, et al. Platelet engraftment in patients with hematologic malignancies following unmanipulated haploidentical blood and marrow transplantation: effects of CD34+ cell dose and disease status. Biol Blood Marrow Transplant. 2009;15(5):632-8. doi:10.1016/j.bbmt.2009.02.001
19. Qu Y, Shourabizadeh H, Subramanian A, Aleman DM, Rousseau LM, Law AD, et al. Differential impact of CD34+ cell dose for different age groups in allogeneic hematopoietic cell transplantation for acute leukemia: a machine learning-based discovery. Exp Hematol. 2025;141:104684. doi:10.1016/j.exphem.2024.104684
20. McGuirk M, Shahzad M, Irfan S, Amin MK, Chaudhary SG, Anwar I, et al. Impact of donor age and gender on

allogeneic hematopoietic stem cell transplantation. Blood. 2024;144(Suppl 1):7408-7408. doi:10.1182/blood-2024-193409
21. Rezvani AR, Storer BE, Guthrie KA, Schoch HG, Maloney DG, Sandmaier BM, et al. Impact of donor age on outcome after allogeneic hematopoietic cell transplantation. Biol Blood Marrow Transplant. 2015;21(1):105-12. doi:10.1016/j.bbmt.2014.09.021
22. Remberger M, Törlén J, Ringdén O, Engström M, Watz E, Uhlin M, et al. Effect of total nucleated and CD34+ cell dose on outcome after allogeneic hematopoietic stem cell transplantation. Biol Blood Marrow Transplant. 2015;21(5):889-93. doi:10.1016/j.bbmt.2015.01.025
23. Lin H, Li D, Thompson J, Winstone D, Lankester A, Li Y. The impact of age and gravidity on CD34+ yields in female peripheral blood stem cell donors. Transfus Apher Sci. 2025;64(4):104196. doi:10.1016/j.transci.2025.104196
24. Cao X, Li Z, Zhang Y, Cui Q, Dai H, Ma Y, et al. Chidamide combined with a modified Bu-Cy conditioning regimen improves survival in patients with T-cell acute lymphoblastic leukemia/lymphoma undergoing allogeneic hematopoietic stem cell transplantation. Ann Hematol. 2024;103(8):3083-93. doi:10.1007/s00277-024-05849-y
25. Eder S, Canaani J, Beohou E, Labopin M, Sanz J, Arcese W, et al. Thiotepa-based conditioning versus total body irradiation as myeloablative conditioning prior to allogeneic stem cell transplantation for acute lymphoblastic leukemia: a matched-pair analysis from the Acute Leukemia Working Party of the European Society for Blood and Marrow Transplantation. Am J Hematol. 2017;92(10):997-1003. doi:10.1002/ajh.24823
26. Siddiq A, Khan MA, Rehman JU, Abbas Y, Khan H, Rahim U. Prognostic factors affecting day+100 survival in patients undergoing allogeneic haematopoietic stem cell transplantation for acute leukaemia - a single centre experience. J Coll Physicians Surg Pak. 2024;34(11):1287-93. doi:10.29271/jcpsp.2024.11.1287
27. Zhang H, Fan Z, Huang F, Han L, Xu Y, Xu N, et al. Busulfan plus cyclophosphamide versus total body irradiation plus cyclophosphamide for adults acute B lymphoblastic leukemia: an open-label, multicenter, phase III trial. J Clin Oncol. 2023;41(2):343-53. doi:10.1200/JCO.22.00767
28. Bayraktar UD, De Lima M, Saliba RM, Maloy M, Castro-Malaspina HR, Chen J, et al. Ex vivo T cell-depleted versus unmodified allografts in patients with acute myeloid leukemia in first complete remission. Biol Blood Marrow Transplant.2013;19(6):898-903. doi:10.1016/j.bbmt.2013.02.018
29. Spitzer B, Jakubowski AA, Papadopoulos EB, Fuller K, Hilden PD, Young JW, et al. A chemotherapy-only regimen of busulfan, melphalan, and fludarabine, and rabbit antithymocyte globulin followed by allogeneic T-cell depleted hematopoietic stem cell transplantations for the treatment of myeloid malignancies. Biol Blood Marrow Transplant. 2017;23(12):2088-95. doi:10.1016/j.bbmt.2017.07.004
30. Kernan N, Bordignon C, Heller G, Cunningham I, Castro-Malaspina H, Shank B, et al. Graft failure after T-cell-depleted human leukocyte antigen identical marrow transplants for leukemia: I. Analysis of risk factors and results of secondary transplants. Blood. 1989;74(6):2227-36. doi:10.1182/blood.V74.6.2227.bloodjournal7462227
31. Storb R, Deeg HJ, Whitehead J, Appelbaum F, Beatty P, Bensinger W, et al. Methotrexate and cyclosporine compared with cyclosporine alone for prophylaxis of acute graft versus host disease after marrow transplantation for leukemia. N Engl J Med. 1986;314(12):729-35. doi:10.1056/NEJM198603203141201
32. Storb R, Deeg HJ, Pepe M, Appelbaum F, Anasetti C, Beatty P, et al. Methotrexate and cyclosporine versus cyclosporine alone for prophylaxis of graft-versus-host disease in patients given HLA-identical marrow grafts for leukemia: long-term follow-up of a controlled trial. Blood. 1989;73(6):1729-34. doi:10.1182/blood.V73.6.1729.1729
33. Hamilton BK, Liu Y, Hemmer M, Wang T, Chhabra S, Costa LJ, et al. Cyclosporine in combination with mycophenolate mofetil leads to increased incidence of graft-versus-host disease and inferior outcomes after myeloablative allogeneic hematopoietic cell transplantation: a CIBMTR analysis. Biol Blood Marrow Transplant. 2018;24(3):S185. doi:10.1016/j.bbmt.2017.12.137
34. Abadir E, Othman J, Kwan J, Gottlieb DJ, Kennedy GA, Bajel A, et al. Peripheral blood haploidentical allogeneic stem cell transplantation in older adults with acute myeloid leukemia and myelodysplastic syndromes demonstrates long term survival, results from Australia and New Zealand Transplant and Cellular Therapies. Transplant Cell Ther. 2024;30(3):334.e1-334.e7. doi:10.1016/j.jtct.2023.11.018
35. Heider U, Solano-Vega J, Sandoval-Vargas YG, Díaz-Brochero C. Incidence and factors associated with graft-versus-host disease in the first year after allogeneic peripheral blood stem cell transplantation. J Immunother Precis Oncol. 2025;8(2):99-107. doi:10.36401/JIPO-24-25
36. Iyer P, Jasdanwala SS, Bhatia K, Bhatt S. Mitochondria and acute leukemia: a clinician's perspective. Int J Mol Sci. 2024;25(17):9704.doi:10.3390/ijms25179704