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Cost-effectiveness and clinical outcomes of double versus single cord blood transplantation in adults with acute leukemia in France

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ABSTRACT

Double cord blood transplantation extends the use of cord blood to adults for whom a single unit is not available, but the procedure is limited by its cost. To evaluate outcomes and cost-effectiveness of double compared to single cord blood transplantation, we analyzed 134 transplants in adults with acute leukemia in first remission. Transplants were performed in France with reduced intensity or myeloablative conditioning regimens. Costs were estimated from donor search to 1 year after transplantation. A Markov decision analysis model was used to calculate quality-adjusted life-years and cost-effectiveness ratio within 4 years. The overall survival at 2 years after single and double cord blood transplants was 42% versus 62%, respectively ($P=0.03$), while the leukemia-free-survival was 33% versus 53%, respectively ($P=0.03$). The relapse rate was 21% after double transplants and 42% after a single transplant ($P=0.006$). No difference was observed for non-relapse mortality or chronic graft-versus-host-disease. The estimated costs up to 1 year after reduced intensity conditioning for single and double cord blood transplantation were € 165,253 and € 191,827, respectively. The corresponding costs after myeloablative conditioning were € 192,566 and € 213,050, respectively. Compared to single transplants, double cord blood transplantation was associated with supplementary costs of € 21,302 and € 32,420 up to 4 years, but with increases in quality-adjusted life-years of 0.616 and 0.484, respectively, and incremental cost-effectiveness ratios of € 34,581 and € 66,983 in the myeloablative and reduced intensity conditioning settings, respectively. Our results showed that for adults with acute leukemia in first complete remission in France, double cord transplantation is more cost-effective than single cord blood transplantation, with better outcomes, including quality-adjusted life-years.

Introduction

Allogeneic stem cell transplantation (HSCT) is effective treatment for patients with various hematologic disorders. It is, however, a complex, resource-intensive and costly procedure.^{1,4} The cost of HSCT has been previously evaluated, mainly in the setting of HLA identical sibling⁵ and matched unrelated donor transplants.

The first studies on the cost-efficacy of HSCT compared allogeneic HSCT to chemotherapy in patients with acute leukemia.^{7,8} Despite the high cost of HSCT, the results demonstrated the advantages of the procedure due to the impact on long-term survival adjusted to the quality of life. In the first published studies, the estimated costs for HSCT varied greatly (Online Supplementary Table S1) depending on the country in

which they were performed, type of donor, transplant center procedures and year of transplantation.^{5,7,9-11} A more recent comparative study of autologous and allogeneic HSCT for patients transplanted for hematologic malignancies in the USA estimated a 100-day total cost of US\$ 203,026 for allogeneic HSCT.¹²

Unrelated donor cord blood transplantation (UCBT) has become a widely accepted transplant modality in the absence of an HLA-matched donor.¹³⁻¹⁶ However, the delay of engraftment and the increased risk of graft failure remain problems in adults transplanted with a single cord blood unit. The possibility of using two cord blood units has extended the use of UCBT to patients for whom a single unit containing a minimum of 2.5×10^7 /kg total nucleated cells is not available.¹⁷⁻¹⁹ Studies have been performed comparing outcomes after single (s) UCBT and double (d) UCBT,²⁰ but, none focused on a homo-

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geneous population.

To date, few studies have been published evaluating the cost of UCBT.^{21,22} The acquisition cost of two cord blood units is one of the main limitations of using dUCBT. The median cost for the first 100 days after UCBT was estimated to be around US\$ 80,407 in Canada in 2007²² and around US\$ 137,564 in the USA in 2009,²¹ not including the cost for the donor search. In a more recent study from the Erasmus University,²³ the cost of UCBT over 1 year was estimated to be around € 250,000.

The French healthcare system is mainly financed by the French government. Approximately 75% of health expenditure is covered by government-funded agencies. In 2011, in France, total health expenses added up to € 225.5 billion, or 11.6% of the gross domestic product (GDP) in 2010. According to the World Health Organization (WHO) this figure places France in the higher range among countries that are members of the Organization for Economic Co-operation and Development (OECD) (The World Health Report 2000: WHO).

Since almost all healthcare expenses in France are covered by a common system, we were able to perform a cost-effectiveness study comparing dUCBT and sUCBT in France, by evaluating the cost over a year and outcomes of adult patients transplanted for acute leukemia in first complete remission.

Methods

To estimate cost-effectiveness, which was the primary outcome of the study, we analyzed clinical outcomes and the cost of the transplant procedures.

We analyzed outcomes and cost of UCBT in 134 consecutive patients transplanted for acute leukemia in first complete remission. The transplants were performed in 26 centers between 2002 and 2009. Patients received a single or a double unmanipulated cord blood unit as a first graft, after myeloablative conditioning (MAC) or reduced intensity conditioning (RIC). The Institutional Review Board of the Eurocord-Netcord scientific committee approved this study.

The primary endpoint for clinical outcome was overall survival. Other endpoints were leukemia-free survival, neutrophil recovery, graft-versus-host disease (GVHD), relapse, and non-relapse mortality. The characteristics of the patients and their transplants were compared with appropriate statistical tests.^{24,25} Cox proportional-hazard was used for multivariate analyses.²⁶ Hospital costs were estimated from the search for a donor to 1 year after UCBT, according to the French public health system. Major resources considered were stem cell procurement, initial hospitalization for the transplant, readmissions to hospital and outpatient clinics. The cost for the search for and acquisition of the graft included expenses related to the donor request, typing, and cost of the cord blood unit, and varied by country and cord blood bank (*Online Supplementary Table S2*). The daily cost of hospitalization was estimated using the average cost published by the French National Scale of Costs (*Online Supplementary Table S3*).

Resources were estimated in euros, adjusted to the 2010 French consumer price index. Cost-effectiveness was estimated by the incremental cost-effectiveness ratio (ICER), which is the extra cost generated by an additional (quality-adjusted life-year (QALY). ICER per capita was calculated by dividing ICER by French GDP per capita in 2010.

Following the recommendation of the WHO, the GDP was used as the indicator to derive the categories of cost-effectiveness.^{27,28} The cost-effectiveness of a health technology can be categorized as follows: (i) very cost-effective: ICER below the per capita GDP; (ii) cost-effective: ICER between one and three times the per capita GDP; (iii) not cost-effective: ICER above three times the per capita GDP. A QALY can be used to compare claims for finite healthcare resources. One QALY corresponds to 1 year spent in perfect health.²⁹ An ICER is the difference between average costs divided by the difference in average effects. Events occurring after transplantation that were considered for their impact on quality of life were the occurrence of chronic GVHD and disease relapse. A Markov³⁰ decision analysis model was used to calculate the ICER up to 4 years. RIC and MAC were studied separately for the cost-effectiveness analysis. The model started at 1 year after transplantation and allowed 36 cycles of 1 month each. At any given time, the model considered a patient to be in one of the four following clinical states: alive and well, alive with chronic GVHD, alive in relapse, or dead. To calculate QALY, time spent in each state was weighted for the quality of life experienced while in that state.³¹ The utility values used were 0.979, 0.9, 0.5 and 0.0 for the four health states, respectively. Some of the utility values used were derived from the literature, others were estimated using the "standard gamble question". All transitional probabilities included in the model were estimated on our population. Sensitivity analyses were performed around some of the utility values used to weigh survival to calculate QALY.

Results

Patient, disease and transplant characteristics

The characteristics of the patients, their diseases and transplants are shown in Table 1. Forty patients were transplanted for acute lymphoblastic leukemia and 94 for acute myeloid leukemia in first complete remission. The median age of the patients was 42 years and the median time from diagnosis to UCBT was 180 days. Sixty-one patients received a sUCBT and 73 a dUCBT. There was no statistical difference between poor-risk cytogenetic groups for patients with acute lymphoblastic or myeloid leukemia receiving single or double UCBT ($P=0.73$ and $P=0.5$, respectively). Twenty-eight percent of the cord blood units were HLA identical to the recipient (at the antigen level for HLA-

Table 1. Patient and disease characteristics.

Characteristics	sUCBT n=61	dUCBT n=73	P value
Follow-up; months	49	47	
Median age; years (range)	41 (19-66)	43 (18-66)	0.39
Diagnosis; AML (%)	43 (70%)	51 (70%)	0.94
Gender; female (%)	35 (57%)	34 (47%)	0.21
Type of conditioning; RIC, n. (%)	36 (59%)	43 (59%)	0.99
HLA disparities; ≥ 2 mismatches, n. (%)	42 (71%)	51 (70%)	0.94
TNC infused $\times 10^7/\text{Kg}$	2.7 (1-6.1)	3.8 (1.1-6.9)	<0.001

sUCBT: single umbilical cord blood transplant; dUCBT: double umbilical cord blood transplant; AML: acute myeloid leukemia; RIC: reduced intensity conditioning; HLA: human leukocyte antigen; TNC: total nucleated cells.

A and B and the allelic level for DRB1) or had one HLA disparity and 72% had two or three HLA disparities (for dUCBT the highest number of HLA disparities between the unit and the recipient was considered). The median infused total nucleated cell count was $2.7 \times 10^7/\text{kg}$ for patients receiving a sUCBT and $3.8 \times 10^7/\text{kg}$ for those receiving a dUCBT ($P < 0.001$). The conditioning regimen was reduced intensity in 79 patients (97% total body irradiation < 6 Gy) and myeloablative in 55 (84% total body irradiation ≥ 6 Gy). The median follow-up was 49 months after sUCBT and 47 months after dUCBT.

Outcomes and risk factors

Neutrophil recovery, graft-versus-host disease and infections

Ninety-nine patients achieved neutrophil engraftment (42 of 61 patients who received a sUCBT and 57 of 73 of those who received a dUCBT) in a median time of 23 days (range, 6-53). The cumulative incidence of neutrophil engraftment was $70 \pm 6\%$ and $84 \pm 4\%$ for sUCBT and dUCBT, respectively ($P = 0.28$). The cumulative incidence of acute GVHD grade II-IV was higher after dUCBT than after sUCBT: 52% versus 34%, respectively ($P = 0.03$). No difference was found in the cumulative incidence of acute GVHD grade III-IV between the single and double transplants (sUCBT 17%, dUCBT 20%) ($P = 0.63$). At day +100, 53% of patients experienced cytomegalovirus reactivation (37% after sUCBT and 71% after dUCBT; $P = 0.01$), 46% had a viral infection other than cytomegalovirus infection and 47% had bacterial infections. The cumulative incidence of chronic GVHD was 18% versus 25% after sUCBT and dUCBT, respectively ($P = 0.22$). Twelve patients (11%) had a further allogeneic transplant: seven because of graft failure (4 in the sUCBT group and 3 in the dUCBT group) and five because of relapse (4 in the sUCBT group and 1 in the dUCBT group).

Non-relapse mortality and relapse

The cumulative incidence of non-relapse mortality at 2 years was $25 \pm 6\%$ and $26 \pm 5\%$ after sUCBT and dUCBT, respectively ($P = 0.79$). In adjusted multivariate analysis, the

non-relapse mortality rate was lower for patients receiving a RIC regimen [hazard ratio (HR) 0.21, 95% confidence interval (95% CI) 0.08-0.52; $P = 0.001$] and for patients younger than 50 years at the time of transplantation (HR 0.35, 95% CI 0.15- 0.76; $P = 0.02$) (Table 2).

The cumulative incidence of relapse at 2 years was $21 \pm 5\%$ after dUCBT and $42 \pm 6\%$ after sUCBT ($P = 0.006$). The cumulative incidence of relapse at 2 years was $20 \pm 6\%$ and $34 \pm 5\%$ for patients with acute lymphoblastic leukemia and acute myeloid leukemia, respectively ($P = 0.14$). In mul-

Table 2. Multivariate analysis for outcomes after single and double cord blood transplantation.

Variable	P value	Hazard ratio	95% CI
Overall survival			
dUCBT vs. sUCBT	0.01	0.53	0.33-0.86
ALL vs. AML	0.04	0.54	0.30-0.97
Age < 50 years	0.04	0.53	0.29-0.96
RIC vs. MAC	0.05	0.56	0.31-1.01
Leukemia-free survival			
dUCBT vs. sUCBT	0.02	0.56	0.36-0.89
ALL vs. AML	0.14	0.67	0.39-1.13
Age < 50 years	0.2	0.69	0.39-1.20
RIC vs. MAC	0.31	0.75	0.43-1.31
Relapse incidence			
dUCBT vs. sUCBT	0.01	0.41	0.21-0.80
ALL vs. AML	0.39	0.7	0.32-1.53
Age < 50 years	0.86	0.93	0.45-0.45
MAC vs. RIC	0.06	0.45	0.19-1.04
Non-relapse mortality			
dUCBT vs. sUCBT	0.59	0.84	0.44-1.60
ALL vs. AML	0.31	0.68	0.33-1.40
Age < 50 years	0.03	0.35	0.14-0.88
RIC vs. MAC	<0.01	0.21	0.09-0.52

CI: confidence interval; OS: overall survival; dUCBT: double umbilical cord blood transplant; vs.: versus; sUCBT: single umbilical cord blood transplant; AML: acute myeloid leukemia; ALL: acute lymphoid leukemia; RIC: reduced intensity conditioning; MAC: myeloablative conditioning;

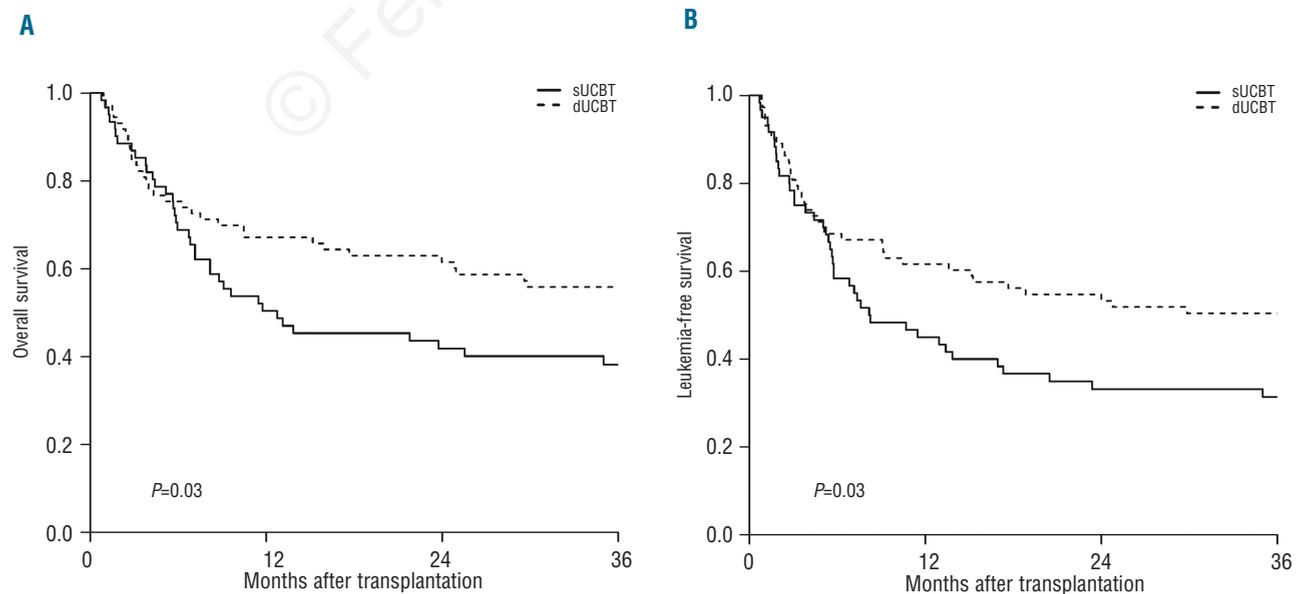


Figure 1. (A) The probability of overall survival after dUCBT and sUCBT; (B) The probability of leukemia-free survival after dUCBT and sUCBT.

tivariate analysis, dUCBT (HR 0.41, 95% CI 0.21-0.80; $P=0.009$) and use of MAC (HR 0.45, 95% CI 0.19-0.83; $P=0.06$) were independently associated with a lower relapse incidence.

Overall survival and leukemia-free survival

The estimated overall survival at 2 years was $42\pm 6\%$ and $62\pm 6\%$ after sUCBT and dUCBT, respectively ($P=0.03$) (Figure 1A). In adjusted multivariate analysis, use of dUCBT (HR 0.53, 95% CI 0.33-0.86; $P=0.01$), a diagnosis of acute lymphoblastic leukemia (HR 0.54, 95% CI 0.30-0.97; $P=0.04$) and age younger than 50 years at transplantation (HR 0.53, 95% CI 0.29-0.96, $P=0.04$) were independently associated with higher overall survival.

The leukemia-free survival rate at 2 years was $33\pm 6\%$ in the sUCBT group *versus* $53\pm 6\%$ in the dUCBT group ($P=0.03$) (Figure 1B). In the multivariate analysis, the use of dUCBT was the only factor independently associated with a higher leukemia-free survival rate (HR 0.56, 95% CI 0.36-0.89; $P=0.01$).

Cost analysis

Cost up to 1 year after umbilical cord blood transplantation

The data on duration of hospitalization and costs by type of graft and conditioning regimen are detailed in Table 3.

The mean duration of hospitalization for patients undergoing sUCBT and dUCBT after MAC was 61 and 68 days, respectively, while for those receiving a RIC regimen, it was 48 and 53 days, respectively. The mean cost per day of hospitalization in the transplant unit was € 2,019 while that for the out-patient clinic was € 858.

The mean cost for identifying a donor and obtaining the cord blood was € 28,164 for sUCBT and € 48,929 for dUCBT. Up to 1 year, the estimated cost for MAC sUCBT was € 192,566 and that for RIC sUCBT was € 165,253. For dUCBT, the estimated cost was € 213,050 with MAC and € 191,827 with RIC.

Chronic GVHD required a mean of 12 additional days of hospitalization, leading to an incremental cost of € 9,180. The occurrence of disease relapse was associated with a mean additional 15 days of hospitalization and, in 12% of the patients, with a second transplantation, leading to a supplemental cost of € 29,775.

Cost-effectiveness up to 4 years

In the MAC group, dUCBT was associated with a supplementary cost of € 21,302 up to 4 years and with an improvement in terms of QALY of 0.616. The ICER was € 34,581 after dUCBT *versus* sUCBT. In the RIC group, dUCBT was associated with an additional cost of € 32,420 up to 4 years and with an improvement in term of QALY of 0.484. In this case, the ICER was € 66,983 after dUCBT *versus* sUCBT (Table 4).

Considering that in France in 2010, the per capita GDP was € 32,000, the ICER per capita was 1.08 in MAC transplants and 2.09 in RIC ones. In sensitivity analysis varying the utility values, the ICER ranged from € 31,679 to € 47,647 for MAC and from € 59,243 to € 99,386 for RIC.

Discussion

In our study we showed an advantage of dUCBT compared to sUCBT in terms of lower relapse rate and better survival, despite a higher incidence of acute GVHD.

Table 3. Estimated costs from donor search to 1 year after transplantation for single UCBT, double UCBT and type of conditioning regimen (MAC or RIC).

Cost analysis for MAC (1 year)		
	sUCBT	dUCBT
Search for cord blood unit	€ 28,164	€ 48,929
Initial hospitalization		
Mean duration (days)	61	68
Cost per day	€ 2,019	€ 2,019
Mean total cost	€ 123,327	€ 136,570
2 nd transplant for graft failure	7%	4%
Cost of 2 nd transplant	€ 1,971	€ 1,127
Total cost of hospitalization	€ 125,299	€ 137,697
Outpatient visits		
Number of days	11	6.5
Cost per day	€ 858	€ 858
Mean cost	€ 9,095	€ 5,577
Further hospitalizations		
Mean duration (days)	39	27
Cost per day	€ 765	€ 765
Mean cost	€ 30,009	€ 20,846
Total mean cost up to 1 year	€ 192,566	€ 213,050
Cost analysis for RIC (1 year)		
	sUCBT	dUCBT
Search for cord blood unit	€ 28,164	€ 48,929
Initial hospitalization		
Mean duration (days)	48	53
Cost per day	€ 2,019	€ 2,019
Mean total cost	€ 96,970	€ 106,712
2 nd transplant for graft failure	7%	4%
Cost of 2 nd transplant	€ 1,971	€ 1,127
Total cost of hospitalization	€ 98,941	€ 107,838
Outpatient visits		
Number of days	15	13
Cost per day	€ 858	€ 858
Mean cost	€ 13,213	€ 11,522
Further hospitalizations		
Mean duration (days)	33	31
Cost per day	€ 765	€ 765
Mean cost	€ 24,934	€ 23,538
Total mean cost up to 1 year	€ 165,253	€ 191,827

MAC: myeloablative conditioning; RIC: reduced intensity conditioning; sUCBT: single umbilical cord blood transplant; dUCBT: double umbilical cord blood transplant.

Recently, the Center of International Blood and Marrow Research (CIBMTR) in collaboration with the New York Cord Blood program reported no significant differences in relapse or leukemia-free survival for adults with acute leukemias in all disease states, transplanted after single or double UCBT after MAC or RIC regimens.²⁰ There are several differences between that study and the one we report here. The CIBMTR study analyzed patients in all disease states while we focused only on patients given UCBT for acute leukemia in first complete remission. Another important difference is that in the CIBMTR study, only sUCBT with a total nucleated cell dose greater than $2.5 \times 10^7/\text{Kg}$ at cryopreservation were considered. In our series we did not select the study population based on a specific threshold for the total nucleated cell count; however, no differences in outcomes were found for patients receiving a total nucleated cell dose lower than $2.5 \times 10^7/\text{Kg}$ in sUCBT (*data not shown*). Another important point regarding this French

Table 4. Cost-effectiveness analysis for sUCBT versus dUCBT by conditioning regimen.

Conditioning regimen	sUCBT	dUCBT	Difference
MAC			
Total cost	€ 199 314 [199 025-201 201]	€ 220 616 [220 057-221 757]*	€ 21 302
QALY	1.369 [1.258-1.428]	1.985 [1.928-2.132]*	0.616
ICER	€ 34 581		
RIC			
Total cost	€ 171 868 [170 693-172 986]	€ 204 288 [202 314-205 049]*	€ 32 420
QALY	1.491 [1,487-1,692]	1.975 [1,863-2,057]*	0.484
ICER	66 983 €		

sUCBT: single umbilical cord blood transplant; dUCBT: double umbilical cord blood transplant; QALY: quality-adjusted life year; MAC: myeloablative conditioning; ICER: incremental cost-effectiveness ratio; RIC: reduced intensity conditioning. *P<10⁻³.

study is that the protocols for induction, consolidation therapy, transplant procedures and supportive care were highly standardized throughout the country.

Our study is the first of its kind to address the cost and cost-effectiveness of sUCBT and dUCBT. The total cost up to 1 year for sUCBT was € 192,000 when MAC was used and €165,000 when RIC was given. The corresponding costs for dUCBT were € 213,000 and € 192,000, respectively.

The cost of HSCT has been previously evaluated mainly in the setting of transplants from HLA identical siblings⁵ and matched unrelated donors.⁶ The reported costs varied greatly, from US\$ 60,000 to 200,000.^{9,11} This difference in costs may be explained by differences in methodologies, inclusion periods, countries, populations, health coverage policies and graft type. In 2002, van Agthoven¹¹ reported that, for patients with acute leukemia, the cost over a period of 2 years, including the donor search, was € 151,754 per patient and increased to €173,587 for patients still alive 2 years after transplantation. More recent studies have estimated the 1-year cost of related and unrelated donor HSCT using bone marrow or peripheral blood stem cells as € 139,414 in Sweden³² and € 128,800 in the USA.³³

Cordonnier *et al.*³⁴ reported the total cost of HLA identical sibling HSCT after RIC and MAC in France. The cost for 1 year after HSCT was around € 60,000. It should, however, be noted that the study included very few patients (n=23), from only two transplant centers. In another study, conducted by Esperou *et al.* in 2004 on 85 patients from five transplant centers, the mean cost for the first 6 months after transplantation, restricted to a specific protocol, was € 76,000.³⁵

The average cost for initial hospitalization for UCBT in Canada²² and in the USA²¹ was consistent with that in our series. However in both studies, only costs up to 100 days were included whereas in other studies costs were considered over a much longer period. For instance, Svahn *et al.*³² analyzed costs of allogeneic transplantation up to 5 years and the study by Saito *et al.*³³ relates to 1-year costs. However, when making comparisons with other countries, it is important to point out that the average cost of transplantation in France and other European countries may be

lower, because of different salaries and different healthcare systems, than in countries such as the USA and Canada.

The cost for graft acquisition is an important issue, especially when a double UCBT is necessary. In France, the cost of buying a cord blood unit was highly dependent on the country and the bank of origin of the unit (less than € 7,000 for a unit from Taiwan, approximately € 10,000 for one from France and more than € 30,000 for a cord blood unit from some American banks) (Online Supplementary Table S2).

One could argue that the possible difference in costs may be due to the conditioning regimens. There was no difference in the 1-year cost in Cordonnier's study,³⁴ whereas Saito *et al.*³⁶ reported lower costs for patients receiving RIC than those given MAC: € 80,499 versus € 128,254, respectively. In our study, we also found a cost increase of approximately € 30,000 for patients receiving MAC.

With regards to the complications considered, chronic GVHD and disease recurrence required additional days of hospitalization, leading to further costs. The role of complications in increasing costs of transplantation has been described previously. In 2007, Costa *et al.*²² reported a cost increment of US\$ 2,716 for chronic GVHD and US\$ 10,576 for relapse. The additional cost for chronic GVHD reported by Esperou *et al.*³⁵ was much higher, at around € 20,000, but also included costs due to transplant-related complications and infections.

Importantly in our study, the survival advantage found for dUCBT allowed us to perform a cost-effectiveness analysis to determine the ICER of dUCBT versus sUCBT. Our results showed that dUCBT was cost-effective according to the WHO's definition when MAC was used (ICER per capita: 1.08) and also when RIC was used (ICER twice the per capita GDP: 2.09).

By sensitivity analysis, even considering the worst scenario (low utility for chronic GVHD and higher utility for relapse for dUCBT), the ICER remained below € 50,000. The ICER of dUCBT increased when the utility value of chronic GVHD decreased and when the utility value of relapse increased.

In summary, this analysis was performed to evaluate the outcomes and cost-effectiveness of dUCBT compared to sUCBT in the treatment of adults with acute leukemia in France. The results suggest that, in both the MAC and RIC settings, dUCBT is associated with better outcomes than sUCBT and is a more cost-effective strategy for adult patients with acute leukemia in first complete remission. Based on 1-year cost calculations, dUCBT was associated with higher costs than sUCBT. In the long-term analysis, with the estimation of QALY, dUCBT was more cost-effective, regardless of the conditioning regimen.

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