The Effect of Imatinib Mesylate on Patients with Philadelphia Chromosome-positive Chronic Myeloid Leukemia with Secondary Chromosomal Aberrations

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ABSTRACT

Purpose and Experimental Design: The acquisition of secondary chromosomal aberrations in chronic myeloid leukemia (CML) patients with Philadelphia chromosome-positive (Ph+) karyotype signifies clonal evolution associated with disease progression to accelerated/blastic phase. Therefore, these aberrations are of clinical and biological importance. We identified 58 cases with secondary abnormalities in addition to t(9;22)(q34;q11.2) or its variants in a review of 137 CML patients treated with imatinib mesylate (STI571). Clinically 13 patients were in chronic phase, 24 in accelerated phase, and 21 in blastic phase.

Results: More than 50% of cases showed the major routes of CML clonal evolution [+8, i(17q), +Ph, and/or +19]. The remainder exhibited minor routes of secondary abnormalities with −17/17p−, 11p−/rearr(11p), and −7/ rearr(7) as the most frequent abnormalities. Of particular interest, one case developed an inv(16)(p13q22) as a secondary abnormality during blastic transformation. The bone marrow was consistent with myelomonocytic morphology with eosinophilia. Cytogenetic responses to imatinib mesylate occurred in 15 of 58 (26%) patients; 12 achieved complete cytogenetic remission, 2 had a major response, and 1 had a minor response, with most responses noted within 3–6 months. Seven patients remain in remission >17–30 months, 2 patients relapsed between 12 and 19 months on therapy, and 1 patient was treated by bone marrow transplantation.

Conclusions: Although some Ph+ CML patients with clonal evolution can have a complete cytogenetic response to imatinib mesylate, responses tend to be brief, and such patients may benefit from subsequent stem cell transplantation. Therefore, CML patients with clonal evolution may require therapy additional to imatinib mesylate for maximal eradication of the Ph+ leukemic cells.

INTRODUCTION

CML is a clonal myeloproliferative disorder of pluripotential hematopoietic progenitor cells characterized by massive proliferation and accumulation of myeloid cells that differentiate normally (1, 2). The cytogenetic hallmark of CML is the Ph chromosome that results from a reciprocal t(9;22)(q34;q11.2) translocation or its variants t(V;9;22) (3). The molecular consequence of this translocation is the formation of the BCR/ABL gene fusion usually located on the Ph chromosome (4, 5). The BCR/ABL encodes a chimeric protein of M210,000, the predominant fusion protein in CML (6). Whereas the native c-abl protein is mainly nuclear and has tightly regulated kinase activity, the chimeric bcr/abl oncoprotein is localized in the cytoplasm and has a constitutively activated tyrosine kinase. Similar to other kinases, the bcr/abl functions by binding to ATP and transfers phosphate from ATP to tyrosine residues, activating multiple signal transduction pathways. The latter causes excessive cellular proliferation, arrests apoptosis, and decreases cellular adhesion. It has been shown that the enhanced tyrosine kinase activity of bcr/abl protein is essential for CML pathogenesis and is likely to represent the initiating event (7).

Clinically, CML progresses through three distinct phases: a chronic phase that is easily controlled followed by an ill-defined unstable accelerated phase, leading to a terminal blastic phase. The latter phase resembles acute leukemia and is highly refractory to chemotherapy with ≤20% response rate and a median survival of 3–6 months (8). The majority of CML patients show the Ph chromosome as the sole change throughout the chronic phase. As CML transforms to advanced phases, the Ph+ cells acquire new karyotypic abnormalities, most often a second copy of the Ph chromosome, i(17q), and trisomy 8 and 19. The increased genetic instability of the Ph+ leukemic clone facilitates the emergence of subclones with highly malignant phenotypes (9, 10).

The abbreviations used are: CML, chronic myeloid leukemia; Ph, Philadelphia; imatinib mesylate, signal transduction inhibitor 571 (STI571); KCI, Karmanos Cancer Institute; CCR, complete cytogenetic response; MCR, major cytogenetic response; FISH, fluorescence in situ hybridization; CR, cytogenetic response.
lines expressing bcr/abl and in vivo was also successful in eradicating bcr/abl-containing tumors in nude mice (12–14). Furthermore, initial clinical trials with STI571 demonstrated promising results in all phases of CML (15–17). In this study, we evaluated the effects of STI571 (Novartis, Pharma AG) therapy on CML patients with additional cytogenetic changes superimposed on the Ph chromosome as part of Phase II international clinical trials conducted at the KCI.

**MATERIALS AND METHODS**

**Patients.** Patients were enrolled into three Phase II clinical trials of STI571 for the treatment of CML in chronic phase after IFN-α failure, accelerated phase, and blastic phase. Some of these patients were treated on protocols of which the clinical results have been described recently, whereas others were treated on subsequent “expanded access” studies at the KCI. Briefly, male or female patients were eligible for the studies if they were ≥18 years of age and had a diagnosis of CML. The patients were required to be positive for Ph chromosome t(9;22)(q34;q11.2) or its variant t(V;9;22). CML patients who were Ph negative but BCR/ABL gene fusion-positive were also eligible. The chronic phase of CML was defined as the presence of ≤15% blasts, ≤20% basophils, and ≤30% blasts plus promyelocytes in the peripheral blood and marrow, and a platelet count of at least 100,000/mm³. In addition to the above criteria, CML patients were eligible for the chronic phase trial if they were resistant or refractory to a regimen containing IFN therapy. A failure of treatment with IFN was defined as lack of complete hematological response despite >6 months of IFN-α therapy (hematologic resistance), lack of CR (≥65% Ph+) after 1 year of therapy (cytogenetic resistance), or hematological or cytogenetic relapse. Patients with severe intolerance to IFN-α were also eligible. Accelerated phase CML was defined by at least 15% to <30% blasts, ≥30% blasts plus promyelocytes in peripheral blood or marrow, at least 20% peripheral basophils, or thrombocytopenia defined as platelet counts of <100,000/mm³, unrelated to therapy. CML in blastic phase was defined by at least 30% blasts in peripheral blood or marrow, or the presence of extramedullary disease other than liver or spleen enlargement. Patients with karyotypic evolution without other criteria of advanced disease were treated on chronic phase trials. All of the patients gave written informed consent to participate in the studies, and the studies were reviewed and approved by our Institutional Clinical Research Review Board. CML patients in studies, and the studies were reviewed and approved by our Institutional Clinical Research Review Board. CML patients in chronic phase received 400 mg of STI571 p.o. once a day, BP, blastic phase.

**Cytogenetic Analysis.** Cytogenetic studies were performed on metaphase cells derived from short-term unstimulated bone marrow aspirate or peripheral blood cultures. Briefly, colcemid was added to culture (0.05 μg/ml) for 1 h. After incubation in hypotonic solution for 30 min (0.075 M KCl), cells were fixed with a mixture of 3 parts methanol to 1 part glacial acetic acid. Metaphase cells were Q- or G-banded, and karyotypes were interpreted according to the 1995 International System for Human Cytogenetic Nomenclature (18). Chromosome analysis was performed before imatinib mesylate therapy and every 3 months thereafter to monitor the size and progression of the Ph+ clone. CRs were determined by the percentage of metaphase cells that were negative for the Ph chromosome. On the basis of analysis of 20 metaphase cells, CRs were classified as: CCR = all cells normal, MCR = >65% of cells normal, and minor CR = 1–65% of cells normal.

FISH was performed using LSI BCR (spectrum green)/ABL (spectrum orange) extra signal DNA probe (Vysis, Inc., Downers Grove, IL). The probe is useful for the detection of t(9;22)(q34;q11.2) or its variant in metaphase and interphase cells. In a Ph+ cell, the hybridization produces one fused yellow signal, two orange signals (native ABL and residual ABL), and one green signal (native BCR). The normal control produces two green and two orange signals. All of the details concerning pretreatment of slides and hybridization were carried out according to instructions accompanying the probes. The chromosomes were counterstained with 4′,6-diamidino-2-phenylindole and viewed with Zeiss Axioskop fluorescence microscope using triple excitation/emission bandpass filters. At least 200 nuclei and 10 metaphase cells were analyzed from each specimen. The cutoff value of this probe was >1%.

**RESULTS**

We have identified 58 cases Ph+ CML with secondary abnormalities in a review of 137 CML patients treated with STI571 at KCI as part of multicenter Phase II clinical trials. The characteristics of the patients are summarized in Table 1.

**Chromosome Analyses.** Chromosome analysis of the 58 patients revealed the presence of the classic Ph chromosome, t(9;22)(q34;q11.2), in 50 patients (86%). In 5 patients, the Ph chromosome originated through a complex variant translocation involving chromosomes 9 and 22, and a third chromosome. Three patients were lacking the Ph chromosome, but FISH testing revealed BCR/ABL gene fusion located on the normal-looking 22q. In addition to the Ph chromosome, all 58 of the cases demonstrated additional secondary numerical and/or structural abnormalities at the time of entry on these trials.

<table>
<thead>
<tr>
<th>Table 1 Characteristics of the 58 Patients</th>
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<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>Phase</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Sex</td>
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<td>Age</td>
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<td></td>
</tr>
<tr>
<td>WBC, baseline</td>
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<td></td>
</tr>
<tr>
<td>Platelet counts baseline</td>
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</tr>
</tbody>
</table>

<sup>a</sup> CP, chronic phase; AP, accelerated phase; BP, blastic phase.  
<sup>b</sup> No. of cases.  
<sup>c</sup> Years.  
<sup>d</sup> Cells/mm³.
CRs. CRs were observed in 15 of 58 (26%) CML patients with secondary chromosomal abnormalities who were treated with STI571. These 15 patients included 6 of 13 CP, 6 of 24 AP, and 3 of 21 BP patients. Their cytogenetic data are summarized in Table 2. A single additional abnormality was observed in 11 of 15 (74%) CR cases and 2 additional abnormalities in the other 4 cases. As seen in Table 2, none of the 15 CR cases had chromosome 7 or 5 abnormality. On the other hand, 30 of 43 (70%) non-CR cases had 2 or more additional abnormalities.

Of those 15 CR patients, 12 patients achieved a CCR. Three of the 12 patients with CCR had advanced disease, and 1 was in accelerated phase after relapse from allogeneic bone marrow transplantation (Table 2, case 11). CCRs were achieved as early as 3 months and as late as 15 months after the initiation of therapy. Eleven of the 12 patients who had a CCR tested negative for BCR/ABL gene fusion by FISH (Table 2). Three patients showed partial CRs, 2 major responses, and 1 minor response. Seven of 15 CR patients continue on STI571, in contrast to the majority of patients (9, 10). Because BCR/ABL alone is sufficient to initiate CML, one might assume that STI571 is an ideal therapy to block this genetic defect. Results from clinical trials have revealed that STI571 therapy is able to induce hematological remission in the vast majority of newly diagnosed CML patients and those in CP for whom previous IFN therapy.

### Table 2  Cytogenetics and BCR/ABL FISH analyses on 15 CML patients with cytogenetic responses

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Phase</th>
<th>Prior to ST1571</th>
<th>3m Ph:N&lt;sup&gt;a&lt;/sup&gt;</th>
<th>6m Ph:N</th>
<th>9m Ph:N</th>
<th>12m Ph:N</th>
<th>15m Ph:N</th>
<th>CR</th>
<th>Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CP</td>
<td>t(9;15;22),+8</td>
<td>4:16</td>
<td>3:17</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>A 30m+</td>
</tr>
<tr>
<td>2</td>
<td>CP</td>
<td>t(9;22),t(9;11)</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>A 24m+</td>
</tr>
<tr>
<td>3</td>
<td>CP</td>
<td>t(9;22),+21</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>A 30m+</td>
</tr>
<tr>
<td>4</td>
<td>CP</td>
<td>t(9;22),14q+</td>
<td>4:16</td>
<td>4:16</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>A progressed 12m</td>
</tr>
<tr>
<td>5</td>
<td>CP</td>
<td>t(9;22),inv(11)</td>
<td>20:0</td>
<td>2:18</td>
<td>6:14</td>
<td>12:8</td>
<td>0:20</td>
<td>CCR</td>
<td>A 30m+</td>
</tr>
<tr>
<td>6</td>
<td>CP</td>
<td>t(9;22),+8,+19</td>
<td>8:12</td>
<td>3:17</td>
<td>20:0</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>A 19 m+</td>
</tr>
<tr>
<td>7</td>
<td>AP</td>
<td>t(9;22),+8,+Ph</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>D 13m</td>
</tr>
<tr>
<td>8</td>
<td>AP</td>
<td>t(9;22),i(17q)</td>
<td>5:15</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>A progressed 19m</td>
</tr>
<tr>
<td>9</td>
<td>AP</td>
<td>t(9;22),i(Ph)</td>
<td>20:0</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>D 18 m</td>
</tr>
<tr>
<td>10</td>
<td>AP</td>
<td>t(9;22),+Ph</td>
<td>9:11</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>A 17 m+</td>
</tr>
<tr>
<td>11</td>
<td>AP</td>
<td>BCR:ABL+,i(17q)</td>
<td>BCR:ABL~</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>D 18m</td>
</tr>
<tr>
<td>12</td>
<td>AP</td>
<td>t(9;22),+8,8p~</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>A 30m+</td>
</tr>
<tr>
<td>13</td>
<td>BP</td>
<td>t(9;22),+8,6q~</td>
<td>12:8</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>mCR</td>
<td>D 7 m</td>
</tr>
<tr>
<td>14</td>
<td>BP</td>
<td>t(9;22),13q~</td>
<td>6:14</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>CCR</td>
<td>D 14 m</td>
</tr>
<tr>
<td>15</td>
<td>BP</td>
<td>t(9;20;22),+8</td>
<td>6:14</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>0:20</td>
<td>mCR</td>
<td>A 8 m</td>
</tr>
</tbody>
</table>

<sup>a</sup>Ph:N, ratio ph: normal based on analysis of 20 metaphases. BCR:ABL+, BCR:ABL fusion positive; BCR:ABL~, BCR:ABL fusion negative; AP, accelerated phase; BP, blastic phase; CP, chronic phase; CR, cytogenetic response; CCR, complete CR; MCR, major CR; mCR, minor CR; D, dead; A, alive; m, month.

These secondary abnormalities appeared exclusively in the Ph+ clone in all of the patients, a sign of clonal evolution. Most of the cases showed the major pathways of CML karyotypic evolution including an extra copy of the Ph chromosome in 25 cases, trisomy 8 in 21 cases, trisomy 19 in 7 cases, trisomy 21 in 7 cases, and isochromosome 17q in 5 cases. Other less frequent abnormalities observed in our cases were loss of 17p in 4 cases, rearrangement of 17q in 4 cases,+17 in 2 cases, loss/ rearrangement of chromosome 7 in 5 cases, rearrangement of chromosome 11 (mostly 11p) in 6 cases, and 8q− in 2 cases. Of particular interest, 1 patient had a pericentric inversion of chromosome 16, inv(16)(p13q22), as a secondary abnormality during blastic transformation of the disease. The bone marrow was morphologically and phenotypically consistent with myelomonocytic (M4) differentiation and eosinophilia. The karyotype of another case displayed a t(15;17)(q22;q25) translocation as an extra abnormality. Additional evaluation with FISH using the dual color PML/RARA DNA probes (Vysis Inc.) revealed that the PML gene was translocated to chromosome 17, but not fused with the RARA gene, indicating that the t(15;17) in this case differed from the usual form associated with acute promyelocytic leukemia. Of the 58 cases, 34 had more than one secondary aberration, and various combinations were seen at variable frequencies.

### DISCUSSION

The role of Ph chromosome in the development and pathogenesis of CML is well documented. Early in the chronic phase of CML, the Ph chromosome is likely the sole genetic event in the majority of patients (9, 10). Because BCR/ABL alone is sufficient to initiate CML, one might assume that STI571 is an ideal therapy to block this genetic defect. Results from clinical trials have revealed that STI571 therapy is able to induce hematological remission in the vast majority of newly diagnosed CML patients and those in CP for whom previous IFN therapy...
was either not successful or limited by toxicity (16, 19). The rate of MCR in patients with chronic-phase CML in whom treatment with IFN-\(\alpha\) had failed was \(\sim 60\%\). Among those patients, the IFN-intolerant subgroup responded most favorably to STI571, possibly because some of these patients had previously had CRs from the IFN therapy (19, 20). The CCR rate is even higher, \(\sim 70\%\), in newly diagnosed CML patients (21). However, in later-stage CML, the Ph+ clone of most cases acquires additional molecular and/or cytogenetic aberrations, driving the disease to more aggressive phenotypes (9, 10). Thus, MCR was observed in only 24% of patients in accelerated phase and 16% in blastic phase (17, 22, 23). Moreover, the remissions, particularly in blastic phase, were not durable, because most patients relapsed within a few months.

Is imatinib mesylate effective as a single agent in CML with additional cytogenetics changes? Our results suggest that there is a small subset of patients whose Ph+ leukemic cells remain sensitive to imatinib therapy despite the presence of additional abnormalities. Fifteen of the 58 (26%) patients in this study demonstrated CRs, of whom 7 maintained a complete remission with a follow-up ranging from 17 to 30 months. Other studies have reported similar CRs in accelerated and blastic phases defined by hematological criteria, a patient population with a high frequency of secondary cytogenetic abnormalities (17, 22, 23). Of considerable interest is the subgroup of patients in chronic phase clinically and hematologically but with clonal evolution. These patients are often faced with the decision about the advisability of immediate allogeneic transplantation versus awaiting the results of a trial with imatinib. Only 6 of 13 such patients had CRs in our series, and 2 of these responders have since had progressive disease. O’Dwyer et al. (24) reported recently on 15 patients in chronic-phase CML with clonal evolution noting CCRs in 9 of 15 patients (60%), which have been sustained for the relatively short follow-up of 1 year. Although it is possible that some secondary changes might remain more responsive to imatinib than others, this is difficult to discern from these relatively small patient numbers. CRs were noted in patients with an additional copy of the Ph chromosome as well as in some individuals with complex additional abnormalities. However, based on both of these series, it is clear that a sustained response in chronic-phase patients with clonal evolution is far from certain and that such individuals who are transplant candidates should be monitored closely for response should they elect an initial trial of imatinib. The finding that STI571 is effective in eradicating the Ph+ clone completely or partially in some patients with secondary aberrations supports the concept that the Ph+ clone is still dependent on bcr/abl tyrosine kinase for proliferation in these patients, and that the secondary genetic changes are not sufficient to drive the proliferation activity.

On the other hand, we observed a larger group of patients (43 of 58 patients, 74%) who did not attain a CR with STI571 therapy. The karyotype profile of those cases tended to be more complex than the CR cases. Follow-up study on the Ph+ non-responding CML patients revealed that the majority of patients also failed to respond clinically to STI571 or progressed after an initial brief response to therapy. One likely explanation for STI571 nonresponsiveness in such patients is that the Ph+ leukemic cells no longer depend on BCR/ABL for survival but proliferate as a consequence of the secondary genetic abnormalities arising within the Ph+ clone. These secondary genetic changes may provide alternative pathway signals to enhance proliferation despite effective targeting of BCR/ABL by STI571. An alternative possibility is that the Ph+ leukemic cells are a heterogeneous population, and STI571 promotes selection of an STI571-resistant clone that eventually becomes predominant. Both BCR/ABL and the other secondary genetic changes might drive the proliferation of this resistant clone.

The issue of resistance to STI571 has become a subject of intense interest and study (25–27). In a recent study by Gorre et al. (27), it was found that resistance to STI571 therapy was associated with reactivation of BCR/ABL signal transduction in all of the cases examined, caused either by gene amplification of BCR/ABL or point mutations in the BCR/ABL kinase domain. Later the same investigators found that mutations of BCR/ABL gene were common in both acquired and de novo-resistant CML (28). Other mechanisms of STI571 drug resistance have been suggested to include plasma sequestration of drug via \(\alpha\) 1 acid glycoprotein, multidrug resistance pathways, involvement of other protein kinases, and reentry of the bcr/abl protein in the cellular cytoplasm (29–31). On the basis of these findings, the mechanisms of STI571 resistance appear to be complex and possibly multifactorial. However, the observation that continued BCR/ABL signaling was present in most imatinib-resistant patients (27) suggests that alternative strategies directed at decreasing BCR/ABL should be pursued in such patients. The heat shock protein 90 inhibitor, 17-allylamino-demethoxygeldanamycin, has been shown to increase BCR/ABL catabolism in vitro, perhaps synergizing with imatinib in this regard, and studies evaluating this agent in combination with imatinib are planned (32).

In conclusion, the impact of additional genetic abnormalities on clinical response to STI571 therapy in CML has important clinical and biological implications. Our study suggests that in CML patients with secondary chromosomal abnormalities, STI571 therapy was capable to eradicate the Ph+ clone in a small subset of patients. Those patients may benefit from subsequent stem cell transplantation (33). However, in many patients, STI571 failed to induce cytogenetic remission suggesting that the Ph+ clone genetically evolved and escaped the dependence on bcr/abl kinase for proliferation. The limited activity of STI571 on CML patients with advanced genetic changes raises the need for combining STI571 with other therapeutic agents to enhance treatment outcome. Recently, in vitro studies have demonstrated either additive or synergistic effect for a number of agents used in combination with STI571, and several Phase I combined therapy clinical trials have been proposed (34, 35).

REFERENCES
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