



HAL
open science

Ovarian Function and Spontaneous Pregnancy After Hematopoietic Stem Cell Transplantation for Leukemia Before Puberty: An L.E.A. Cohort Study

Mathilde Chabut, Pascale Schneider, Blandine Courbiere, Paul Saultier, Yves Bertrand, Marie-Dominique Tabone, Cécile Pochon, Stéphane Ducassou, Catherine Paillard, Virginie Gandemer, et al.

► **To cite this version:**

Mathilde Chabut, Pascale Schneider, Blandine Courbiere, Paul Saultier, Yves Bertrand, et al.. Ovarian Function and Spontaneous Pregnancy After Hematopoietic Stem Cell Transplantation for Leukemia Before Puberty: An L.E.A. Cohort Study. *Transplantation and Cellular Therapy*, 2023, 29 (6), pp.378.e1-378.e9. 10.1016/j.jtct.2023.02.019 . hal-04241100

HAL Id: hal-04241100

<https://univ-rennes.hal.science/hal-04241100>

Submitted on 3 Nov 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

HIGHLIGHTS

- Spontaneous puberty is possible after hematopoietic stem cell transplantation
- Spontaneous pregnancies are possible after hematopoietic stem cell transplantation
- Older age at transplantation is a risk factor for premature ovarian insufficiency
- Contraceptive methods is needed even if there was an induction of puberty

TITLE PAGE

Article title : Ovarian function and spontaneous pregnancy after hematopoietic stem cell transplantation for leukemia before puberty

An L.E.A. cohort study

Authors :

Mathilde Chabut

Pascale Schneider

Blandine Courbiere

Paul Saultier^{4,5}

Yves Bertrand

Marie-Dominique Tabone

Cécile Pochon

Stéphane Ducassou

Catherine Paillard

Virginie Gandemer

Justyna Kanold

Jean-Hugues Dalle

Maryline Poiree¹⁵

Geneviève Plat¹⁶

Sandrine Thouvenin¹⁷

Dominique Plantaz¹⁸

Nicolas Sirvent¹⁹

Sara Weinhard⁸

Julie Berbis²⁰

André Baruchel¹⁴

Guy Leverger⁷

Zeinab Hamidou²⁰

Pascal Auquier²⁰

G rard Michel^{4,20}

Affiliations :

¹Department of Pediatrics, University Hospital of Rouen, France.

²Department of Pediatric Hematology and Oncology, University Hospital of Rouen, France.

³Department of Gynecology Obstetric and Reproductive Medicine, AP-HM, H pital La Conception / Aix Marseille Universit , IMBE, CNRS, IRD, Avignon Universit , Marseille, France.

⁴Department of Pediatric Hematology, Immunology and Oncology, APHM, La Timone Children's Hospital, Marseille, France.

⁵Aix Marseille Univ, INSERM, INRAe, C2VN, Marseille, France.

⁶Department of Pediatric Hematology and Oncology, University Hospital of Lyon, Lyon, France.

⁷Department of Pediatric Hematology and Oncology, Armand Trousseau Hospital, AP-HP, Sorbonne University, Paris, France.

⁸Department of Pediatric Hematology and Oncology, Children's Hospital of Brabois, Vandoeuvre-Les-Nancy, France.

⁹Department of Pediatric Hematology and Oncology, University Hospital of Bordeaux, Bordeaux, France.

¹⁰Department of Pediatric Hematology-Oncology, University Hospital, Strasbourg, France.

¹¹Department of Pediatric Hematology and Oncology, University Hospital of Rennes, Rennes, France.

¹²Department of Pediatric Hematology and Oncology, CIC Inserm 501, University Hospital of Clermont-Ferrand, Clermont-Ferrand, France.

¹³Department of Pediatric Onco-Hematology, University Hospital of Saint Louis, Paris, France.

¹⁴Department of Hematology and immunology, Hôpital Robert-Debré, GHU APHP-Nord Université de Paris-Cité, Paris, France

¹⁵Department of Pediatric Hematology and Oncology, University Hospital L'Archet, Nice, France.

¹⁶Department of Pediatric Hematology and Oncology, University Hospital of Toulouse, Toulouse, France.

¹⁷Department of Pediatric Onco-hematology, CHU de Saint-Etienne, Saint-Etienne, France.

¹⁸Department of Pediatric Hematology and Oncology, University Hospital of Grenoble, Grenoble, France.

¹⁹Department of Pediatric Hematology and Oncology, University Hospital of Montpellier, Montpellier, France.

²⁰CEReS Research Unit EA 3279 and Department of Public Health, Hôpital de la Timone, 13385 Marseille, France.

Corresponding author :

Mathilde Chabut, Department of Pediatrics, University Hospital of Rouen, 37 Boulevard Gambetta, 76000 Rouen, France

mathilde.chabut@chu-rouen.fr

ABSTRACT

Background: Ovarian function impairment and infertility are among the most frequent late effects after hematopoietic stem cell transplantation (HSCT).

Objective: The aim of this study was to evaluate ovarian function, occurrence of premature ovarian insufficiency (POI), and spontaneous pregnancy in a large cohort of adult survivor women who had received HSCT for leukemia before puberty.

Study design: We conducted a retrospective observational study in women from the national cohort L.E.A., the long term French follow-up program after childhood leukemia.

Results: The median follow-up duration was 18 years [14.2-23.3] after HSCT. Among 178 women, 106 (60%) needed pubertal induction with hormone substitution treatment, whereas 72 (40%) had spontaneous menarche. After spontaneous menarche, 33 (46%) developed POI, mostly within 5 years of HSCT. Older age at time of HSCT and cryopreservation of ovarian tissue appeared as significant risk factors for POI. More than 65% of patients who underwent HSCT before the age of 4.8 years had spontaneous menarche and almost 50% didn't have POI at last evaluation whereas more than 85% with HSCT after the age of 10.9 years didn't have spontaneous menarche and needed induction of puberty with hormone replacement therapy. Twenty-two women (12%) had at least one spontaneous pregnancy, with 17 live-births, 14 miscarriages, 4 legal abortions and 2 therapeutic abortions.

Conclusion: These results add supplementary data to better counsel patients and their families on the chances of ovarian residual function and pregnancy post-HSCT as well as on the potential interest of fertility preservation.

KEYWORDS

Leukemia, Premature ovarian insufficiency, Hematopoietic stem cell transplantation

INTRODUCTION

Leukemia is the most common childhood cancer, accounting for one third of cases. Over the last decades, innovation in diagnosis and treatment have increased the overall survival rate to over 80 %.¹ The remarkable improvement in the prognosis of children with acute leukemia (AL) has been mainly achieved through the administration of risk-adapted therapy, including intensive chemotherapy and hematopoietic stem cell transplantation (HSCT). As a consequence, there is a growing population of adult survivors that will face the long term side effects of cancer treatments such as growth failure, hypothyroidism, gonadal or uterine dysfunction or alteration of quality of life.^{2,3} Indeed, Berbis and al in 2013 described that more than 70% of childhood leukemia survivors from the French cohort L.E.A. (Leucémie de l'Enfant et de l'Adolescent) were found to have at least one late side effect.

The human ovary contains a fixed number of non-growing follicles (NGFs) established before birth that declines with age until the menopause occurs, physiologically around the age of 50. Ovarian reserve damage causes hypergonadotropic hypogonadism with a high risk of premature ovarian insufficiency (POI), defined by ESHRE (European Society of Human Reproduction and Embryology) as oligo/amenorrhea for at least 4 months, and an elevated FSH level > 25 IU/l on two occasions > 4 weeks apart before the age of 40.⁴ The ovarian reserve is particularly sensitive to the toxicity of cancer treatment, especially conditioning regimens preparing for HSCT, which cause disorders of both endocrine and reproductive functions. Indeed, POI and infertility are among the most frequent late effects after HSCT.^{2,5} POI includes pubertal development impairment; amenorrhea can be primary but also secondary depending on the residual post-HSCT ovarian reserve. According to various published data, the incidence of POI ranges from 44 to 100% patients who received HSCT in childhood for either malignant or non-malignant hematological disorders.⁶⁻⁸ Risk factors for POI after HSCT have been described : younger age at HSCT predicted spontaneous

menarche whereas myeloablative conditioning (MAC) regimen was shown as the main risk factor for ovarian failure.⁹ Indeed, the age at HSCT is known to be critical for ovarian function : HSCT in prepubertal girls means better chances of recovery and achievement of puberty.^{5,10,11}

Fertility impairment in women transplanted during childhood and adolescence is high, ranging around 83%.⁵ Pregnancy rate after HSCT is described in the literature as quite low, below 1%.^{12,13} In this context, fertility preservation before HSCT remains a major challenge for childhood cancer survivors.

In AL, ovarian stimulation and oocyte vitrification is possible only after puberty, often constrained by cancer treatment emergency and not recommended immediately after the first-line of chemotherapy cycles due to a mutagenic risk. In AL and for prepubertal girls, the only fertility preservation strategy available before HSCT is ovarian tissue cryopreservation (OTC).

The aim of our study was to evaluate puberty development, long term ovarian function, and occurrence of spontaneous pregnancy on a population of prepubertal HSCT survivors who underwent HSCT for acute leukemia in childhood.

MATERIALS AND METHODS

Characteristics of childhood cancer survivor women

Women described here were all included in the L.E.A. program. L.E.A. is the long-term follow-up program involving childhood acute leukemia survivors in France. Patients were included in L.E.A. if they met the following criteria: treated for acute leukemia after 1980 in one of the participating centers, younger than 18 years of age at the time of diagnosis and agreed (or their parents/legal guardians) to participate in the study. Participants are summoned to the follow-up clinic at predefined dates, starting one year after completion of anti-leukemic therapy.¹⁵ These visits are repeated every two years until the age of 20 and at least 10 years after complete remission, and every four years thereafter. The program began in 2004 and relies on the constitution of a multicenter historical and prospective cohort, which includes both incident cases (diagnosed after the starting date of the participation of the center in the L.E.A. program) and prevalent cases (diagnosed between 01/01/1980 and the starting date of the participation of the center in the L.E.A. program).

Patients were eligible for the present study if they had been included in the L.E.A. program between 2004 and 2020, were female, were treated with HSCT after a MAC regimen, without menarche at the time of transplant and more than 18 years old at the time of last evaluation. Patients were excluded from the study if they underwent more than 2 HSCT. Among 186 women who fulfilled these inclusion/exclusion criteria, clinical and biological data were obtained in 178 and all these 178 women were included in the study group.

All patients (or their parents) provided written informed consent. This study was approved by the Sud Mediterranee V ethics committee (opinion n° 2012-A00984-39), in compliance with the General Data Protection Regulation.

Evaluation of the ovarian function after hematopoietic stem cell transplantation

In the L.E.A. program, post-HSCT ovarian function evaluation was systematically proposed to all adolescents and women who had previously received HSCT. Typically, during the medical L.E.A. visits, hormone levels were tested and various clinical data were collected including spontaneous menarche/induction of puberty, puberty progress, sex steroid hormone replacement therapy (HRT), primary or secondary amenorrhea, pregnancy occurrence and outcome.

POI was defined by ESHRE as the association of an oligo/amenorrhea for at least 4 months, and an elevated FSH level > 25 IU/l on two occasions at 4 weeks apart before the age of 40.⁴ Spontaneous pregnancy was defined as a pregnancy obtained without any medically assisted reproductive procedure.

Depending on the level of damage to the ovarian reserve, three groups of ovarian hormonal status were distinguished. Girls who didn't have spontaneous menarche and needed HRT to induce puberty were classified as having immediate POI (IPOI). Girls who had spontaneous puberty and then presented a POI after a period of residual ovarian function were classified as having secondary POI (SPOI). Finally, women with neither clinical nor biological evidence of POI and without HRT at time of their last evaluation constituted the group without POI (noPOI).

Quality of Life (QoL) was evaluated with the SF-36 self-questionnaire (the Medical Outcome Study Short Form 36 Health Survey).¹⁶

Statistical methods are described in the supplemental data.

RESULTS

Childhood hematopoietic stem cell transplantation survivors' characteristics

We included 178 women from 15 L.E.A. centers. Their characteristics are summarized in Table 1.

The median age at HSCT was 7.7 [IQR25-75: 4.79-10.90] years old and the median age at last evaluation was 24.9 [21.08-30.1] years old. The median follow up duration since HSCT was 18 years [14.2-23.3].

In the studied cohort, 169 patients were treated with one HSCT and 9 were treated with two HSCT. Out of the 169 patients treated with one HSCT, 135 received an allogeneic and 34 an autologous HSCT. Among the 9 patients with two HSCT, 2 had autologous followed by allogeneic HSCT and 7 had 2 allogeneic HSCT.

Thirteen patients from the studied population had an ovarian tissue cryopreservation (OTC) before HSCT.

Conditioning regimen before hematopoietic stem cell transplantation

Conditioning regimen depended on protocols in use at the time of HSCT, underlying diseases and their status, and history of previous CNS irradiation. All 178 women had received a MAC regimen, among which 116 had total-body irradiation (TBI) and 62 a Busulfan-based conditioning protocol (Table 1).

Most women prepared with TBI were treated with the commonly used French pre-transplant radiation regimen : they (107/116, 92%) received a total dose of 12 Gy divided in 6 fractions (i.e. 2 Gy twice daily during 3 days) with lung shielding at 8 Gy. Only 8 other women received a fractionated 10 to 11 Gy total dose and one a single 8 Gy dose. The cytostatic drugs used in association with TBI were: cyclophosphamide only in 53 patients, cyclophosphamide and fludarabine in 2, melphalan only in 3, cytarabine and melphalan in 50 and etoposide in 8 patients. Mean calculated cumulative alkylating dose per patient, using the cyclophosphamide equivalent dose (CED) was 4661 mg/m² (range: 0 to 15435).¹⁷

All 62 women who did not receive TBI were given busulfan (BU) at a myeloablative dose. BU was given per os or IV in 16 divided doses (4 doses per day for 4 days) at a total dose of 16 mg/kg or 480 mg/m² when given per os, and according to a previously published weight-based protocol when given IV. In addition to BU, patients also received cyclophosphamide (49 patients), melphalan (6 patients), aracytine and melphalan (5 patients) or fludarabine and thiotepa (2 patients). Mean cumulative CED dose was 9285 mg/m² (range: 5600 to 19 235).

Ovarian function after hematopoietic stem cell transplantation in leukemia survivors

Out of the 178 included women, 106 (59.6%) needed an induction of puberty with HRT whereas 72 (40.4%) had spontaneous menarche. Among the 72 patients with spontaneous menarche, 33 developed POI secondarily and 39 women still had a residual ovarian function (Figure 1).

Table 2 resumes the mean FSH levels before introduction of HRT in the IPOI and SPOI groups and at last evaluation for the noPOI group (Table 2).

In the IPOI group, the median age for the introduction of HRT to induce puberty was 13.7 years [12.7-14.9] and the median age at last evaluation was 25.5 years [21.3-30].

In the SPOI group, the median age for spontaneous menarche was 13 years [11.9-14.1] , the median age for the introduction of HRT was 15.1 years [14.2-16.4] and the median age at last evaluation was 24.3 years [20.3-29.6].

In the noPOI group, the median age for spontaneous menarche was 12.7 years [12-13.5] and they still had spontaneous menstruations at 24.8 years [21.3-29.8].

Cumulative incidence of POI in women who had spontaneous menarche is shown in Figure 2. During the follow-up, among the 72 women of the cohort who had spontaneous menarche, 33 (45.8%) progressed to a POI. The cumulative incidence of POI occurrence increased rapidly affecting 40% of women within 5 years of having spontaneous menarche and more slowly thereafter, reaching 45% at 10 years (Figure 2).

Risk factors for premature ovarian insufficiency in hematopoietic stem cell transplantation survivors

Potential risk factors influencing ovarian function are analyzed in Table 3. There is a continuous effect of age at time of HSCT on ovarian status: using the median age and the quartile distribution of the cohort as a cut-off, older children at time of HSCT had a higher risk of developing POI. Indeed, more than 80% of the patients who underwent HSCT after the age of 10.9 years were in the IPOI group. In contrast, more than 65% of the patients who underwent HSCT before the age of 4.79 years had spontaneous menarche and almost 50% of them were in the noPOI group at last evaluation (Figure 3)

Thirteen patients from the study cohort had fertility preservation with OTC . Among them, 12 (92.3%) were in the IPOI group, one in the SPOI but none belonged to the noPOI group. OTC is a significant risk factor for POI. However, there was a statistically significant association between older age at first HSCT and history of OTC ($p < 0.001$), more than 90% of

women with history of OTC being older than 7.70 years old at HSCT (median age of the study cohort)(Table 3).

Spontaneous pregnancy and outcomes in hematopoietic stem cell transplantation survivors

Among the 178 women included in our cohort, 22 had at least one spontaneous pregnancy (12 %), with a total number of 37 spontaneous pregnancies leading to 17 live births, 14 miscarriages, 4 legal abortions and 2 therapeutic abortions.

Potential factors influencing the occurrence of spontaneous pregnancy in our study cohort are shown in Table 4. We observed a continuous effect of age at last evaluation on the occurrence of spontaneous pregnancies, older patients at last evaluation having higher probabilities of spontaneous pregnancy. Age at HSCT was not a prognostic factor, perhaps due to a statistically significant correlation between age at HSCT and age at last evaluation (Figure 4). Women from the noPOI group had a significantly better chance of spontaneous pregnancy than women in the IPOI and SPOI groups. Interestingly, none of those who had OTC enjoyed spontaneous pregnancy, although the difference did not reach the level of statistical significance (Table 4).

Premature ovarian insufficiency and spontaneous pregnancies consequences on quality of life

We compared the QoL profile in our study population with that of the French general population.¹⁸ There was a highly statistically significant decline in the mental component

score of the study population, as well as for almost all subscales of SF-36 (additional Table 1A). However, we didn't find any statistically significant effect of the women's ovarian status or the occurrence of spontaneous pregnancy on their quality of life (additional Table 1B and 1C).

DISCUSSION

We report the evolution of residual ovarian function and spontaneous pregnancies in 178 adult females treated before puberty for AL by HSCT prepared with a MAC regimen. Ovarian function after HSCT has been described in other studies but the survivors cohorts were often heterogeneous with various indications such as leukemia, Hodgkin lymphoma or severe aplastic anemia.^{7,19} A strength of our study is to have included a large and homogeneous population of women, all treated before puberty for a similar pathology with similar treatments.

Temporary recovery of ovarian function has been previously described on prepubertal and midpubertal girls.^{11,13} Based on these data, we chose to focus on girls who were prepubertal at the time of HSCT and had attained adulthood at last evaluation. Another significant strength of our study is its extended longitudinal follow up duration (median duration of 18 years after HSCT).

Several other studies which evaluated gonadal function after cancer treatment did not respond with a clear and uniform definition of ovarian impairment with, for example, heterogeneous thresholds of gonadotropin plasma levels.^{10,20} Our study was based on the European Society of Human Reproduction and Embryology (ESHRE 2016), definition of POI.⁴

Moreover, some previous studies have reported pregnancies in cancer survivors after HSCT without specifying whether these were spontaneous or required assisted reproductive techniques such as oocytes donation.^{5,9} In this study, we only report spontaneous pregnancies with a view to assess as accurately as possible residual ovarian function.

A number of risk factors have already been described regarding ovarian toxicity after MAC regimen for bone marrow transplantation. The age at HSCT is critical: POI is more frequent after HSCT in adult women, whereas in prepubertal girls, there is a higher probability of spontaneous menarche.^{5,10,11}

Our data show that age at HSCT strongly influences residual ovarian function: more than 65% of patients who underwent HSCT before the age of 4.8 years had spontaneous menarche and almost 50% didn't have POI at last evaluation whereas more than 85% of patients who received HSCT after the age of 10.9 years didn't have spontaneous menarche and needed induction of puberty with HRT. Jadoul et al²¹ observed that patients under the age of 10 at the time of HSCT for malignant and nonmalignant diseases showed significant and independently-associated higher rates of clinically proven persistent ovarian function. The protective effect of young age might be related to the higher number of NGFs in the ovarian reserve of younger girls. During the reproductive life, the decline in NGFs occurs in an exponential way.²² We were surprised to observe a significantly increased chance of keeping functional ovaries when girls were treated before the age of 5 (48.8 %); Similarly, we report a gradual increase in the risk for POI with age at HSCT beginning much earlier than the previously described threshold of 10 years.

The identification of women endowed with residual ovarian function after HSCT and the timing until the definitive POI occurs remains a major challenge for counseling a long-term

fertility preservation strategy such as oocyte cryopreservation after puberty. According to our study, 40% of transplanted girls have spontaneous menarche but among them, 40% will progress to POI within 5 years of menarche, which is quite a short critical therapeutic window to consider fertility procedure.²³ Indeed, it could be discussed to perform an oocyte banking before definitive POI in these young adolescents as already described in case of risk of POI in women with a history of benign ovarian tumor and high risk of ovarian depletion.²⁴

Infertility is a very frequent late effect after HSCT.²⁵ Pregnancy in transplanted women has been documented by Salooja et al. with a pregnancy rate of 0,6% (232/37362). This study included girls and adult women transplanted at different ages ranging from 6 to 36 with a median age at HSCT of 19 years.¹² The study of Diesch-Furlanetto et al. focused on pregnancies (naturally or by artificial insemination) both in childhood disease survivor transplanted women and partner pregnancies of childhood disease survivor transplanted males with a pregnancy rate of 0.7% (406/61047). The studied population included less than 30% of leukemia as HSCT indication.¹³ Indeed, pregnancies after HSCT have been documented in several studies but with heterogeneous inclusion criteria : underlying diseases including malignant and non-malignant ones^{26,27}; including patients transplanted at any age¹²; including men and women indifferently or without reporting whether the conception method was natural or involved medically assisted reproduction.^{5,13}

To our knowledge, our study is the first one to assess spontaneous pregnancy in women who received HSCT at a prepubertal age. In the other cohort studies, the follow-up was too short to include pregnancies at ages for which family planning is considered. However, compared with the mean age of healthy women at their first child's birth (29 years old), our studied women delivered 5 years earlier (mean 24,3 years old).¹³ With a median age at last evaluation of 24.9 years old, we probably underestimate the total number of pregnancies after HSCT.

We describe that more than 12% of women had spontaneous pregnancies. Surprisingly, we report more than 10% of legal abortions in these pregnancies with half of them in the IPOI group.

One of the main messages to highlight from this result is the absolute necessity to replace the HRT with a contraceptive method for the young adults to avoid non desired pregnancies, especially in girls with a history of induction of puberty.

Fertility impairment being such an important late effect after cancer treatment, fertility preservation procedures before treatment is one of the most important issue for survivor patients and for their quality of life.²⁸ OTC is the only option for fertility preservation in prepubertal girls. On the other hand, we observed an impairment of residual ovarian function in girls who have benefited from an OTC. In our study, only around 7% of the women had undergone an OTC before HSCT. OTC appears as a statistically significant risk factor for POI with more than 90% of these women being in the group IPOI. However, there is a potential age bias, because women who underwent OTC were older at time of HSCT and we previously described age at HSCT as an independent risk factor for POI. In addition, we did not describe any spontaneous pregnancy in women with a history of OTC. Consequently, we suggest that OTC before HSCT for AL might influence future ovarian function and fertility but this result must be confirmed in other cohorts because of the relatively small number of women and the potential age bias.

More than 200 live births after OTC and autotransplantation^{29,30} have been reported worldwide, which gives OTC a rightful place in fertility preservation to patients of different ages^{31,32} or treated for various diseases, especially non malignant ones.³³ In AL however, there is a concern about possible contamination of ovarian tissue by residual leukemic disease, which can potentially induce disease recurrence after ovarian autograft.³⁴ AL

remains a discussed indication for OTC.^{35,36} One animal model study concluded that reimplantation of cryopreserved ovarian tissue from patients with acute lymphoblastic leukemia is potentially unsafe.³⁷ Consequently, only a few women around the world have been transplanted after leukemia and this was done with maximal safety procedures to ensure that there was no residual disease in the graft.³⁸⁻⁴¹ Even for centers that do not consider autotransplantation of OTC in AL, OTC could be discussed in view of the emerging technology of in vitro folliculogenesis in human. To date, the “artificial ovary” technology has been successful in nonhuman animals, but not yet in humans.^{42,43} Finally, the usefulness of OTC in young girls suffering from AL is questionable if ovarian tissue autograft couldn't be proposed. In the end, other studies assessing the potential impact of OTC on future ovarian function and fertility are needed to answer this important question.

Teinturier et al⁴⁴, showed that unilateral oophorectomy in cancer survivors was associated with a 7-year earlier age at onset of menopause.

Several previous studies have documented an impairment of quality of life in childhood leukemia survivors.^{36,45-47} Studies focusing on HSCT survivors also showed a decrease in their perceived QoL.^{48,49} Our study showed significantly lower scores of QoL in HSCT survivors compared to the French general population especially on the mental component score. However, we were unable to detect an impact of the ovarian function status on QoL, perhaps because the impairment of QoL in these cases is multifactorial and might require a larger cohort to become visible.

Our study reported that spontaneous puberty and spontaneous pregnancies are possible and not so rare after HSCT. We evidenced a more resilient residual ovarian function especially when HSCT was performed before the age of 5. Age at HSCT remains a major risk factor for ovarian dysfunction with a continuous effect on ovarian function. It is important to identify

the therapeutic window of fertility preservation for those who had spontaneous menarche. As spontaneous pregnancies may occur, it is essential to propose contraceptive methods. More studies with a larger cohort of survivors are necessary to identify the potential impact of OTC on ovarian function in leukemia survivors who received HSCT during childhood.

REFERENCES

1. Bertuccio P, Alicandro G, Malvezzi M, et al. Childhood cancer mortality trends in Europe, 1990–2017, with focus on geographic differences. *Cancer Epidemiology* 2020;67:101768.
2. Berbis J, Michel G, Chastagner P, et al. A French Cohort of Childhood Leukemia Survivors: Impact of Hematopoietic Stem Cell Transplantation on Health Status and Quality of Life. *Biology of Blood and Marrow Transplantation* 2013;19(7):1065–1072.
3. Courbiere B, Drikes B, Grob A, et al. Uterine volume is dramatically decreased after Hematopoietic Stem Cell Transplantation during childhood regardless of the conditioning regimen. *Fertility and Sterility* 2023;S001502822202132X.
4. Webber L, Davies M, Anderson R. ESHRE Guideline: management of women with premature ovarian insufficiency. *Hum Reprod* 2016;31(5):926–937.
5. Borgmann-Staudt A, Rendtorff R, Reinmuth S, et al. Fertility after allogeneic haematopoietic stem cell transplantation in childhood and adolescence. *Bone Marrow Transplant* 2012;47(2):271–276.

6. Diesch-Furlanetto T, Gabriel M, Zajac-Spychala O, Cattoni A, Hoeben BAW, Balduzzi A. Late Effects After Haematopoietic Stem Cell Transplantation in ALL, Long-Term Follow-Up and Transition: A Step Into Adult Life. *Front Pediatr* 2021;9773895.
7. Sarafoglou K, Boulad F, Gillio A, Sklar C. Gonadal function after bone marrow transplantation for acute leukemia during childhood. *The Journal of Pediatrics* 1997;130(2):210–216.
8. Elchuri SV, Williamson Lewis R, Quarmyne M-O, Haight AE, Cottrell HN, Meacham LR. Longitudinal Description of Gonadal Function in Sickle-cell Patients Treated With Hematopoietic Stem Cell Transplant Using Alkylator-based Conditioning Regimens. *Journal of Pediatric Hematology/Oncology* 2020;42(7):e575–e582.
9. Vatanen A, Wilhelmsson M, Borgström B, et al. Ovarian function after allogeneic hematopoietic stem cell transplantation in childhood and adolescence. *European Journal of Endocrinology* 2014;170(2):211–218.
10. Sanders JE, Buckner CD, Amos D, et al. Ovarian function following marrow transplantation for aplastic anemia or leukemia. *JCO* 1988;6(5):813–818.
11. Spinelli S, Chiodi S, Bacigalupo A, et al. Ovarian recovery after total body irradiation and allogeneic bone marrow transplantation: long-term follow up of 79 females. *Bone Marrow Transplant* 1994;14(3):373–380.
12. Salooja N, Szydlo R, Socie G, et al. Pregnancy outcomes after peripheral blood or bone marrow transplantation: a retrospective survey. *The Lancet* 2001;358(9278):271–276.
13. Diesch-Furlanetto T, Rovó A, Galimard JE, et al. Pregnancy and pregnancy outcomes after hematopoietic stem cell transplantation in childhood: a cross-sectional survey of the EBMT Pediatric Diseases Working Party. *Human Reproduction* 2021;36(11):2871–2882.

14. Meirow D, Epstein M, Lewis H, Nugent D, Gosden RG. Administration of cyclophosphamide at different stages of follicular maturation in mice: effects on reproductive performance and fetal malformations. *Human Reproduction* 2001;16(4):632–637.
15. Berbis J, Michel G, Baruchel A, et al. Cohort Profile: The French Childhood Cancer Survivor Study For Leukaemia (LEA Cohort). *International Journal of Epidemiology* 2015;44(1):49–57.
16. Leplège A, Ecosse E, Verdier A, Perneger TV. The French SF-36 Health Survey. *Journal of Clinical Epidemiology* 1998;51(11):1013–1023.
17. Green DM, Nolan VG, Goodman PJ, et al. The cyclophosphamide equivalent dose as an approach for quantifying alkylating agent exposure: A report from the childhood cancer survivor study: Cyclophosphamide Equivalent Dose. *Pediatr Blood Cancer* 2014;61(1):53–67.
18. Leplège A, Ecosse E, Pouchot J. Le questionnaire MOS SF-36: Manuel de l'utilisateur et guide d'interprétation des scores. Paris: Ed ESTEM; 2001.
19. Jadoul P, Donnez J. How does bone marrow transplantation affect ovarian function and fertility? *Current Opinion in Obstetrics & Gynecology* 2012;24(3):164–171.
20. Chemaitilly W, Li Z, Krasin MJ, et al. Premature Ovarian Insufficiency in Childhood Cancer Survivors: A Report From the St. Jude Lifetime Cohort. *The Journal of Clinical Endocrinology & Metabolism* 2017;102(7):2242–2250.
21. Jadoul P, Anckaert E, Dewandeleer A, et al. Clinical and biologic evaluation of ovarian function in women treated by bone marrow transplantation for various indications during childhood or adolescence. *Fertility and Sterility* 2011;96(1):126-133.e3.
22. Wallace WHB, Kelsey TW. Human Ovarian Reserve from Conception to the

- Menopause. PLoS ONE 2010;5(1):e8772.
23. Das M, Shehata F, Son W-Y, Tulandi T, Holzer H. Ovarian reserve and response to IVF and in vitro maturation treatment following chemotherapy. *Human Reproduction* 2012;27(8):2509–2514.
 24. Legrand C, Keller L, Collinet P, et al. Oocyte accumulation for fertility preservation in women with benign ovarian tumours with a history of previous surgery, multiple or large cysts. *Reprod Biomed Online* 2021;43(2):205–214.
 25. Mosher CE, DuHamel KN, Rini C, Corner G, Lam J, Redd WH. Quality of life concerns and depression among hematopoietic stem cell transplant survivors. *Support Care Cancer* 2011;19(9):1357–1365.
 26. Chiodi S, Spinelli S, Bruzzi P, Anserini P, Di Grazia C, Bacigalupo A. Menstrual patterns, fertility and main pregnancy outcomes after allogeneic haematopoietic stem cell transplantation. *Journal of Obstetrics and Gynaecology* 2016;36(6):783–788.
 27. Loren AW, Chow E, Jacobsohn DA, et al. Pregnancy after Hematopoietic Cell Transplantation: A Report from the Late Effects Working Committee of the Center for International Blood and Marrow Transplant Research (CIBMTR). *Biology of Blood and Marrow Transplantation* 2011;17(2):157–166.
 28. Brodigan K, Kapadia M, Frazier AL, et al. Safety of Surgical Fertility Preservation Procedures in Children Prior to Hematopoietic Stem Cell Transplant. *Transplantation and Cellular Therapy* 2021;27(8):696.e1-696.e4.
 29. Dolmans M-M, Falcone T, Patrizio P. Importance of patient selection to analyze in vitro fertilization outcome with transplanted cryopreserved ovarian tissue. *Fertility and Sterility* 2020;114(2):279–280.
 30. Dolmans M-M, von Wolff M, Poirot C, et al. Transplantation of cryopreserved

- ovarian tissue in a series of 285 women: a review of five leading European centers. *Fertility and Sterility* 2021;115(5):1102–1115.
31. Chambon F, Brugnon F, Grèze V, et al. Cryopreservation of ovarian tissue in pediatric patients undergoing sterilizing chemotherapy. *Human Fertility* 2016;19(1):23–31.
 32. Meirow D, Ra'anani H, Shapira M, et al. Transplantations of frozen-thawed ovarian tissue demonstrate high reproductive performance and the need to revise restrictive criteria. *Fertility and Sterility* 2016;106(2):467–474.
 33. Hovatta O. Ovarian function and in vitro fertilization (IVF) in Turner syndrome. *Pediatr Endocrinol Rev* 2012;9 Suppl 2713–717.
 34. Courbiere B, Prebet T, Mozziconacci M-J, Metzler-Guillemain C, Saias-Magnan J, Gannerre M. Tumor cell contamination in ovarian tissue cryopreserved before gonadotoxic treatment: should we systematically exclude ovarian autograft in a cancer survivor? *Bone Marrow Transplant* 2010;45(7):1247–1248.
 35. Imbert R, Moffa F, Tsepelidis S, et al. Safety and usefulness of cryopreservation of ovarian tissue to preserve fertility: a 12-year retrospective analysis. *Human Reproduction* 2014;29(9):1931–1940.
 36. Shapira M, Raanani H, Cohen Y, Meirow D. Fertility Preservation in Young Females with Hematological Malignancies. *Acta Haematol* 2014;132(3–4):400–413.
 37. Dolmans M-M, Marinescu C, Saussoy P, Van Langendonck A, Amorim C, Donnez J. Reimplantation of cryopreserved ovarian tissue from patients with acute lymphoblastic leukemia is potentially unsafe. *Blood* 2010;116(16):2908–2914.
 38. Rodriguez-Wallberg KA, Milenkovic M, Papaikonomou K, et al. Successful pregnancies after transplantation of ovarian tissue retrieved and cryopreserved at time of childhood acute lymphoblastic leukemia – A case report. *haematol*

2021;106(10):2783–2787.

39. Shapira M, Raanani H, Barshack I, et al. First delivery in a leukemia survivor after transplantation of cryopreserved ovarian tissue, evaluated for leukemia cells contamination. *Fertility and Sterility* 2018;109(1):48–53.
40. Silber SJ, DeRosa M, Goldsmith S, Fan Y, Castleman L, Melnick J. Cryopreservation and transplantation of ovarian tissue: results from one center in the USA. *J Assist Reprod Genet* 2018;35(12):2205–2213.
41. Sonmezer M, Ozkavukcu S, Sukur YE, Kankaya D, Arslan O. First pregnancy and live birth in Turkey following frozen-thawed ovarian tissue transplantation in a patient with acute lymphoblastic leukemia who underwent cord blood transplantation. *J Assist Reprod Genet* 2020;37(8):2033–2043.
42. Pampanini V, Hassan J, Oliver E, Stukenborg J-B, Damdimopoulou P, Jahnukainen K. Fertility Preservation for Prepubertal Patients at Risk of Infertility: Present Status and Future Perspectives. *Horm Res Paediatr* 2020;93(11–12):599–608.
43. McLaughlin M, Albertini DF, Wallace WHB, Anderson RA, Telfer EE. Metaphase II oocytes from human unilaminar follicles grown in a multi-step culture system. *MHR: Basic science of reproductive medicine* 2018;24(3):135–142.
44. Thomas-Teinturier C, El Fayeck C, Oberlin O, et al. Age at menopause and its influencing factors in a cohort of survivors of childhood cancer: earlier but rarely premature. *Human Reproduction* 2013;28(2):488–495.
45. Chiou S-S, Jang R-C, Liao Y-M, Yang P. Health-related quality of life and cognitive outcomes among child and adolescent survivors of leukemia. *Support Care Cancer* 2010;18(12):1581–1587.
46. Maunsell E, Pogany L, Barrera M, Shaw AK, Speechley KN. Quality of Life Among Long-Term Adolescent and Adult Survivors of Childhood Cancer. *JCO*

2006;24(16):2527–2535.

47. Speechley KN, Barrera M, Shaw AK, Morrison HI, Maunsell E. Health-Related Quality of Life Among Child and Adolescent Survivors of Childhood Cancer. *JCO* 2006;24(16):2536–2543.
48. Berbis J, Oudin C, Alessandrini M, et al. Quality of life in minor siblings of childhood leukemia survivors, long-term after diagnosis: A LEA study (for Leucemies de l'Enfant et de l'Adolescent-childhood and adolescent leukemia): Quality of life in minor siblings of childhood leukemia survivors. *Psycho Oncology* 2015;24(6):661–668.
49. Clarke S-A, Skinner R, Guest J, et al. Clinical outcomes and health-related quality of life (HRQOL) following haemopoietic stem cell transplantation (HSCT) for paediatric leukaemia: Quality of life after paediatric bone marrow transplant. *Child: Care, Health and Development* 2011;37(4):571–580.

TABLES

| | Study patients <i>n</i> = 178 | % |
|---|-------------------------------|------|
| Age at diagnosis - median [IQ25-75] | 5.88±3.8 [3.01-8.95] | |
| Age at HSCT – median [IQ25-75] | 7.70±3.9 [4.79-10.90] | |
| Age at last evaluation – median [IQ25-75] | 24.90±6.1[21.08-30.1] | |
| Leukemia type | | |
| ALL | 108 | 60.7 |
| AML | 70 | 39.3 |
| Number of HSCT | | |
| 1 | 169 | 94.9 |
| 2 | 9 | 5.1 |
| Type of HSCT n°1 | | |
| Autograft | 36 | 20.2 |
| Allograft | 142 | 79.8 |
| GvHD | | |
| No | 55 | 38.2 |
| Yes | 88 | 61.1 |
| Sin data | 1 | 0.7 |
| MAC Regimen | | |
| TBI-based | 116 | 65.2 |
| Radiation dose | | |
| - 12 Gy (2 twice daily x 3 days) | 107 | 92.2 |
| - 10-11 Gy | 8 | 6.9 |
| - 8 Gy | 1 | 0.9 |
| Chemotherapy cumulative dose (CED, mg/m2) | | |
| - Mean : 4661 | | |
| - Range : 0 to 15435 | | |
| Bu-based | 62 | 34.8 |
| Chemotherapy cumulative dose (CED, mg/m2 including BU dose) | | |
| - Mean : 9285 | | |
| - Range : 5600 to 19235 | | |
| OTC before HSCT | | |
| No | 158 | 88.8 |
| Yes | 13 | 7.3 |
| Sin data | 7 | 3.9 |

Table 1: Hematopoietic stem cell transplantations and survivors study population characteristics

ALL, acute lymphoblastic leukemia; AML, acute myeloid leukemia; HSCT, hematopoietic stem cell transplantation; TBI, total body irradiation; GvHD, graft vs host disease; BU, Busulfan; OTC, ovarian tissue cryopreservation. Ages are expressed in medians±standard deviation and quartiles.

| | Ovarian status | | | <i>p</i> |
|------------|----------------|----------|--------|----------|
| | IPOI | SPOI | noPOI | |
| FSH (UI/L) | 69.2±4.8 | 62.1±7.4 | 16.5±3 | <.0001 |

Table 2 : Mean FSH levels before introduction of HRT in the IPOI and SPOI group and at last evaluation for the noPOI group

FSH levels are shown in UI/L with the mean± standard error

IPOI (Immediate Premature Ovarian Insufficiency); SPOI (Secondary Premature Ovarian Insufficiency); noPOI (without Premature Ovarian Insufficiency at last evaluation)

| | Ovarian Status | | | p |
|--|----------------|-----------|-----------|---------|
| | IPOI | SPOI | noPOI | |
| Leukemia Type | | | | |
| ALL | 58 (53.7) | 24 (22.2) | 26 (24.1) | 0.128 |
| AML | 48 (68.6) | 9 (12.9) | 13 (18.5) | |
| Number of HSCT | | | | |
| 1 | 98 (58) | 32 (18.9) | 39 (23.1) | 0.215 |
| 2 | 8 (88.9) | 1 (11.1) | 0 (0) | |
| HSCT Type | | | | |
| Autograft | 19 (55.9) | 10 (29.4) | 5 (14.7) | 0.155 |
| Allograft | 87 (60.4) | 23 (16) | 34 (23.6) | |
| GvHD | | | | |
| No | 29 (52.7) | 8 (14.6) | 18 (32.7) | 0.138 |
| Yes | 58 (65.9) | 14 (15.9) | 16 (18.2) | |
| Conditioning regimen | | | | |
| BU | 38 (61.2) | 12 (19.4) | 12 (19.4) | 0.862 |
| TBI | 68 (58.6) | 21 (18.1) | 27 (23.3) | |
| Age at leukemia diagnosis (years) | | | | |
| <= 3.01 (IQR 0-25) | 17 (37.8) | 10 (22.2) | 18 (40) | <0.0001 |
| 3.02 - 5.88 (IQR 25-50) | 20 (45.5) | 11 (25) | 13 (29.5) | |
| 5.89 - 8.94 (IQR 50-75) | 30 (66.7) | 9 (20) | 6 (13.3) | |
| >=8.95 (IQR 75-100) | 39 (88.6) | 3 (6.8) | 2 (4.6) | |
| Age at first HSCT (years) | | | | |
| <= 4.79 (IQR 0-25) | 15 (33.3) | 8 (17.8) | 22 (48.9) | <0.0001 |
| 4.80 - 7.70 (IQR 25-50) | 23 (52.3) | 10 (22.7) | 11 (25) | |
| 7.71 - 10.89 (IQR 50-75) | 30 (66.7) | 10 (22.2) | 5 (11.1) | |
| >= 10.90 (IQR 75-100) | 38 (86.3) | 5 (11.4) | 1 (2.3) | |
| Age at first HSCT (years) | | | | |
| BU | | | | |
| <= 4.79 (IQR 0-25) | 7 (29.1) | 7 (29.1) | 10 (41.8) | <0.01 |
| 4.80 - 7.70 (IQR 25-50) | 9 (75) | 2 (16.7) | 1 (8.3) | |
| 7.71 - 10.89 (IQR 50-75) | 8 (80) | 2 (20) | 0 (0) | |
| >= 10.90 (IQR 75-100) | 14 (87.6) | 1 (6.2) | 1 (6.2) | |
| TBI | | | | |
| <= 4.79 (IQR 0-25) | 8 (38.1) | 1 (4.8) | 12 (57.1) | <0.0001 |
| 4.80 - 7.70 (IQR 25-50) | 14 (43.7) | 8 (25) | 10 (31.3) | |
| 7.71 - 10.89 (IQR 50-75) | 22 (62.8) | 8 (22.9) | 5 (14.3) | |
| >= 10.90 (IQR 75-100) | 24 (85.7) | 4 (14.3) | 0 (0) | |
| Age at last evaluation | | | | |
| L.E.A. (years) | | | | |
| <= 21.08 (IQR 0-25) | 21 (46.7) | 14 (31.1) | 10 (22.2) | 0.325 |
| 21.09 - 24.90 (IQR 25-50) | 28 (63.6) | 6 (13.7) | 10 (22.7) | |
| 24.91 - 30.10 (IQR 50-75) | 30 (68.2) | 6 (13.6) | 8 (18.2) | |
| >= 30.11 (IQR 75-100) | 27 (60) | 7 (15.6) | 11 (24.4) | |
| OTC | | | | |
| No | 92 (58.2) | 30 (19) | 36 (22.8) | <0.05 |
| Yes | 12 (92.3) | 1 (7.7) | 0 (0) | |

Table 3: Evaluation of potential risk factors impacting ovarian status after hematopoietic stem cell transplantation for leukemia in childhood

ALL, acute lymphoblastic leukemia; AML, acute myeloid leukemia; HSCT, hematopoietic stem cell transplantation; TBI, total body irradiation; GvHD, graft vs host disease; BU, Busulfan; OTC, ovarian tissue cryopreservation

IPOI (Immediate Premature Ovarian Insufficiency); SPOI (Secondary Premature Ovarian Insufficiency); noPOI (without Premature Ovarian Insufficiency at last evaluation)

Ages are expressed in quartiles.

| | Patients with spontaneous pregnancy | | |
|---|-------------------------------------|-----------|----------|
| | No | Yes | <i>p</i> |
| Leukemia type | | | |
| ALL | 95 (88) | 13 (12) | 1.000 |
| AML | 61 (87.1) | 9 (12.9) | |
| Number of HSCT | | | |
| 1 | 147 (87) | 22 (13) | 0.604 |
| 2 | 9 (100) | 0 (0) | |
| HSCT Type | | | |
| Autograft | 28 (82.4) | 6 (17.6) | 0.382 |
| Allograft | 128 (88.9) | 16 (11.1) | |
| GvHD | | | |
| No | 49 (89.1) | 6 (10.9) | 1 |
| Yes | 79 (89.8) | 9 (10.2) | |
| Conditioning regimen | | | |
| BU | 55 (88.7) | 7 (11.3) | 0.816 |
| TBI | 101 (87.1) | 15 (12.9) | |
| Age at leukemia diagnosis | | | |
| <= 3.01 | 39 (86.7) | 6 (13.3) | 0.989 |
| 3.02 - 5.88 | 39 (88.6) | 5 (11.4) | |
| 5.89 - 8.94 | 40 (88.9) | 5 (11.1) | |
| >=8.95 | 38 (86.4) | 6 (13.6) | |
| Age at last evaluation (years) | | | |
| <= 21.08 | 45 (100) | 0 (0) | <0.001 |
| 21.09 - 24.90 | 39 (88.6) | 5 (11.4) | |
| 24.91 - 30.10 | 40 (90.9) | 4 (9.1) | |
| >=30.11 | 32 (71.1) | 13 (28.9) | |
| Age at first HSCT (years) | | | |
| <= 4.79 | 40 (88.9) | 5 (11.1) | 0.703 |
| 4.80 - 7.70 | 40 (90.9) | 4 (9.1) | |
| 7.71 - 10.89 | 37 (82.2) | 8 (17.8) | |
| >= 10.90 | 39 (88.6) | 5 (11.4) | |
| Follow up duration from HSCT (years) | | | |
| <= 14.34 | 44 (97.8) | 1 (2.2) | <0.01 |
| 14.35 - 18.18 | 38 (86.4) | 6 (13.6) | |
| 18.19 - 23.56 | 42 (93.3) | 3 (6.7) | |
| 23.57+ | 32 (72.7) | 12 (27.3) | |
| OTC | | | |
| No | 136 (86.1) | 22 (13.9) | 0.22 |
| Yes | 13 (100) | 0 (0) | |
| Ovarian status | | | |
| POI (IPOI&SPOI) | 126 (90.6) | 13 (9.4) | <0.05 |
| noPOI | 30 (76.9) | 9 (23.1) | |

Table 4: Evaluation of potential factors influencing spontaneous pregnancy occurrence after hematopoietic stem cell transplantation for leukemia in childhood

ALL, acute lymphoblastic leukemia; AML, acute myeloid leukemia; HSCT, hematopoietic stem cell transplantation; TBI, total body irradiation; GvHD, graft vs host disease; BU, Busulfan; OTC, ovarian tissue cryopreservation; IPOI (Immediate Premature Ovarian Insufficiency); SPOI (Secondary Premature Ovarian Insufficiency); noPOI (without Premature Ovarian Insufficiency at last evaluation). Ages are expressed in quartiles.

FIGURE LEGENDS

Figure 1: Ovarian function evolution of the survivors cohort after hematopoietic stem cell transplantation for leukemia before puberty

In the studied cohort, of a total of 178 eligible survivors, 106 patients (59.6%) are in the group IPOI, 33 patients (18.5%) are in the SPOI group and 39 patients (21.9%) are in the group noPOI.

IPOI (Immediate Premature Ovarian Insufficiency); SPOI (Secondary Premature Ovarian Insufficiency); noPOI (without Premature Ovarian Insufficiency at last evaluation)

Figure 2: Cumulative incidence of occurrence of premature ovarian insufficiency in women who had spontaneous menarche in the survivors cohort after hematopoietic stem cell transplantation for leukemia before puberty

Figure 3: Ovarian status depending on age at hematopoietic stem cell transplantation in the survivors cohort after hematopoietic stem cell transplantation for leukemia before puberty

Variable ages are divided between quartiles of age (years): ≤ 4.79 (IQR 0-25); 4.80-7.70 (IQR 25-50); 7.71-10.89 (IQR 50-75); ≥ 10.90 (IQR 75-100).

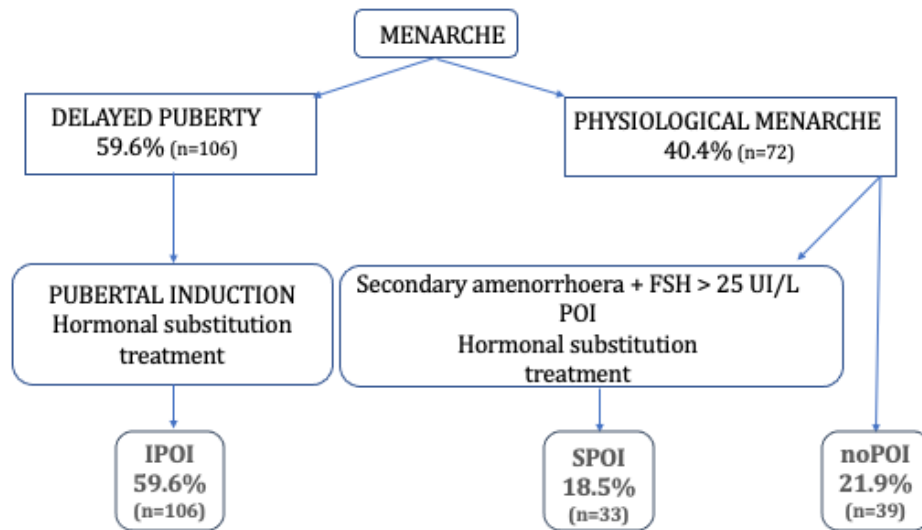
IPOI (Immediate Premature Ovarian Insufficiency); SPOI (Secondary Premature Ovarian Insufficiency); noPOI (without Premature Ovarian Insufficiency at last evaluation)

$p < 0.0001$

Figure 4: Correlation between age at hematopoietic stem cell transplantation and age at last evaluation in the study cohort of leukemia women survivors

HSCT, hematopoietic stem cell transplantation

FIGURES

*Figure 1*

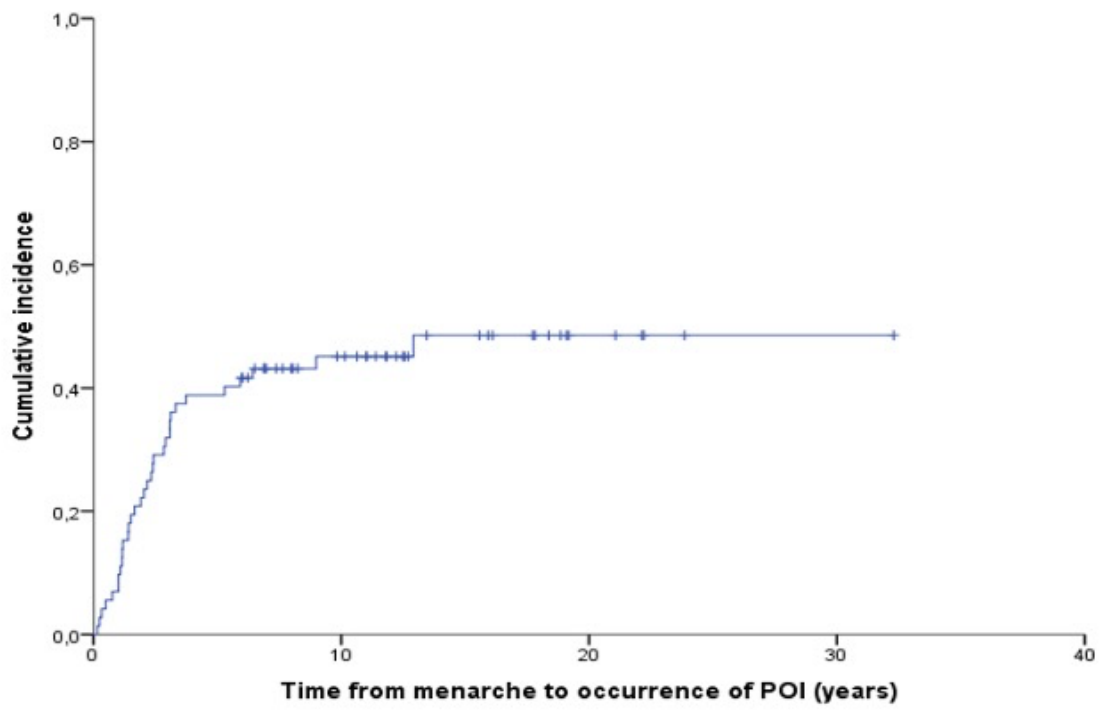


Figure 2

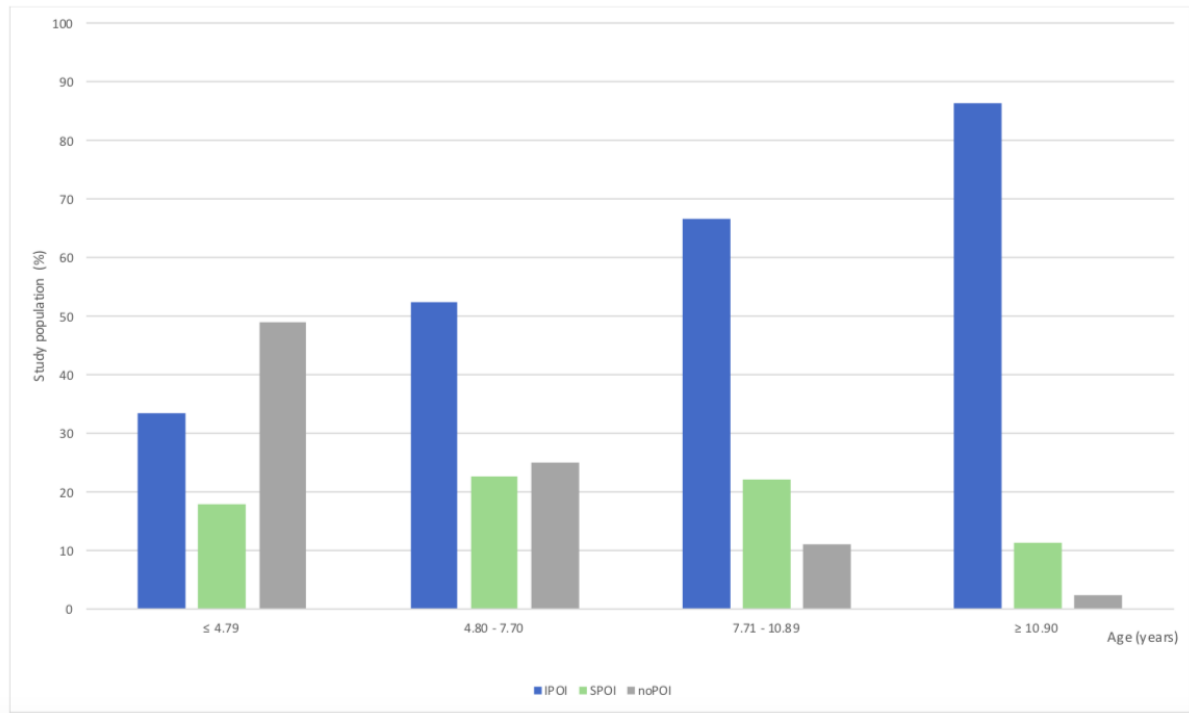


Figure 3

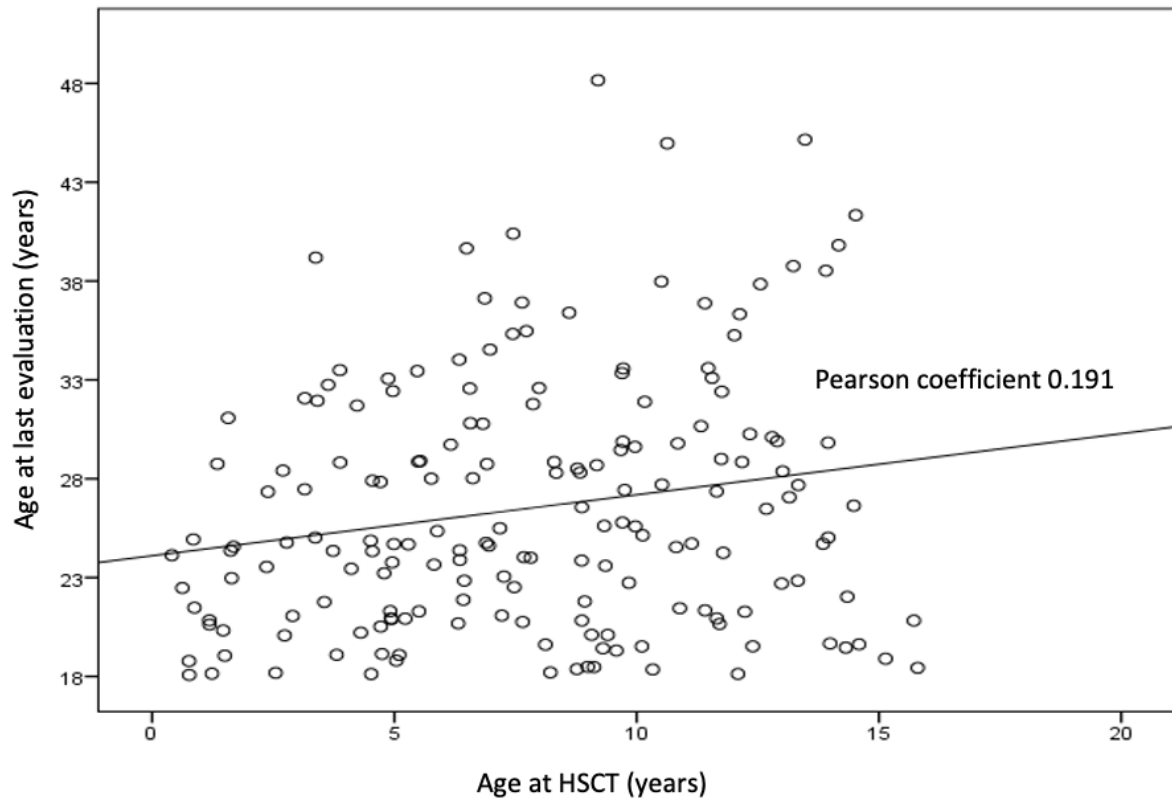


Figure 4

SUPPLEMENTARY DATA

Quality of life (QoL) focusing on health was evaluated with the SF-36 self-questionnaire (the Medical Outcome Study Short Form 36 Health Survey), a widely used QoL measure that provides a non-disease-specific measure of adult functioning and well-being, allowing for comparison with a broad range of same-age norm groups.^{2,47,48} SF36 includes 36 items describing eight dimensions. Two summary scores are also calculated from the subscales, a physical component score and a mental component score. All scores range between 0 and 100, with higher scores indicating better QoL.

Statistical analysis

Statistical analysis was performed using SPSS 20.0 (SPSS Inc., Chicago, IL, USA). Continuous age variables age at leukemia diagnosis, age at last evaluation and age at first HSCT-, were categorized into quartiles and shown as median [IQR 25-IQR 75] in the main text. Qualitative data were expressed as percentages. Quantitative data were shown as mean±Standard Error of Mean (SEM). Chi2 and Fisher exact tests were used to compare qualitative variables. Quantitative variables were compared using the Student test or the Mann-Whitney test and ANOVA or Kruskal-Wallis test. A pairwise t-test with a Bonferroni correction was used to test the difference between each possible *pair* of means.

The SF 36 scores were compared according to ovarian function and spontaneous pregnancies in our study population. Quality of life scores were also compared with age- and sex-matched controls from the French population.

Cumulative incidence of occurrence of POI in women who had spontaneous menarche over time were estimated using the Kaplan-Meier method. The proportional hazards assumption was assessed *via* examination of the log-minus-log survival plot. For the analysis of cumulative incidence rates of occurrence of POI, patients were censored when there was no POI identified.

ADDITIONAL TABLE

| A | General population | Study population | | |
|--|--------------------|------------------|------------------|----------|
| | M \pm ES | N | M \pm ES | p |
| Physical functioning | 93.59 \pm 0.14 | 131 | 84.44 \pm 1.74 | < 0.0001 |
| Social functioning | 81.22 \pm 0.15 | 129 | 68.02 \pm 2.3 | < 0.0001 |
| Role limitations due to physical health | 88.1 \pm 0.15 | 126 | 79 \pm 2.21 | < 0.0001 |
| Role limitations due to emotional problems | 83.64 \pm 0.19 | 128 | 66.18 \pm 1.7 | < 0.0001 |
| Emotional well-being | 66.36 \pm 0.14 | 131 | 58.69 \pm 1.65 | < 0.0001 |
| Energy/fatigue | 60.54 \pm 0.04 | 131 | 49.98 \pm 1.53 | < 0.0001 |
| Pain | 79.52 \pm 0.08 | 129 | 69.88 \pm 2.34 | < 0.0001 |
| General health | 73.26 \pm 0.14 | 131 | 55.16 \pm 1.98 | < 0.0001 |
| Physical component score | 54.04 \pm 0.06 | 124 | 52.39 \pm 0.87 | 0.06 |
| Mental component score | 46.35 \pm 0.1 | 124 | 38.48 \pm 0.91 | < 0.0001 |

| B | IPOI | | SPOI | | noPOI | | P |
|--|------|------------------|------|------------------|-------|------------------|-------|
| | N | M \pm ES | N | M \pm ES | N | M \pm ES | |
| Physical functioning | 85 | 83.77 \pm 2.1 | 23 | 84.57 \pm 4.62 | 32 | 88.11 \pm 3.08 | 0.560 |
| Social functioning | 83 | 68.07 \pm 2.81 | 23 | 69.57 \pm 5.26 | 32 | 71.48 \pm 4.8 | 0.815 |
| Role limitations due to physical health | 82 | 77.72 \pm 2.63 | 22 | 85.7 \pm 4.88 | 31 | 79.7 \pm 4.71 | 0.393 |
| Role limitations due to emotional problems | 83 | 64.26 \pm 2.02 | 22 | 70.83 \pm 4.13 | 32 | 68.62 \pm 3.38 | 0.255 |
| Emotional well-being | 85 | 58.4 \pm 2.14 | 23 | 59.13 \pm 3.61 | 32 | 62.03 \pm 3.43 | 0.661 |
| Energy/fatigue | 85 | 49.61 \pm 1.88 | 23 | 51.63 \pm 4.31 | 32 | 52.73 \pm 3.25 | 0.682 |
| Pain | 84 | 69.08 \pm 2.93 | 23 | 67.7 \pm 5.28 | 31 | 73.94 \pm 4.66 | 0.618 |
| General health | 84 | 55.32 \pm 2.39 | 23 | 51.61 \pm 5.04 | 32 | 60.75 \pm 4.2 | 0.314 |
| Physical component score | 79 | 52.3 \pm 1.05 | 22 | 52.5 \pm 2.11 | 31 | 53.23 \pm 1.77 | 0.900 |
| Mental component score | 79 | 38.12 \pm 1.15 | 22 | 39.42 \pm 2.02 | 31 | 40.21 \pm 1.85 | 0.594 |

| C | Patients with spontaneous pregnancy | | | | |
|--|-------------------------------------|------------------|-----|------------------|-------|
| | No | | Yes | | p |
| | N | M \pm ES | N | M \pm ES | |
| Physical functioning | 119 | 84.48 \pm 1.79 | 21 | 87.25 \pm 4.09 | 0.547 |
| Social functioning | 117 | 68.8 \pm 2.35 | 21 | 70.83 \pm 6.18 | 0.740 |
| Role limitations due to physical health | 114 | 80.54 \pm 2.17 | 21 | 73.71 \pm 6.48 | 0.237 |
| Role limitations due to emotional problems | 116 | 65.45 \pm 1.74 | 21 | 71.23 \pm 4.09 | 0.195 |
| Emotional well-being | 119 | 58.6 \pm 1.75 | 21 | 63.57 \pm 4.23 | 0.275 |
| Energy/fatigue | 119 | 50.61 \pm 1.66 | 21 | 50.89 \pm 4.01 | 0.948 |
| Pain | 117 | 70.22 \pm 2.37 | 21 | 68.38 \pm 6.66 | 0.768 |
| General health | 118 | 55.92 \pm 2.09 | 21 | 56.14 \pm 5.09 | 0.967 |
| Physical component score | 111 | 52.93 \pm 0.87 | 21 | 50.55 \pm 2.41 | 0.293 |
| Mental component score | 111 | 38.33 \pm 0.95 | 21 | 41.42 \pm 2.25 | 0.198 |

Additional Table 1:

A. Comparison of quality of life between the study population and the general French population with age and sex- matching

B. Comparison of quality of life of the study population depending on ovarian status

C. Comparison of quality of life of the study population depending on pregnancy outcome