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NCCN Clinical Practice Guidelines in Oncology (NCCN Guidelines®)

Chronic Myeloid Leukemia

Version 2.2017 — January 19, 2017

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NCCN Guidelines Version 2.2017 Panel Members

Chronic Myeloid Leukemia

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[Discussion](#)

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To find clinical trials online at NCCN Member Institutions, [click here: nccn.org/clinical_trials/physician.html](#).

NCCN Categories of Evidence and Consensus: All recommendations are category 2A unless otherwise specified.

See [NCCN Categories of Evidence and Consensus](#).

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NCCN Guidelines Version 2.2017 Updates

Chronic Myeloid Leukemia

Updates in Version 2.2017 of the NCCN Guidelines for Chronic Myeloid Leukemia from Version 1.2017 include:

[MS-1](#)

- The Discussion section has been updated to reflect the changes in the algorithm.

Updates in Version 1.2017 of the NCCN Guidelines for Chronic Myeloid Leukemia from Version 1.2016 include:

[General](#)

- Title of the Guidelines changed from "Chronic Myelogenous Leukemia" to "Chronic Myeloid Leukemia."
- Significant revisions were made to the formatting and presentation of the recommendations.
- Many footnotes were replaced with links to attachment pages (eg, toxicity pages).
- Many attachment pages shifted location from the previous version.
- Previous CML-C "Supportive Care Strategies for Leukocytosis and Thrombocytosis" was removed.

[CML-1](#)

- **Workup**
 - ▶ **Bullet 4 modified: "Bone marrow aspirate and biopsy" changed to "Bone marrow evaluation."**
 - ◊ First sub-bullet modified "*Aspirate and biopsy for morphologic review*"
 - ◊ "Percent blasts" and "Percent basophils" deleted.
 - ▶ **Bullet 5, Cytogenetics**
 - ◊ The following was added to FISH: "blood, if bone marrow not available."
 - ▶ **Bullet 6 added: Molecular**
 - ◊ First sub-bullet modified: "Quantitative RT-PCR (QPCR) using International Scale (IS) for *BCR-ABL1* (blood or bone marrow)"
 - ▶ **Bullet 7 added: "ECG for prolonged QTc"**
 - ▶ **Bullet 8 added: "Hepatitis panel"**
 - ▶ **The following bullets were removed:**
 - ◊ "Determine risk score"
 - ◊ "Human leukocyte antigen (HLA) testing, if considering HCT"
 - ▶ Any corresponding footnotes to deleted text were removed.
- **Column heading of "Clinical Presentation" added.**
 - ▶ Ph negative and *BCR-ABL1* negative: link added to the NCCN Guidelines for Myeloproliferative Neoplasms.
- **Column heading of "Additional Evaluation" added.**
 - ▶ Ph positive or *BCR-ABL1* positive; Chronic phase CML:
 - ◊ "Determine risk score" added with link to CML-A.
 - ▶ Ph positive or *BCR-ABL1* positive; Advanced Phase CML: Additional Evaluation added for Accelerated and Blast Phase.
 - ◊ **Additional testing includes:**
 - Flow cytometry to determine cell lineage
 - Mutational analysis
 - HLA testing, if considering allogeneic HCT



NCCN Guidelines Version 2.2017 Updates

Chronic Myeloid Leukemia

Updates in Version 1.2017 of the NCCN Guidelines for Chronic Myeloid Leukemia from Version 1.2016 include:

[CML-2](#)

- Primary treatment recommendations were differentiated based on risk score.
 - ▶ Low-risk score: "Clinical trial" added
 - ▶ Intermediate- or high-risk score: Nilotinib and Dasatinib are noted as preferred. Imatinib and clinical trial are also included as options.
- Treatment considerations were added:
 - ▶ "Patient comorbidities and drug toxicities"
 - ▶ "Monitor response"
 - ▶ "Evaluate patient compliance and drug interactions"
 - ▶ "Early toxicity monitoring"
 - ▶ Footnote "e" added: "Preliminary data from these studies also suggest that patients with an intermediate- or high-risk Sokal or Hasford score may preferentially benefit from dasatinib or nilotinib. See Discussion for additional information."

[CML-3](#)

- This is a new page that replaces previous pages CML-3 through CML-5.
- It is a visual guide to clinical considerations and treatment options based on response milestones and *BCR-ABL1* (IS) values.
- Footnote "h" is new to the page: "Patients with *BCR-ABL1* only slightly >10% at 3 months and/or with a steep decline from baseline, may achieve <10% at 6 months and have generally favorable outcomes. Therefore, it is important to interpret the value at 3 months in this context, before making drastic changes to the treatment strategy."
- Footnote "i" is new to the page: "Achievement of response milestones must be interpreted within the clinical context. Patients with more than 50% reduction compared to baseline or minimally above the 10% cutoff can continue the same dose of dasatinib or nilotinib for another 3 months."
- Footnote "j" is new to the page: "Discontinuation of TKI with careful monitoring is feasible in selected patients. See Discontinuation of TKI Therapy (CML-D)."

[CML-4](#)

- This page now addresses Advanced phase CML (previously addressed on page CML-5).
- Workup moved to page CML-1.
- "Blast crisis" changed to "Blast phase."
- Treatment considerations were added:
 - ▶ "Role of allogeneic HCT should be discussed based on response."
 - ▶ "Disease progression to advanced phase while on TKI therapy has worse prognosis than presenting with advanced phase CML."
 - ▶ "Treatment options are based on patient comorbidities and age."
 - ▶ "Selection of TKI is based on prior therapy and/or *BCR-ABL* mutation profile."
 - ▶ "CNS involvement has been described in blast phase-CML. Lumbar puncture and CNS prophylaxis is recommended for lymphoid blast phase."
- Footnote "k" added: Omacetaxine is a treatment option for patients with disease progression to accelerated phase CML. Omacetaxine is not a treatment option for patients that present with accelerated phase CML.



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Updates in Version 1.2017 of the NCCN Guidelines for Chronic Myeloid Leukemia from Version 1.2016 include:

[CML-5](#)

- This is a new page that replaces previous page CML-6.
- Recommended treatment options based on *BCR-ABL1* mutation profiles are presented in a table versus an algorithm format.

[CML-6](#)

- Not in CCyR or in relapse: "Monitored withdrawal of immune suppression" removed.
- Follow-up Therapy: The following guidance was added to TKI "choice depending on prior TKI, tolerance, mutation profile, post HCT morbidities."
- Footnote "o" modified: "Indications for allogeneic HCT: Advanced phase CML at presentation or disease progression to blast phase. Outcomes of allogeneic HCT are dependent on age and comorbidities, donor type, and transplant center."
- Footnote "q" modified: ~~"There are data to support the use of posttransplant imatinib but not in patients who have disease that previously failed imatinib. Other TKIs may be more appropriate. Very limited data are available on the use of dasatinib and nilotinib in a small number of patients with posttransplant relapse. There are no data for the use of bosutinib, or omacetaxine for patients posttransplant. In patients who have disease that has failed prior TKI therapy, see CML-5 for the selection of posttransplant TKI."~~

[CML-B](#)

- World Health Organization (WHO) Criteria updated.

[CML-D 1 OF 2](#)

- This page was previously CML-A.
- Recommendation for bone marrow cytogenetics changed:
 - ▶ At diagnosis
 - ▶ Failure to reach response milestones
 - ▶ Any sign of loss of response (defined as hematologic or cytogenetic relapse)
- Quantitative RT-PCR (QPCR) using IS noted as preferred. If QPCR not available, referred to CML-D 2 of 2.
 - ▶ Bullet 2 modified: Every 3 months after initiating treatment. ~~After CCyR *BCR-ABL1* 0.1% - <1% (IS) has been achieved, every 3 months for 2 years and every 3–6 months thereafter.~~
 - ▶ Bullet 3 modified: If there is 1-log increase in *BCR-ABL1* transcript levels with MMR, QPCR ~~analysis~~ should be repeated in 1–3 months.
- *BCR-ABL* kinase domain mutation analysis
 - ▶ Chronic phase
 - ◊ Sub-bullet 1 "Inadequate initial response to TKI therapy (lack of PCyR or *BCR-ABL1* transcripts >10% [IS] at 3 and 6 months or less than a CCyR or *BCR-ABL1* transcripts >1% [IS] at 12 months)" replaced with "Failure to reach response milestones"

[CML-D 2 OF 2](#)

- Addresses cytogenetic assessment of response, if QPCR is not available.

[CML-F](#)

- This is a new page addressing discontinuation of TKI therapy, including criteria for TKI discontinuation.

[CML-G](#)

- This is a new landing page with a link to the toxicity pages.



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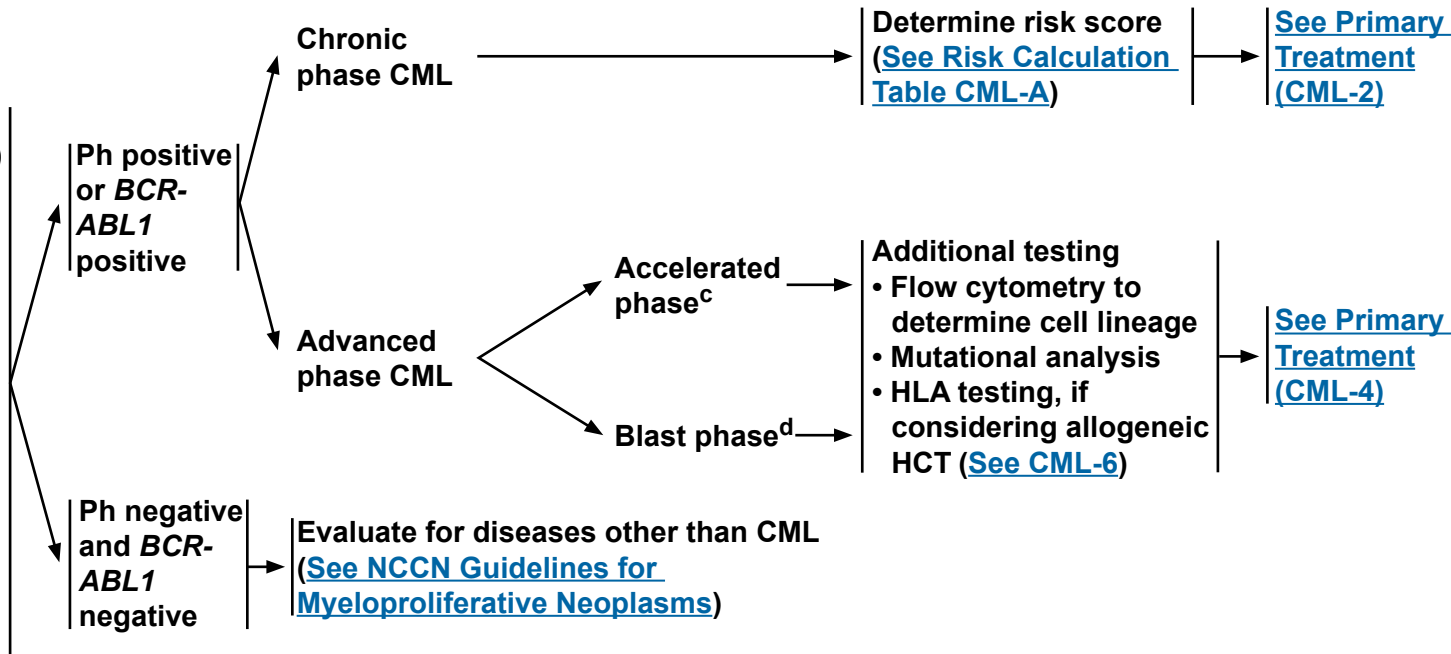
Chronic Myeloid Leukemia

WORKUP

- H&P, including spleen size by palpation (cm below costal margin)
- CBC with differential, platelets
- Chemistry profile
- Bone marrow evaluation^a
 - Aspirate and biopsy for morphologic review
- Cytogenetics
 - FISH (blood, if bone marrow not available)^b
- Molecular
 - Quantitative RT-PCR (QPCR) using International Scale (IS) for *BCR-ABL1* (blood)
- ECG for prolonged QTc
- Hepatitis panel

CLINICAL PRESENTATION

ADDITIONAL EVALUATION



^aBone marrow evaluation should be done for the initial workup, not only to provide morphologic review, but also to detect chromosomal abnormalities that are not detectable on peripheral blood FISH.

^bSee [Discussion](#) for further details.

^c[See Definitions of Accelerated Phase \(CML-B\)](#).

^d[See Definitions of Blast Phase \(CML-C\)](#).

Note: All recommendations are category 2A unless otherwise indicated.

Clinical Trials: NCCN believes that the best management of any patient with cancer is in a clinical trial. Participation in clinical trials is especially encouraged.

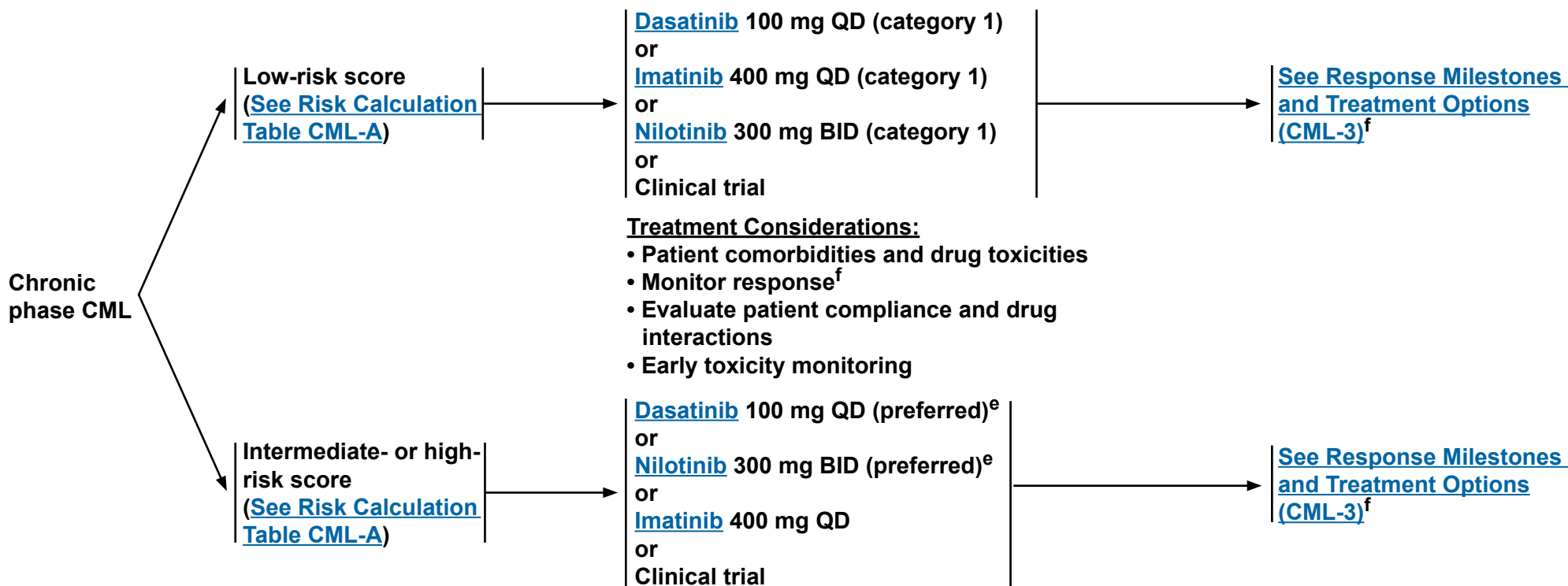


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CLINICAL PRESENTATION

PRIMARY TREATMENT



^ePreliminary data suggest that patients with an intermediate- or high-risk Sokal or Hasford score may preferentially benefit from dasatinib or nilotinib. See [Discussion](#) for additional information.

^fSee [Monitoring Response to TKI Therapy and Mutational Analysis \(CML-D\)](#).

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Chronic Myeloid Leukemia

RESPONSE MILESTONES^{f,9}

| <i>BCR-ABL1</i> (IS) | 3 months | 6 months | 12 months | >12 months |
|----------------------|----------|----------|-----------|------------|
| >10% ^h | YELLOW | RED | | |
| 1%–10% | GREEN | | YELLOW | RED |
| 0.1%–<1% | GREEN | | | YELLOW |
| <0.1% | GREEN | | | |

CLINICAL CONSIDERATIONS

SECOND-LINE AND SUBSEQUENT TREATMENT OPTIONS

| | | |
|---------------|--|--|
| RED | <ul style="list-style-type: none"> Evaluate patient compliance and drug interactions Mutational analysis | Switch to alternate TKI (CML-5) and Evaluate for HCT (CML-6) |
| YELLOW | <ul style="list-style-type: none"> Evaluate patient compliance and drug interactions Mutational analysis | Switch to alternate TKI (CML-5) or Continue same TKI (CML-G) ⁱ or Dose escalation of imatinib (to a max of 800 mg) and Evaluate for HCT (CML-6) |
| GREEN | <ul style="list-style-type: none"> Monitor response (CML-D) and side effects | Continue same TKI (CML-G) ^j |

^fSee [Monitoring Response to TKI Therapy and Mutational Analysis \(CML-D\)](#).

⁹See [Criteria for Hematologic, Cytogenetic, and Molecular Response and Relapse \(CML-E\)](#).

^hPatients with *BCR-ABL1* only slightly >10% at 3 months and/or with a steep decline from baseline, may achieve <10% at 6 months and have generally favorable outcomes. Therefore, it is important to interpret the value at 3 months in this context, before making drastic changes to the treatment strategy.

ⁱAchievement of response milestones must be interpreted within the clinical context. Patients with more than 50% reduction compared to baseline or minimally above the 10% cutoff can continue the same dose of dasatinib or nilotinib for another 3 months.

^jDiscontinuation of TKI with careful monitoring is feasible in selected patients. See [Discontinuation of TKI Therapy \(CML-F\)](#).

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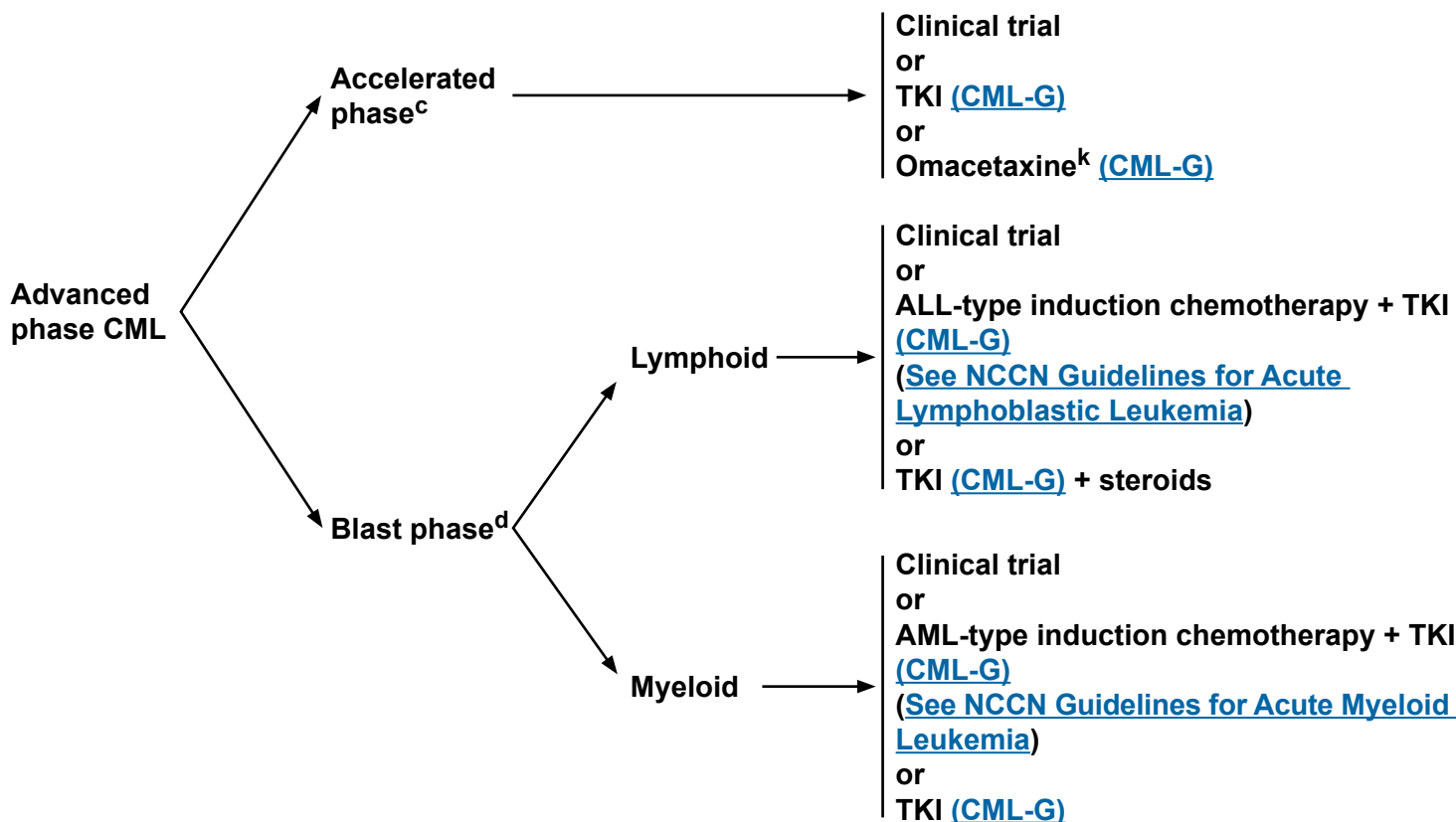


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CLINICAL PRESENTATION

PRIMARY TREATMENT



Treatment Considerations

- Role of [allogeneic HCT](#) should be discussed based on response.
- Disease progression to advanced phase while on TKI therapy has worse prognosis than presenting with advanced phase CML.
- Treatment options are based on patient comorbidities and age.
- Selection of TKI is based on prior therapy and/or BCR-ABL [mutation profile](#).
- CNS involvement has been described in blast phase CML. Lumbar puncture and CNS prophylaxis is recommended for lymphoid blast phase.

^cSee [Definitions of Accelerated Phase \(CML-B\)](#).

^dSee [Definitions of Blast Phase \(CML-C\)](#).

^kOmacetaxine is a treatment option for patients with disease progression to accelerated phase CML. Omacetaxine is not a treatment option for patients that present with accelerated phase CML.

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TREATMENT OPTIONS BASED ON BCR-ABL1 MUTATION PROFILE

| Mutation | Treatment Recommendation ¹ |
|--|--|
| Y253H, E255K/V, or F359V/C/I | Dasatinib |
| F317L/V/I/C, T315A, or V299L | Nilotinib |
| E255K/V, F317L/V/I/C, F359V/C/I, T315A, or Y253H | Bosutinib |
| T315I | Ponatinib , ^m Omacetaxine , ⁿ allogeneic HCT (CML-6) or clinical trial |

¹Patients with disease that is resistant to primary treatment with imatinib should be treated with nilotinib, dasatinib, or bosutinib in the second-line setting. Patients with disease that is resistant to primary treatment with nilotinib or dasatinib could be treated with an alternate TKI (other than imatinib) in the second-line setting.

^mPonatinib is a treatment option for patients with a T315I mutation or for patients for whom no other TKI is indicated

ⁿOmacetaxine is a treatment option for patients with disease that is resistant and/or intolerant to 2 or more TKIs.

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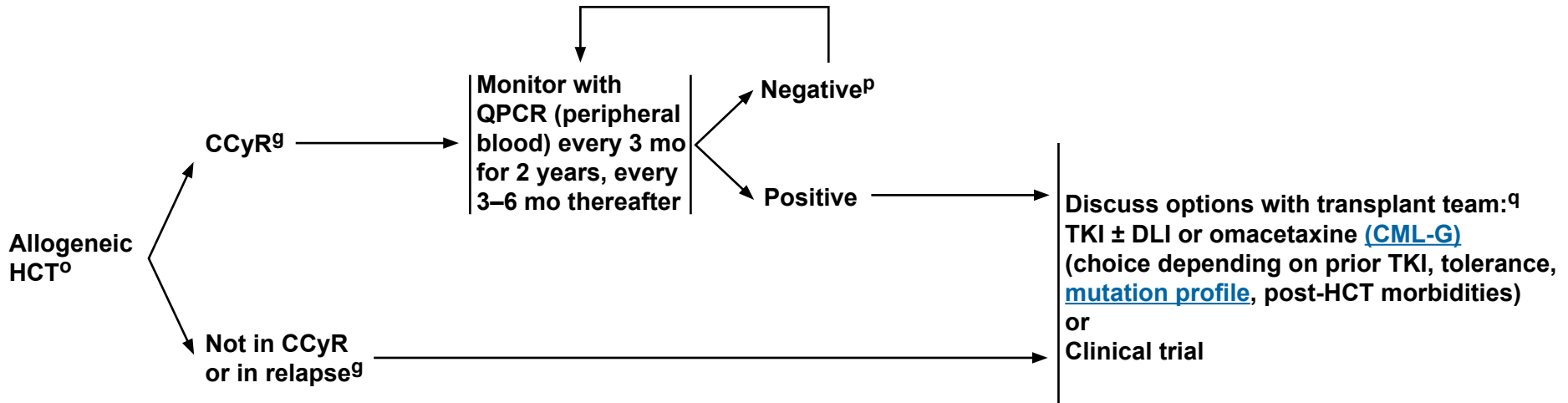
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FOLLOW-UP THERAPY



^ᑈSee [Criteria for Hematologic, Cytogenetic, and Molecular Response and Relapse \(CML-E\)](#).

^ᑍIndications for allogeneic HCT: Advanced phase CML at presentation or disease progression to blast phase. Outcomes of allogeneic HCT are dependent on age and comorbidities, donor type, and transplant center.

^ᑎIn patients with prior accelerated or blast phase, consider TKI therapy post-HCT for at least one year.

^ᑏIn patients who have disease that has failed prior TKI therapy, see [CML-5](#) for the selection of post-HCT TKI.

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Chronic Myeloid Leukemia

RISK CALCULATION TABLE

| Study | Calculation | Risk Definition by Calculation | |
|----------------------------------|--|--------------------------------|------------|
| Sokal et al, 1984 ¹ | $\text{Exp } 0.0116 \times (\text{age in years} - 43.4) + (\text{spleen} - 7.51) + 0.188 \times [(\text{platelet count} \div 700)^2 - 0.563] + 0.0887 \times (\text{blast cells} - 2.10)$ | Low | <0.8 |
| | | Intermediate | 0.8 - 1.2 |
| | | High | >1.2 |
| Hasford et al, 1998 ² | 0.666 when age \geq 50 years + (0.042 x spleen) + 1.0956 when platelet count $>$ 1500 x 10⁹/L + (0.0584 x blast cells) + 0.20399 when basophils $>$ 3% + (0.0413 x eosinophils) x 100 | Low | \leq 780 |
| | | Intermediate | 781 - 1480 |
| | | High | >1480 |

Calculation of relative risk found at <http://www.icsg.unibo.it/rccalc.asp>. Age is in years. Spleen is in centimeter below the costal margin (maximum distance). Blast cells, eosinophils, and basophils are in percents of peripheral blood differential. All factors must be collected prior to any treatment.

Reprinted with permission. © 2009 American Society of Clinical Oncology. All Rights Reserved. Baccarani M, Cortes J, Pane F, Niederwieser D, et al. European LeukemiaNet. Chronic myeloid leukemia: an update of concepts and management recommendations of European LeukemiaNet. J Clin Oncol 2009;27(35):6041-6051.

¹Sokal J, Cox E, Baccarani M, et al. Prognostic discrimination in "good-risk" chronic granulocytic leukemia. Blood 1984;63:789-799. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/6584184>.

²Hasford J, Pfirrmann M, Hehlmann R, et al. A new prognostic score for survival of patients with chronic myeloid leukemia treated with interferon alfa. Writing Committee for the Collaborative CML Prognostic Factors Project Group. J Natl Cancer Inst 1998;90:850-858. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/9625174>.

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DEFINITIONS OF ACCELERATED PHASE^{1,2}

Modified Criteria Used at MD Anderson Cancer Center^{3,4} (most commonly used in clinical trials)

- Peripheral blood blasts $\geq 15\%$ and $< 30\%$
- Peripheral blood blasts and promyelocytes combined $\geq 30\%$
- Peripheral blood basophils $\geq 20\%$
- Platelet count $\leq 100 \times 10^9/L$ unrelated to therapy
- Clonal evolution

World Health Organization (WHO) Criteria⁵ (most commonly used by pathologists)

Any 1 or more of the following hematologic/cytogenetic criteria or response-to-TKI criteria:

- | | |
|--|---|
| <ul style="list-style-type: none"> • Persistent or increasing WBC ($>10 \times 10^9/L$), unresponsive to therapy • Persistent or increasing splenomegaly, unresponsive to therapy • Persistent thrombocytosis ($>1000 \times 10^9/L$), unresponsive to therapy • Persistent thrombocytopenia ($<100 \times 10^9/L$) unrelated to therapy • 20% or more basophils in the peripheral blood • 10%–19% blasts* in the peripheral blood and/or bone marrow • Additional clonal chromosomal abnormalities in Ph+ cells at diagnosis that include “major route” abnormalities (second Ph, trisomy 8, isochromosome 17q, trisomy 19), complex karyotype, or abnormalities of 3q26.2 • Any new clonal chromosomal abnormality in Ph+ cells that occurs during therapy | <p>“Provisional” response-to-TKI criteria</p> <ul style="list-style-type: none"> • Hematologic resistance to the first TKI (or failure to achieve a complete hematologic response** to the first TKI); or • Any hematologic, cytogenetic, or molecular indications of resistance to 2 sequential TKIs; or • Occurrence of 2 or more mutations in BCR-ABL1 during TKI therapy |
|--|---|

*The finding of bona fide lymphoblasts in the blood or marrow, even if 10%, should prompt concern that lymphoblastic transformation may be imminent and warrants further clinical and genetic investigation; 20% or more blasts in blood or BM, or an infiltrative proliferation of blasts in an extramedullary site is CML, blast phase.

**Complete hematologic response: WBC, $<10 \times 10^9/L$; platelet count, $<450 \times 10^9/L$, no immature granulocytes in the differential, and spleen nonpalpable.

¹The table refers to myeloblasts. Any increase in lymphoblasts is concerning for (nascent) blast phase.

²Sokal criteria (Sokal JE, Baccarani M, Russo D, et al. Staging and prognosis in chronic myelogenous leukemia. *Semin Hematol* 1988;25:49-61) and IBMTR criteria (Savage DG, Szydlo RM, Chase A, et al. Bone marrow transplantation for chronic myeloid leukemia: The effects of differing criteria for defining chronic phase on probabilities of survival and relapse. *Br J Haematol* 1997;99:30-35) are historically used when HCT is the recommended treatment option.

³Kantarjian HM, Deisseroth A, Kurzrock R, et al. Chronic myelogenous leukemia: A concise update. *Blood* 1993;82:691-703.

⁴Talpaz M, Silver RT, Druker BJ, et al. Imatinib induces durable hematologic and cytogenetic responses in patients with accelerated phase chronic myeloid leukemia: results of a phase 2 study. *Blood* 2002;99:1928-1937.

⁵Arber DA, Orazi A, Hasserjian R, et al. The 2016 revision to the World Health Organization classification of myeloid neoplasms and acute leukemia. *Blood* 2016;127:2391-2405.

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DEFINITIONS OF BLAST PHASE¹

| World Health Organization (WHO) Criteria ² | International Bone Marrow Transplant Registry ³ |
|---|---|
| <ul style="list-style-type: none"> • Blasts $\geq 20\%$ of peripheral white blood cells or of nucleated bone marrow cells • Extramedullary blast proliferation • Large foci or clusters of blasts in the bone marrow biopsy | <ul style="list-style-type: none"> • $\geq 30\%$ blasts in the blood, marrow, or both • Extramedullary infiltrates of leukemic cells |

¹The table refers to myeloblasts. Any increase in lymphoblasts is concerning for (nascent) blast crisis.

²From Jaffe ES, Harris NL, Stein H, et al. WHO Classification of Tumours, Pathology, and Genetics of Tumours of Haematopoietic and Lymphoid Tissues, IARC, Lyon, 2001.

³Druker BJ. Chronic Myelogenous Leukemia In: DeVita VT, Lawrence TS, Rosenberg SA, eds. DeVita, Hellman, and Rosenberg's Cancer: Principles & Practice of Oncology. Vol. 2 (ed 8): Lippincott, Williams and Wilkins; 2007:2267-2304.

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MONITORING RESPONSE TO TKI THERAPY AND MUTATIONAL ANALYSIS

| Test | Recommendation |
|---|---|
| Bone marrow cytogenetics ¹ | <ul style="list-style-type: none"> • At diagnosis • Failure to reach response milestones • Any sign of loss of response (defined as hematologic or cytogenetic relapse) |
| Quantitative RT-PCR (QPCR) using IS (preferred, if available) If QPCR (IS) not available, see CML-D 2 of 2) | <ul style="list-style-type: none"> • At diagnosis • Every 3 months after initiating treatment. After <i>BCR-ABL1</i> 0.1% – <1% (IS) has been achieved, every 3 months for 2 years and every 3–6 months thereafter • If there is 1-log increase in <i>BCR-ABL1</i> transcript levels with MMR, QPCR should be repeated in 1–3 months |
| BCR-ABL kinase domain mutation analysis | <ul style="list-style-type: none"> • Chronic phase <ul style="list-style-type: none"> ▶ Failure to reach response milestones ▶ Any sign of loss of response (defined as hematologic or cytogenetic relapse) ▶ 1-log increase in <i>BCR-ABL1</i> transcript levels and loss of MMR • Disease progression to accelerated or blast phase |

¹FISH has been inadequately studied for monitoring response to treatment.

Note: All recommendations are category 2A unless otherwise indicated.

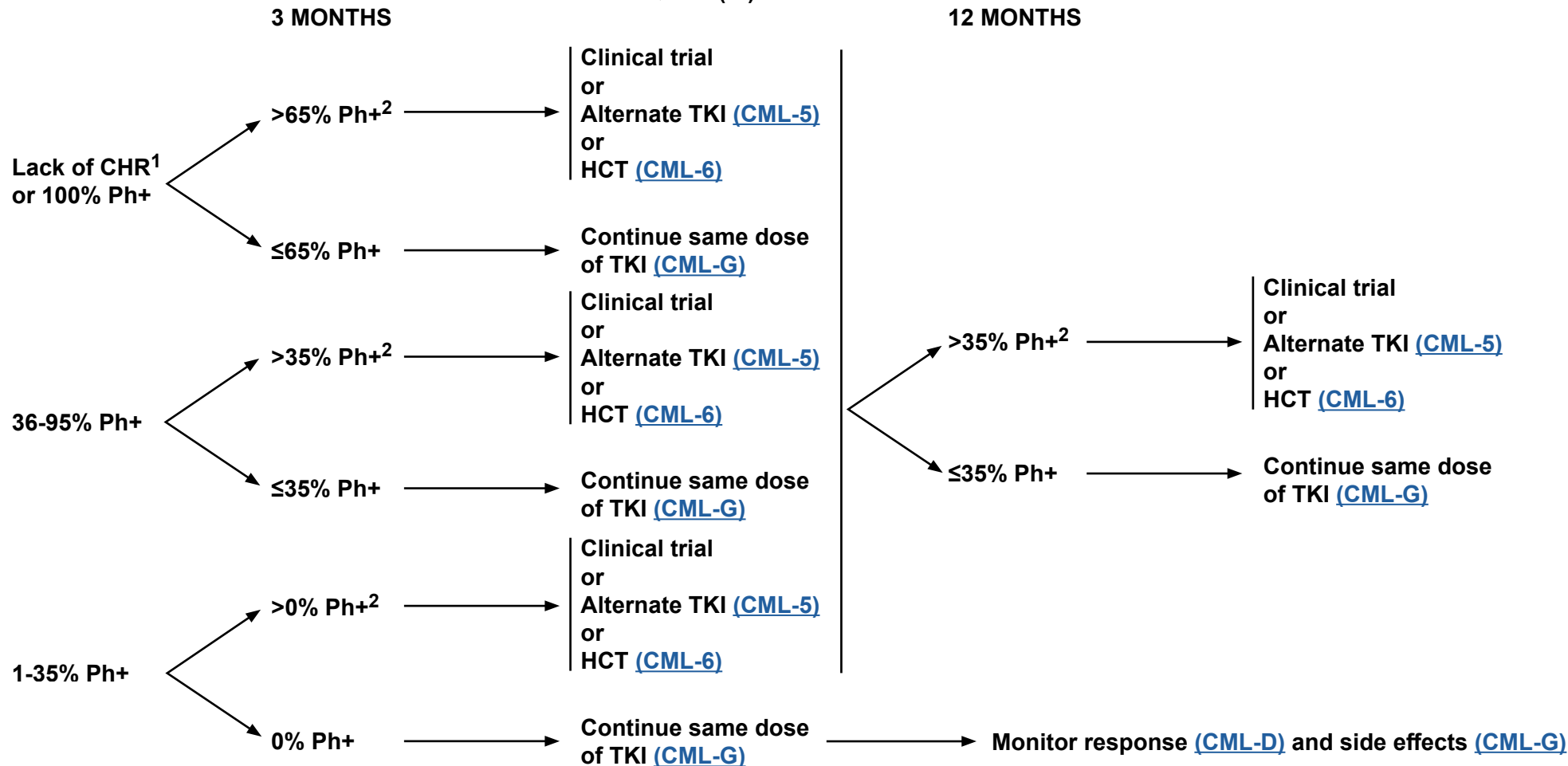
Clinical Trials: NCCN believes that the best management of any patient with cancer is in a clinical trial. Participation in clinical trials is especially encouraged.



NCCN Guidelines Version 2.2017

Chronic Myeloid Leukemia

CYTOGENETIC ASSESSMENT OF RESPONSE TO TKI THERAPY IF QPCR (IS) NOT AVAILABLE



¹See [Criteria for Hematologic, Cytogenetic, and Molecular Response and Relapse \(CML-E\)](#).

²Evaluate patient compliance and drug interactions. Perform mutational analysis.

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Clinical Trials: NCCN believes that the best management of any patient with cancer is in a clinical trial. Participation in clinical trials is especially encouraged.



CRITERIA FOR HEMATOLOGIC, CYTOGENETIC, AND MOLECULAR RESPONSE AND RELAPSE

Complete hematologic response¹

- Complete normalization of peripheral blood counts with leukocyte count $<10 \times 10^9/L$
- Platelet count $<450 \times 10^9/L$
- No immature cells, such as myelocytes, promyelocytes, or blasts in peripheral blood
- No signs and symptoms of disease with disappearance of palpable splenomegaly

Cytogenetic response^{2,3}

- Complete Cytogenetic Response (CCyR) - No Ph-positive metaphases
- Partial Cytogenetic Response (PCyR) - 1%–35% Ph-positive metaphases
- Major Cytogenetic Response - 0%–35% Ph-positive metaphases (complete + partial)
- Minor Cytogenetic Response - $>35\%$ Ph-positive metaphases

Molecular response^{4,5}

- Early molecular response (EMR) - *BCR-ABL1* $\leq 10\%$ (IS) at 3 and 6 months
- Major molecular response (MMR) - *BCR-ABL1* $<0.1\%$ (IS) or ≥ 3 -log reduction in *BCR-ABL1* mRNA from the standardized baseline, if QPCR (IS) is not available
- Complete molecular response (CMR) - no detectable *BCR-ABL1* mRNA using a QPCR assay with a sensitivity of at least 4.5 logs below the standardized baseline. CMR is variably described, and is best defined by the the assay's level of sensitivity (eg, MR 4.5).

Relapse

- Any sign of loss of response (defined as hematologic or cytogenetic relapse)
- 1-log increase in *BCR-ABL1* transcript levels with loss of MMR should prompt bone marrow evaluation for loss of CCyR but is not itself defined as relapse.

¹Faderl S et al: Chronic myelogenous leukemia: Biology and therapy. Ann Intern Med 1999;131:207-219. The American College of Physicians-American Society of Internal Medicine is not responsible for the accuracy of the translation.

²A minimum of 20 metaphases should be examined.

³O'Brien SG, Guilhot F, Larson RA, et al. Imatinib compared with interferon and low-dose cytarabine for newly diagnosed chronic-phase chronic myeloid leukemia. N Engl J Med 2003;348:994-1004.

⁴Hughes TP, Kaeda J, Branford S, et al. Frequency of major molecular responses to imatinib or interferon alfa plus cytarabine in newly diagnosed chronic myeloid leukemia. N Engl J Med 2003;349:1423-1432.

⁵Hughes T, Deininger M, Hochhaus A, et al. Monitoring CML patients responding to treatment with tyrosine kinase inhibitors: review and recommendations for harmonizing current methodology for detecting BCR-ABL transcripts and kinase domain mutations and for expressing results. Blood 2006;108:28-37.

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DISCONTINUATION OF TKI THERAPY

- Discontinuation of TKI therapy appears to be safe in select CML patients.
- Clinical studies that have evaluated the safety and efficacy of TKI discontinuation have employed strict eligibility criteria and have mandated more frequent molecular monitoring than typically recommended for patients on TKI therapy.
- Some patients have experienced significant adverse events that are believed to be due to TKI discontinuation.
- Discontinuation of TKI therapy should only be performed in consenting patients after a thorough discussion of the potential risks and benefits.
- Outside of a clinical trial, TKI discontinuation should be considered only if ALL of the criteria included in the list below are met.

Criteria for TKI Discontinuation

- Age ≥ 18 years.
- Chronic phase CML. No prior history of accelerated or blast phase CML.
- On approved TKI therapy (imatinib, dasatinib, nilotinib, bosutinib, or ponatinib) for at least three years.
- Prior evidence of quantifiable *BCR-ABL1* transcript.
- Stable molecular response (MR4; $\leq 0.01\%$ IS) for ≥ 2 years, as documented on at least four tests, performed at least three months apart.
- No history of resistance to any TKI.
- Access to a reliable QPCR test with a sensitivity of detection of ≥ 4.5 logs that reports results on the IS and provides results within 2 weeks. Monthly molecular monitoring for the first six months following discontinuation, bimonthly during months 7–24, and quarterly thereafter (indefinitely) for patients who remain in MMR (MR3; $\leq 0.1\%$ IS).
- Consultation with a CML Specialty Center to review the appropriateness for TKI discontinuation and potential risks and benefits of treatment discontinuation, including TKI withdrawal syndrome.
- Prompt resumption of TKI, with a monthly molecular monitoring for the first six months following resumption of TKI and every 3 months thereafter is recommended indefinitely for patients with a loss of MMR. For those who fail to achieve MMR after six months of TKI resumption, *BCR-ABL1* kinase domain mutation testing should be performed, and monthly molecular monitoring should be continued for another six months.
- Reporting of the following to a member of the NCCN CML panel is strongly encouraged:
 - ▶ Any significant adverse event believed to be related to treatment discontinuation.
 - ▶ Progression to accelerated or blast phase CML at any time.

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NCCN Guidelines Version 2.2017

Chronic Myeloid Leukemia

MANAGEMENT OF TOXICITIES

[BOSUTINIB \(CML-G 1 of 6\)](#)

[DASATINIB \(CML-G 2 of 6\)](#)

[IMATINIB \(CML-G 3 of 6\)](#)

[NILOTINIB \(CML-G 4 of 6\)](#)

[OMACETAXINE \(CML-G 5 of 6\)](#)

[PONATINIB \(CML-G 6 of 6\)](#)

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**MANAGEMENT OF BOSUTINIB TOXICITY¹****Dose Adjustments:****Hematologic Toxicities**

- **ANC <1.0 x 10⁹/L or platelets <50 x 10⁹/L:** Hold bosutinib until ANC ≥1.0 x 10⁹/L and platelets ≥50 x 10⁹/L. Resume treatment with bosutinib at the same dose if recovery occurs within 2 weeks. If blood counts remain low for greater than 2 weeks, upon recovery reduce dose by 100 mg and resume treatment. If cytopenia recurs, reduce dose by an additional 100 mg upon recovery and resume treatment. Doses less than 300 mg/d have not been evaluated.
- **Growth factors can be used in combination with bosutinib for patients with resistant neutropenia and thrombocytopenia.**
- **Grade 3-4 anemia:⁴** Check reticulocyte count, ferritin, iron saturation, B12, folate, and correct nutritional deficiencies if present. Transfusion support should be used if patient is symptomatic.

Non-Hematologic Toxicities

- **Liver transaminases >5 x IULN:** Hold bosutinib until recovery to ≤2.5 x IULN and resume dose at 400 mg once daily thereafter. If recovery takes longer than 4 weeks, discontinue bosutinib. If transaminase elevations ≥3 x IULN occur concurrently with bilirubin elevations >2 x IULN and alkaline phosphatase <2 x IULN (Hy's law case definition), discontinue bosutinib.
- **Diarrhea:** For NCI CTCAE Grade 3-4 diarrhea (increase of ≥7 stools/day over baseline/pretreatment), withhold bosutinib until recovery to Grade ≤1. Bosutinib may be resumed at 400 mg once daily.
- **For other clinically significant, moderate, or severe non-hematologic toxicity,** withhold bosutinib until the toxicity has resolved, then consider resuming bosutinib at 400 mg once daily. If clinically appropriate, consider re-escalating the dose of bosutinib to 500 mg once daily.

Special Populations

- **In patients with pre-existing mild, moderate, and severe hepatic impairment,** the recommended dose of bosutinib is 200 mg daily. A daily dose of 200 mg in patients with hepatic impairment is predicted to result in an area under the curve (AUC) similar to the AUC seen in patients with normal hepatic function receiving 500 mg daily. However, there are no clinical data for efficacy at the dose of 200 mg once daily in patients with hepatic impairment and CML.

Specific Interventions

- **Fluid retention events (pulmonary and or peripheral edema, pleural and pericardial effusion):** diuretics, supportive care.
- **GI upset:** take medication with a meal and large glass of water.
- **Rash:** topical or systemic steroids, dose reduction, interruption, or discontinuation.

¹Please refer to package insert for full prescribing information and monitoring of hematologic or biochemical abnormalities, available at www.fda.gov.

⁴Although erythropoietin is effective, recent guidelines from the Centers for Medicare & Medicaid Services (CMS) and the U.S. Food and Drug Administration (FDA) do not support the use of erythropoiesis-stimulating agents (ESAs) in myeloid malignancies.

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**MANAGEMENT OF DASATINIB TOXICITY¹****Dose Adjustments:****Hematologic Toxicities**

- **Chronic phase, ANC <0.5 x 10⁹/L or platelets <50 x 10⁹/L:** Hold dasatinib until ANC ≥1.0 x 10⁹/L and platelets ≥50 x 10⁹/L, then resume dasatinib at the starting dose if recovery occurs in ≤7 days. If platelets <25 x 10⁹/L or recurrence of ANC <0.5 x 10⁹/L for >7 days, hold drug until ANC ≥1.0 x 10⁹/L and platelets ≥50 x 10⁹/L, then resume dasatinib at reduced dose of 80 mg once daily for second episode. For third episode, further reduce dose to 50 mg once daily (for newly diagnosed patients) or discontinue dasatinib (for patients with disease that is resistant or intolerant to prior therapy including imatinib).
- **Accelerated phase and blast phase, ANC <0.5 x 10⁹/L and/or platelets <10 x 10⁹/L:** Patients may have cytopenias related to disease. If cytopenia is unrelated to disease, hold dasatinib until ANC ≥1.0 x 10⁹/L and platelets ≥20 x 10⁹/L, and resume at original starting dose. If recurrence, hold dasatinib until ANC ≥1.0 x 10⁹/L and platelets ≥20 x 10⁹/L, and resume dasatinib at reduced dose of 100 mg once daily (second episode) or 80 mg once daily (third episode).
- **Growth factors can be used in combination with dasatinib for patients with resistant neutropenia and thrombocytopenia.**
- **Grade 3-4 anemia:⁴** Check reticulocyte count, ferritin, iron saturation, B12, folate, and correct nutritional deficiencies if present. Transfusion support should be used if patient is symptomatic.

Non-Hematologic Toxicities

- **If a severe, non-hematologic, adverse reaction develops with dasatinib, treatment must be held until the event has resolved or improved. Thereafter, treatment can be resumed as appropriate at a reduced dose depending on the initial severity of the event.**

Rare But Serious Toxicities

- **Pulmonary arterial hypertension (PAH):** Dasatinib may increase the risk of developing PAH, which may occur anytime after initiation, including after more than one year of treatment. PAH may be reversible on discontinuation of dasatinib. Evaluate patients for signs and symptoms of underlying cardiopulmonary disease prior to initiating dasatinib and during treatment. If PAH is confirmed, dasatinib should be permanently discontinued.

Specific Interventions

- **Fluid retention events (ascites, edema, pleural and pericardial effusion):** diuretics, supportive care.
- **Pleural/pericardial effusion:** diuretics, dose interruption. If patient has significant symptoms, consider short course of steroids (prednisone 20–50 mg/d x 3–4 days, may taper with 20 mg/d x 3–4 days); when resolved, reduce one dose level.
- **GI upset:** Take medication with a meal and large glass of water.
- **Rash:** topical or systemic steroids, dose reduction, interruption, or discontinuation

¹Please refer to package insert for full prescribing information and monitoring of hematologic or biochemical abnormalities, available at www.fda.gov.

⁴Although erythropoietin is effective, recent guidelines from the Centers for Medicare & Medicaid Services (CMS) and the U.S. Food and Drug Administration (FDA) do not support the use of erythropoiesis-stimulating agents (ESAs) in myeloid malignancies.

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**MANAGEMENT OF IMATINIB TOXICITY^{1,2}****Dose Adjustments:****Hematologic Toxicities**

- **Chronic phase, absolute neutrophil count (ANC) <1.0 x 10⁹/L, and/or platelets <50 x 10⁹/L: Hold imatinib until ANC ≥1.5 x 10⁹/L and platelets ≥75 x 10⁹/L, then resume imatinib at the starting dose of 400 mg. If recurrence of ANC <1.0 x 10⁹/L and/or platelets <50 x 10⁹/L, hold drug until ANC ≥1.5 x 10⁹/L and platelets ≥75 x 10⁹/L, then resume imatinib at reduced dose of 300 mg.**
- **Accelerated phase and blast phase, ANC <0.5 x 10⁹/L and/or platelets <10 x 10⁹/L: Patients may have cytopenias related to disease. If cytopenia is unrelated to disease, reduce dose to 400 mg. If cytopenia persists for 2 weeks, reduce dose further to 300 mg. If cytopenia persists for 4 weeks, stop imatinib until ANC ≥1.0 x 10⁹/L and platelet count ≥20 x 10⁹/L and then resume treatment at 300 mg.**
- **Growth factors can be used in combination with imatinib for patients with resistant neutropenia.³**
- **Grade 3-4 anemia:⁴ Check reticulocyte count, ferritin, iron saturation, B12, folate, and correct nutritional deficiencies if present. Transfusion support should be used if patient is symptomatic.**

Non-Hematologic Toxicities

- **Bilirubin >3 x institutional upper limit of normal (IULN) or liver transaminases >5 x IULN: hold imatinib until bilirubin <1.5 x IULN and transaminase levels <2.5 x IULN. Resume imatinib at a reduced daily dose (400 mg to 300 mg, 600 mg to 400 mg, or 800 mg to 600 mg).**
- **Severe hepatotoxicity or severe fluid retention: hold imatinib until the event has resolved. Treatment can be resumed as appropriate depending on the severity of the event.**
- **Patients with moderate renal impairment (CrCL = 20–39 mL/min) should receive a 50% decrease in the recommended starting dose and future doses can be increased as tolerated. Doses greater than 600 mg are not recommended in patients with mild renal impairment (CrCL = 40–59 mL/min). For patients with moderate renal impairment, doses greater than 400 mg are not recommended. Imatinib should be used with caution in patients with severe renal impairment.**

Specific Interventions

- **Fluid retention (pleural effusion, pericardial effusion, edema, and ascites): diuretics, supportive care, dose reduction, interruption, or discontinuation. Consider echocardiogram to check LVEF.**
- **GI upset: Take medication with a meal and large glass of water.**
- **Muscle cramps: calcium supplement, tonic water.**
- **Rash: topical or systemic steroids, dose reduction, interruption, or discontinuation.**

¹Please refer to package insert for full prescribing information and monitoring of hematologic or biochemical abnormalities, available at www.fda.gov.

²Many toxicities are self-limiting; consider re-escalating dose at a later time.

³Quintas-Cardama A, Kantarjian H, O'Brien S, et al. Granulocyte-colony-stimulating factor (filgrastim) may overcome imatinib-induced neutropenia in patients with chronic-phase chronic myelogenous leukemia. *Cancer* 2004;100(12):2592-2597.

⁴Although erythropoietin is effective, guidelines from the Centers for Medicare & Medicaid Services (CMS) and the U.S. Food and Drug Administration (FDA) do not support the use of erythropoiesis-stimulating agents (ESAs) in myeloid malignancies.

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**MANAGEMENT OF NILOTINIB TOXICITY¹**

- Nilotinib prolongs the QT interval. Prior to administration of nilotinib and periodically, monitor for hypokalemia or hypomagnesemia and correct deficiencies. ECGs should be obtained to monitor the QTc at baseline, seven days after initiation, and periodically thereafter, as well as following any dose adjustments.
- Sudden deaths have been reported in patients receiving nilotinib.
- Avoid use of concomitant drugs known to prolong the QT interval and strong CYP3A4 inhibitors.
- Patients should avoid food 2 hours before and 1 hour after taking dose.

QT Interval Prolongation

- ECGs with a QTc >480 msec: Hold drug. If serum potassium and magnesium levels are below lower limit of normal, correct with supplements to within normal limits. Review concomitant medication usage. Resume within 2 weeks at prior dose if QTcF is <450 msec and within 20 msec of baseline. If QTcF is between 450 and 480 msec after 2 weeks, resume at reduced dose (400 mg once daily). Following dose reduction, if QTcF returns to >480 msec, nilotinib should be discontinued. ECG should be obtained 7 days after any dose adjustment to monitor QTc.

Dose Adjustments:**Hematologic Toxicities**

- Chronic or accelerated phase, ANC <1.0 x 10⁹/L, and/or platelets <50 x 10⁹/L: Hold nilotinib and monitor blood counts. Resume within 2 weeks at prior dose if ANC >1.0 x 10⁹/L and platelets >50 x 10⁹/L. If blood counts remain low for >2 weeks, reduce dose to 400 mg once daily.
- Growth factors can be used in combination with nilotinib for patients with resistant neutropenia and thrombocytopenia.
- Grade 3–4 anemia:⁴ Check reticulocyte count, ferritin, iron saturation, B12, folate, and correct nutritional deficiencies if present. Transfusion support should be used if patient is symptomatic.

Non-Hematologic Toxicities

- Elevated serum lipase, amylase, bilirubin, or hepatic transaminases grade ≥3: hold nilotinib and monitor serum levels. Resume nilotinib at 400 mg once daily if serum levels return to grade ≤1.

Hepatic Impairment:

- Consider alternate therapies. See prescribing information for dose adjustments related to hepatic impairment.

Glucose:

- Assess glucose levels before initiating treatment and monitor treatment as clinically indicated.

Rare But Serious Toxicities

- Peripheral arterial occlusive disease (PAOD): Nilotinib is associated with an increased risk of vascular adverse events, including PAOD, and should be used with caution in patients with cardiovascular risk factors or a history of PAOD. Evaluate patients for a history of PAOD and for vascular risk factors prior to initiating nilotinib and during treatment. If PAOD is confirmed, nilotinib should be permanently discontinued.

Specific Interventions

- Rash: topical or systemic steroids, dose reduction, interruption, or discontinuation.

¹Please refer to package insert for full prescribing information and monitoring of hematologic or biochemical abnormalities, available at www.fda.gov.

⁴Although erythropoietin is effective, recent guidelines from the Centers for Medicare & Medicaid Services (CMS) and the U.S. Food and Drug Administration (FDA) do not support the use of erythropoiesis-stimulating agents (ESAs) in myeloid malignancies.

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MANAGEMENT OF OMACETAXINE TOXICITY¹

Dose Adjustments:

Hematologic Toxicities

- Complete blood counts (CBCs) should be performed weekly during induction and initial maintenance cycles. After initial maintenance cycles, monitor CBCs every two weeks or as clinically indicated. ANC $<0.5 \times 10^9/L$ or platelet count $<50 \times 10^9/L$: Delay starting the next cycle until ANC $\geq 1.0 \times 10^9/L$ and platelet count $\geq 50 \times 10^9/L$ and reduce the number of dosing days by 2 days for the next cycle.

Non-Hematologic Toxicities

- Grade 3 or 4 hyperglycemia: Monitor blood glucose levels frequently, especially in patients with diabetes or risk factors for diabetes. Avoid omacetaxine in patients with poorly controlled diabetes mellitus until good glycemic control has been established.
- Manage other clinically significant non-hematologic toxicity symptomatically. Interrupt and/or delay omacetaxine until toxicity is resolved.

¹Please refer to package insert for full prescribing information and monitoring of hematologic or biochemical abnormalities, available at www.fda.gov.

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MANAGEMENT OF PONATINIB TOXICITY¹

- **Vascular occlusion:** Arterial and venous thrombosis and occlusions, including fatal myocardial infarction and stroke have occurred in patients treated with ponatinib. Monitor for evidence of thromboembolism and vascular occlusion. Interrupt or stop ponatinib immediately for vascular occlusion.
- **Heart failure** has occurred in patients treated with ponatinib. Monitor cardiac function. Interrupt or stop ponatinib for new or worsening heart failure.
- **Hepatotoxicity:** Hepatotoxicity, liver failure, and death have occurred in patients treated with ponatinib. Monitor hepatic function prior to and during treatment. Interrupt ponatinib if hepatotoxicity is suspected.
- **Cardiovascular risk:** Identify and control traditional risk factors for atherosclerosis (eg, diabetes mellitus [DM], hypertension, hyperlipidemia, smoking, estrogen use) before starting ponatinib. Patients with cardiovascular risk factors should be referred to a cardiologist. Consider the use of low dose aspirin if there is no contraindication.
- Ponatinib is also associated with grade ≥3 skin rash and pancreatitis leading to dose modifications (dose delays or dose reductions).

Dosing

- The recommended initial dose of ponatinib is 45 mg once daily. However, an initial starting dose of 30 mg may be a safer and effective dose for patients with risk factors. Safety and efficacy of ponatinib at initial doses lower than 45 mg is being evaluated in a randomized clinical trial.

Dose Adjustments:

Hematologic Toxicities

- **ANC <1.0 x 10⁹/L or platelets <50 x 10⁹/L**
 - ▶ First occurrence: Hold ponatinib until ANC ≥1.5 x 10⁹/L and platelets ≥75 x 10⁹/L and resume at initial dose of 45 mg.
 - ▶ Second occurrence: Hold ponatinib until ANC ≥1.5 x 10⁹/L and platelets ≥75 x 10⁹/L and resume at 30 mg.
 - ▶ Third occurrence: Hold ponatinib until ANC ≥1.5 x 10⁹/L and platelets ≥75 x 10⁹/L and resume at 15 mg.
- Growth factors can be used in combination with ponatinib for patients with resistant neutropenia and thrombocytopenia.
- **Grade 3-4 anemia:**⁴ Check reticulocyte count, ferritin, iron saturation, B12, folate, and correct nutritional deficiencies if present. Transfusion support should be used if patient is symptomatic.

Non-Hematologic Toxicities

- **Liver transaminase >3 x ULN (grade ≥2):** Monitor hepatic function. Hold drug until serum levels are <3 x IULN. Resume at lower dose after recovery (30 mg if patient receiving 45 mg; 15 mg if patient receiving 30 mg). Discontinue ponatinib if patient receiving 15 mg.
- **AST or ALT ≥3 x ULN concurrent with bilirubin >2 x ULN and alkaline phosphatase <2 x ULN:** Discontinue ponatinib.

- **Serum lipase elevation, grade 1 or 2 (asymptomatic):** Consider dose interruption or reduction. Serum lipase elevation, grade 3 or 4 (>2 x IULN) (asymptomatic) or asymptomatic radiologic pancreatitis: Hold drug until serum levels are <1.5 x ULN. Resume at lower dose after recovery (30 mg if patient receiving 45 mg; 15 mg if patient receiving 30 mg). Discontinue ponatinib if patient receiving 15 mg.
- **Pancreatitis (symptomatic), grade 3:** Hold drug until serum lipase levels are ≤grade 1. Resume at lower dose after recovery (30 mg if patient receiving 45 mg; 15 mg if patient receiving 30 mg). Discontinue ponatinib if patient receiving 15 mg. Grade 4: Discontinue ponatinib.

Rare But Serious Toxicities

- **Hemorrhage:** Hemorrhagic events were reported in clinical trials. Cerebral and gastrointestinal hemorrhage were the most commonly reported serious bleeding events. Serious hemorrhage should be managed with dose interruption.
- **Cardiac arrhythmias:** Advise patients to report signs and symptoms suggestive of alterations in heart rate (fainting, dizziness, chest pain, or palpitations).
- **Tumor lysis syndrome:** Ensure adequate hydration and correct high uric acid levels prior to initiating therapy with ponatinib in patients with advanced-phase CML.

Specific Interventions

- **Fluid retention events (edema, ascites, pleural and pericardial effusion)** are managed with dose interruption, dose reduction, or discontinuation of ponatinib as clinically indicated.
- **Hypertension:** Monitor and manage blood pressure elevations.
- **Rash:** topical or systemic steroids, dose reduction, interruption, or discontinuation.

¹Please refer to package insert for full prescribing information and monitoring of hematologic or biochemical abnormalities, available at www.fda.gov.

⁴Although erythropoietin is effective, recent guidelines from the Centers for Medicare & Medicaid Services (CMS) and the U.S. Food and Drug Administration (FDA) do not support the use of erythropoiesis-stimulating agents (ESAs) in myeloid malignancies.

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Discussion

NCCN Categories of Evidence and Consensus

Category 1: Based upon high-level evidence, there is uniform NCCN consensus that the intervention is appropriate.

Category 2A: Based upon lower-level evidence, there is uniform NCCN consensus that the intervention is appropriate.

Category 2B: Based upon lower-level evidence, there is NCCN consensus that the intervention is appropriate.

Category 3: Based upon any level of evidence, there is major NCCN disagreement that the intervention is appropriate.

All recommendations are category 2A unless otherwise noted.

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Table 1. Summary of Limited Longer-term Follow-up Data from the TKI Discontinuation Trials

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Overview

Chronic myeloid leukemia (CML) accounts for 15% of adult leukemias. The median age of disease onset is 67 years; however, CML occurs in all age groups (SEER statistics). In 2017, an estimated 8,950 people will be diagnosed with CML in the United States, and 1,080 people will die from the disease.¹

CML is defined by the presence of Philadelphia chromosome (Ph) in a patient with a myeloproliferative neoplasm (MPN). Ph results from a reciprocal translocation between chromosomes 9 and 22 [t(9;22)] that gives rise to a *BCR-ABL1* fusion gene; the product of this fusion gene is a protein with deregulated tyrosine kinase activity (p210) that plays a central role in the pathogenesis of CML.² Another fusion protein, p190, is also produced, usually in the setting of Ph-positive acute lymphoblastic leukemia (ALL). p190 is detected only in 1% of patients with CML.³

CML occurs in three different phases (chronic, accelerated, and blast phase) and is usually diagnosed in the chronic phase. Untreated chronic phase CML (CP-CML) will eventually progress to advanced phase in 3 to 5 years.⁴ Gene expression profiling has shown a close correlation of gene expression between the accelerated phase CML (AP-CML) and blast phase CML (BP-CML). The bulk of the genetic changes in progression occur in the transition from CP-CML to AP-CML.⁵ The activation of beta-catenin signaling pathway in CML granulocyte-macrophage progenitors (which enhances the self-renewal activity and leukemic potential of these cells) may also be a key pathobiologic event in the evolution to BP-CML.⁶

The NCCN Guidelines for CML discuss the clinical management of CML in all three phases (chronic, accelerated, or blast phase). Evaluation for diseases other than CML as outlined in the NCCN

Guidelines for MPN is recommended for all patients with *BCR-ABL1*-negative MPN.

Literature Search Criteria and Guidelines Update Methodology

Prior to the update of this version of the NCCN Guidelines® for Chronic Myelogenous Leukemia, an electronic search of the PubMed database was performed to obtain key literature in Chronic Myelogenous Leukemia published between May 2015 and May 2016 using the following search terms: chronic myeloid (or myelogenous) leukemia, chronic phase, accelerated phase, blast phase, advanced phase, tyrosine kinase inhibitors, *BCR-ABL1* mutations, response, monitoring, adherence and discontinuation. The PubMed database was chosen as it remains the most widely used resource for medical literature and indexes only peer-reviewed biomedical literature.⁷

The search results were narrowed by selecting studies in humans published in English. Results were confined to the following article types: Clinical Trial, Phase II; Clinical Trial, Phase III; Clinical Trial, Phase IV; Guideline; Randomized Controlled Trial; Meta-Analysis; Systematic Reviews; and Validation Studies.

The PubMed search resulted in 36 citations and their potential relevance was examined. The data from key PubMed articles selected by the panel for review during the Guidelines update meeting as well as articles from additional sources deemed as relevant to these Guidelines have been included in this version of the Discussion section. Recommendations for which high-level evidence is lacking are based on the panel's review of lower-level evidence and expert opinion.

The complete details of the Development and Update of the NCCN Guidelines are available on the NCCN [website](#).



Diagnosis and Workup (CML-1)

Initial evaluation of patients with CML should consist of a history and physical exam, including palpation of spleen, complete blood count (CBC) with differential, chemistry profile, electrocardiogram (ECG) for QTc prolongation, and hepatitis panel. Bone marrow evaluation (aspirate and biopsy for morphologic review and cytogenetics for the detection of Ph and other chromosomal abnormalities) and molecular testing using quantitative reverse transcriptase polymerase chain reaction (QPCR) to establish the presence of quantifiable *BCR-ABL1* mRNA transcripts at baseline are recommended to confirm the diagnosis of CML.

Bone marrow cytogenetics should be done at initial workup to confirm the disease phase. If collection of bone marrow is not feasible, fluorescence in situ hybridization (FISH) on a peripheral blood specimen with dual probes for *BCR* and *ABL1* genes is an acceptable method to confirm the diagnosis of CML. Interphase FISH is performed on peripheral blood but is associated with a background level of 1% to 5% (depending on the specific probe used in the assay).⁸ Hypermetaphase FISH is more sensitive and can analyze up to 500 metaphases at a time but it is applicable only to dividing cells in the bone marrow.⁹ Double-fusion FISH is also associated with low false-positive rates and can detect all variant translocations of the Ph-chromosome.¹⁰

QPCR (peripheral blood) is the most sensitive assay available for the measurement of *BCR-ABL1* mRNA and it can detect one CML cell in a background of $\geq 100,000$ normal cells. QPCR assay reports the actual percentage of *BCR-ABL1* mRNA transcripts and the results are expressed as the ratio of *BCR-ABL1* transcript numbers to the number of control gene transcripts.^{11,12} Alternatively, this ratio is also

expressed as a percentage whereby equal copy numbers of the *BCR-ABL1* gene and the control gene at diagnosis would be expressed as 100%.¹² Thus, the choice of an appropriate control gene is important for generating reliable and reproducible data. *BCR*, *ABL1*, beta-glucuronidase (*GUSB*), and beta-2-microglobulin (*B2M*) have been widely studied for *BCR-ABL1* quantification.^{13,14} *BCR* was used as the control gene in the IRIS trial.¹³

BCR-ABL1 transcripts in the peripheral blood at very low levels (1–10 out of 10^8 peripheral blood leukocytes) can also be detected in approximately 30% of normal individuals, and the incidence of *BCR-ABL1* transcripts increases with advancing age in healthy individuals.^{15,16} Tyrosine kinase inhibitor (TKI) is not indicated, as the risk of developing CML for these individuals is extremely low.

Additional Evaluation

Chronic Phase CML

Determination of risk score (using either the Sokal or Hasford scoring systems) prior to initiation of treatment with tyrosine kinase inhibitors (TKIs) is recommended for patients diagnosed with chronic phase CML. Sokal and Hasford (Euro) scoring systems stratify patients into three risk groups (low, intermediate, and high) and have been used for the risk stratifications of patients in clinical trials evaluating TKIs.^{17,18} The Sokal score is based on the patient's age, spleen size, platelet count, and percentage of blasts in the peripheral blood.¹⁷ The Euroscore includes eosinophils and basophils in the peripheral blood in addition to the same clinical variables used in the Sokal score.¹⁸

European Treatment and Outcome Study (EUTOS) score is based only on the percentage of basophils in the blood and spleen size. The predictive value of EUTOS score was validated in a cohort of 2060

patients enrolled in studies of first-line treatment with imatinib-based regimens.¹⁹ EUTOS score was better than Sokal and Hasford score in predicting the probability of achieving CCyR at 18 months and 5-year progression-free survival (PFS). However, the predictive value of EUTOS score has not been confirmed in subsequent studies by other investigators.²⁰⁻²² Additional studies are necessary to validate the EUTOS score for predicting clinical outcomes of patients receiving TKI therapy.

Advanced Phase CML

Flow cytometry to determine cell lineage, mutational analysis, and HLA testing, if considering allogeneic HCT, are recommended for patients with advanced-phase CML.

The revised 2016 WHO diagnostic criteria for AP-CML include a “provisional” response to TKI criteria in addition to hematologic and cytogenetic criteria.²³ These diagnostic criteria require validation in prospective clinical trials. It should be noted that clinical trials of TKIs have largely reported efficacy data using the modified MD Anderson Cancer Center accelerated phase criteria (15% and <30% peripheral blood or bone marrow blasts, ≥ 30% or more of peripheral blood blasts and promyelocytes, ≥ 20% peripheral blood or bone marrow basophils, platelet count ≤100 x 10⁹/L unrelated to therapy, and clonal evolution).²⁴

Clonal evolution, defined by the presence of additional chromosomal abnormalities (trisomy 8, isochromosome 17, trisomy 19, abnormalities of 3q26.2, second Ph and complex abnormalities) besides the Ph, is associated with unfavorable prognosis.²⁵⁻²⁹ Clonal evolution is considered to be a feature of AP-CML and has a significant adverse impact when associated with other features of accelerated phase.²⁸ However, clonal evolution is associated with a better prognosis when it is considered as the only criteria for accelerated phase.²⁵ Clonal

cytogenetic abnormalities in Ph-negative cells have also been reported in a small subset of patients during the course of imatinib therapy.³⁰⁻³⁵ The significance of these chromosomal abnormalities is unclear, but the most common abnormalities include trisomy 8 and loss of Y chromosome. The overall prognosis for patients with Ph-negative CML and clonal cytogenetic evolution seems to be good and is dependent on response to imatinib therapy.³⁴ The exceptions are chromosome 7 abnormalities, particularly monosomy 7, where progression to myelodysplastic syndromes (MDS) and acute myeloid leukemia (AML) have been reported.^{36,37}

The WHO diagnostic criteria define blast phase as the presence of ≥20% blast cells in the peripheral blood or bone marrow, the presence of extramedullary blast proliferation, and large foci or clusters of blasts in the bone marrow biopsy.²³ The International Bone Marrow Transplant Registry (IBMTR) criteria define blast phase as the presence of ≥30% blasts in the blood, bone marrow, or both, or as the presence of extramedullary disease.³⁸ The same definition was used in most of the clinical trials leading to the approval of TKIs.

Management of Chronic Phase CML (CML-2 and CML-3)

Primary Treatment

Imatinib

In the IRIS trial 1106 patients with newly diagnosed CP-CML were randomized to receive either imatinib 400 mg or interferon-alpha plus low-dose cytarabine. After a median follow-up of 60 months, the estimated 5-year overall survival (OS) rate and the best observed major cytogenetic response (MCyR) and complete cytogenetic response (CCyR) rates were 89%, 89%, and 82%, respectively.³⁹ The estimated rates of 8-year event-free survival (EFS), Freedom-from-progression (FFP) to accelerated or blast phase, and 8-year OS were 81%, 92%,

and 85%, respectively.⁴⁰ The overall rate of progression to accelerated or blast phase was 0.4%. The rate of major molecular response (MMR; <0.1% *BCR-ABL1* IS) increased from 24% at 6 months to 39% at 12 months, and the best observed MMR rate was 86% and none of the patients with documented MMR at 12 months progressed to accelerated or blast phase. In an analysis that evaluated the safety and efficacy of imatinib in 359 patients who crossed over from interferon-alpha plus cytarabine to imatinib in the IRIS study, after a median follow-up of 54 months on imatinib, MCyR and CCyR were observed in 86% and 81% of patients, respectively. Estimated rates of FFP to accelerated or blast phase and OS at 48 months were 91% and 89%, respectively.⁴¹

Several studies have evaluated the efficacy of high-dose imatinib in newly diagnosed patients.⁴²⁻⁴⁶ In the TOPS study, although imatinib 800 mg induced higher and faster CCyR and MMR compared to imatinib 400 mg early on, there is no difference in response rates between the two arms at 12 months and beyond.⁴⁴ After a minimum follow-up of 42 months, the MMR rates were 75.8% and 79.0% for 400 mg and 800 mg respectively ($P = .4807$). Other studies have reported higher MMR rates at 12 months for imatinib 800 mg.^{45,46} In the CML IV study, after a median follow-up of 7 years, the cumulative incidence of deep molecular response (MR4.0) were higher for imatinib 800 mg (66% vs. 56% for imatinib 400 mg).⁴⁵ The SWOG (S0325) study also reported higher rates of MR4.0 with imatinib 800 mg at 12 months (25% vs. 10% respectively, $P = .038$).⁴⁶ However, imatinib 800 mg was not associated with lower rates of disease progression than imatinib 400 mg in any of the studies, despite improved early responses. Imatinib 800 mg was associated with higher rates of dose interruption, reduction, or discontinuation in a substantial number of patients due to grade 3 or 4 adverse events in all of the studies. However, patients who

can actually tolerate the higher dose of imatinib do achieve better response rates than those receiving standard-dose imatinib. Given the recent data showing superior efficacy of nilotinib and dasatinib in newly diagnosed patients, imatinib 800 mg is not recommended as initial therapy.

Dasatinib

In the DASISION study, 519 patients with newly diagnosed CP-CML were randomized to receive dasatinib (100 mg once daily; 259 patients) or imatinib (400 mg once daily; 260 patients). In the final 5-year analysis, the rates of CCyR (83% vs. 78%; $P = .187$), MMR ($\leq 0.1\%$ *BCR-ABL1* IS; 76% vs. 64%; $P = .002$), and MR4.5 (42% vs. 33%; $P = .025$) were significantly higher with dasatinib than with imatinib.⁴⁷ The proportion of patients achieving $\leq 10\%$ *BCR-ABL1* IS at 3 months was also higher with dasatinib (84% vs. 64%) and fewer patients transformed to accelerated or blast phase on dasatinib (12 patients; 4.6%) than on imatinib (19 patients; 7.3%). The estimated 5-year PFS (85% vs. 86%) and OS (91% vs. 90%) rates were similar for dasatinib and imatinib.⁴⁷

The 3-year follow-up results of the Intergroup phase II randomized trial (S0325; $n = 250$) also confirmed that dasatinib (100 mg once daily) induced more CCyR and deeper molecular responses, compared with imatinib (400 mg once daily) in patients with newly diagnosed CP-CML.⁴⁸ The molecular response rates (3-log reductions in *BCR-ABL1* transcript level) at 12 months were 59% and 44%, respectively, for dasatinib and imatinib ($P = .059$) and the estimated 3-year OS (97% for both dasatinib and imatinib) and PFS (93% for dasatinib and 90% for imatinib) rates were similar in both arms.

Nilotinib

The ENESTnd study compared the safety and efficacy of nilotinib at two different dose levels (300 mg twice daily; n = 282 or 400 mg twice daily; n = 281) with that of imatinib (400 mg once daily; n = 283) in patients with newly diagnosed CP-CML. At 5 years, significantly more patients in the nilotinib arms had achieved MMR (77% for nilotinib 300 mg and 400 mg twice daily vs. 60% for imatinib 400 mg once daily; $P < .0001$) and MR4.5 (54% for nilotinib 300 mg twice daily, 52% for nilotinib 400 mg twice daily vs. 31% for imatinib 400 mg once daily; $P < .0001$).⁴⁹ Fewer patients progressed to accelerated or blast phase in the nilotinib arm (10 patients treated with nilotinib 300 mg twice daily and 6 patients treated with nilotinib 400 mg twice daily) than in the imatinib arm (21 patients). The estimated 5-year OS rates were 93.7%, 96.2%, and 91.7%, respectively. The corresponding 5-year PFS rates were 92.2%, 95.8%, and 91%, respectively.

Bosutinib

In the phase III randomized trial (BELA trial; n = 500), although bosutinib resulted in higher MMR rate (47% vs. 41% for imatinib; $P < .001$) and fewer transformations to AP-CML or BP-CML at 24 months (2% vs. 4% on imatinib) in newly diagnosed patients with CP-CML than imatinib 400 mg, there was no difference in CCyR rate at 12 months between the 2 treatment arms (70% and 68%, respectively, for bosutinib and imatinib; $P = .601$).⁵⁰ Bosutinib is not recommended as first-line therapy for newly diagnosed patients with CP-CML.

Treatment Considerations (CML-2)

The selection of first-line TKI therapy in a given patient should be based on the risk score, toxicity profile of TKI, patient's age, ability to tolerate therapy, and the presence of comorbid conditions. Allogeneic HCT is no longer recommended as a first-line treatment option for patients with CP-CML.

Treatment Recommendations Based on Risk Stratification

Long-term follow-up data from DASISION and ENESTnd studies have shown that dasatinib or nilotinib are associated with higher rates of molecular response and lower risk of disease progression than imatinib in intermediate- and high-risk patients, suggesting that this group of patients may preferentially benefit from dasatinib or nilotinib.^{47,49} In the DASISION study, the MMR rates were higher for dasatinib than for imatinib in patients with intermediate (71% and 65%, respectively) and high (67% and 54% respectively) Hasford (Euro) risk scores and achievement of MMR after first-line dasatinib is associated with reduced risk of progression AP or BP.^{47,51} In the ENESTnd study, fewer patients with intermediate and high Sokal risk score progressed to AP or BP in the nilotinib arm (2 patients with intermediate risk score and 7 patients with high risk score) than in the imatinib arm (10 patients with intermediate risk score and 11 patients with high risk score).⁴⁹ The estimated 5-year PFS rates were 93% and 86% for patients with intermediate-, and high-risk scores respectively in the nilotinib arm. The corresponding PFS rates for imatinib were 88% and 82.6% respectively.

Dasatinib (100 mg once daily), imatinib (400 mg daily) and nilotinib (300 mg twice daily) are included as options (category 1) for primary treatment in patients with low-risk score. Nilotinib and dasatinib are preferred for patients with intermediate or high risk scores.

Since both dasatinib and nilotinib have very good efficacy in the upfront setting, differences in their potential toxicity profiles would be helpful in the selection of either one of these TKIs over imatinib in patients with low-risk score. Dasatinib may be preferred in patients with a history of arrhythmias, heart disease, pancreatitis, or hyperglycemia. Nilotinib may be preferred for patients with a history of lung disease or deemed to be at risk of developing pleural effusions.

Toxicity Profile

Dasatinib

Nonhematologic adverse events are mild to moderate and most of the adverse events are manageable with dose modification. The incidences of grade 3 or 4 cytopenias (neutropenia, 29% vs. 24%; anemia, 13% vs. 9%; and thrombocytopenia, 22% vs. 14%) were higher with dasatinib compared to imatinib.

Pleural effusion is an adverse effect of dasatinib. In the DASISION study, drug-related pleural effusion was more common with dasatinib (28%) than with imatinib (0.8%).⁴⁷ The incidences of pleural effusion are higher in patients with advanced phase CML (occurring in 50% of patients with AP-CML, and 33% of patients with BP-CML compared to 29% of patients with CP-CML.⁵² The occurrence of pleural effusion is significantly reduced with dasatinib 100 mg once daily compared with 70 mg twice daily.⁵³ Lymphocytosis related to dasatinib treatment has been associated with increased incidences of pleural effusion and improved cytogenetic response rates.⁵⁴ Patients with prior cardiac history, hypertension, and those receiving twice-daily dosing of dasatinib at 70 mg are at increased risk of developing pleural effusions. Close monitoring and timely intervention are necessary for patients at risk of developing pleural effusions. Dasatinib is also associated with significant but reversible inhibition of platelet aggregation that may contribute to bleeding in some patients, especially if accompanied by thrombocytopenia.⁵⁵

Reversible pulmonary arterial hypertension has been reported as a rare but serious side effect associated with dasatinib.^{56,57} In the DASISION study, pulmonary hypertension was reported in 5% of patients compared to 0.4% of patients treated with imatinib.⁴⁷ Evaluation for signs and symptoms of underlying cardiopulmonary disease prior to initiating and during treatment with dasatinib is recommended. If

pulmonary arterial hypertension is confirmed, dasatinib must be permanently discontinued.

The recommended starting dose of dasatinib is 100 mg once daily for patients with CP-CML. Data from case reports and retrospective analysis suggest that lower doses of dasatinib (20 mg–120 mg) may potentially have similar efficacy.^{58,59} Treatment interruption of dasatinib at standard dose and reintroduction of dasatinib at a lower dose of 40 mg twice daily also resolved all pulmonary complications without recurrence.⁶⁰ However, the minimum effective dose has not been established in randomized clinical trials. Initiation of dasatinib at 50 mg (20 mg with careful monitoring in selected patients) should be considered for patients with clinically significant intolerance to dasatinib at 100 mg once daily to avoid serious adverse events necessitating the discontinuation of dasatinib (eg, pleural effusion, myelosuppression).

Imatinib

Imatinib (400 mg daily) is generally well tolerated. Most frequently reported non-hematologic adverse events include gastrointestinal disturbances, edema, rash, and musculoskeletal complaints. Skin hypopigmentation has also been reported as a benign side effect of imatinib and is reversible upon discontinuation or dose reduction.^{61,62} Chronic fatigue (mostly correlated with musculoskeletal pain and muscular cramps) is a major factor reducing quality of life.⁶³ Hypophosphatemia and decrease in bone mineral density has been noted in a small group of patients, suggesting that monitoring bone health should be considered for patients taking imatinib.^{64,65}

Nilotinib

Fluid retention, pleural effusion, pericardial effusion, pulmonary edema, or muscle cramps were less common with nilotinib than with imatinib. Neutropenia and thrombocytopenia (grade 3-4) were reported only in



12% and 10% of patients treated with nilotinib 300 mg twice daily. Grade 3 or 4 elevations in lipase and bilirubin, hypophosphatemia, and hyperglycemia were observed in 9%, 4%, 8%, and 7% of patients, respectively. Patients with a previous history of pancreatitis may be at greater risk of elevated serum lipase. However, these abnormalities were transient and clinically asymptomatic.

Nilotinib labeling contains a black box warning regarding the risk of QT interval prolongation, and sudden cardiac death has been reported in patients receiving nilotinib. QT interval prolongation could be managed with dose reduction. Electrolyte abnormalities should be corrected prior to initiation of treatment with nilotinib and should be monitored periodically. Drugs that prolong QT interval should be avoided. ECG should be obtained to monitor the QT interval at baseline, 7 days after initiation of nilotinib and periodically thereafter, as well as following any dose adjustments.

Nilotinib is associated with an increased risk of peripheral arterial occlusive disease (PAOD).⁶⁶⁻⁶⁸ Patients should be evaluated for pre-existing PAOD and vascular risk factors prior to initiating and during treatment with nilotinib. If PAOD is confirmed, nilotinib should be permanently discontinued. Patients with cardiovascular risk factors should be referred to a cardiologist.

Drug Interactions

Dasatinib, imatinib, and nilotinib are metabolized in the liver by cytochrome P450 (CYP) enzymes. Drugs that induce or inhibit CYP3A4 or CYP3A5 enzymes may alter the therapeutic effect of TKIs.⁶⁹ CYP3A4 or CYP3A5 inducers may decrease the therapeutic plasma concentration of TKIs whereas CYP3A4 inhibitors and drugs that are metabolized by the CYP3A4 or CYP3A5 enzyme might result in increased plasma levels of TKIs. In addition, imatinib is also a weak

inhibitor of the CYP2D6 and CYP2C9 isoenzymes and nilotinib is a competitive inhibitor of CYP2C8, CYP2C9, CYP2D6, and UGT1A1, potentially increasing the plasma concentrations of drugs eliminated by these enzymes. Concomitant use of drugs that are metabolized by these enzymes should be used with caution and appropriate alternatives should be explored to maximize treatment outcome. If coadministration cannot be avoided, dose modification should be considered. Concomitant use with H2 blockers or proton pump inhibitors (PPIs) is not recommended in patients receiving dasatinib.

Management of Hematologic Toxicities of TKI Therapy

Cytopenias (anemia, neutropenia, and thrombocytopenia) should be managed with transient interruptions of TKI therapy and dose modifications. Please see the package insert for full prescribing information available at www.fda.gov, for the recommended dose modifications of specific TKI therapy. Routine monitoring of reticulocyte count, ferritin, iron saturation, B12, and folate and correction of nutritional deficiencies if present, is recommended for patients with grade 3-4 anemia. Transfusion support should be used in symptomatic patients. Growth factor support can be used in combination with TKI therapy for the management of neutropenia.^{70,71} The use of erythropoiesis-stimulating agents (ESAs) did not impact survival or cytogenetic response rate, but was associated with a higher thrombosis rate in patients with CP-CML.⁷² Recent guidelines from the U.S. Centers for Medicare & Medicaid Services (CMS) and the FDA do not support the use of ESAs in patients with myeloid malignancies.

Adherence to Therapy

Treatment interruptions and non-adherence to therapy may lead to undesirable clinical outcomes.⁷³⁻⁷⁵ In the ADAGIO study, non-adherence to imatinib was associated with poorer response and patients with suboptimal response had significantly higher mean

percentages of imatinib not taken (23%) than did those with optimal response (7%).⁷³ Marin and colleagues identified adherence as the only independent predictor for achieving complete molecular response (CMR) on standard-dose imatinib.⁷⁴ Patients whose imatinib doses were increased had poor adherence (86%), and in these patients adherence was the only independent predictor for inability to achieve an MMR. Poor adherence to imatinib therapy has also been identified as the most important factor contributing to cytogenetic relapse and imatinib failure.⁷⁵ Patients with an adherence rate of 85% or less had a higher probability of losing their CCyR at 2 years than those with an adherence rate of more than 85% (27% and 1.5%, respectively). *BCR-ABL1* doubling time has been reported as a marker to identify non-adherence to TKI therapy in patients with CP-CML.⁷⁶

Poor adherence to therapy has also been reported in patients receiving dasatinib and nilotinib following imatinib failure.^{77,78} However, the impact of non-adherence to dasatinib and nilotinib on treatment efficacy has not yet been reported. In the absence of such data, findings from the studies involving patients treated with imatinib should be extrapolated to patients receiving second-generation TKI therapy.

Patient education on adherence to therapy and close monitoring of patient's adherence is critical to achieve optimal responses. In a significant proportion of patients with TKI-induced toxicities, responses have been observed with doses well below their determined maximum tolerated doses.⁷⁹ Short interruptions or dose reductions, when medically necessary, may not have a negative impact on the control of disease or other outcomes. Adequate and appropriate management of side effects and scheduling appropriate follow-ups to review side effects may be helpful to improve patient adherence to therapy.⁸⁰

Monitoring Response to TKI Therapy

Response to TKI therapy is determined by the measurement of hematologic (normalization of peripheral blood counts), cytogenetic (decrease in the number of Ph-positive metaphases using bone marrow cytogenetics), and molecular responses (decrease in the amount of *BCR-ABL1* chimeric mRNA using QPCR). The goal of TKI therapy is to achieve a CCyR within 12 months of initiation of therapy and to prevent disease progression to accelerated or blast phase.

Conventional bone marrow cytogenetics is the standard method for monitoring cytogenetic responses and clinical trial response analyses are most often based on conventional bone marrow cytogenetics. If conventional bone marrow cytogenetics showed no analyzable metaphases, cytogenetic response can be evaluated by FISH; however, it has a false-positive rate of 1% to 10%.^{81,82} Although some investigators have reported that interphase FISH can be used to monitor CCyR, endpoints for TKI failure have not been defined on the basis of FISH analysis.^{83,84} The panel feels that FISH has been inadequately studied for monitoring response to TKI therapy. Therefore, FISH is not generally recommended for monitoring response if conventional cytogenetics or QPCR are available.

QPCR is the only tool capable of monitoring responses after the patient has achieved CCyR since *BCR-ABL1* transcripts typically remain detectable after CCyR is achieved. A major advantage of the QPCR is the strong correlation between the results obtained from the peripheral blood and the bone marrow, allowing molecular monitoring without the necessity of obtaining bone marrow aspirations.^{85,86}

Standardization of Molecular Monitoring Using the International Scale

In 2006, the National Institutes of Health Consensus Group proposed the use of an International Scale (IS) to standardize molecular



monitoring with QPCR across different laboratories.¹² This group recommended the use of one of three control genes (*BCR*, *ABL1*, or *GUSB*) and a QPCR assay with a sensitivity of at least 4-log reduction from the standardized baseline.

In the IS, the standardized baseline (defined as the median value of *BCR-ABL1* mRNA at the time of diagnosis in 30 CML patients as established in the IRIS study) is taken to represent 100%. MMR, 3-log reduction in the *BCR-ABL1* transcripts from this standardized baseline, is fixed at 0.1%.^{12,87,88} A 2-log reduction (1% *BCR-ABL1* IS) from the standardized baseline generally correlates with CCyR. CMR is defined as undetectable *BCR-ABL1* transcripts as assessed by QPCR with a sensitivity of 4.5-log reduction or more from the standardized baseline. CMR is variably described, and is best defined by the assay's level of sensitivity. The *BCR-ABL1* transcripts obtained in a given laboratory are converted to the IS by applying a laboratory-specific conversion factor (CF).^{12,89} Typically each laboratory has to exchange 20 to 30 pre-treatment samples with a reference laboratory, to obtain a laboratory-specific CF. Both laboratories analyze the samples and the results are plotted on a log scale for comparison. The antilog of the estimated mean bias between the methods is designated as the CF.⁸⁹ Once a laboratory-specific CF is established, it is validated again through a second sample exchange with the reference laboratory.

QPCR (IS) is still not available in many laboratories because the process is relatively cumbersome, time consuming, and is not seen as practical if the laboratory does not have a high volume of assays to perform, or if the prescribing physicians do not demand it. Alternatively, laboratories with no access to QPCR (IS) may establish their own standardized baseline, based on a large number of pre-treatment samples. Molecular response to TKI therapy is then measured as the log-reduction of *BCR-ABL1* mRNA from the standardized baseline (not

a reduction from the actual baseline level in an individual patient). This is an effective method, and was used in the IRIS trial to establish the 3-log reduction in the *BCR-ABL1* transcripts from the standardized baseline (not a reduction from the actual baseline level in an individual patient) as the MMR.¹³ In addition, this technique was recently used in the U.S. Intergroup CML trial.⁴⁸ The findings from the post hoc analyses of the RIGHT study also confirmed the feasibility of this technique.⁸⁶ The probability of achieving MMR at 18 months was higher in patients with >2-log reduction in *BCR-ABL1* levels at 3, 6, and 9 months than those with ≤2-log reduction.⁸⁶

Recommendations for Monitoring Response to TKI Therapy (CML-D)

QPCR (IS) is the preferred method to monitor response to TKI therapy. QPCR assays with a sensitivity of ≥4.5-log reduction from the standardized baseline are recommended for the measurement of *BCR-ABL1* transcripts. If QPCR (IS) is not available, it is acceptable to use the log-reduction from the laboratory-specific standardized baseline to monitor molecular response. In patients with prolonged myelosuppression who may not be in complete hematologic response (CHR) due to persistent cytopenias or unexplained drop in blood counts during therapy, bone marrow cytogenetics may be useful to confirm response to TKI therapy and exclude other pathology, such as MDS or the presence of chromosomal abnormalities other than Ph.

Monitoring with QPCR (IS) every 3 months is recommended for all patients after initiating TKI therapy, including those who meet response milestones at 3, 6, and 12 months (1% to 10% *BCR-ABL1* IS at 3 and 6 months, 0.1% to <1% *BCR-ABL1* IS at 12 months and <0.1% *BCR-ABL1* IS at 18 months). After CCyR has been achieved, molecular monitoring is recommended every 3 months for 2 years and every 3 to 6 months thereafter.

Frequent molecular monitoring with QPCR (IS) can help to identify non-adherence to TKI therapy early in the treatment course.⁹⁰ Since adherence to TKI therapy is associated with better clinical outcomes, frequent molecular monitoring is essential if there are concerns about the patient's adherence to TKI therapy after CCyR has been achieved. In patients with deeper molecular responses (MMR and below) and who are compliant with TKI therapy, the frequency of molecular monitoring could be reduced, though the optimal frequency is unknown.

Response Milestones after First-Line TKI Therapy

Early molecular response ($\leq 10\%$ *BCR-ABL1* IS after 3 months or $\leq 1\%$ *BCR-ABL1* IS at 6 months) after first-line TKI therapy has emerged as an effective prognostic indicator of long-term outcomes.^{47,49,91-93}

In an analysis of 282 patients with CP-CML treated with imatinib 400 mg as first-line therapy, patients with $\leq 9.84\%$ *BCR-ABL1* IS at 3 months had significantly higher rates of OS, PFS, and EFS at 8 years than patients with $>9.84\%$ *BCR-ABL1* IS at 3 months ($P < .001$).⁹¹ The OS, PFS, and EFS rates were 93.3%, 92.8%, and 65%, respectively, for patients with $\leq 9.84\%$ *BCR-ABL1* IS at 3 months compared to 56.9%, 57%, and 6.9%, respectively, for those with $>9.84\%$ *BCR-ABL1* IS. In the CML IV study (1,303 newly diagnosed patients treated with imatinib), $>10\%$ *BCR-ABL1* IS at 3 months and $>1\%$ *BCR-ABL1* IS at 6 months after imatinib correlated with significantly lower OS and PFS rates at 5 years. At 3 months, the 5-year OS rate was 87% for patients with a $>10\%$ *BCR-ABL1* IS compared to 95% for those who achieved $\leq 10\%$ *BCR-ABL1* at 3 months ($P < .0001$).⁹² The 5-year PFS rates were 87% and 92%, respectively ($P = .037$). Similarly, at 6 months, the 5-year OS rate was 89% for those with a $>1\%$ *BCR-ABL1* IS compared to 97% for patients with *BCR-ABL1* $\leq 1\%$ IS ($P < .0001$). The

corresponding 5-year PFS rates were 89% and 96%, respectively ($P = .006$).

In the DASISION study, patients who achieved $\leq 10\%$ *BCR-ABL1* IS at 3 months were more likely to achieve CCyR, MMR, and MR4.5 by 5 years and they also had higher rates of PFS and OS rates in both treatment arms.⁴⁷ In the dasatinib arm, the 5-year response rates for CCyR, MMR, and MR4.5 were 94%, 87%, and 54%, respectively, for patients with $\leq 10\%$ *BCR-ABL1* IS at 3 months compared to 41%, 38%, and 5%, respectively, for those with $>10\%$ *BCR-ABL1* IS at 3 months. In the imatinib arm, the corresponding response rates were 92%, 81%, and 48%, respectively, for patients with $\leq 10\%$ *BCR-ABL1* IS at 3 months compared to 59%, 41%, and 12% for patients with $>10\%$ *BCR-ABL1* IS at 3 months. The 5-year PFS rates for patients with *BCR-ABL1* $\leq 10\%$ and $>10\%$ at 3 months were 89% and 72%, respectively, for dasatinib ($P = .0014$) and 93% and 72%, respectively, for imatinib ($P < .001$).⁴⁷ The corresponding 5-year OS rates were 94% and 84%, respectively, for dasatinib ($P = .0028$) and 95% and 80.5%, respectively, for imatinib ($P < .001$). The rates of transformation to accelerated or blast phase were also lower among patients who achieved $\leq 10\%$ *BCR-ABL1* IS at 3 months (3% for dasatinib and imatinib) vs. $>10\%$ *BCR-ABL1* IS at 3 months (14% for dasatinib and 15% for imatinib) in both treatment arms.

In the ENESTnd study, $>10\%$ *BCR-ABL1* IS at 3 months was associated with lower rates of MR4.5, an increased risk of progression, and lower PFS and OS.⁴⁹ Patients who achieved $>1\%$ to $\leq 10\%$ *BCR-ABL1* at 3 months were more likely to achieve MR4.5 by 5 years than those with $>10\%$ *BCR-ABL1* at 3 months (52% vs. 8% on nilotinib 300 mg twice daily, $P < .0001$; 42% vs. 21% on nilotinib 400 mg twice daily, $P = .0001$ and 34% vs. 16% on imatinib, $P < .0001$). The estimated 5-year PFS rates (95.3% vs. 78.3% for nilotinib 300 mg twice

daily, $P = .0014$; 95.7% vs. 89.0% for nilotinib 400 mg twice daily, $P = .0597$; 98.5% vs. 79.3% for imatinib, $P < .0001$) and OS rates (97.6% and 81.9%, respectively, for nilotinib 300 mg twice daily; $P = .0005$; 95.7% and 92.7%, respectively, for nilotinib 400 mg twice daily; $P = .5256$ and 99.2% and 79.1%, respectively, for imatinib; $P < .0001$) were significantly higher for patients with $>1\%$ to $\leq 10\%$ *BCR-ABL1* than those with $>10\%$ *BCR-ABL1* at 3 months.

Achievement of CCyR (0.1 % to $<1\%$ *BCR-ABL1* IS) at 12 months after first-line TKI therapy is an established prognostic indicator of long-term survival.^{39,94} In the IRIS study, at the median follow-up of 60 months, PFS rate was better for patients who achieved a CCyR or PCyR at 12 months compared to those who did not have a MCyR at 12 months (97%, 93%, and 81%, respectively).³⁹ In an analysis of patients with newly diagnosed CP-CML treated with imatinib or second-generation TKIs, the 3-year EFS and OS rates were 98% and 99% for patients who achieved CCyR at 12 months compared to 67% and 94% in patients who did not achieve a CCyR.⁹⁴

Achievement of MMR is associated with durable long-term cytogenetic remission and a lower rate of disease progression.³⁹ However, it may not be of prognostic significance in patients who are in CCyR.^{85,95-100} In the 7-year follow-up data from the IRIS study, among patients who were in CCyR, achievement of MMR at 12 months had no significant impact on EFS or OS but the achievement of MMR at 18 months was associated with a modest but statistically significant benefit for EFS. The EFS rate was 95% for patients with MMR ($< 0.1\%$ *BCR-ABL1*) at 18 months compared with 86% for patients with $>0.1\% \leq 1\%$ *BCR-ABL1* at 18 months.⁸⁵ In the German CML IV study, MMR at 12 months was associated with a better PFS (99% vs. 94%; $P = .0023$) and OS (99% vs. 93%; $P = .0011$) at 3 years when compared with $>1\%$ *BCR-ABL1* IS or no MMR.⁹⁸ However, there was no difference in PFS

and OS when compared with the 0.1% to 1% *BCR-ABL1* IS group (which closely correlates with CCyR).⁹⁸ The 3-year survival rates for MMR at 12 months and 0.1% to 1% *BCR-ABL1* IS at 12 months were 99% and 98%, respectively, implying that MMR is not of prognostic significance in patients who have achieved CCyR at 12 months. The achievement of MMR is also not a significant prognostic indicator of outcome in patients who are in stable CCyR after first-line treatment with dasatinib or nilotinib.^{99,100} Although some investigators have reported that dose escalation of imatinib might benefit patients in CCyR with no MMR,¹⁰¹ there are no randomized studies to show that a change of therapy would improve survival, PFS, or EFS in this group of patients.¹⁰²

Resistance to TKI Therapy and *BCR-ABL1* Kinase Domain Mutational Analysis

Primary Resistance

Aberrant expressions of drug transporters¹⁰³⁻¹⁰⁵ and plasma protein binding of TKI¹⁰⁶⁻¹⁰⁸ could contribute to primary resistance by altering the intracellular and plasma concentration of TKI. Monitoring imatinib plasma levels may be useful in determining patient adherence to therapy. However, there are no data to support that change of therapy based on plasma imatinib levels will affect treatment outcomes. Pretreatment levels of organic cation transporter 1 (OCT1) have been reported as the most powerful predictor of response to imatinib.¹⁰⁹ On the other hand, cellular uptake of dasatinib or nilotinib seems to be independent of OCT1 expression, suggesting that patients with low hOCT1 expression might have better outcomes with dasatinib or nilotinib.¹¹⁰⁻¹¹³

Secondary Resistance

Point mutations in the *BCR-ABL1* kinase domain are the most frequent mechanism of secondary resistance to TKI therapy and are associated



with poor prognosis and higher risk of disease progression.¹¹⁴⁻¹¹⁸

Among the BCR-ABL1 kinase domain mutations, T315I mutation confers the complete resistance to imatinib, dasatinib, nilotinib and bosutinib.^{119,120} In addition to T315I, F317L and V299L mutants are resistant to dasatinib and Y253H, E255K/V, and F359V/C mutants are resistant to nilotinib.¹²¹⁻¹²⁵

In an analysis of 1043 patients with imatinib-resistant CP-CML, the presence of T315I and F317L mutations at baseline was associated with less favorable responses.¹²³ Patients with an F317L mutation had a high rate of CHR (93%) but low rates of MCyR and CCyR (14% and 7%, respectively), whereas favorable CCyR rates were achieved in patients with highly imatinib-resistant mutations such as E255K/V (38%) and L248V (40%). A few responses (CHR and MCyR) were observed in patients with T315I mutation but no CCyRs. In another analysis that assessed the occurrence and impact of baseline *BCR-ABL1* mutations on nilotinib therapy in patients with imatinib-resistant CP-CML, 253H, E255V/K, and F359V/C mutations were associated with less favorable MCyR rates (13%, 43%, and 9%, respectively) and none of the patients with these mutations achieved CCyR within 12 months of therapy.¹²⁴ E255K/V, F359C/V, Y253H, and T315I mutations were most commonly associated with disease progression and relapse.

Bosutinib has demonstrated activity in patients with BCR-ABL1 mutations resistant to dasatinib (F317L) and nilotinib (Y253H, E255K/V, and F359C/I/V).¹²⁶ The most common baseline mutations were T315I, F359C/I/S/V, F317L, G250E, Y253F/H, and M351T. T315I and V299L mutations are resistant to bosutinib. Ponatinib was also active against other *BCR-ABL1* mutations resistant to dasatinib or nilotinib, including E255V, Y253H, and F359V, in addition to T315I.¹²⁷

Rising Levels of BCR-ABL1 Transcripts

Rising levels of *BCR-ABL1* transcripts may be associated with an increased likelihood of detecting BCR-ABL1 mutations and cytogenetic relapse.¹²⁸⁻¹³² In patients who had achieved very low levels of *BCR-ABL1* transcripts, emergence of BCR-ABL1 mutations was more frequent in those who had more than a 2-fold increase in *BCR-ABL1* levels compared to those with stable or decreasing *BCR-ABL1*.¹²⁸ A serial rise has been reported to be more reliable than a single ≥ 2 -fold increase in *BCR-ABL1* transcripts.^{129,130} Among patients in CCyR with ≥ 0.5 -log increase in *BCR-ABL1* transcripts on at least two occasions, those with the highest risk were those who lost MMR with more than 1-log increase in *BCR-ABL1* transcripts had the highest risk of disease progression compared to those who never achieved a MMR and had 1-log increase in *BCR-ABL1* transcripts.¹³⁰

The precise increase in *BCR-ABL1* transcripts that warrants a mutation analysis depends on the performance characteristics of QPCR assay in the laboratory.¹³² Some labs have advocated a 2- to 3-fold range,^{97,131,132} while others have taken a more conservative approach (0.5-log to 1-log).¹³⁰ Obviously, some common sense must prevail, since the amount of change in absolute terms depends on the MMR level. For example, a finding of any *BCR-ABL1* compared to CMR is an infinite increase in *BCR-ABL1* level, though a change from CMR to a barely detectable level is clearly different from a 5-fold increase in a case hovering at the MMR level.

Second-Line and Subsequent Therapy (CML-3)

Based on data demonstrating the prognostic significance of early molecular response at 3 and 6 months, the panel has included $\leq 10\%$ (1%–10%) *BCR-ABL1* IS as the response milestone at 3 and 6 months. 0.1% to $< 1\%$ *BCR-ABL1* and $< 0.1\%$ *BCR-ABL1* are included as response milestones at 12 months and > 12 months, respectively.

Continuation of the same dose of TKI therapy (ie, imatinib, dasatinib, nilotinib) and assessment of *BCR-ABL1* transcripts with QPCR (IS) every 3 months is recommended for patients who meet response milestones. If the 3-month response milestone (1%–10% *BCR-ABL1*) is not achieved after first-line TKI therapy, patients are considered to be at high risk for disease progression and should be considered for alternate treatment options. Evaluation for allogeneic HCT (that is, a discussion with a transplant specialist, which might include initiating HLA typing) is recommended if the response milestones are not achieved at 3, 6, and 12 months.

Quite recently, studies have suggested that the rate of decline in *BCR-ABL1* transcripts correlates with longer-term response.¹³³⁻¹³⁶ Among patients with >10% *BCR-ABL1* IS after 3 months of treatment with imatinib, those with a faster decline in *BCR-ABL1* (*BCR-ABL1* halving time < 76 days) had a superior outcome compared to those with a slower decline (4-year PFS rate was 92% vs. 63%, respectively).¹³³ A rapid initial *BCR-ABL1* decline also identifies a subgroup of Sokal high-risk patients with outcomes similar to those of Sokal low-risk patients.¹³⁴ Among Sokal high-risk patients, *BCR-ABL1* halving time of ≤11 days at 1 month was associated with significantly improved FFS (4-year FFS rate was 79% for patients with halving time of ≤11 days at 1 month vs. 53% for those with halving time of > 11 days; *P* = .03). In the German CML IV study, lack of a half-log reduction of *BCR-ABL1* transcripts at 3 months was associated with a higher risk of disease progression on imatinib therapy.¹³⁵ The results of the D-First study also showed that in patients treated with dasatinib, *BCR-ABL1* halving time of ≤14 days was a significant predictor of MMR by 12 months and deep molecular response (*BCR-ABL1* <0.01% IS) by 18 months.¹³⁶

The guidelines emphasize that achievement of response milestones months must be interpreted within the clinical context, before making

drastic changes to the treatment strategy. Evaluation of compliance to therapy and mutational analysis are recommended prior to changing therapy. Mutational analysis is helpful in the selection of subsequent TKI therapy for patients with inadequate initial response to first-line or second-line TKI therapy.¹³⁷ Treatment options based on *BCR-ABL1* mutation status are outlined in [CML-5](#). The guidelines recommend mutational analysis for patients who do not achieve response milestones, any sign of loss of response (hematologic or cytogenetic relapse), and if there is a 1-log increase in *BCR-ABL1* level with loss of MMR. Currently there are no specific guidelines for changing therapy based on rising *BCR-ABL1* levels as detected by QPCR. Changes of therapy based solely on rising *BCR-ABL1* levels should be done only in the context of a clinical trial.

Management of Patients with Inadequate Response to Imatinib

Dose escalation of imatinib or switching to an alternate TKI is recommended for patients with *BCR-ABL1* transcripts >10% IS after initial treatment with imatinib.

Dose escalation of imatinib up to 800 mg daily has been shown to overcome some of the primary resistance, but the duration of responses has typically been short.¹³⁸⁻¹⁴¹ Dose escalation was particularly effective in patients with cytogenetic relapse who had achieved cytogenetic response with imatinib 400 mg daily.¹⁴⁰ However, it is unlikely to benefit those with hematologic failure or those who never had a cytogenetic response with standard-dose imatinib.

Dasatinib, nilotinib, and bosutinib are active against many of the imatinib-resistant *BCR-ABL1* kinase domain mutants, except T315I, and are effective second-line and subsequent treatment options for patients intolerant to imatinib or those with resistance.

Dasatinib at different dose levels (70 mg twice daily or 100 mg once daily) has shown equal efficacy in patients with CP-CML intolerant to or resistant to imatinib.^{142,143} In the START-R trial, at a minimum follow-up of 2 years, dasatinib (70 mg twice a day) demonstrated higher rates of MCyR (53% vs. 33%), CCyR (44% vs. 18%) and MMR (29% vs. 12%) compared to high-dose imatinib and the estimated PFS also favored dasatinib.¹⁴² In the dose-optimization study (CA180-034) after 7-year follow-up, the MMR, PFS, and OS rates were 46%, 42%, and 65%, respectively for dasatinib 100 mg once daily and the corresponding rates were 46%, 44% and 68% for dasatinib 70 mg twice daily.¹⁴³ Severe grade 3 or 4 adverse events including pleural effusion were less frequent with dasatinib 100 mg once daily compared to dasatinib 70 mg twice daily.

In a phase II study, nilotinib (400 mg twice daily) resulted in MCyR and CCyR rates of 59% and 45% respectively, in patients with CP-CML (n = 280) intolerant or resistant to imatinib. The estimated PFS and OS rates at 48 months were 57% and 78%, respectively.¹⁴⁴ The estimated PFS rate at 48 months was higher for patients with CCyR at 12 months (89% compared to 56% for those with no CCyR at 12 months). In the TIDEL-II study, the cohort of patients with >10% *BCR-ABL1* IS at 3 months after imatinib who were switched directly to nilotinib had higher rates of MMR and CMR at 12 months (but not at 24 months) than the cohort of patients who received dose escalation of imatinib before switching to nilotinib.¹⁴⁵

Bosutinib also has demonstrated activity in patients intolerant to imatinib or in patients with CP-CML resistant to imatinib. In a phase I-II study of 288 patients (196 patients with CP-CML resistant to imatinib and 90 patients intolerant to imatinib), after a median follow-up of 44 months, bosutinib resulted in MCyR and CCyR rates of 59%, and 49%, respectively.¹⁴⁶ The estimated 2-year OS rate was 88% for patients with

resistance to imatinib and 98% for patients with intolerance to imatinib. At 4 years, the cumulative incidence of disease progression to AP-CML or BP-CML was 22% for patients with resistance to imatinib and 10% for patients with intolerance to imatinib. Diarrhea (86%), nausea (46%), rash (36%) and vomiting (37%) were the most common adverse events.

Management of Patients with Inadequate Response to Dasatinib or Nilotinib

Although failure to achieve $\leq 10\%$ *BCR-ABL1* IS at 3 months after first-line therapy with dasatinib or nilotinib is associated with a high risk for disease progression, there is no clear evidence to support that switching to alternate TKI therapy would improve long-term clinical outcome for this group of patients. Some investigators have suggested that response assessment at 3 months has a superior prognostic value over response assessment at 6 months.⁹³ In a more recent report, Marin and colleagues established the superior prognostic value of molecular response assessment at 3 months over molecular response assessment at 6 months.⁹³ The 8-year probability of OS for those with low *BCR-ABL1* transcripts at 3 months and high *BCR-ABL1* transcripts at 6 months following imatinib therapy was similar to that of patients who had low *BCR-ABL1* transcripts at both time points (92.4% and 93.5%, respectively; $P = .78$). However, others have reported that assessment of response at 6 months may provide a better predictor for long-term outcome.¹⁴⁷ In an analysis of 456 patients with CP-CML treated with first-line TKI therapy (imatinib, dasatinib, or nilotinib), patients with >10% *BCR-ABL1* IS at 3 months who subsequently achieved <10% *BCR-ABL1* IS at 6 months had survival outcomes very similar to that of patients who initially achieved <10% *BCR-ABL1* IS) at 3 months. At a median follow-up of 95 months, the 5-year OS rates were 100% and 93% respectively.¹⁴⁷ The 5-year OS rate is significantly lower (81%) for patients with >10% *BCR-ABL1* IS at 3 and 6 months.

Patients with *BCR-ABL* only slightly >10% at 3 months and/or with a steep decline from baseline, may achieve <10% at 6 months and have generally favorable outcomes. Therefore, it is important to interpret the value at 3 months in this context, before making drastic changes to the treatment strategy. Patients with >50% reduction in *BCR-ABL1* compared to baseline or minimally >10% *BCR-ABL1* can continue the same dose of dasatinib or nilotinib for another 3 months, if response milestones are not achieved at 3 months after first-line dasatinib or nilotinib. Patients with intolerance to first-line dasatinib or nilotinib or those with disease that is resistant to dasatinib or nilotinib could be treated with an alternate TKI (other than imatinib) in the second-line setting.

Bosutinib is an effective treatment option for patients with CP-CML pretreated with dasatinib or nilotinib. In the cohort of 119 patients with CP-CML pretreated with more than one TKI (imatinib followed by dasatinib and/or nilotinib), at 40 months of follow-up, CHR, MCyR, and estimated 4-year OS rates were 74%, 40%, 32%, and 78%, respectively.¹⁴⁸ Diarrhea (83%), nausea (48%), vomiting (38%), and thrombocytopenia (39%) were the most common adverse events.

Ponatinib is an option for patients with T315I mutation and for those with disease that has not responded to multiple TKIs. In the PACE trial, after the median follow-up was 37 months, in the cohort of 267 patients with CP-CML refractory ≥3 prior TKIs or those with T315I mutation (51% of patients had disease that is resistant to prior TKI or intolerant dasatinib or nilotinib and 70% of patients had T315I mutation), ponatinib induced durable MCyR, CCyR, MMR, and MR4.5 in 59%, 54%, 39%, and 23% of patients, respectively.¹⁴⁹ Among patients who achieved MCyR and MMR, responses were durable for 82% and 61% of patients, respectively. The estimated 4-year PFS and OS rates were 56% and 77%, respectively. In a post hoc analysis,

exposure to fewer prior TKIs and shorter duration of leukemia were identified as predictors of response.¹⁵⁰ Response rates were higher in patients who were exposed to fewer prior TKIs (MCyR, CCyR, and MMR rates were 84%, 79%, and 53%, respectively, for patients treated with one prior TKI compared to 46%, 38%, and 29%, respectively, for those treated with 3 prior TKIs).

Hepatotoxicity, liver failure, and death have been rarely reported in patients treated with ponatinib. Liver function tests should be done at baseline, and at least monthly or as clinically indicated during treatment. Dose interruption and dose reductions or discontinuation of ponatinib should be considered for hepatotoxicity. Serious arterial and venous thrombosis and occlusions occurred in approximately 27% of patients: cardiovascular occlusion, cerebrovascular occlusion, and peripheral arterial occlusive events occurred in 12%, 6%, and 8% of patients, respectively. Heart failure, including fatalities, occurred in 8% of patients.¹⁵¹ These adverse events were seen in patients with and without cardiovascular risk factors (such as history of ischemia, hypertension, diabetes, or hyperlipidemia). Ponatinib labeling contains a black box warning regarding vascular occlusion, heart failure, and hepatotoxicity. Cardiovascular risk factors (eg, diabetes mellitus, hypertension, hyperlipidemia, smoking, estrogen use) should be identified and controlled before starting ponatinib. Patients should be monitored for evidence of thromboembolism and vascular occlusion. Ponatinib should be interrupted or stopped immediately for vascular occlusion and for new or worsening heart failure. Patients with cardiovascular risk factors should be referred to a cardiologist.

Ponatinib is now indicated only for the treatment of patients with T315I mutation and for the treatment of patients for whom no other TKI therapy is indicated in all phases of CML. The recommended initial dose of ponatinib is 45 mg once daily. Dose intensity of ponatinib is



significantly associated with increased risk of adverse events.¹⁵² Therefore, dose modifications may be necessary for the management of adverse events. In a post hoc analysis that assessed the clinical impact of dose modification and dose intensity on outcomes of patients treated with ponatinib in the PACE trial, dose intensity was also the most significant predictor of MCyR by 12 months.¹⁵³ However substantial responses were observed at lower dose levels. The estimated MCyR rates were approximately 75% at 45 mg, 60% at 30 mg, and 30% at 15 mg. Thus, an initial dose of 30 mg may be a safer and effective dose for patients with cardiovascular risk factors. Safety and efficacy of ponatinib at initial doses lower than 45 mg are being evaluated in a randomized clinical trial.

Omacetaxine has demonstrated safety and efficacy in patients with T315I mutation and in those with CML that is resistant to ≥ 2 TKIs.¹⁵⁴⁻¹⁵⁶ In a phase II study (CML 202 study), among 62 evaluable patients with T315I mutation and CP-CML resistant to prior TKI therapy, CHR, MCyR, and CCyR were seen in 77%, 23%, and 16% of patients, respectively.¹⁵⁴ MMR was achieved in 17% of patients and the T315I clone declined to below detection limits in 61% of patients. Median duration of CHR and MCyR was 9 and 7 months, respectively. After a median follow-up of 19 months, median PFS was 7.7 months and the median OS had not yet been reached. In the cohort of 46 patients with CP-CML that is resistant to ≥ 2 TKIs (CML 203 study), hematologic response was achieved or maintained in 67% of patients, with median response duration of 7.0 months; MCyR and CCyR were achieved in 22% and 4% of patients, respectively. Median PFS and OS were 7.0 months and 30 months, respectively.¹⁵⁵ Omacetaxine had an acceptable toxicity profile and the most common grade 3/4 adverse events were thrombocytopenia (67%), neutropenia (47%), and anemia (37%).¹⁵⁶

Response Milestones after Second-Line TKI Therapy

Early cytogenetic response or molecular response to second-line and subsequent TKI therapy has been reported to be a predictor of OS and PFS. Achievement of cytogenetic response and early molecular response to second-line dasatinib was associated with improved PFS and OS.^{143,157} The estimated rates 7-year PFS, OS and transformation-free survival rates were 56%, 72% and 93% respectively for patients with $\leq 10\%$ *BCR-ABL1* at 3 months compared to 21%, 56% and 88% respectively for those with $>10\%$ *BCR-ABL1* at 3 months.¹⁴³ The estimated 6-year rates of transformation-free survival were 87% and 89% respectively for patients who achieved CCyR or PCyR at 3 months compared to 65% for those who achieved neither at 3 months.¹⁵⁷ The corresponding OS rates were 88%, 90% and 61% for patients who achieved CCyR, PCyR or neither at 6 months. The achievement of early molecular response to second-line nilotinib at 12 months was associated with higher PFS rates at 48 months in patients with CP-CML (n = 280) intolerant of or resistant to imatinib.¹⁴⁴ The estimated PFS rates at 48 months were 85% for patients with $\leq 1\%$ *BCR-ABL1* at 3 months compared to 67% and 42% respectively for those with $>1\%$ to 10% *BCR-ABL1* and $>10\%$ *BCR-ABL1* at 3 months. Landmark analyses of the PACE trial also showed that greater reductions in *BCR-ABL1* transcript levels at 3, 6, and 12 months after treatment with ponatinib were associated with improved PFS and OS at 3 years.¹⁵⁸

Based on the available data, patients who do not achieve cytogenetic or molecular responses at 3, 6, or 12 months after second-line and subsequent TKI therapy should be considered for alternative therapies or allogeneic HCT if deemed eligible. The use of an alternate TKI after treatment failure with two prior TKIs is not associated with durable responses, except in occasional patients in chronic phase.¹⁵⁹

Mutational analysis may identify a subgroup of patients who require careful monitoring (as these patients are at a higher risk of progression) and the subset of patients who will be eligible for allogeneic HCT.

Discontinuation of TKI Therapy

TKI therapy has significantly reduced the annual mortality rate among patients with CML and it is the standard first-line therapy for patients with newly diagnosed CP-CML. In the majority of patients achieving CCyR, CML is now managed like a chronic disease, requiring long-term treatment and supportive care. However, majority of patients who achieve a clinically undetectable level of *BCR-ABL1* transcripts by the most sensitive QPCR assay continue to harbor minimal residual disease that may eventually lead to disease recurrence. Several clinical studies have evaluated the feasibility of discontinuation of TKI therapy (with close monitoring) in carefully selected patients who have achieved and maintained deep molecular response (\geq MR 4.0; \leq 0.01% *BCR-ABL1* IS) for 2 or more years.¹⁶⁰⁻¹⁷²

The possibility of treatment-free remission (TFR) after discontinuation of imatinib was first evaluated in the Stop Imatinib (STIM) study in 100 patients with a CMR for at least 2 years (5-log reduction in *BCR-ABL1* levels and undetectable minimal residual disease on QPCR with a sensitivity of \geq 4.5-log reduction from the standardized baseline).^{160,161} At the median follow-up of 65 months, the probabilities of relapse-free survival and treatment-free survival were 38% and 41%, respectively, at 24 months after discontinuation of imatinib.¹⁶¹ Other subsequent TKI discontinuation trials have also reported similar findings.¹⁶²⁻¹⁷² Limited longer-term follow-up data from the TKI discontinuation trials are summarized in [Table 1](#).¹⁷³

Approximately 40% to 60% of patients who have discontinued TKI therapy after achieving deep molecular remission usually have a

recurrence within 6 months of treatment cessation, in some cases as early as one month after discontinuation of TKI therapy. In the STIM study, molecular relapse (trigger to resume TKI therapy) was defined as positivity for *BCR-ABL1* transcripts by QPCR confirmed by a 1-log increase in *BCR-ABL1* transcripts between two successive assessments or loss of MMR at one point.^{160,161} The results of the A-STIM study showed the loss of MMR (\leq 0.1% *BCR-ABL1* IS) could be used as a practical criterion for restarting therapy since the estimated probability of losing MMR at 24 months after discontinuation of imatinib was lower than the probability of losing CMR (36% compared to 54%).¹⁶⁵ Resumption of TKI therapy immediately after recurrence results in the achievement of undetectable minimal residual disease in almost all patients.¹⁶⁰⁻¹⁷²

Some patients may experience significant adverse events that are believed to be due to TKI discontinuation. An imatinib withdrawal syndrome (aggravation or new development of musculoskeletal pain and/or pruritus after discontinuation of imatinib) was reported in 30% patients in the KIDs study and the occurrence of imatinib withdrawal syndrome was associated with a lower rate of molecular relapse.¹⁶⁷ ENESTFreedom and ENESTop studies also reported musculoskeletal pain during the TFR period in 25% and 42% of patients, respectively.^{170,171}

Several factors may help predict relapse after discontinuation of TKI therapy (eg a higher Sokal risk score, female gender, natural killer (NK) and T-cell counts, suboptimal response or resistance to imatinib, duration of TKI therapy and deep molecular response prior to TKI discontinuation).^{160,161,166,168,169,172} However, only the duration of TKI therapy and deep molecular response prior to TKI discontinuation therapy have been associated with TFR with a high level of consistency.^{160,169,172}

Based on the available evidence from clinical studies that have evaluated the feasibility of TFR, the panel members feel that discontinuation of TKI therapy (with *close monitoring*) is feasible in carefully selected patients (in early CP-CML with no history of resistance to TKI therapy) who have achieved and maintained a deep molecular response (\geq MR4) for \geq 2 years. Clinical studies that have evaluated the safety and efficacy of TKI discontinuation have employed strict eligibility criteria and have mandated more frequent molecular monitoring than typically recommended for patients on TKI therapy. Access to a reliable QPCR (IS) with a sensitivity of detection of \geq 4.5 log reduction and the availability of test results within 2 weeks is one of the key requirements to monitor patients after TKI discontinuation and ascertain their safety. The criteria for the selection of patients suitable for discontinuation of TKI therapy are outlined in [CML-F](#). The guidelines emphasize that discontinuation of TKI therapy outside of a clinical trial should be considered only if ALL of the criteria included in the list are met.

Management of Advanced Phase CML (CML-4)

TKI Therapy

Imatinib has induced favorable hematologic and cytogenetic response rates in patients with AP-CML or BP-CML.¹⁷⁴⁻¹⁷⁹ Dasatinib,^{180,181} nilotinib,^{182,183} bosutinib,¹⁸⁴ and ponatinib¹⁸⁵ have demonstrated activity in imatinib-resistant or imatinib-intolerant AP-CML or BP-CML.

Dasatinib 140 mg once daily has similar efficacy to 70 mg twice-daily dosing with an improved safety profile in patients with AP-CML and BP-CML.^{180,181} In a phase III study of 317 patients with AP-CML randomized to 140 mg once daily (n = 158) or 70 mg twice-daily (n = 159), the rates of MCyR and the estimated PFS and OS rates at 24 months were comparable in the 2 treatment groups (MCyR, 39% vs.

43%; PFS, 51% vs. 55%; OS, 63% vs. 72%).¹⁸⁰ In a phase III study of patients with BP-CML, dasatinib 140 mg once daily and 70 mg twice-daily resulted in similar rates of MCyR (25% vs. 28%) and OS rates at 24 months (24% vs. 28%) in patients with myeloid BP-CML.¹⁸¹ In patients with lymphoid BP-CML, dasatinib 140 mg once daily resulted in higher rates of MCyR compared to 70 mg twice daily (50% vs. 40%), and the OS rates at 24 months were 21% and 16%, respectively. In patients with imatinib-resistant or imatinib-intolerant AP-CML, after a median 24 months of follow-up (n = 137), nilotinib resulted in MCyR and CCyR in 32% and 20% of patients, respectively.¹⁸² The durability of MCyR and CCyR were 66% at 24 months and 83% at 12 months, respectively. The estimated PFS and OS rates at 24 months were 70% and 33%, respectively. In a phase II study of 136 patients (MBC, n = 105; LBC, n = 31), after a minimum follow-up of 24 months, MCyR was achieved in 38% of patients with MBC and 52% of patients with LBC.¹⁸³ CCyR was seen in 30% of patients with MBC and 32% of patients with LBC. The OS rate was 42% at 12 months and 27% at 24 months. The duration of MCyR was 11 months for patients with MBC and 3 months for those with LBC.

Long-term efficacy and safety data (\geq 4 years of follow-up) showed that bosutinib induces hematologic response and MCyR in patients with advanced-phase CML with and without *BCR-ABL1* mutations.¹⁸⁴ In the cohort of patients with AP-CML (n = 79), MCyR was attained or maintained in 40% of patients.¹⁸⁴ Among patients with BP-CML (n = 64), the corresponding response rates in patients with BP-CML evaluable for response were 28% and 37%, respectively. Responses were durable in approximately 50% of patients with AP-CML at 4 years; approximately 25% of patients with BP-CML responded at one year.

The PACE trial confirmed the efficacy of ponatinib in patients with advanced phase CML intolerant to \geq 3 TKIs or those with resistant



disease.¹⁸⁵ After a median follow-up of 28 months, MaHR and 2-year OS rates were 62% and 72%, respectively, for patients with AP-CML. The corresponding MaHR and 2-year OS rates were 32% and 18%, respectively, for patients with BP-CML. Among patients with T315I mutation, MaHR rates were 61%, and 29%, respectively, for patients with AP-CML and BP-CML.

The efficacy of imatinib in combination with decitabine or cytarabine-based chemotherapy in AP-CML and myeloid BP-CML has been demonstrated in several small studies.¹⁸⁶⁻¹⁸⁹ Hyper-CVAD in combination with imatinib or dasatinib is also effective for patients with lymphoid BP-CML, particularly when followed by allogeneic HCT.^{190,191} Among 42 patients with BP-CML, CCyR and CMR were achieved in 58% and 25% of patients, respectively. The median remission duration and median OS were 14 months and 17 months, respectively. In multivariate analysis, the median remission duration was longer among HCT recipients ($P = .01$); the median OS was longer among HCT recipients ($P < .001$) and in patients treated with dasatinib ($P = .07$).¹⁹¹

Omacetaxine is a feasible treatment option for advanced phase CML that is resistant to multiple TKIs as well as for patients with T315I mutation.¹⁹² Among the 51 patients with AP-CML, after a median follow-up of 16 months, MaHR, CHR, and minor cytogenetic response were achieved or maintained in 37%, 29%, and 11% of patients, respectively.¹⁹² MaHR rates were 55% and 58%, respectively, for patients with a history of T315I mutation and for those with confirmed T315I mutation at baseline. The median PFS and OS were 4.8 months and 17.6 months, respectively. The most common grade 3/4 hematologic adverse events were thrombocytopenia (51%), anemia (39%), neutropenia (20%), and febrile neutropenia (14%).

Allogeneic Hematopoietic Cell Transplant

Allogeneic HCT is a potentially curative treatment for patients with CML, but the excellent results with TKI therapy have challenged the role of allogeneic HCT as a first-line therapy for patients with CP-CML. Allogeneic HCT is no longer recommended as a first-line treatment option for CP-CML. Allogeneic HCT is an appropriate first-line treatment option for the very rare patients presenting with blast phase at diagnosis, patients with T315I and other BCR-ABL1 mutations that are resistant to all TKIs, and for the rare patients intolerant to all TKIs.¹⁹³⁻¹⁹⁶

Ongoing advances in alternative donor sources (such as unrelated donors and cord blood), more accurate HLA typing for a stringent selection of unrelated matched donors,^{197,198} and the use of reduced-intensity conditioning regimens¹⁹⁹⁻²⁰³ have improved outcomes following allogeneic HCT. Several studies have confirmed that TKI therapy prior to allogeneic HCT does not compromise the outcome following allogeneic HCT or increase transplant-related toxicity.²⁰⁴⁻²¹⁰

Disease phase, HLA matching, age and sex of the donor and recipient, and time from diagnosis to transplant have been identified as pretransplant risk factors.²¹¹ Low HCT comorbidity index has been identified as prognostic indicators of lower non-relapsed mortality rate and a somewhat improved survival rate.²¹² The disease phase at the time of transplant remains an important prognostic factor and the survival outcomes following transplant are clearly better for patients in CP-CML compared to patients with AP-CML or BP-CML.²¹³⁻²¹⁸ Therefore, the potential use of transplantation must be tied to faithful monitoring of disease, since the major potential pitfall in delaying transplantation is “missing” the chronic phase interval.

Treatment Considerations

Participation in clinical trials (evaluating TKI in combination with chemotherapy or other novel treatment options) is recommended for all patients with AP-CML or BP-CML. Treatment options are based on patient's age and comorbidities. Disease progression to advanced phase while on TKI therapy has worse prognosis than de novo advanced phase CML. In patients with disease progression to AP-CML or BP-CML, the selection of TKI therapy is based on prior therapy and/or mutational analysis. Mutational analysis is recommended for all patients with AP-CML and BP-CML prior to initiation of TKI therapy. A significant portion of patients with AP-CML or BP-CML treated with TKI therapy achieve a MCyR but not a concomitant CHR because of persistent cytopenias and because the absence of a CHR at the time of MCyR was associated with an inferior outcome.²¹⁹ The role of allogeneic HCT should be discussed based on response to therapy.

Accelerated phase CML

TKI therapy is recommended as first-line treatment for patients with newly diagnosed AP-CML. Allogeneic HCT can be considered based on response to TKI therapy. In patients with disease progression to AP-CML on prior TKI therapy, treatment with a course of alternate TKI (not received before) will be beneficial as a “bridge” to allogeneic HCT. Omacetaxine is an option for patients with disease progression to AP-CML on TKI therapy.¹⁹²

Blast Phase CML

Allogeneic HCT is an appropriate first-line treatment option for the very rare patients presenting with BP-CML at diagnosis. In patients with disease progression to BP-CML on prior TKI therapy, treatment with a course of alternate TKI (not received before) will be beneficial as a “bridge” to allogeneic HCT. TKI therapy in combination with chemotherapy or steroids is recommended for patients with myeloid or

lymphoid BP-CML. ALL-type chemotherapy is recommended for patients with lymphoid BP-CML and AML-type chemotherapy is recommended for those with myeloid BP-CML.

Central nervous system (CNS) involvement has been described in case reports of BP-CML.²²⁰⁻²²³ Lumbar puncture and CNS prophylaxis is recommended for lymphoid blast phase. Documented CNS involvement in patients with lymphoid BP-CML should be managed according to the standard of care for AML or ALL. TKI therapy has not been optimized for patients with CNS involvement. Dasatinib has been reported to cross the blood brain barrier and may represent the best TKI option for patients with CNS disease.²²⁴

Monitoring Response after Allogeneic HCT (CML-6)

BCR-ABL1 transcripts may persist after many years in most patients after allogeneic HCT. The prognostic significance of *BCR-ABL1* positivity is influenced by the time of testing after allogeneic HCT. While a QPCR assay positive for *BCR-ABL1* at 6 to 12 months after transplant is associated with a high risk of relapse, a positive QPCR assay at a much later time point after transplant is associated with a lower risk of relapse.²²⁵⁻²³² Early detection of *BCR-ABL1* transcripts after transplant may be useful to identify patients who may be in need of alternative therapies before the onset of a complete relapse.

Management of Post-transplant Relapse (CML-6)

Donor lymphocyte infusion (DLI) is effective in inducing durable molecular remissions in the majority of patients with relapsed CML following allogeneic HCT, though it is more effective in patients with chronic phase relapse than advanced phase relapse.²³³⁻²³⁸ However, DLI is associated with complications such as graft-vs-host disease (GVHD), susceptibility to infections, and immunosuppression.²³³ Improvements in the methods of detecting *BCR-ABL1* transcripts to



predict relapse, the development of reduced-intensity conditioning regimens, modified delivery of lymphocytes with the depletion of CD8+ cells, and the use of escalating cell dosage regimens have reduced the incidence of GVHD associated with DLI.²³⁹⁻²⁴³

Imatinib is very effective in inducing durable cytogenetic and molecular responses in the majority of patients relapsing with chronic and advanced phase CML following allogeneic HCT, and the response rates are higher in patients with chronic phase relapse than advanced phase relapse.²⁴⁴⁻²⁵¹ Very limited data are available on the use of dasatinib and nilotinib in a small number of patients with post-transplant relapse.²⁵²⁻²⁵⁸ Imatinib is also effective in the prophylactic setting to prevent relapse following HCT in high-risk patients.^{259,260}

There are also data suggesting that the use of DLI in combination with imatinib may be more effective at inducing rapid molecular remissions than either modality alone.²⁶¹ Recent retrospective studies have shown that TKIs are better than DLI alone or in combination with TKI for post-transplant relapse.^{262,263} However, these observations are yet to be confirmed in randomized trials.

Patients who are in CCyR (QPCR-negative) should undergo regular QPCR monitoring (every 3 months for 2 years, then every 3–6 months thereafter). Given the high risk for hematologic relapse in patients with prior accelerated or blast phase, post-transplant TKI therapy should be considered for at least one year in this cohort of patients who are in remission following allogeneic HCT.^{259,260}

TKI with or without DLI or omacetaxine can be considered for patients who are not in remission or in cytogenetic relapse or those with an increasing level of molecular relapse. The selection of TKI depends on prior TKI, agent's side effect profile, the presence of comorbidities, and

mutational status. Pre-existing mutations in the ABL kinase domain, frequently associated with resistance to TKIs are persistently detectable in the majority of patients who relapse after allogeneic HCT.²⁶⁴ Mutational analysis is therefore essential prior to the selection of TKI for the treatment of post-transplant relapse.

In patients with CML that has previously failed imatinib, there are no data to support the use of post-transplant imatinib. Dasatinib, nilotinib, bosutinib, ponatinib, or omacetaxine may be more appropriate for patients with CML that has previously failed imatinib. However, there are no data to support the use of post-transplant bosutinib, ponatinib, or omacetaxine. CNS relapse of CML following allogeneic HCT has been described in few case reports.^{265,266} Dasatinib may also be an effective treatment for extramedullary relapse following allogeneic HCT.^{224,267,268} Participation in a clinical trial should be encouraged.

Management of CML During Pregnancy

The median age of disease onset is 67 years, but CML occurs in all age groups. The EUTOS population-based registry has reported that approximately 36.5% of patients at the time of diagnosis are of reproductive age.²⁶⁹ Clinical care teams should be prepared to address issues relating to fertility and pregnancy as well as counsel these patients about the potential risks and benefits of treatment discontinuation and possible resumption of TKI therapy should CML recur during pregnancy. Referral to a CML specialty center is recommended.

TKI Therapy and Conception

Imatinib, dasatinib, and nilotinib have been shown to be teratogenic and are known to cause embryonic or fetal toxicities in animal studies. TKI therapy appears to affect some male hormones at least transiently, but

these drugs do not appear to have an effect on fertility in men, nor is the miscarriage or fetal abnormality rate higher in female partners of men on TKI therapy.²⁷⁰⁻²⁷⁴ The situation is more complex for women as TKI therapy during pregnancy has been associated with both a higher rate of miscarriage and fetal abnormalities^{275,276} Pye and colleagues reported the outcome of pregnancies in 180 women exposed to imatinib during pregnancy. Fifty percent of pregnancies with known outcome were normal and 10% of pregnancies with known outcome had fetal abnormalities.²⁷⁵ Eighteen pregnancies ended in spontaneous abortion. Cortes and colleagues reported the outcomes of pregnancy and conception during treatment with dasatinib.²⁷⁶ Among 46 women treated with dasatinib, 15 women (33%) delivered a normal infant. Elective or spontaneous abortions were reported in 18 women (39%) and 8 women (17%), respectively, and 5 women (11%) had an abnormal pregnancy. Fetal abnormalities were reported in 7 cases. Among 33 women fathered by dasatinib-treated men, 30 women (91%) delivered infants who were normal at birth. Although there are no data regarding the outcome of pregnancy in patients receiving bosutinib and ponatinib at the time of conception, these agents must be considered unsafe to use in pregnant women.

Discontinuation of TKI therapy because of pregnancy in women who were not in a CMR has only been reported in two small series.^{277,278} Ault and colleagues have reported 10 women who stopped imatinib because of pregnancy after a median of 8 months of therapy.²⁷⁷ Five of the nine women who had achieved a CHR lost the response after stopping therapy, and six had an increase in Ph-positive metaphases. At 18 months after resuming therapy, all nine patients had achieved a CHR but only three women achieved a CCyR and none had achieved an MMR. Kuwabara and colleagues reported outcomes of seven women who were not in a CMR at the time imatinib was stopped

because of pregnancy, three of whom were in an MMR.²⁷⁸ All seven women had disease progression. The three women who had an MMR at the time imatinib was stopped were able to regain the same response once the drug was restarted, whereas the remaining four patients were not.

Depending on other factors such as age, a natural pregnancy may occur months after stopping TKI therapy. Assuming the earliest time a woman could conceive and give birth naturally, without any wash out period, is 10 months after stopping her TKI, the likelihood is in the range of 60% that her PCR will become positive if she was in a CMR when she became pregnant; it is even higher if she was not in a CMR when she became pregnant.^{277,278}

Planning a Pregnancy

Prior to attempting pregnancy, women and their partners should be counseled that no guidelines exist regarding how best to monitor CML during pregnancy, nor how best to manage progressive disease should it occur during pregnancy. Conception while on active TKI therapy is strongly discouraged due to the risk of fetal abnormalities.

TKI therapy does not appear to have a deleterious effect on male sperm and the general recommendation is that men who take TKIs do not need to stop therapy if a pregnancy is planned, although experience is limited. Sperm banking can also be performed prior to starting TKI therapy, although there are no data regarding quality of sperm in untreated men with CML.

In women, due to the risk of miscarriage and fetal abnormalities during pregnancy, TKI therapy should be stopped prior to natural conception and the patient should remain off therapy during pregnancy.^{275,276} Consultation with a high-risk obstetrician is recommended. Referral to

an IVF center is recommended and in coordination with the patient's obstetrician, TKI therapy should be stopped prior to oocyte retrieval. It is not known how long TKI should be stopped prior to attempting a natural pregnancy or oocyte retrieval. Compounding the high incidence of disease recurrence off TKI therapy are the significant obstacles that exist for women who choose one of the above forms of IVF, chief among which is the lack of access to centers that perform the procedure, high costs associated with the drugs and surgical procedures that may not be covered by insurance, costs of embryo/oocyte storage, and access to surrogate programs. Some women may require more than one IVF cycle to obtain enough potentially viable embryos for implantation. In addition, women may need a family medical leave from work to attend IVF appointments. It is also important to note that not all states allow surrogacy.

TKI therapy can be restarted after the baby is born. Women on TKI therapy should also be advised not to breast feed, as TKIs pass into human breast milk.^{279,280} If TKI therapy should be provided during pregnancy, the potential benefit for the mother and the potential risk to the fetus of continuing TKI therapy vs. the risk of treatment interruption leading to the loss of optimal disease response must be carefully evaluated on an individual basis prior to initiation of TKI therapy. Fertility preservation should be discussed with all patients of childbearing age prior to the initiation of TKI therapy.

Monitoring and Treatment During Pregnancy

It is recommended to check monthly peripheral blood QPCR, and initiate treatment if the *BCR-ABL1* increases to >1.0% IS. Most of the literature regarding treatment during pregnancy consists of case reports. Leukapheresis can be initiated for a rising WBC, although there are no data that recommend at what level WBC this should be

started.²⁸¹⁻²⁸³ Low-dose aspirin or low-molecular-weight heparin can also be considered for patients with thrombocytosis.^{284,285} Interferon alpha (in wide range of doses: 3–6 million units every other day to 5–8 million units daily) has been shown to be safe during pregnancy, although it has a low rate of molecular response.^{282,286-289} Hydroxyurea (in wide range of doses) is also considered safe during pregnancy.^{282,290-292} The potential risk and benefit balance should be carefully evaluated in terms of maternal health and fetal risk prior to initiation of treatment during pregnancy, especially during the first trimester.

Specific Considerations for Children with CML

CML accounts for less than 3% of all pediatric leukemias. In general, children are diagnosed at a median age of 11 to 12 years, with approximately 10% presenting in advanced phase. As a consequence of its rarity, there are no evidence-based recommendations for the management of CML in the pediatric population. Many pediatric oncologists follow treatment guidelines that are designed for adult patients. However, clinical presentations and host factors are different between children and adults, and some factors should be considered when treating pediatric patients with CML.²⁹³⁻²⁹⁵

Selection of TKI

Imatinib has been evaluated in pediatric patients with newly diagnosed chronic phase CML in clinical studies.²⁹⁶⁻²⁹⁸ It is the only TKI that is currently approved as first-line treatment for children with CML by the U.S. Food and Drug Administration. In the French National phase IV study, 44 patients from age 10 months to 17 years with newly diagnosed chronic phase CML were treated with imatinib (260 mg/m²).²⁹⁷ At a median follow-up of 31 months, a CHR was achieved in 98% of the patients and the estimated PFS rate at 36 months was 98%.

At 12 months, the rates of CCyR and MMR were 61% and 31%, respectively. The updated results of this trial showed that early molecular response at 3 months ($\leq 10\%$ *BCR-ABL1* IS) correlated with better PFS and higher rates of CCyR and MMR at 12 months.²⁹⁸

Higher dose imatinib (340 mg/m²) has also been shown to be effective and well tolerated in children, inducing a high rate of hematologic, cytogenetic, and molecular responses.^{299,300} Long-term results of an Italian multicenter study (47 patients with chronic phase CML) showed that higher dose imatinib (340 mg/m²) induced CCyR in 91.5% of the evaluable patients at a median time of 6 months.³⁰⁰ At 12 months, MMR ($\leq 0.1\%$ *BCR-ABL1*) and MR ($\leq 0.01\%$ *BCR-ABL1*) were observed in 66.6% and 33% of patients, respectively. Imatinib has also been effective in children with late chronic phase and advanced phase CML as well as for disease relapse following allogeneic HCT.³⁰¹

Dasatinib has been evaluated in phase I/II studies in the pediatric population with relapsed or refractory CML.^{302,303} In a dose escalation study that evaluated dasatinib (60 mg/m² to 120 mg/m²) in 58 children with relapsed or refractory leukemia, CCyR and MMR were achieved in 82% and 47% of patients with imatinib pretreated chronic phase CML.³⁰³ After 24 months of follow-up, median CHR and MCyR durations were not reached. Nilotinib has also been evaluated in a small series of pediatric patients with CML refractory to prior TKI therapy.³⁰⁴ The efficacy and safety of nilotinib in pediatric patients with newly diagnosed CML is being evaluated in an ongoing phase II trial. Bosutinib and ponatinib³⁰⁵ have not been tested in children in clinical trials; therefore, there is little information on the safety of these drugs in children.

The validity of prognostic scores (eg, Sokal, Hasford, and EUTOS scores) has not been established in the pediatric population. In an

analysis that attempted to validate the three prognostic scoring systems in a cohort of 90 children (median age 12 years), there was a high discordance among the scoring methods.³⁰⁶ Therefore, it is not recommended to use these scoring systems for risk assessment or to make treatment decisions for children with CML.

Monitoring for Long-Term Side Effects

Children have a much longer life expectancy than adults and TKI therapy may be needed for many decades; therefore, there is potential long-term morbidity that may not be seen in adults. There are no data available on the cessation of TKI therapy in the pediatric population and discontinuation of TKI therapy in children is not recommended outside the context of a clinical trial.³⁰⁷

A number of studies have reported impaired longitudinal growth in children with CML treated with TKIs.³⁰⁸⁻³¹⁶ It appears that prepubertal children are affected more significantly.^{313,316,317} Growth should be monitored closely and a bone age x-ray should be obtained if longitudinal growth is delayed. A DEXA scan should be obtained if bone mineral density is decreased on plain radiograph or if there is unprovoked fracture. Further evaluation and referral to an endocrinologist is also warranted.

Immunizations

There are little data on immune function with patients on TKI therapy, and it potentially hinders routine vaccination for children with CML.³¹⁸ In general, administration of inactivated killed vaccines to children on TKI therapy is safe, although response may be insufficient as in any immunocompromised patient. A study showed a higher seroconversion rate to H1N1 influenza vaccine in adult CML patients compared to patients with B-cell malignancies or HCT recipients.³¹⁹ Administration of live vaccines during TKI therapy is not recommended in general,



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although one study showed that varicella vaccine could be safely given to some children with immune deficiency.³²⁰ Live vaccines could be considered after stopping TKI therapy for several weeks in patients with a deep molecular response. In the United States, all required live vaccines are completed by the age of 4 to 6 years (<http://www.cdc.gov/vaccines/>). As CML is rarely seen in children younger than this age, few patients face this issue. For the annual influenza vaccine, the live attenuated vaccine (nasal spray) should be avoided, and the inactivated killed vaccine (flu shot) should be used for children receiving TKI.


Table 1. Summary of Limited Longer-term Follow-up Data from the TKI Discontinuation Trials

| Study | Treatment prior to discontinuation | No. of patients | Depth and duration of molecular response (MR) required for discontinuation | Trigger to resume TKI therapy | Median duration of follow-up | Treatment-free remission (TFR) rate |
|------------------------------------|--|-----------------|--|---------------------------------|------------------------------|---|
| STIM ^{160,161} | Imatinib ± interferon | 100 | MR5.0 for at least 2 years | Loss of MR5.0 | 65 months | 41% at 24 months |
| STIM2 ¹⁶² | Imatinib | 124 | MR5.0 for at least 2 years | Loss of MR5.0 | 12 months | 61% at 12 months |
| TWISTER ¹⁶³ | Imatinib ± interferon | 40 | MR4.5 for at least 2 years | Loss of MR5.0 | 42 months | 47% at 24 months |
| HOVON ¹⁶⁴ | Imatinib + cytarabine | 15 | MR4.5 for at least 2 years | Loss of MR4.5 | 36 months | 33% at 24 months |
| A-STIM ¹⁶⁵ | Imatinib ± interferon | 80 | MR5.0 for at least 2 years | Loss of MMR | 31 months | 64% at 24 months; 61% at 36 months |
| ISAV ¹⁶⁶ | Imatinib | 112 | CMR for at least 18 months | Loss of MMR | 22 months | 52% |
| KIDS ¹⁶⁷ | Imatinib ± interferon | 90 | MR4.5 for at least 2 years | Loss of MMR | 27 months | 62% at 12 months; 58.5% at 24 months |
| Stop 2G-TKI ¹⁶⁸ | Dasatinib/Nilotinib (first-line or second-line) | 52 | MR4.5 for at least 24 months | Loss of MMR | 12 months | 61% at 12 months; 57% at 24 months |
| DADI ¹⁶⁹ | Dasatinib (second-line) | 63 | MR4.0 for at least 12 months | Loss of MR4.0 | 20 months | 49% at 6 months |
| ENESTFreedom ¹⁷⁰ | Nilotinib (first-line) | 190 | MR4.5 for 12 months | Loss of MMR | 12 months | 52% |
| ENESTop ¹⁷¹ | Nilotinib (second-line) | 126 | MR4.5 for 12 months | Loss of MR4.0 or Loss of MMR | 48 weeks | 58% |
| EuroSKI ¹⁷² | Imatinib/Dasatinib/Nilotinib (first-line or second-line) | 717 | MR4.0 for at least one year | Loss of MMR | 10 months | 53% |

MR5.0: 5-log reduction in *BCR ABL1* levels and undetectable minimal residual disease on QPCR with a sensitivity of ≥ 4.5 -log reduction;

MR4.5: $\leq 0.0032\%$ *BCR-ABL1* IS or >4.5 -log reduction of *BCR-ABL1* and undetectable minimal residual disease on QPCR with a sensitivity of ≥ 4.5 -log reduction;

MR4.0: $<0.01\%$ *BCR-ABL1* IS;

Major molecular response (MMR): $\leq 0.1\%$ *BCR-ABL1* IS;

Complete molecular response (CMR): undetectable *BCR-ABL1* by QPCR as determined by local laboratory.

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