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Original Research

Favourable outcome of *de novo* advanced phases of childhood chronic myeloid leukaemia☆

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Abstract ***Background:*** Chronic myeloid leukaemia (CML) is very rare in children. The aim of the study is to report the experience within the I-CML-Ped study in children and adolescents presenting at diagnosis with advanced phase disease and to describe their characteristics and outcomes.

Methods: Of 479 children and adolescents enrolled in the international registry for childhood chronic myeloid leukaemia (I-CML-Ped Study; www.clinicaltrials.gov NCT01281735), 36 children (7.5%) presented at initial diagnosis with CML in advanced phase according to the European LeukemiaNet criteria.

Results: Nineteen (4%) patients were diagnosed in accelerated phase (CML-AP), and among the 17 patients (3.5%) diagnosed in blastic phase (CML-BP), 70% presented with lymphoid immunophenotype. Initial treatment of CML-AP/CML-BP consisted of tyrosine kinase inhibitors (TKIs) with or without chemotherapy, leading to complete haematologic response in 33 of 36 (92%) patients. Seventeen patients proceeded to haematopoietic stem cell transplantation. At the last follow-up, 18 of 19 patients with *de novo* CML-AP are alive in at least major molecular response (MMR) (n = 16), in progression (n = 1) or in molecular relapse (n = 1) and 13 of 17 patients with *de novo* CML-BP are alive in at least MMR. Five-year overall survival rates are 94% (95% confidence interval [CI]: 66%–99%) and 74% (95% CI: 44%–89%) for patients diagnosed in CML-AP and CML-BP, respectively.

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Conclusion: Children with advanced phase at diagnosis of CML seem to have a better survival rate than that reported for advanced phases evolving under TKI treatment.

1. Introduction

Chronic myeloid leukaemia (CML) is characterised by the translocation t(9; 22) (q34; q11.2) named the Philadelphia chromosome (Ph) leading to the production of the oncogenic BCR-ABL1 transcript [1,2]. In the absence of efficient treatment, CML progresses from chronic phase (CML-CP) to accelerated (CML-AP) and blastic phases (CML-BP) [2]. CML usually presents as CML-CP in adults, while advanced phases at diagnosis represent 2.3–5.7% of the cases. Only scant data are available regarding the outcome compared with advanced phases evolving under treatment [3,4].

CML is very rare in children with an annual incidence of 1 and 2.2 cases per million in children younger than 15 years and in adolescents between 15 and 19 years, respectively [5]. Based on an international collaboration for collection of data, the international registry of CML in children and adolescents (I-CML-Ped Study; www.clinicaltrials.gov NCT01281735) has provided unique and valuable data to better describe this disease in pediatric cohorts [6,7]. The increasing size of the registry now allows analysis of rare subcohorts of pediatric CML. The aim of the present study is to report the experience within the I-CML-Ped study in children and adolescents presenting at diagnosis with advanced phase disease and to describe their characteristics and outcomes.

2. Materials and methods

The I-CML-Ped Study was set up to assess epidemiology, management and outcome of CML in children and adolescents. National pediatric study groups were invited to include newly diagnosed patients younger than 18 years with Ph-positive (Ph+) CML with whatever phase of the disease diagnosed later than January 2000. Data were collected on standardized forms. Written informed consent was obtained from the children and/or their guardians. The study is registered at www.clinicaltrials.gov as NCT01281735 and was open to recruitment in January 2011. From January 2011 to April 2017, 479 children and adolescents with CML from 14 countries have been registered. Among these 479 patients, 262 (55%) diagnosed in the time frame from 2000 until the end of 2010 were studied retrospectively, whereas 217 (45%) diagnosed in the time frame from 2011 until 2017 were studied prospectively. The phase of the disease was determined according to the criteria of the European leukemiaNet (ELN) recommendations [8]. The myeloid or lymphoid immunophenotype was determined by flow cytometry for patients in blastic phases [9].

Chromosome G or Q banding analysis was performed on bone marrow metaphases as previously reported [10,11]. In case of failure of the cytogenetic analysis, fluorescence *in situ* hybridisation (FISH) was used for the diagnosis of CML [10]. Determination of BCR-ABL1 transcript level in the blood was performed using quantitative reverse transcriptase-polymerase chain reaction as reported previously and was expressed according to the international scale (IS) [12]. Conversion of local laboratory BCR-ABL1 values to the IS was performed for assessment performed before 2006 [12].

BCR-ABL1 kinase domain mutation analysis was performed as previously reported [13]. Biological assessments were performed at local laboratories. Return to CML-CP under treatment was defined as <15% blasts and <30% blasts + promyelocytes in blood or bone marrow and <20% basophils according to the ELN definition (8). A complete haematologic response (CHR) required the normalisation of platelet and white cell differential counts, less than 5% blasts in bone marrow and absence of extramedullary involvement. Cytogenetic responses and molecular responses were defined as reported previously [8,14]. Major molecular response (MMR), MR4 and MR4.5 were defined as a BCR-ABL/ABL ratio of <0.1%, <0.01% and <0.0032% according to the IS, respectively [12]. For patients achieving CML-CP and CHR after diagnosis of CML in advanced phase, relapse was defined as reappearance of blasts in peripheral blood and 5% or more of blasts in bone marrow or extramedullary disease. Overall survival (OS) was assessed from the diagnosis of advanced phase until the date of death or last follow-up. Survival analysis was based on the Kaplan–Meier method [15].

3. Results

Among 479 children and adolescents registered (median age: 12.2 years, range: 0.8–18), 36 patients (7.5%) were diagnosed in *de novo* advanced phases of CML. According to the date of diagnosis (before or after the opening of the registry in 2011), 20 of 36 children were

studied retrospectively and 16 of 36 prospectively. The total number of patients with *de novo* CML-AP at the onset of the disease was 19 (4%) including 11 patients initially notified as CML-CP by the local investigator who were reclassified according to the ELN criteria at the time of the present analysis and were upstaged from CML-CP to CML-AP (% of blasts equal or more than 15%: 4 patients; % of blasts + promyelocytes more than 30% with blasts less than 30%: 7 patients). Seventeen patients (3.5%) presented with CML-BP: lymphoid immunophenotype (13 patients), myeloid immunophenotype (3 patients) or unknown immunophenotype (1 patient). Six of them (35%) had extramedullary disease: leukaemia cutis (1 patient), lymph nodes with blastic infiltration assessed by biopsy (1 patient), myeloid sarcoma (2 patients) and central nervous system disease (2 patients). The presence of extramedullary disease was the sole criteria of blastic phase in 2 of these patients (patients #5 and #13, Supplementary data). The main clinical and biological characteristics of the children in advanced phases at diagnosis of CML are reported in Table 1. Only 27 of 36 patients had an analysable karyotype at diagnosis: additional chromosomal aberrations (ACAs) beside the Ph + chromosome were observed in 3 (27%) of the 11 assessable patients in CML-AP. Among the 16 assessable patients in CML-BP, ACA and/or variant translocations were observed in 6 patients.

Data on treatment and outcome are reported in detail in Supplementary Table. Considering the 19 patients in CML-AP, only one patient of the 8 patients non-upstaged from CML-CP to CML-AP received a second-generation tyrosine kinase inhibitor (TKI) as first-line therapy according to the recommendation in children [14]. Among these 19 patients, 17 achieved a CHR after first-line treatment including 15 patients who received imatinib alone (nine of these patients received at least a second line of treatment because of loss of CHR [n = 1], progression to lymphoid blastic phase [n = 2] or myeloid blastic phase [n = 1], loss of molecular response [n = 2], no achievement of complete cytogenetic response [CCyR] [n = 1] or treating physicians' choice [n = 2]). All but one patient achieved a CHR within a median time of 3 months (range 1–8). Six patients proceeded to haematopoietic stem cell transplantation (HSCT) from an unrelated donor (n = 1) or a sibling donor (n = 5) with a median time of 8 months (range: 4–21) after initial diagnosis of CML-AP. Five of them were transplanted in CHR, whereas the remaining patient was transplanted in myeloid blastic phase 3 months after transformation. The reason for HSCT was the occurrence of blastic phase in 2 patients, non-achievement of CCR (1 patient) and choice of the treating physician for the 3 remaining patients. With a median follow-up of 36 months (range: 5 to 117), 5 of 6 transplanted children are in deep molecular response

Table 1
Clinical and biological characteristics of the children with accelerated phases and blastic phases at diagnosis of chronic myeloid leukaemia.

Characteristics	Accelerated phase (n = 19)	Blastic phase (n = 17)
Age: median, years (range)	12.7 (3–18)	11.1 (5–17)
Sex		
Female (%)	7 (37)	6 (35)
Male (%)	12 (63)	11 (65)
Splenomegaly (%)		
Median (cm) below the costal margin	18 (95%)	13 (76%)
n = 16 and n = 11, respectively	9 (1–20)	9.5 (4–20)
Leukocytes (10^9/L)	269 (5–657)	295 (37–653)
Haemoglobin (g/dL)	8.7 (5.1–11.5)	7.4 (2.2–12.3)
Blasts in blood (%)	6 (0–23.5)	32 (0–84)
Blasts in bone marrow (%)	7 (0–28)	48 (0–96)
Immunophenotype		
Lymphoid		13 (76%)
Myeloid	–	3(18%)
Unknown		1(6%)
Cytogenetics		
Additional cytogenetic abnormalities and/or variant translocation (%)	3/11* (27%)	6/16* (37.5%)
Transcript/protein		
b2a2	3 (16%)	6 (36%)
b3a2	4 (21%)	5 (28%)
Others	0	3 (18%)
p210	8 (42%)	3 (18%)
Unknown	4 (21%)	0
Extramedullary disease (%)		6 (35%) Leukaemia cutis (n = 1) Lymph nodes (n = 1) Myeloid sarcoma (n = 2) Central nervous system disease (n = 2)

and one patient, who was transplanted in progression to lymphoid blastic phase, is in uncontrolled disease at the last follow-up.

Thirteen patients diagnosed with *de novo* CML-AP were not transplanted including 8 of the 11 patients who were initially notified as CML-CP and reclassified as CML-AP. Three events (loss of CHR, loss of molecular response and progression to lymphoid blastic phase leading to the death of the patient) occurred in this cohort. Eleven patients are at least in MMR with a median follow-up of 53 months (range, 14–114). We have limited data on the mutational status of the BCR-ABL1 kinase domain before treatment and during therapy. No mutation was found when mutation analyses were performed in one patient who progressed to blastic phase (patient 3), in 2 slow responder patients (patients #15 and #19) and in one patient with a fluctuation of BCR-ABL1 transcript level without the loss of MMR (patient #11). With a median follow-up of 4.3 years (range: 8 months to 13.8 years), the probability of 5-year OS of the patients in CML-AP at diagnosis was 94% (95% confidence interval, CI: 65–99%) (Fig. 1).

For the 17 patients with *de novo* CML-BP, first-line treatment consisted of imatinib (n = 7), while 10 patients were treated as per the recommendations in children with a combination of chemotherapy with either imatinib or second-generation TKI [14]. Sixteen of 17 patients returned to CML-CP and achieved a CHR with a median time of 2 months (range, 1–4), whereas one patient did not respond (presence of F317L mutation). Eleven patients in CML-BP at diagnosis proceeded to HSCT with a median time of 7 months (range, 4–10 months) after diagnosis as recommended in children with CML-BP [14]. Donors were Human Leukocyte Antigen fully matched, unrelated in 8 patients and sibling donors in 3 patients. Five of them were transplanted after first-line treatment (TKI in combination with chemotherapy), and 6 patients received more than one line of therapy before transplantation because of no response (1 patient), toxicity (1 patient), no achievement of CCyR (2 patients) and relapse to blastic phase (2 patients). All of these patients were transplanted in chronic phase, CHR, CCyR or MMR. Relapse after HSCT occurred in 5 of 11 patients with a median time of 5 months (range, 3–17 months). With a median follow-up of 29 months (range, 5–108) after HSCT, 8 patients are alive in at least MMR and 3 patients died (progressive disease, n = 2; uncontrolled graft-versus-host disease, n = 1).

Six patients in CML-BP did not undergo HSCT. These patients achieved a CHR with 1 or 2 lines of treatment after a median time of 2 months (range, 2–3). One of them required a second line of treatment to achieve a MMR. Among these 6 patients, one patient died of relapse 7 months after diagnosis and the remaining 5 patients are alive in MMR or better response with a median follow-up of 28 months (range, 16–78 months). Mutation analyses of the BCR-ABL 1 domain kinase was performed in 2 patients in CM-BP phase at diagnosis (T315I: patient #21; no mutation found: patient #23) (Supplementary data). In 5 patients with no response or loss of response or switched for toxicity of the treatment, domain kinase mutation analyses were performed: mutations were found in all of them (T315I: patient #20; F317L: patients #28 and #22; G250E: patient #24 and E279K: patient #27) (Supplementary data). With a median follow-up of 52 months (range, 7–113 months), the probability of 5-year OS of all patients in CML-BP at diagnosis was 74% (95% CI: 44–89%) (Fig. 1). For the subgroup of the six non-transplanted patients, the median follow-up is 25 months (range 7–78 months) with a patient dying from disease at month 7 (pt # 31, Supplementary data).

4. Discussion

This is the largest database analysis describing the characteristics and outcome of childhood CML

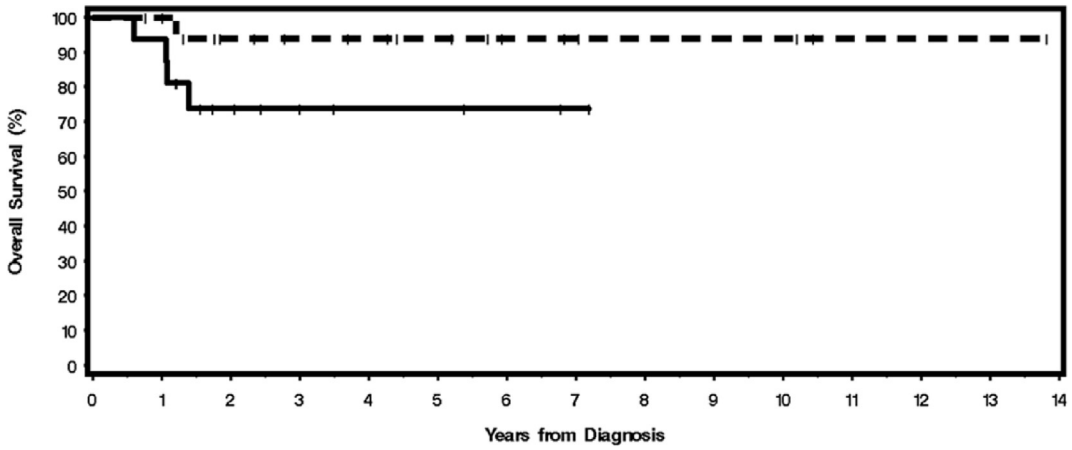

Fig. 1. Overall survival curve of the children and adolescents in accelerated phase (doted line) and blastic phase (solid line) at initial diagnosis of chronic myeloid leukaemia.

presenting in the advanced phase of the disease. According to the European Treatment and Outcome Study registry, 94.3% of the adults presented in chronic phase at diagnosis of CML, whereas the remaining 5.7% presented in accelerated (3.5%) or blastic (2.2%) phase [4]. A quite similar proportion is observed in children and adolescent according to the present study (4% and 3.5%, respectively).

A predominance of myeloid immunophenotype is observed in adults evolving from chronic to blastic phase under treatment [16,17]. In contrast to adults with CML, we previously observed a majority of lymphoid blast crisis in 21 children in CML-CP at initial diagnosis who transformed under TKI treatment from this CML-CP status [18]. Unfortunately, data regarding the immunophenotype is lacking in the rare series of adults who presented as *de novo* CML-BP [16,19,20]. In the present pediatric cohort, the lymphoid immunophenotype was predominantly observed (76%) in *de novo* blastic phase. We cannot exclude the possibility that some patients presented with a Ph + acute lymphoid blastic phase leukaemia rather than in *de novo* CML-BP with a lymphoid immunophenotype. In patients with Ph + lymphoid blasts, the detection of the BCR-ABL1 rearrangement in granulocytes by the interphase FISH technique was recently reported as a helpful decisive tool to prove the myeloid origin of the malignant clone and could be used prospectively [21]. The proportion of children (35%) in the present cohort with extramedullary disease seems to be higher than in the adult population [16,22]. This may in part be explained by the higher frequency of lymphoid blast crisis in the present cohort with a propensity of central nervous system disease.

Presentation with advanced stage of CML at diagnosis must be separated from CML-AP and CML-BP evolving under treatment. Dismal outcome is reported in adults treated after progression from CML-CP with a median survival in the range of 6–37 months and less than 12 months for patients with CML-AP and CML-BP, respectively [17,19,22,23]. HSCT can significantly improve the survival of some of these patients in advanced phases compared with TKI treatment alone [24,25]. Patients exhibiting a myeloid immunophenotype of CML-BP appear to have inferior survival compared with patients exhibiting the lymphoid immunophenotype, but this remains controversial in the adult population [16,22,26,27]. We previously reported an OS rate of 41% at 60 months in 21 children receiving imatinib for CML-CP who progressed to predominant lymphoid blastic phase [18].

Most of adult studies reported on advanced phases as events occurring in pretreated patients diagnosed in chronic phase with only a limited proportion (15–20%) of *de novo* CML-AP or CML-BP [16,19,22,23]. Interestingly, patients with *de novo* CML-AP or CML-BP seem to have better OS compared with patients who transformed from CML-CP or CML-AP [19,20,28]. In one of these studies, Geelen et al reported on a cohort of 15 adult patients who presented in advanced phase (8 CML-AP and 7 CML-BP) with 5-year OS rates of 38% and 57%, respectively [20]. Ohanian et al. reported an OS of 87% and 95% at 36 months in 51 adult patients with *de novo* CML-AP treated with imatinib or second generation TKI, respectively [28]. In another cohort of 71 adults with *de novo* CML-BP, the 5-year OS rate was 34% [19]. The good survival rates of pediatric patients with *de novo* CML-AP are consistent with these findings.

This analysis raised the question of compliance to our published recommendations: second generation tyrosine TKI as first-line therapy followed by HSCT in case of an available sibling donor for children with AP-CML, second generation TKI in combination with chemotherapy followed by HSCT with a sibling or an alternative donor for children with BP-CML [14]. However, it must be kept in mind that this publication came out in the year 2014 and thus could not be followed in the majority of patients analysed in our cohort. Most of our patients in advanced phase were treated upfront with TKIs alone (17/19 patients with CML-AP and 7/17 with CML-BP) with objective responses. Interestingly, a high rate of patients (17/19 of the patients with CML-AP and 16/17 of the patients with CML-BP) achieved a CHR with the first line of treatment including TKIs. Moreover, a high proportion of non-transplanted patients (11/13 of the patients with CML-AP and 5/6 of the patients in CML-BP) are alive with a notable follow-up including one patient treated for a myeloid blastic phase at diagnosis being alive in MMR with a follow-up of 28 months without HSCT. Among the 4 alive patients of a recently published cohort of 10 adults with myeloid blastic phase at presentation of CML, one patient is alive without transplantation with a follow-up of 43.6 months [29] Early HSCT could be avoided in some children with advanced phase at diagnosis and restricted to second or third line of treatment. However, because of the limited number of pediatric cases, further data collection is needed to determine the optimal treatment of advanced phases at diagnosis of CML in children and adolescents.

5. Conclusion

A quite similar frequency of advanced phase at diagnosis of CML is observed in children and adults. In contrast to the adult population, a predominance of a lymphoid immunophenotype is observed in pediatric patients with *de novo* CML-BP. The outcome of children and adolescents in advanced phase at diagnosis seems to be favorable even without HSCT in some cases. Upfront treatment recommendations for newly diagnosed CML-AP and CML-BP in pediatric patients are based on TKI, but the optimal treatment remains to be determined. Keeping in mind the small number of pediatric

cases analysed in this study, treatment approaches for advanced phases of CML diagnosed *de novo* in children might be different from progress of the disease under upfront TKI treatment.

Conflict of interest statement

None declared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejca.2019.03.020.

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