Biol Blood Marrow Transplant 25 (2019) 233–238

Biology of Blood and Marrow Transplantation

journal homepage: www.bbmt.org

Autologous

Mobilization of Hematopoietic Progenitor Cells for Autologous Transplantation Using Pegfilgrastim and Plerixafor: Efficacy and Cost Implications

Nicole L. Watts[1], Marisa B. Marques[2], Daniel B. Peavey[2], Racquel Innis-Shelton[3], Ayman Saad[3], A. Di Stasi[3], Donna Salzman[3], Lawrence S. Lamb Jr[3], Luciano J. Costa[3,*]

[1] *Department of Pharmacy, University of Alabama at Birmingham Hospital, Birmingham, Alabama*
[2] *Department of Pathology, University of Alabama at Birmingham, Birmingham, Alabama*
[3] *Division of Hematology and Oncology, Department of Medicine, University of Alabama at Birmingham, Birmingham, Alabama*

Article history:
Received 8 July 2018
Accepted 7 September 2018

Key Words:
Pegfilgrastim
Plerixafor
Stem cell mobilization
Cost analysis

A B S T R A C T

Filgrastim (FIL) is the most common growth factor combined with plerixafor for autologous hematopoietic progenitor cell mobilization, but requires daily, multi-injection administration. We adopted a standardized mobilization regimen with pegfilgrastim (PEG) and upfront plerixafor, allowing for a single injection given the long half-life and slow elimination of PEG. Between 2015 and 2017, a total of 235 patients with lymphoma or plasma cell dyscrasias underwent mobilization with PEG 6 mg on day 1 and upfront plerixafor 24 mg on day 3, followed by apheresis on day 4 regardless of peripheral blood $CD34^+$ cells. The median $CD34^+$ cells/mm^3 in peripheral blood on first day of collection was 48 and median collection yield was 7.27×10^6 $CD34^+$ cells/kg (range, 0.32 to 39.6×10^6 $CD34^+$ cells/kg) after a mean of 1.6 apheresis collections. Overall, 83% of patients achieved the mobilization target, and 95% reached the minimum necessary $CD34^+$ cell yield to proceed with transplantation (2×10^6 $CD34^+$ cells/kg). Because FIL is weight-based and dosed daily, the cost comparison with PEG is influenced by patient weight and number of apheresis sessions required. A cost simulation using actual patient data indicates that PEG is associated with lower cost than FIL for the majority of patients. Autologous hematopoietic progenitor cell mobilization with PEG and plerixafor is practical, effective, and not associated with increased cost compared with FIL mobilization.

INTRODUCTION

Autologous hematopoietic cell transplantation (auto-HCT) is a mainstay treatment for such hematologic malignancies as multiple myeloma and lymphomas. Peripheral blood (PB) hematopoietic progenitor cells (HPCs) offer faster hematopoietic recovery than HPCs from bone marrow, making it the most common source of cells for auto-HCT [1,2]. Three general approaches for mobilizing PB-HPCs are available: myeloid growth factors with or without the CXCR4 antagonist plerixafor and chemotherapy plus growth factors. Chemotherapy mobilization has been shown to produce similar failure rates with increased cost and toxicity compared with myeloid growth factor alone [3-8]. Filgrastim (FIL) is the most commonly used growth factor for auto-HPC mobilization. Whereas FIL offers predictable mobilization kinetics to optimize apheresis scheduling compared with chemotherapy mobilization, failure rates can be high [4-6,9,10]. In 2 phase III trials, upfront plerixafor, a reversible CXCR4 antagonist, in combination with FIL improved $CD34^+$ cell collection yields with fewer apheresis sessions and lower failure rates compared with FIL plus placebo [11]. Preemptive plerixafor also has been reported in single-institution studies using PB $CD34^+$ cell counts to indicate poor mobilizers [12-16].

FIL requires daily, multi-injection administration which can be inconvenient and uncomfortable for patients and staff. Pegfilgrastim (PEG), a pegylated formulation of granulocyte-colony stimulating factor (G-CSF), is approved for the prevention of chemotherapy-induced neutropenia. Given the long half-life and slower elimination rate, a single injection of PEG produces increased serum concentrations compared with multiday administration of FIL [17]. This allows for a predictable pharmacokinetic profile without multi-injection administration. Small single-center studies have demonstrated the efficacy of PEG as a mobilizing agent with or without plerixafor [18,19] or in combination with chemotherapy mobilization [20-26], but cost is a major concern.

Financial disclosure: See Acknowledgments on page 237.

* Correspondence and reprint requests: Luciano J. Costa, MD, PhD, Department of Medicine and UAB-CCC, University of Alabama at Birmingham, 1802 6th Avenue South, North Pavilion–NP 2554, Birmingham, AL 35294.
E-mail address: Ljmegale@gmail.com (L.J. Costa).

https://doi.org/10.1016/j.bbmt.2018.09.005
1083-8791/

We adopted a standardized mobilization regimen with PEG and upfront plerixafor for auto-HSCT mobilization. Given the limited data on the use of PEG for autologous PB-HPC mobilization, we conducted a retrospective analysis to evaluate mobilization outcomes with PEG and an upfront plerixafor and cost comparison with FIL or tbo-FIL (TBO) [27], a lower-cost FIL formulation with similar mobilization outcomes.

METHODS

Mobilization and Collection

In April 2015, we adopted a standardized regimen for mobilization of auto-HPCs for patients with lymphoma or plasma cell dyscrasias consisting of PEG 6 mg on day 1, upfront plerixafor 24 mg (fixed dose) on day 3, and collection of auto-HPCs by apheresis on day 4 regardless of PB $CD34^+$ cell content. For clarity, planned plerixafor was part of the mobilizing regimen for all patients and was not triggered by clinical parameters of PB $CD34^+$ cells. Plerixafor was given on day 3 based on the pharmacodynamics in healthy volunteers demonstrating that PEG 100 μg/kg resulted in peak $CD34^+$ cell count in the blood on days 2 to 3 after single administration [17]. Fixed-dose PEG (6 mg) is based on the pharmacokinetics and pharmacodynamics of weight-based dosing, which were estimated based on the average total PEG dose given (60 μg/kg and 100 μg/kg cohorts) in a phase 2 study in breast cancer patients [28]. Autologous PB-HPCs were collected by apheresis with processing of approximately 3 blood volumes using the Cobe Spectra (Terumo BCT, Lakewood, CO) or Amicus (Fresenius Kabi USA, Lake Zurich, IL) device. When the $CD34^+$ cell collection target (3×10^6 $CD34^+$ cells/kg for patients collecting for 1 transplantation and 6×10^6 $CD34^+$ cells/kg for patients collecting for 2 transplantations) was not met on the first day of collection, evening (18:00) plerixafor administration followed by next-day collection were repeated until the target was met or a maximum of 3 collections were completed. The target was previously identified by program consensus to be an operational parameter for decision making and was defined as the minimal cumulative yield that would be considered sufficient to justify not pursuing an additional dose of plerixafor and another apheresis session.

If the cumulative $CD34^+$ cell yield of collection was <15% of the target after 1 collection (ie, $\leq .45 \times 10^6$ $CD34^+$ cells/kg for patients collecting for 1 transplantation and $.9 \times 10^6$ $CD34^+$ cells/kg for patients collecting for 2 transplants) or 30% below the target after 2 collections (ie, $\leq .9 \times 10^6$ $CD34^+$ cells/kg for patients collecting for 1 transplantation and $\leq 1.8 \times 10^6$ $CD34^+$ cells/kg for patients collecting for 2 transplantations), the mobilization was considered unsuccessful, and subsequent mobilization and collection were discontinued (Figure 1). Patients with unsuccessful mobilization were offered the opportunity for a repeat mobilization cycle with the same regimen 2 to 4 weeks later. Patients who achieved the collection target typically proceeded to initiate auto-HCT conditioning within 1 week of completing collection. Patients who completed mobilization but did not reach the target often proceeded to auto-HCT if $\geq 2 \times 10^6$ $CD34^+$ cells/kg were available. For this analysis, we defined mobilization failure as a cumulative yield of $<2 \times 10^6$ $CD34^+$ cells/kg, the minimum cell dose considered acceptable for 1 transplantation [29].

Data were collected prospectively for quality purposes until December 2017 as part of the apheresis quality management program and were analyzed retrospectively. All patients signed written informed consent allowing data to be collected, analyzed, and presented without patient identifiers.

Cost Analysis

Our mobilization regimen uses single-dose PEG as an alternative to daily dosing of FIL. We compared the estimated cost of mobilization drugs with PEG versus the simulated cost with FIL and TBO at a dose of 10 μg/kg/day administered for 4 days before the first collection and then daily until the completion of collection completion [11]. In this simulation, FIL and TBO regimens

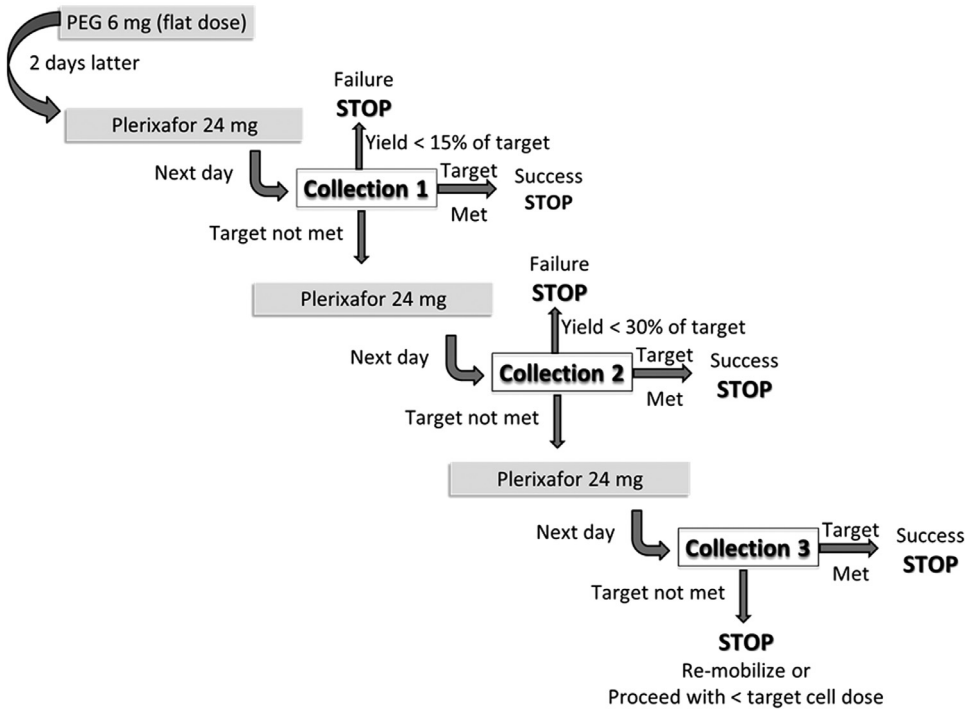

Figure 1. Schematics of mobilization and collection. Step-by-step and decision points involved in mobilization with PEG + plerixafor.

Table 1
Patient Characteristics

Characteristic	PCD	Lymphomas	Total
Number	185	50	235
Age, yr, median (range)	61 (34-77)	50.5 (19-74)	60 (19-77)
Male sex, n (%)	106 (57)	27 (54)	133 (56)
Weight, kg, median (range)	83 (50-180)	86 (54-175)	84 (50-180)
Diagnosis, n (%)			
Multiple myeloma	178 (96)		
Other PCD	7 (4)		
Hodgkin lymphoma		18 (36)	
Non-Hodgkin lymphoma		32 (64)	
Previous lines of therapy, median (range)	1 (0-5)	2 (1-4)	1 (0-5)
Cycles of lenalidomide, median (range)	4 (0-24)	0 (0-0)	4 (0-24)
Collection target, n (%)			
3×10^6 CD34$^+$ cells/kg	4 (2)	50 (100)	54 (23)
6×10^6 CD34$^+$ cells/kg	181 (98)	0 (0)	181 (77)

PCD indicates plasma cell dyscrasia.

were assumed to be of similar efficacy as PEG. Drug cost estimates included plerixafor in all regimens. Drug costs were estimated using average sales price: PEG, $4191.34/6 mg; FIL, $1.009/1 μg; TBO, $0.665/1 μg; and plerixafor, $312.10/1 mg. Actual body weight was used for estimation of FIL and TBO doses. Cost simulations used actual data from all patients included in the analysis of our mobilization regimen. For example, if a 90-kg patient receiving PEG + plerixafor met the collection target after 1 apheresis session, the simulated cost for FIL-based mobilization for this patient included 5 doses of FIL 900 μg/dose (10 μg/kg/dose) and 1 dose of plerixafor 24 mg (1 vial).

Statistics

Numeric variables were described as mean ± SD, and numeric variables with a skewed distribution were described as median (range). Comparisons of estimated costs of mobilization drugs among the 3 different growth factors were performed using ANOVA. We assessed the impact of body weight on mobilization of PB CD34$^+$ cells by univariate and multivariable linear regression analyses, adjusting for other variables influencing mobilization. For the multivariable analysis, we used a stepwise forward algorithm for variable selection, with retention of the independent variable of interest (weight) in the model. We performed all statistical calculations in SPSS for Windows, version 24.0 (IBM, Armonk, NY). For all comparisons, a 2-sided *P* value was considered significant at $<.05$.

RESULTS

A total of 235 patients underwent mobilization using PEG + plerixafor and are included in the analysis (Table 1). The majority of patients (78.7%) had multiple myeloma or another plasma cell dyscrasia; their median age was 60 years (range, 19 to 77 years), and 56% were male.

Performance of Mobilization Regimen

All patients received both PEG and plerixafor and underwent at least 1 session of apheresis. Performance of mobilization and collection is summarized in Table 2.

The median PB CD34$^+$ cell collection yield on the first day of collection was 48 cells/mm^3 (range, 2 to 481 cells/mm^3), and the median collection yield on the first day was 4.81×10^6 CD34$^+$ cells/kg (range, 0.22 to 39.6×10^6 CD34$^+$ cells/kg). Overall, 107 patients (46%) met the target with 1 day of collection, including 31 (57%) with a target of 3×10^6 CD34$^+$ cells/kg and 76 (42%) with a target of 6×10^6 CD34$^+$ cells/kg. For patients requiring >1 day of apheresis, there was no significant day-to-day decay in collection yield. The average day 2 collection yield was 103% of the day 1 yield (n = 122), and the day 3 collection yield was 93% of the day 1 yield (n = 24).

Overall, 83% of patients reached the mobilization target, and 95% reached the minimum necessary number of CD34$^+$ cells to proceed with auto-HCT (2×10^6 CD34$^+$ cells/kg). The rate of compliance with the mobilization and collection regimen was 96%, and noncompliance was driven mostly by physician decision or patient fatigue preventing an additional day of collection. Among the 12 patients (5%) with mobilization failure, 9 attempted remobilization with the same regimen (8 eventually underwent transplantation). There were no severe adverse toxicities from the mobilization regimen. Most of the documented adverse events were associated with central line placement or the apheresis procedure (2 patients experienced hypotension after line placement, and 1 patient had anemia after collection). One patient reported a headache after PEG administration, and another patient experienced fever at home 4 days after collection (all cultures negative). All patients who underwent transplantation successfully engrafted neutrophils and platelets.

Because all patients received the same dose of PEG (6 mg) irrespective of weight and effectively the same dose of plerixafor (24 mg) because dose was rounded to the nearest vial size, a departure for the more traditional weight-based administration of mobilizing agents, we questioned whether this practice led to underdosing and consequently inadequate mobilization in heavier patients by exploring the association between actual body weight and PB CD34$^+$ cell enumeration on the first day of collection. There was no significant association between weight and PB CD34$^+$ cell number (Supplementary Table 1 and Supplementary Figure 1). A multivariable model indicated that patient age and underlying disease, but not body weight, influenced PB CD34$^+$ cell count, suggesting no detrimental effect of using flat doses of PEG and plerixafor.

Table 2
Outcomes of Mobilization and Collection

	Mobilization Target		
Outcome	3×10^6 CD34$^+$ Cells/kg	6×10^6 CD34$^+$ Cells/kg	Total
Number of patients	54	181	235
CD34$^+$ cells/mm^3 in PB on first day of collection, median (range)	39.5 (3-244)	53 (2-481)	48 (2-481)
CD34$^+$ yield on first day of collection, $\times 10^6$/kg, median (range)	3.85 (0.22-18.6)	5.08 (0.34-39.6)	4.81 (0.22-39.6)
Cumulative CD34$^+$ cell yield, $\times 10^6$/kg, median (range)	4.58 (0.32-18.6)	7.91 (0.34-39.6)	7.27 (0.32-39.6)
Number of collections, median (range)	1 (1-3)	2 (1.3)	2 (1-3)
Number of collections, mean	1.5	1.7	1.6
Patients reaching target, n (%)	47 (87)	149 (82)	196 (83)
Patients reaching target in 1 collection, n (%)	31 (57)	76 (42)	107 (46)
Patients reaching 2×10^6 CD34$^+$ cells/kg, n (%)	51 (94)	173 (96)	224 (95)

Cost Analysis

The estimated average cost of mobilization drugs with PEG + plerixafor was $16,431, compared with simulated costs for FIL + plerixafor of $17,230 and TBO + plerixafor of $15,528 (Table 3). Because FIL and TBO are dosed daily and doses are weight-based, the cost comparison with PEG is greatly influenced by patient weight and number of apheresis sessions required (Figure 2). For instance, we found that patients who require a single day of collection, FIL mobilization is expected to have a lower cost than PEG only for patients weighing <83 kg, whereas for patients who require 3 days of collection, FIL mobilization is expected to have lower cost only for patients weighting <60 kg (Figure 2).

DISCUSSION

This retrospective, single-center study is the largest series to date reporting the use of PEG with upfront plerixafor for auto-HPC mobilization. Expert panel has recommended the use of upfront plerixafor to obtain the highest $CD34^+$ cell yield in the fewest days of apheresis [29]. Our analysis of 235 patients showed that this mobilization approach is feasible and highly efficient, because almost one-half of patients collected the target number of $CD34^+$ cells in a single apheresis session. Moreover, our rate of mobilization failure is in line with national consensus recommendations [29] and previous clinical trial experience with growth factor and plerixafor mobilization [11].

There have been previous reports on the performance of PEG mobilization. A retrospective comparison of PEG 12 mg versus weight-based FIL in the setting of preemptive plerixafor found only a 2% risk of mobilization failure and better performance with less use of plerixafor in the group that received PEG. A subsequent analysis found similar performance of PEG 12 mg versus PEG 6 mg and lower cost associated with the lower dose [30]. Other trials and retrospective analyses have indicated that PEG is at least as effective as FIL in either growth factor-only auto-HPC mobilization [31,32] or in the context of chemotherapy mobilization [33,34]. Our study differs from some other PEG-containing mobilization studies [18,19,31,32], using a lower dose of PEG (6 mg versus 12 mg) impacting the cost comparison of PEG and FIL. The other difference is that our study strictly used growth factor and plerixafor mobilization and not chemotherapy mobilization as in previous reports [20-26]. In the context of chemotherapy mobilization, 6 mg of PEG has been shown to have similar results to 12 mg of PEG [20,23] and FIL [20,21,26,33,34].

The performance of our mobilization regimen is remarkably similar that reported in the FIL + plerixafor arm of previous randomized studies. In a phase 3 multicenter study of patients with non-Hodgkin lymphoma [11], 93% of the 150 patients treated with FIL + plerixafor collected $\geq 2 \times 10^6$ $CD34^+$ cells/kg, compared with 94% of the patients in our series. Similarly, in a phase 3 multiple myeloma trial [11], 95% of the 148 patients treated with FIL + plerixafor collected $\geq 2 \times 10^6$ $CD34^+$ cells/kg, compared with 96%

Table 3
Estimated Cost of Mobilization Drugs (in 1000 USD) According to Mobilization Approach

Target	PEG	FIL	*P* Value (PEG versus FIL)	TBO	*P* Value (PEG versus TBO)
3×10^6 $CD34^+$ cells/kg (n = 54)	15.4 ± 4.5	16.3 ± 5.6	.0004	14.6 ± 5.2	<.0001
6×10^6 $CD34^+$ cells/kg (n = 181)	16.7 ± 5.2	17.5 ± 6.0	<.0001	15.8 ± 5.7	<.0001
Total (n = 235)	16.4 ± 5.1	17.2 ± 5.9	<.0001	15.5 ± 5.6	<.0001

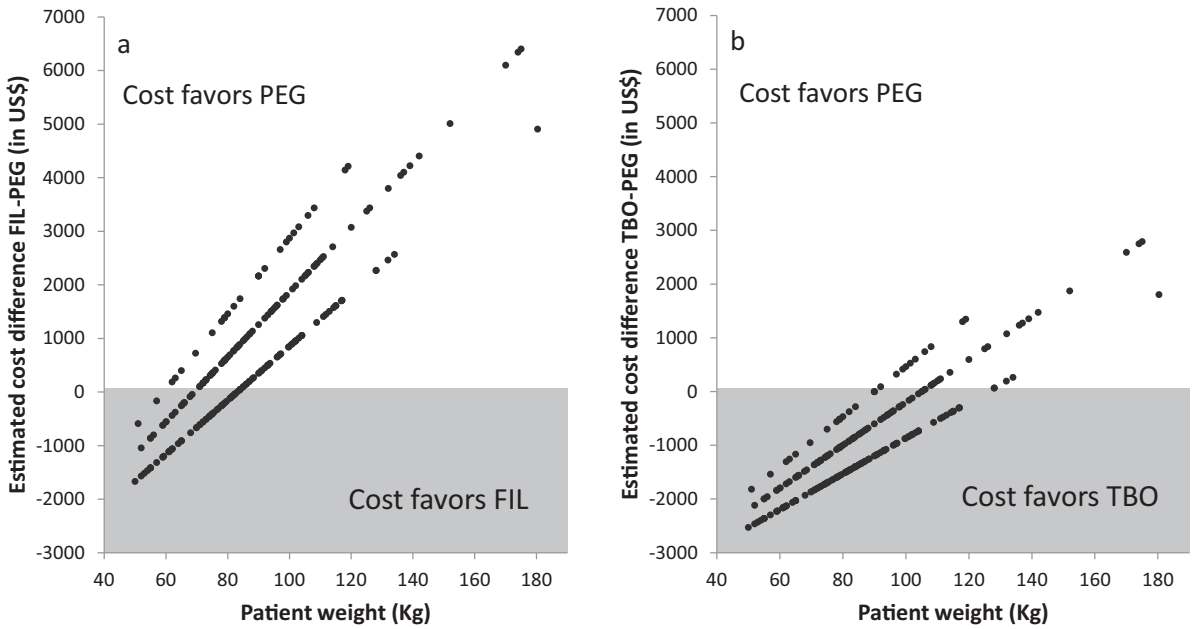

Figure 2. Cost comparison among different growth factors. Comparative cost analyses between PEG and FIL (A) and between PEG and TBO (B) showing the impact of patient weight on the cost difference between the approaches. The cost of the PEG approach is estimated using the actual performance of the regimen in patients included in the analysis. Costs of the FIL and TBO approaches are estimated assuming the same performance as PEG and using data (ie, body weight and number of collections required) from actual patients mobilized with PEG.

of the patients in our series. Although 87% of the patients in that trial reached the target of 6×10^6 $CD34^+$ cells/kg, 82% did so in our series. This difference is likely related to the fact that the study was performed before the expanded use of lenalidomide (a drug known to impair mobilization), with only 6% receiving lenalidomide for multiple myeloma therapy, compared with 75% of lenalidomide-exposed patients in our series.

Our cost analysis shows the PEG approach to be less costly than FIL, particularly in patients requiring multiple apheresis sessions and weighing >60 kg. Whereas the cost of TBO appears to be lower than that of PEG, that difference is small, and the convenience of PEG for patients and programs should be taken into consideration. There are several limitations to this analysis, including the use of average sales price instead of true acquisition cost. We chose this approach because the true acquisition cost varies from institution to institution and is often kept confidential. We also did not factor in other costs outside of drug acquisition, particularly labor costs (which are expected to be higher with more injections).

The costs associated with the FIL and TBO approaches were simulated, and we assumed that FIL or TBO would have similar performance as PEG. TBO has been shown to have similar performance to and lower cost than FIL in auto-HPC mobilization [27]. Although this assumption is itself a limitation, the literature [18,19,30,31,33,34] supports that the performance of PEG is at least equivalent to, if not superior to, that of FIL or TBO. Any superiority of PEG would translate into the need for fewer collections in some patients and fewer doses of plerixafor, and consequently would favor PEG in a cost analysis with FIL or TBO. Cost-effectiveness analyses are complex and influenced by the perspective from which they are performed (ie, patient, payer, or provider) and the structure of contracts between payers and transplantation programs. Therefore, our comparison of costs of pharmaceuticals must be interpreted with caution.

In summary PEG + plerixafor is a predictable and at least cost-neutral approach for growth factor-based mobilization of auto-HPC. Future studies could prospectively compare PEG + plerixafor versus FIL + plerixafor or use PEG as the growth factor backbone in combination with novel mobilizing agents.

ACKNOWLEDGMENTS

Financial disclosure: N.L.W. has received honoraria from Spectrum. L.S.L. is founder and chair of the Scientific Advisory Board of Incysus and serves as a consultant for Immunomic Therapeutics, Gerson Lehrman Group, and Guidepoint. L.J.C. has received honoraria and consulting fees from Sanofi and research funding and honoraria from Amgen.

Conflict of interest statement: There are no conflicts of interest to report.

Authorship statement: N.L.W., M.B.M. D.B.P., R.I.S., A.S., A.D.S., D.S., *and* L.S.L. collected and analyzed data, revised the manuscript, *and* approved the final version of the manuscript. L.J.C. designed the study, analyzed data, wrote the first draft, and approved the final version of the manuscript.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at https://doi.org/10.1016/j.bbmt.2018.09.005.

REFERENCES

1. To LB, Roberts MM, Haylock DN, et al. Comparison of haematological recovery times and supportive care requirements of autologous recovery phase peripheral blood stem cell transplants, autologous bone marrow transplants and allogeneic bone marrow transplants. *Bone Marrow Transplant*. 1992;9:277–284.
2. Körbling M, Champlin R. Peripheral blood progenitor cell transplantation: a replacement for marrow auto- or allografts. *Stem Cells*. 1996;14:185–195.
3. Hamadani M, Kochuparambil ST, Osman S, et al. Intermediate-dose versus low-dose cyclophosphamide and granulocyte colony-stimulating factor for peripheral blood stem cell mobilization in patients with multiple myeloma treated with novel induction therapies. *Biol Blood Marrow Transplant*. 2012;18:1128–1135.
4. Pusic I, Jiang SY, Landua S, et al. Impact of mobilization and remobilization strategies on achieving sufficient stem cell yields for autologous transplantation. *Biol Blood Marrow Transplant*. 2008;14:1045–1056.
5. Alegre A, Tomás JF, Martinez-Chamorro C, et al. Comparison of peripheral blood progenitor cell mobilization in patients with multiple myeloma: high-dose cyclophosphamide plus GM-CSF vs G-CSF alone. *Bone Marrow Transplant*. 1997;20:211–217.
6. Desikan KR, Barlogie B, Jagannath S, et al. Comparable engraftment kinetics following peripheral-blood stem-cell infusion mobilized with granulocyte colony-stimulating factor with or without cyclophosphamide in multiple myeloma. *J Clin Oncol*. 1998;16:1547–1553.
7. Desikan KR, Tricot G, Munshi NC, et al. Preceding chemotherapy, tumour load and age influence engraftment in multiple myeloma patients mobilized with granulocyte colony-stimulating factor alone. *Br J Haematol*. 2001;112:242–247.
8. Dingli D, Nowakowski GS, Dispenzieri A, et al. Cyclophosphamide mobilization does not improve outcome in patients receiving stem cell transplantation for multiple myeloma. *Clin Lymphoma Myeloma*. 2006;6:384–388.
9. Narayanasami U, Kanteti R, Morelli J, et al. Randomized trial of filgrastim versus chemotherapy and filgrastim mobilization of hematopoietic progenitor cells for rescue in autologous transplantation. *Blood*. 2001;98:2059–2064.
10. Kanteti R, Miller K, McCann J, et al. Randomized trial of peripheral blood progenitor cell vs bone marrow as hematopoietic support for high-dose chemotherapy in patients with non-Hodgkin's lymphoma and Hodgkin's disease: a clinical and molecular analysis. *Bone Marrow Transplant*. 1999;24:473–481.
11. DiPersio JF, Stadtmauer EA, Nademanee A, et al. Plerixafor and G-CSF versus placebo and G-CSF to mobilize hematopoietic stem cells for autologous stem cell transplantation in patients with multiple myeloma. *Blood*. 2009;113:5720–5726.
12. Costa LJ, Alexander ET, Hogan KR, Schaub C, Fouts TV, Stuart RK. Development and validation of a decision-making algorithm to guide the use of plerixafor for autologous hematopoietic stem cell mobilization. *Bone Marrow Transplant*. 2011;46:64–69.
13. Abhyankar S, DeJarnette S, Aljitawi O, Ganguly S, Merkel D, McGuirk J. A risk-based approach to optimize autologous hematopoietic stem cell (HSC) collection with the use of plerixafor. *Bone Marrow Transplant*. 2012;47:483–487.
14. Micallef IN, Sinha S, Gastineau DA, et al. Cost-effectiveness analysis of a risk-adapted algorithm of plerixafor use for autologous peripheral blood stem cell mobilization. *Biol Blood Marrow Transplant*. 2013;19:87–93.
15. Li J, Hamilton E, Vaughn L, et al. Effectiveness and cost analysis of "just-in-time" salvage plerixafor administration in autologous transplant patients with poor stem cell mobilization kinetics. *Transfusion*. 2011;51:2175–2182.
16. Vishnu P, Roy V, Paulsen A, Zubair AC. Efficacy and cost-benefit analysis of risk-adaptive use of plerixafor for autologous hematopoietic progenitor cell mobilization. *Transfusion*. 2012;52:55–62.
17. Molineux G, Kinstler O, Briddell B, et al. A new form of filgrastim with sustained duration in vivo and enhanced ability to mobilize PBPC in both mice and humans. *Exp Hematol*. 1999;27:1724–1734.
18. Hosing C, Qazilbash MH, Kebriaei P, et al. Fixed-dose single agent pegfilgrastim for peripheral blood progenitor cell mobilisation in patients with multiple myeloma. *Br J Haematol*. 2006;133:533–537.
19. Costa LJ, Kramer C, Hogan KR, et al. Pegfilgrastim- versus filgrastim-based autologous hematopoietic stem cell mobilization in the setting of preemptive use of plerixafor: efficacy and cost analysis. *Transfusion*. 2012;52:2375–2381.
20. Russell N, Mesters R, Schubert J, et al. A phase 2 pilot study of pegfilgrastim and filgrastim for mobilizing peripheral blood progenitor cells in patients with non-Hodgkin's lymphoma receiving chemotherapy. *Haematologica*. 2008;93:405–412.
21. Steidl U, Fenk R, Bruns I, et al. Successful transplantation of peripheral blood stem cells mobilized by chemotherapy and a single dose of pegylated G-CSF in patients with multiple myeloma. *Bone Marrow Transplant*. 2005;35:33–36.
22. Isidori A, Tani M, Bonifazi F, et al. Phase II study of a single pegfilgrastim injection as an adjunct to chemotherapy to mobilize stem cells into the peripheral blood of pretreated lymphoma patients. *Haematologica*. 2005;90:225–231.
23. Fruehauf S, Klaus J, Huesing J, et al. Efficient mobilization of peripheral blood stem cells following CAD chemotherapy and a single dose of pegylated G-CSF in patients with multiple myeloma. *Bone Marrow Transplant*. 2007;39:743–750.
24. Putkonen M, Rauhala A, Pelliniemi TT, Remes K. Single-dose pegfilgrastim is comparable to daily filgrastim in mobilizing peripheral blood stem cells: a case-matched study in patients with lymphoproliferative malignancies. *Ann Hematol*. 2009;88:673–680.

25. Tricot G, Barlogie B, Zangari M, et al. Mobilization of peripheral blood stem cells in myeloma with either pegfilgrastim or filgrastim following chemotherapy. *Haematologica*. 2008;93:1739–1742.
26. Ria R, Reale A, Melaccio A, Racanelli V, Dammacco F, Vacca A. Filgrastim, lenograstim and pegfilgrastim in the mobilization of peripheral blood progenitor cells in patients with lymphoproliferative malignancies. *Clin Exp Med*. 2015;15:145–150.
27. Bhamidipati PK, Fiala MA, Grossman BJ, et al. Results of a prospective randomized, open-label, noninferiority study of Tbo-filgrastim (Granix) versus filgrastim (Neupogen) in combination with plerixafor for autologous stem cell mobilization in patients with multiple myeloma and non-Hodgkin lymphoma. *Biol Blood Marrow Transplant*. 2017;23:2065–2069.
28. Yang BB, Kido A. Pharmacokinetics and pharmacodynamics of pegfilgrastim. *Clin Pharmacokinet*. 2011;50:295–306.
29. Giralt S, Costa L, Schriber J, et al. Optimizing autologous stem cell mobilization strategies to improve patient outcomes: consensus guidelines and recommendations. *Biol Blood Marrow Transplant*. 2014;20:295–308.
30. Matar S, Dany M, Chhabra S, Costa LJ, Stuart RK. Pegfilgrastim 6 mg versus 12 mg for autologous stem cell mobilization in multiple myeloma patients: efficacy, safety, and cost analysis. *Blood*. 2015;126. 4306.
31. Skopec B, Skerget M, Zontar D, Zadnik V, Zver S. Filgrastim-alone versus pegylated filgrastim-alone for autologous peripheral blood stem cells mobilization in newly diagnosed multiple myeloma patients. *Wien Klin Wochenschr*. 2017;129:545–551.
32. Herbert KE, Gambell P, Link EK, et al. Pegfilgrastim compared with filgrastim for cytokine-alone mobilization of autologous haematopoietic stem and progenitor cells. *Bone Marrow Transplant*. 2013;48:351–356.
33. Kim MG, Han N, Lee EK, Kim T. Pegfilgrastim vs filgrastim in PBSC mobilization for autologous hematopoietic SCT: a systematic review and meta-analysis. *Bone Marrow Transplant*. 2015;50:523–530.
34. Kuan JW, Su AT, Wong SP, et al. A randomized double blind control trial comparing filgrastim and pegfilgrastim in cyclophosphamide peripheral blood hematopoietic stem cell mobilization. *Transfus Apher Sci*. 2015;53:196–204.