National Comprehensive Cancer Network®

NCCN Clinical Practice Guidelines in Oncology (NCCN Guidelines®)

Chronic Myeloid Leukemia

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NCCN Guidelines Panel Disclosures

NCCN Chronic Myeloid Leukemia Panel Members
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Advanced Phase CML (CML-4)
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Abbreviations (ABBR-1)

Find an NCCN Member Institution: https://www.nccn.org/home/member-institutions.

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

See NCCN Categories of Evidence and Consensus.

NCCN Categories of Preference: All recommendations are considered appropriate.

See NCCN Categories of Preference.

Updates in Version 3.2025 of the NCCN Guidelines for Chronic Myeloid Leukemia from Version 2.2025 include:

CML-2
- Footnote i modified: *TKIs (e.g. nilotinib) are available in different approved formulations, dosage forms, and strengths that are subject to different administration instructions. These products are not interchangeable.* Refer to package insert for full prescribing information for *specific* TKIs: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm. (also applies to CML-3A, CML-6)
- Footnote j modified: Innovator and generic drugs approved by the regulatory authorities based on pharmacokinetic equivalence can be used interchangeably. FDA-approved generic versions are appropriate substitutes for innovator drugs ~~An FDA-approved generic version is an appropriate substitute for an innovator drug (imatinib)~~ (Kantarjian H, et al. Lancet Haematol 2022;9:e854-e861; Haddad FG, Kantarjian H. J Natl Compr Canc Netw 2024;22:e237116). ~~Generic versions of other TKIs are likely to be marketed in the near future.~~ (also applies to CML-4A, CML-6)

CML-4A
- Footnote x modified: TKI dose for advanced phase CML may differ from CP-CML. *TKIs (e.g. nilotinib) are available in different formulations, dosage forms, and strengths that are subject to different administration instructions. These products are not interchangeable.* Refer to package insert for full prescribing information for *specific TKIs*: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm.

CML-C 4 of 4
- Gastrointestinal (GI): Diarrhea, nausea and vomiting
  - Supportive Care Interventions
    - Bullet 1 modified: Take medication (except nilotinib *[capsule formulation only]* and asciminib) with a meal and large glass of water to avoid GI upset

MS-1
- Discussion section updated to reflect the all changes in the algorithm.

Continue

Updates in Version 2.2025 of the NCCN Guidelines for Chronic Myeloid Leukemia from Version 1.2025 include:

CML-2
- Primary Treatment;
  - Allosteric TKI (Asciminib; category 1) added as a preferred treatment option for any risk score
- Footnote g modified: Based on follow-up data from the BFORE, DASISION, ~~and~~ ENESTnd, *and ASC4FIRST* trials, 2G TKIs (bosutinib, dasatinib, or nilotinib) *and allosteric TKIs (asciminib)* are preferred for patients with an intermediate- or high-risk score. 2G *and allosteric* TKIs should also be considered for specific subgroups (based on the assessment of treatment goals and benefit/risks), for example, younger patients who are interested in ultimately discontinuing treatment and especially young patients assigned female at birth whose goal is to achieve a deep and rapid molecular response and eventual discontinuation of TKI therapy for family planning purposes.

CML-3A
- Footnote p modified: Achievement of response milestones must be interpreted within the clinical context. Patients achieving MCyR (*BCR::ABL1* IS ≤10%) at 12 months have good long-term survival. Patients with more than 50% reduction compared to baseline or minimally above the 10% cutoff can continue the same dose of TKI for another 3 months. Consider switching to alternate 2G TKI or 3G TKI *or allosteric TKI* in the absence of continuing decline in *BCR::ABL1* transcript levels.
- Footnote t modified: Switching from imatinib to a 2G TKI *or allosteric TKI may* improve~~s~~ response~~, but may be associated with increased toxicity~~. *The side effect profile of alternative TKIs may differ.*

CML-4
- AP-CML
  - Allosteric TKI added before Asciminib

CML-5
- Bullet 1 modified: Patients with disease resistant to primary treatment with imatinib should be treated with ~~a 2G TKI (bosutinib, dasatinib, or nilotinib) in the second-line setting~~ *an alternate TKI*, taking into account *BCR::ABL1* kinase domain mutation status.
- Bullet 2 modified: Patients with disease resistant to primary treatment with *asciminib*, bosutinib, dasatinib, or nilotinib can be treated with an alternate TKI (other than imatinib), taking into account *BCR::ABL1* kinase domain mutation status. Subsequent therapy with an alternate ~~2G~~ TKI would be effective only in patients with identifiable *BCR::ABL1* mutations that confer resistance to TKI therapy. Ponatinib is preferred for patients with no identifiable *BCR::ABL1* mutations.
- Bullet 2; sub-bullet 1 modified: Asciminib is a treatment option for patients with CP-CML having the T315I mutation and/or *previously treated* CP-CML ~~with resistance or intolerance to at least two prior TKIs~~.
- Bullet 2; sub-bullet 2 modified: Ponatinib is ~~the preferred~~ *a* treatment option for patients with a T315I mutation in any phase *(preferred for AP-CML or BP-CML)*. It is also a treatment option for CP-CML with resistance or intolerance to at least two prior TKIs or for patients with AP-CML or BP-CML for whom no other TKI is indicated. (also applies to footnote ee on CML-6)

CML-6
- Footnote gg modified: Asciminib is a treatment option for patients with CP-CML having the T315I mutation and/or *previously treated* CP-CML ~~with resistance or intolerance to at least two prior TKIs~~.

CML-C
- New section added: Special Considerations for the use of TKI Therapy

MS-1
- Discussion section updated to reflect the all changes in the algorithm.

Continue

Updates in Version 1.2025 of the NCCN Guidelines for Chronic Myeloid Leukemia from Version 2.2024 include:

CML-1
- Ph-negative and *BCR::ABL1* negative: Evaluate for *atypical BCR::ABL1 transcripts or for* diseases other than CML
- Footnote b; last sentence modified: Fluorescence in situ hybridization (FISH) on the bone marrow or peripheral blood *(with a minimum of 100 interphase nuclei evaluated)* can be used if bone marrow cytogenetic evaluation is not possible.
- Footnote d modified: Consider *dual fusion FISH (D-FISH)* or qualitative reverse transcription polymerase chain reaction (RT-PCR) for the detection of atypical *BCR::ABL1* transcripts. See Discussion. Referral to centers with expertise in the management of rare hematologic malignancies is recommended *for patients with atypical BCR::ABL1 transcripts*.

CML-2
- Footnote i added: Refer to package insert for full prescribing information for TKI: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm. (also applies to CML-3A, CML-6)
- Footnote j; reference added: Haddad FG, Kantarjian H. J Natl Compr Canc Netw 2024;22:e237116. (also applies to CML-4A, CML-6)

CML-3
- Early Treatment Response Milestones
  - *BCR::ABL1* >1%–10% at 12 months: Yellow changed to orange.
- Yellow; Possible TKI resistance
  - Clinical Considerations
    - Removed: Consider bone marrow cytogenetics analysis to assess for MCyR at 3 mo or CCyR at 12 mo
  - Recommendations
    - Removed: Consider evaluation for allogeneic HCT
- New category: Orange
  - Clinical Considerations
    - Evaluate patient adherence and drug interactions
    - Consider *BCR::ABL1* kinase domain mutational analysis
    - Consider bone marrow cytogenetic analysis to assess for CCyR at 12 mo
  - Recommendations
    - Consider switch to alternate TKI (CML-5) or Continue the same TKI if CCyR is achieved

CML-3A
- New page for footnotes from CML-3
- Footnote o modified: *Achievement of response milestones must be interpreted within the clinical context.* 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. *Same dose of TKI can be continued for another 3 months but imatinib is associated with slower molecular responses.*
- Footnote p modified: Achievement of response milestones must be interpreted within the clinical context. *Patients achieving MCyR (BCR::ABL1 IS ≤10%) at 12 months have good long term survival.* Patients with more than 50% reduction compared to baseline or minimally above the 10% cutoff can continue the same dose of TKI for another 3 months. *Consider switching to alternate 2G TKI or 3G TKI in the absence of continuing decline in BCR::ABL1 transcript levels.*

CML-4
- AP-CML; Treatment
  - Removed: Omacetaxine
  - Added: Asciminib

Continue

Updates in Version 1.2025 of the NCCN Guidelines for Chronic Myeloid Leukemia from Version 2.2024 include:

CML-4A
- Footnote x added: TKI dose for advanced phase CML may differ from CP-CML. Refer to package insert for full prescribing information: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm.
- Footnote removed: Omacetaxine is indicated for the treatment of AP-CML that is resistant and/or intolerant to two or more TKIs. Omacetaxine is a treatment option for patients with disease progression to AP-CML. Omacetaxine is not a treatment option for patients who present with AP-CML.

CML-5
- Treatment Recommendations Based on *BCR::ABL1* Mutation Profile
  - Removed: Omacetaxine
- Footnote removed: Omacetaxine is a treatment option for patients with chronic or AP-CML that is resistant and/or intolerant to two or more TKIs. (also applies to CML-6)

CML-6
- Additional Therapy
  - Removed: Omacetaxine
- Footnote dd modified: Indications for allogeneic HCT: *CP-CML with resistance and/or intolerance to all available TKIs;* advanced phase CML at presentation or disease progression to BP-CML. Outcomes of allogeneic HCT are dependent on age, comorbidities, donor type, and transplant center.
- Footnote gg added: Asciminib is a treatment option for patients with CP-CML with the T315I mutation and/or CP-CML with resistance or intolerance to at least two prior TKIs.

CML-C 1 of 2
- TKI Therapy and Conception
  - Bullet 4: Last sentence added: Referral to a CML specialty center and consultation with a high-risk obstetrician is recommended. (relocated from last sentence of Bullet 5).
  - Bullet 5; Sentences 2-4 added: Referral to an in vitro fertilization (IVF) center is recommended in coordination with the patient's obstetrician. TKI should be stopped prior to attempting oocyte retrieval, but the optimal timing of discontinuation is unknown. There are no data to recommend how long a patient should be off therapy before oocyte retrieval, although usually at least one month off therapy is recommended. (relocated from last sentence of Bullet 2 under Treatment and Monitoring During Pregnancy).
  - Bullet 5; Sentence 5 modified: ~~While sperm banking can be performed prior to starting TKI therapy,~~ *Sperm banking can also be performed prior to starting TKI therapy, although* there are no data regarding the quality of sperm in patients with untreated CML.
- Treatment and Monitoring During Pregnancy
  - Bullet 1; Sentence 2 removed: Sperm banking can also be performed prior to starting TKI therapy, although there are no data regarding the quality of sperm in patients with untreated CML.
  - Bullet 3; Sentence 1 modified: If treatment is needed during pregnancy, it is preferable to initiate treatment with interferon alfa-2a~~; in the United States, peginterferon alfa-2a is the only interferon available for clinical use~~.
  - Bullet 3; Last sentence added: Ropeginterferon alfa-2b is also available for clinical use but there are very limited data for its use in CML during pregnancy.

Continue

Updates in Version 1.2025 of the NCCN Guidelines for Chronic Myeloid Leukemia from Version 2.2024 include:

CML-E
- Monitoring Response to TKI Therapy and Mutational Analysis
  - Test added: Hematologic
    - ◊ Recommendation added: CBC every 1–2 weeks for the first 1–2 months (or until stable normalization of blood counts) and thereafter as indicated based on the persistence of cytopenias

CML-G
- Toxicity pages for individual drugs removed.
- Please refer to footnote i noted within the algorithm: Refer to package insert for full prescribing information for TKI: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm.

CML-G 1 of 2
- Drug Interactions of TKIs
  - Drugs/Supplements
    - ◊ Cardiovascular Medications: added Simvastatin

WORKUP | CLINICAL PRESENTATION | ADDITIONAL EVALUATION

WORKUP

- H&P, including spleen size by palpation (cm below costal margin)
- CBC with differential[a]
- Chemistry profile, including uric acid
- Bone marrow aspirate and biopsy for morphologic review and cytogenetic evaluation[b]
- Quantitative RT-PCR (qPCR) using International Scale (IS) for *BCR::ABL1* (blood)
- Hepatitis B panel[c]

→ **Ph-positive or *BCR::ABL1* positive**

→ **Chronic phase CML (CP-CML)** → **ADDITIONAL EVALUATION:**
- Determine risk score (Risk Calculation Table CML-A)
- Consider myeloid mutational analysis (category 2B)

→ CML-2

→ **Advanced phase CML**
- → **Accelerated phase CML (AP-CML)[e]**
- → **Blast phase CML (BP-CML)[e]**

→ **ADDITIONAL EVALUATION:**
- Flow cytometry to determine cell lineage
- Consider myeloid mutational analysis[e]
- Human leukocyte antigen (HLA) testing, if considering allogeneic hematopoietic cell transplant (HCT) (CML-6)

→ CML-4

→ **Ph-negative and *BCR::ABL1* negative** → **Evaluate for atypical *BCR::ABL1* transcripts or for diseases other than CML[d] (NCCN Guidelines for Myeloproliferative Neoplasms)**

[a] Hydroxyurea is the preferred option (until the initiation of TKI therapy) to lower very high white blood cell (WBC) counts. Leukapheresis is rarely indicated, except for high-risk indications (eg, persistent priapism, shortness of breath, transient ischemic attack).

[b] Bone marrow cytogenetics with a minimum of 20 metaphases is useful to detect chromosomal abnormalities in addition to the Ph chromosome. The presence of major route additional chromosomal abnormalities (ACAs) in Ph-positive cells (trisomy 8, isochromosome 17q, second Ph, trisomy 19, and chromosome 3 abnormalities) may have a negative prognostic impact on survival in patients with accelerated phase. Fluorescence in situ hybridization (FISH) on the bone marrow or peripheral blood (with a minimum of 100 interphase nuclei evaluated) can be used if bone marrow cytogenetic evaluation is not possible.

[c] Hepatitis B virus reactivation has been reported in patients receiving tyrosine kinase inhibitor (TKI) therapy. However, it is not always possible to reliably estimate the frequency or establish a relationship to drug exposure because these incidences are reported voluntarily from a population of uncertain size.

[d] Consider dual fusion FISH (D-FISH) or qualitative reverse transcription polymerase chain reaction (RT-PCR) for the detection of atypical *BCR::ABL1* transcripts. See Discussion. Referral to centers with expertise in the management of rare hematologic malignancies is recommended for patients with atypical *BCR::ABL1* transcripts.

[e] Definitions of Advanced Phase CML (CML-B).

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

CLINICAL PRESENTATION

Chronic phase CML →

Treatment considerations independent of risk score
- **Age**
- **Comorbidities**
- **Toxicity profile of tyrosine kinase inhibitor (TKI) (CML-C)**
- **Possible drug interactions**
- **Patient preference**

PRIMARY TREATMENT[f,g,h,i,j]

Low-risk score (Risk Calculation Table CML-A) →

Preferred regimens
First-generation (1G) TKI (Imatinib [category 1])
or
Second-generation (2G) TKI (alphabetical order) (Bosutinib [category 1] or Dasatinib [category 1] or Nilotinib [category 1])
or
Allosteric TKI (Asciminib; category 1)
or
Clinical trial

→ **Response Milestones and Treatment Options (CML-3)[l,m]**

Intermediate- or high-risk score (Risk Calculation Table CML-A) →

Preferred regimens
2G TKI (alphabetical order) (Bosutinib [category 1] or Dasatinib [category 1] or Nilotinib [category 1])
or
Allosteric TKI (Asciminib; category 1)
or
Other recommended regimen
1G TKI (Imatinib)[k]
or
Clinical trial

→ **Response Milestones and Treatment Options (CML-3)[l,m]**

[f] If treatment is needed during pregnancy, it is preferable to initiate treatment with interferon alfa-2a; in the United States, peginterferon alfa-2a is the only interferon available for clinical use. TKI therapy, particularly during the first trimester, should be avoided because of teratogenic risk. See Management of CML During Pregnancy (CML-E).

[g] Based on follow-up data from the BFORE, DASISION, ENESTnd, and ASC4FIRST trials, 2G TKIs (bosutinib, dasatinib, or nilotinib) and allosteric TKIs (asciminib) are preferred for patients with an intermediate- or high-risk score. 2G and allosteric TKIs should also be considered for specific subgroups (based on the assessment of treatment goals and benefit/risks), for example, younger patients who are interested in ultimately discontinuing treatment and especially young patients assigned female at birth whose goal is to achieve a deep and rapid molecular response and eventual discontinuation of TKI therapy for family planning purposes.

[h] Limited available evidence from small cohort studies suggests that initiation of first-line TKIs (bosutinib, dasatinib, or nilotinib) at lower doses (to minimize treatment-related adverse events) and dose reduction (with close monitoring) in patients who achieve optimal responses are appropriate strategies to reduce the risk of long-term toxicities. However, the minimum effective dose or optimal de-escalation of TKI (bosutinib, dasatinib, or nilotinib) has not yet been established in prospective randomized clinical trials. See the Discussion section for *Dose Modifications of TKI Therapy*.

[i] TKIs (e.g. nilotinib) are available in different formulations, dosage forms, and strengths that are subject to different administration instructions. These products are not interchangeable. Refer to package insert for full prescribing information for specific TKIs: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm.

[j] Innovator and generic drugs approved by the regulatory authorities based on pharmacokinetic equivalence can be used interchangeably. FDA-approved generic versions are appropriate substitutes for innovator drugs (Kantarjian H, et al. Lancet Haematol 2022;9:e854-e861; Haddad FG, Kantarjian H. J Natl Compr Canc Netw 2024;22:e237116).

[k] Imatinib may be preferred for patients who are older with comorbidities such as cardiovascular disease.

[l] Criteria for Response and Relapse (CML-F).

[m] Monitoring Response to TKI Therapy and Mutational Analysis (CML-G).

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

EARLY TREATMENT RESPONSE MILESTONES

CRITERIA FOR RESPONSE AND RELAPSE

BCR::ABL1 (IS)	3 months	6 months	12 months[n]
>10%[o]	YELLOW	RED	RED
>1%–10%[p]	GREEN	GREEN	ORANGE
>0.1%–1%	GREEN	GREEN	LIGHT GREEN
≤0.1%	GREEN	GREEN	GREEN

COLOR	CONCERN	CLINICAL CONSIDERATIONS[r]	RECOMMENDATIONS[r,i]
RED	TKI-resistant disease[q]	• Evaluate patient adherence and drug interactions • Consider *BCR::ABL1* kinase domain mutational analysis[s] • Consider bone marrow cytogenetic analysis to assess additional chromosomal abnormalities (ACAs)	Switch to alternate TKI (CML-5) (other than imatinib) and evaluate for allogeneic HCT
YELLOW	Possible TKI resistance[q]	• Evaluate patient adherence and drug interactions • Consider *BCR::ABL1* kinase domain mutational analysis[s]	Switch to alternate TKI (CML-5) or Continue same TKI[o]
ORANGE **NEW**	Possible TKI resistance[q]	• Evaluate patient adherence and drug interactions • Consider *BCR::ABL1* kinase domain mutational analysis[s] • Consider bone marrow cytogenetic analysis to assess for CCyR at 12 mo	Consider switch to alternate TKI[p] (CML-5) or Continue the same TKI if CCyR is achieved
LIGHT GREEN	TKI-sensitive disease	• Evaluate patient adherence and drug interactions • If treatment goal is long-term survival: ≤1% optimal • If treatment goal is treatment-free remission: ≤0.1% optimal	• If optimal: continue same TKI • If not optimal: shared decision-making with patient[q,t]
GREEN	TKI-sensitive disease	• Evaluate patient adherence and drug interactions • Monitor response (CML-G)	Continue same TKI[u]

Footnotes on CML-3A

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

FOOTNOTES FOR EARLY TREATMENT RESPONSE MILESTONES

[i] TKIs (e.g. nilotinib) are available in different formulations, dosage forms, and strengths that are subject to different administration instructions. These products are not interchangeable. Refer to package insert for full prescribing information for specific TKIs: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm.

[n] *BCR::ABL1* IS ≤0.1% at 12 months is associated with a very low probability of subsequent loss of response and a high likelihood of achieving a subsequent deep molecular response (DMR MR4.0; *BCR::ABL1* IS ≤0.01%), which is a prerequisite for a trial of treatment-free remission (TFR).

[o] Achievement of response milestones must be interpreted within the clinical context. 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. Same dose of TKI can be continued for another 3 months but imatinib is associated with slower molecular responses.

[p] Achievement of response milestones must be interpreted within the clinical context. Patients achieving MCyR (*BCR::ABL1* IS ≤10%) at 12 months have good long-term survival. Patients with more than 50% reduction compared to baseline or minimally above the 10% cutoff can continue the same dose of TKI for another 3 months. Consider switching to alternate 2G TKI or 3G TKI or allosteric TKI in the absence of continuing decline in *BCR::ABL1* transcript levels.

[q] Consider referral to a specialized CML center and/or enrollment in a clinical trial.

[r] Switching to an alternate TKI for intolerance is appropriate for patients with disease responding to TKI therapy. See Special Considerations for the use of TKI Therapy (CML-C).

[s] Consider myeloid mutation panel to identify *BCR::ABL1*–independent resistance mutations in patients with no *BCR::ABL1* kinase domain mutations.

[t] Switching from imatinib to a 2G TKI or allosteric TKI may improves response. The side effect profile of alternative TKIs may differ.

[u] Discontinuation of TKI with careful monitoring is feasible in selected patients. See Discontinuation of TKI Therapy (CML-H).

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

CLINICAL PRESENTATION

Advanced phase CML →

Treatment considerations
- Disease progression to advanced phase while on TKI therapy has worse prognosis than de novo advanced phase CML.
- Evaluation for allogeneic HCT as indicated.
- Selection of TKI is based on prior therapy and/or *BCR*::*ABL1* mutation profile.
- Central nervous system (CNS) involvement has been described in BP-CML. Lumbar puncture and CNS prophylaxis is recommended for lymphoid BP-CML.

TREATMENT[f,j,x]

AP-CML[e,v] →

Clinical trial
or
Preferred regimens
- 2G TKI (alphabetical order) (Bosutinib or Dasatinib or Nilotinib) or third-generation (3G) TKI (Ponatinib)

Useful in certain circumstances
- 1G TKI (Imatinib; if 2G or 3G TKI is contraindicated)[y]
- Allosteric TKI (Asciminib)

→ Lack of response or Disease progression → Allogeneic HCT (CML-6)

BP-CML[e,w]

Lymphoid →

Clinical trial
or
Preferred regimens
- ALL-type induction chemotherapy (NCCN Guidelines for ALL) + TKI[z]

Useful in certain circumstances
- TKI[z] + steroids (if not a candidate for induction chemotherapy)

Myeloid →

Clinical trial
or
Preferred regimens
- AML-type induction chemotherapy (NCCN Guidelines for AML) + TKI[z]

Useful in certain circumstances
- TKI[z] (if not a candidate for induction chemotherapy)

→ **For patients in remission:**
- Allogeneic HCT (CML-6)
- Consolidation chemotherapy and TKI[j,z] maintenance for non-candidates for allogeneic HCT

Footnotes on CML-4A

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

FOOTNOTES FOR ADVANCED PHASE CML

[e] Definitions of Advanced Phase CML (CML-B).

[f] If treatment is needed during pregnancy, it is preferable to initiate treatment with interferon alfa-2a; in the United States, this is the only interferon available for clinical use. TKI therapy, particularly during the first trimester, should be avoided because of teratogenic risk. See Management of CML During Pregnancy (CML-E).

[j] Innovator and generic drugs approved by the regulatory authorities based on pharmacokinetic equivalence can be used interchangeably. FDA-approved generic versions are appropriate substitutes for innovator drugs (Kantarjian H, et al. Lancet Haematol 2022;9:e854-e861; Haddad FG, Kantarjian H. J Natl Compr Canc Netw 2024;22:e237116).

[v] The presence of major route ACAs in Ph-positive cells (trisomy 8, isochromosome 17q, second Ph, trisomy 19, and chromosome 3 abnormalities) may have a negative prognostic impact on survival. Patients who present with accelerated phase at diagnosis should be treated with a TKI at the FDA-approved dose for accelerated phase, followed by evaluation for allogeneic HCT, based on response to therapy. Consider evaluation for allogeneic HCT if response milestones are not achieved at 3, 6, and 12 months as outlined on CML-3.

[w] TKI (alone or in combination with minimal chemotherapy or steroids) is less effective in BP-CML compared to Ph-positive ALL. Interphase FISH for the detection of *BCR::ABL1* transcript on blood granulocytes is recommended to differentiate between de novo BP-CML and de novo Ph-positive ALL.

[x] TKI dose for advanced phase CML may differ from CP-CML. TKIs (e.g. nilotinib) are available in different formulations, dosage forms, and strengths that are subject to different administration instructions. These products are not interchangeable. Refer to package insert for full prescribing information for specific TKIs: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm.

[y] Imatinib is not recommended for patients with disease progression on prior TKI therapy.

[z] 2G or 3G TKI is preferred. Consider imatinib for patients with contraindications to 2G or 3G TKI.

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

TREATMENT RECOMMENDATIONS BASED ON *BCR*::*ABL1* MUTATION PROFILE

- **Patients with disease resistant to primary treatment with imatinib should be treated with an alternate TKI, taking into account *BCR::ABL1* kinase domain mutation status.**
- **Patients with disease resistant to primary treatment with asciminib, bosutinib, dasatinib, or nilotinib can be treated with an alternate TKI (other than imatinib), taking into account *BCR::ABL1* kinase domain mutation status. Subsequent therapy with an alternate TKI would be effective only in patients with identifiable *BCR::ABL1* mutations that confer resistance to TKI therapy. Ponatinib is preferred for patients with no identifiable *BCR::ABL1* mutations.**
  - **Asciminib is a treatment option for patients with CP-CML and AP-CML having the T315I mutation and/or previously treated CP-CML and AP-CML.**
  - **Ponatinib is a treatment option for patients with a T315I mutation in any phase (preferred for AP-CML or BP-CML). It is also a treatment option for CP-CML with resistance or intolerance to at least two prior TKIs or for patients with AP-CML or BP-CML for whom no other TKI is indicated.**
- ***BCR::ABL1* kinase domain mutations that should NOT be treated with asciminib, bosutinib, dasatinib, or nilotinib are listed in the table below.**

THERAPY	CONTRAINDICATED MUTATIONS[aa]
Asciminib	A337T, P465S, M244V, or F359V/I/C
Bosutinib	T315I, V299L, G250E, or F317L[bb]
Dasatinib	T315I/A, F317L/V/I/C, or V299L
Nilotinib	T315I, Y253H, E255K/V, or F359V/C/I
Ponatinib or allogeneic HCT (CML-6)	None[cc]

[aa] Mutations contraindicated for imatinib are too numerous to include. *BCR::ABL35*$_{INS}$ has been reported in patients with disease not responding to imatinib; however, there are not enough data to confirm that 2G TKIs could overcome this resistance (Berman E, et al. Leuk Res 2016;49:108-112). See Discussion.
[bb] Bosutinib has minimal activity against F317L mutation. Nilotinib may be preferred over bosutinib in patients with F317L mutation.
[cc] There are compound mutations (defined as harboring ≥2 mutations in the same *BCR::ABL1* allele) that can cause resistance to ponatinib, but those are uncommon following treatment with bosutinib, dasatinib, or nilotinib.

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

ADDITIONAL THERAPY[i]

Allogeneic HCT[dd]

- **CCyR[l]** → **Monitor with qPCR (peripheral blood) every 3 mo for 2 y, then every 3–6 mo thereafter**
  - **Negative** → (return to monitoring) → **Consider TKI[j,ee,gg] therapy for at least 1 y in patients with prior AP-CML or BP-CML[ff]**
  - **Positive** → **Discuss options with transplant team: TKI[j,ee,gg] ± donor lymphocyte infusion (DLI) (selection of TKI is based on prior therapy, *BCR*::*ABL1* mutation profile, and post-HCT morbidities) or Clinical trial**
- **Less than CCyR or in relapse[l]** → **Discuss options with transplant team: TKI[j,ee,gg] ± donor lymphocyte infusion (DLI) (selection of TKI is based on prior therapy, *BCR*::*ABL1* mutation profile, and post-HCT morbidities) or Clinical trial**

[i] TKIs (e.g. nilotinib) are available in different formulations, dosage forms, and strengths that are subject to different administration instructions. These products are not interchangeable. Refer to package insert for full prescribing information for specific TKIs: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm.

[j] Innovator and generic drugs approved by the regulatory authorities based on pharmacokinetic equivalence can be used interchangeably. FDA-approved generic versions are appropriate substitutes for innovator drugs (Kantarjian H, et al. Lancet Haematol 2022;9:e854-e861; Haddad FG, Kantarjian H. J Natl Compr Canc Netw 2024;22:e237116).

[l] Criteria for Response and Relapse (CML-F).

[dd] Indications for allogeneic HCT: CP-CML with resistance and/or intolerance to all available TKIs; advanced phase CML at presentation or disease progression to BP-CML. Outcomes of allogeneic HCT are dependent on age, comorbidities, donor type, and transplant center.

[ee] Ponatinib is a treatment option for patients with a T315I mutation in any phase (preferred for AP-CML or BP-CML). It is also a treatment option for CP-CML with resistance or intolerance to at least two prior TKIs or for patients with AP-CML or BP-CML for whom no other TKI is indicated. There are compound mutations (defined as harboring ≥2 mutations in the same *BCR::ABL* allele) that can cause resistance to ponatinib, but those are uncommon following treatment with bosutinib, dasatinib, or nilotinib.

[ff] Carpenter PA, et al. Blood 2007;109:2791-2793; Olavarria E, et al. Blood 2007;110:4614-4617; DeFilipp Z, et al. Clin Lymphoma Myeloma Leuk 2016;16:466-471.

[gg] Asciminib is a treatment option for patients with CP-CML and AP-CML having the T315I mutation and/or previously treated CP-CML and AP-CML.

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

RISK CALCULATION TABLE

Risk Score	Calculation	Risk Category
Sokal score[1]	**Exp 0.0116 x (age - 43.4) + 0.0345 x (spleen - 7.51) + 0.188 x [(platelet count ÷ 700)^2 - 0.563] + 0.0887 x (blasts - 2.10)**	**Low <0.8** **Intermediate 0.8 – 1.2** **High >1.2**
Hasford (Euro) score[2]	**(0.6666 x age [0 when age <50 years; 1, otherwise] + 0.042 x spleen size [cm below costal margin] + 0.0584 × percent blasts + 0.0413 × percent eosinophils + 0.2039 × basophils [0 when basophils <3%; 1, otherwise] + 1.0956 × platelet count [0 when platelets <1500 × 10^9/L; 1, otherwise]) × 1000**	**Low ≤780** **Intermediate >780 – ≤1480** **High >1480**
EUTOS long-term survival (ELTS) score[3]	**0.0025 × (age/10)^3 + 0.0615 × spleen size cm below costal margin + 0.1052 × blasts in peripheral blood + 0.4104 × (platelet count/1000)$^{-0.5}$**	**Low ≤1.5680** **Intermediate >1.5680 but ≤2.2185** **High >2.2185**

Calculation of relative risk based on Sokal or Hasford (Euro) score can be found at: https://www.leukemia net.org/content/leukemias/cml/euro__and_sokal_score/index_eng.html

Online calculator for the ELTS score can be found at: https://www.leukemia-net.org/content/leukemias/cml/elts_score/index_eng.html

[1] Sokal J, Cox EB, Baccarani M, et al. Prognostic discrimination in "good-risk" chronic granulocytic leukemia. Blood 1984;63:789-799.
[2] Hasford 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.
[3] Pfirrman M, Baccarani M, Saussele S, et al. Prognosis of long-term survival considering disease-specific death in patients with chronic myeloid leukemia. Leukemia 2016;30:48-56.

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

DEFINITIONS OF ADVANCED PHASE CML[a]

Clinical trials in the TKI era have mostly utilized the modified MD Anderson Cancer Center (MDACC) criteria[1,2] or the International Bone Marrow Transplant Registry (IBMTR) criteria.[3] The use of the International Consensus Classification (ICC)[4] or the World Health Organization (WHO) criteria[5] for the diagnosis of AP-CML and BP-CML is not recommended.

AP-CML[b]	BP-CML
Modified MDACC Criteria[1,2] • Peripheral blood myeloblasts ≥15% and <30% • Peripheral blood myeloblasts and promyelocytes combined ≥30% • Peripheral blood basophils ≥20% • Platelet count ≤100 x 10^9/L unrelated to therapy • Additional clonal cytogenetic abnormalities in Ph+ cells[c]	**IBMTR criteria[3]** • ≥30% blasts in the blood, marrow, or both • Extramedullary infiltrates of leukemic cells

[1] Kantarjian HM, Deisseroth A, Kurzrock R, et al. Chronic myelogenous leukemia: A concise update. Blood 1993;82:691-703.
[2] Talpaz 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.
[3] Gambacorti-Passerini C, le Coutre P. Chronic myelogenous leukemia In: DeVita VT, Lawrence TS, Rosenburg SA, eds. DeVita, Hellman, and Rosenberg's Cancer: Principles & Practice of Oncology (12th edition); 2022:1773-1784.
[4] Arber DA, Orazi A, Hasserjian RP, et al. International consensus classification of myeloid neoplasms and acute leukemias: Integrating morphologic, clinical, and genomic data. Blood 2022;140:1200-1228.
[5] Khoury JD, Solary E, Abla O, et al. The 5th edition of the World Health Organization classification of haematolymphoid tumours: Myeloid and histiocytic/dendritic neoplasms. Leukemia 2022;36:1703-1719.
[6] Sokal JE, Baccarani M, Russo D, Tura S. Staging and prognosis in chronic myelogenous leukemia. Semin Hematol 1988;25:49-61.
[7] 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.

[a] Any increase in lymphoblasts is concerning for (nascent) blast phase.
[b] Sokal criteria and IBMTR criteria are historically used when allogeneic HCT is the recommended treatment option.[6,7]
[c] The prognostic significance of ACAs in Ph-positive cells (ACA/Ph+) is related to the specific chromosomal abnormality and often other features of accelerated phase. The presence of "major route" ACA/Ph+ (trisomy 8, isochromosome 17q, second Ph, trisomy 19, and chromosome 3 abnormalities) at diagnosis may have a negative prognostic impact on survival.

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

SPECIAL CONSIDERATIONS FOR THE USE OF TKI THERAPY

- **Switching to an alternate TKI should be considered for the following non-hematologic adverse events:[a,b,c]**
  - **Arterial and vascular adverse events (more common with nilotinib and ponatinib)**
  - **Severe hypertension not responsive to antihypertensive medications (ponatinib and asciminib)**
  - **Pulmonary hypertension (dasatinib)**
  - **Recurrent pleural or pericardial effusions despite dose reduction (dasatinib; less common with bosutinib)**
  - **Recurrent pancreatitis despite dose reduction (most common with nilotinib, ponatinib and asciminib)**
  - **Hyperglycemia (most common with nilotinib)**
  - **Persistent moderate to severe nephrotoxicity (all TKIs)**
  - **Liver function test (LFT) abnormalities (more common with bosutinib and imatinib)**
  - **Gastrointestinal bleeding (dasatinib)**
  - **Immune-mediated adverse events (all TKIs; eg, colitis, pneumonitis, hepatitis, myocarditis, pericarditis, or nephritis)**
  - **Neurotoxicity (rarely seen with imatinib and dasatinib; eg, dementia-like condition, parkinsonism, and intracranial hypertension)**
- **Patients should be counseled on the potential risk factors for cardiovascular disease (CVD), increased risk of CVD associated with long-term TKI therapy (based on comorbidity or risk factors), and on the ABCDEs of prevention of CVD.[d] See the Principles of Cardiovascular Disease Risk Assessment in the NCCN Guidelines for Survivorship.**
- **Recommendations for monitoring and management of non-hematologic adverse events are outlined in Table 1.[a]**
- **Hematologic toxicities (anemia, neutropenia, and thrombocytopenia) may persist after switching to alternate TKI. Growth factor support can be considered for persistent cytopenias.[e]**

[a] Lipton JH, et al. Blood Rev 2022;56:100968.
[b] Haddad FG, Kantarjian H. J Natl Compr Canc Netw 2024;22.
[c] Oehler VG, et al. J Natl Compr Canc Netw 2024;22(9):e247044.
[d] Barber MC, et al. Hematology Am Soc Hematol Educ Program 2017;2017:110-114.
[e] Refer to package insert for monitoring hematologic toxicities: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm.

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

SPECIAL CONSIDERATIONS FOR THE USE OF TKI THERAPY

Table 1: Monitoring and Management of Non-Hematologic Adverse Events of TKI Therapy[1]

Adverse Event	Symptom Monitoring	Supportive Care Interventions	TKI Therapy Recommendations
Cardiovascular	• Patients should monitor and report symptoms suggestive of alterations in heart rate (eg, chest pain, palpitations, dizziness, fainting, or numbness). • Patients should monitor and report symptoms of vascular disease (eg, chest pain or heaviness; leg pain, cramping or heaviness; or weakness of the face, arm, or leg, vision changes, loss of balance, or confusion).	• Identify and control potential risk factors (eg, diabetes, hypertension, hyperlipidemia, smoking, estrogen use). • Identify drug interactions of TKIs with cardiovascular medications. • Referral to a cardiologist is recommended for patients with cardiovascular risk factors for additional monitoring and/or assessments. • Hold TKI	• Switch to alternate TKI whenever possible for the onset of new arterial and/or vascular adverse events (more frequently seen with nilotinib or ponatinib)
QT Interval Prolongation		• Monitor for hypokalemia or hypomagnesemia. • Correct deficiencies, prior to initiation of TKI therapy and periodically thereafter. • Avoid concomitant use of drugs known to prolong the QT interval (Drug Interactions of TKIs). • Electrocardiograms (ECGs) to monitor the QT interval at baseline, 7 days after initiation of treatment, and periodically thereafter, as well as following any dose modifications.	• Switch to alternate TKI if symptoms are persistent despite adequate supportive care interventions (more frequently seen with nilotinib)
Hypertension		• Monitor blood pressure. • Manage with anti-hypertensive medications. • Referral to a cardiologist is recommended.	• Switch to alternate TKI, if possible, for severe hypertension not responsive to antihypertensive medications (more frequently seen with ponatinib and asciminib)
Pulmonary arterial hypertension	• Patients should monitor and report symptoms (eg, shortness of breath, fainting, or fatigue).	• Hold TKI. • Consider oral corticosteroids and/or sildenafil. • Referral to a cardiologist or pulmonary vascular specialist is recommended.	• Switch to alternate TKI (more frequently seen with dasatinib)

[1] Adapted with permission from Lipton J, Brümmendorf TH, Gambacorti-Passerini C, et al. Long-term safety review of tyrosine kinase inhibitors in chronic myeloid leukemia - What to look for when treatment-free remission is not an option. Blood Rev 2022;56:100968.

Continued

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

SPECIAL CONSIDERATIONS FOR THE USE OF TKI THERAPY

Table 1: Monitoring and Management of Non-Hematologic Adverse Events of TKI Therapy[1] (*continued*)

<table>
<tr><th>Adverse Event</th><th>Symptom Monitoring</th><th>Supportive Care Interventions</th><th>TKI Therapy Recommendations</th></tr>
<tr><td>Pneumonitis</td><td>• Patients should monitor and report symptoms of pneumonitis (eg, cough, shortness of breath, or fever).</td><td>• Monitor for hypoxemia
• Hold TKI
• Consider oral corticosteroids</td><td>• Switch to alternate TKI</td></tr>
<tr><td>Pleural or pericardial effusion</td><td>• Patients should monitor and report symptoms (eg, chest pain or discomfort, cough or shortness of breath).</td><td>• Hold TKI
• Consider diuretics and/or oral corticosteroids for pleural effusion
• Consider echocardiogram to check left ventricular ejection fraction (LVEF)</td><td rowspan="2">• Consider dose reduction (with close monitoring) if not controlled by adequate supportive care interventions
• Switch to alternate TKI if persistent despite dose reduction</td></tr>
<tr><td>Fluid retention and superficial edema</td><td>• Patients should monitor and report symptoms of weight gain, peripheral and periorbital edema, bloating.</td><td>• Consider compression stockings for lower extremity peripheral edema
• May consider diuretics</td></tr>
<tr><td>Hyperglycemia</td><td></td><td>• Monitor blood glucose levels before initiating treatment and periodically thereafter
• Referral to primary care physician or endocrinologist is recommended</td><td rowspan="4">• Consider dose reduction (with close monitoring) if not controlled by adequate supportive care interventions
• Switch to alternate TKI if persistent despite dose reduction</td></tr>
<tr><td>Pancreatitis</td><td>• Patients should report abdominal pain</td><td>• Hold TKI
• Assess amylase and lipase levels
• Consider imaging by contrast-enhanced CT or MRI</td></tr>
<tr><td>Other laboratory or biochemical abnormalities</td><td></td><td>• Consider lifestyle modifications
• Identify potential risk factors or drug interactions of TKI with concomitant medications
• Hypophosphatemia, hypocalcemia, hypothyroidism or hypovitaminosis D should be corrected prior to initiating treatment and during TKI treatment
• Additional monitoring and/or assessments may be necessary</td></tr>
<tr><td>Muscle spasms, cramps or musculoskeletal pain</td><td>• Patients should monitor and report symptoms</td><td>• Evaluate levels of potassium, calcium, and phosphate
• Correct serum electrolyte abnormalities. Consider potassium and calcium supplements.
• Consider non-pharmacologic interventions (eg, adequate hydration, stretching/gentle exercise, and tonic water)
• Assess serum creatine kinase (CK) levels</td></tr>
</table>

[1] Adapted with permission from Lipton J, Brümmendorf TH, Gambacorti-Passerini C, et al. Long-term safety review of tyrosine kinase inhibitors in chronic myeloid leukemia - What to look for when treatment-free remission is not an option. Blood Rev 2022;56:100968.

Continued

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

SPECIAL CONSIDERATIONS FOR THE USE OF TKI THERAPY

Table 1: Monitoring and Management of Non-Hematologic Adverse Events of TKI Therapy[1] (*continued*)

Adverse Event	Symptom Monitoring	Supportive Care Interventions	TKI Therapy Recommendations
Osteopenia/ osteoporosis	• Monitor baseline bone mineral density	• Consider lifestyle modifications • Identify potential risk factors other than TKI therapy • Check vitamin D levels before initiating treatment and periodically thereafter	• None
Dermatologic: Rash or dry skin	• Patients should monitor and report symptoms	• Consider lifestyle modifications (eg, avoid prolonged bathing, hot water when washing/showering, and tight clothing). • Manage with appropriate supportive care interventions (eg, moisturizers, antihistamines, or topical steroids, systemic antibiotics and/or short-term systemic steroids). • Consultation with a dermatologist is recommended for patients with severe rash and/or dry skin.	• Consider dose reduction (with close monitoring) if not controlled by adequate supportive care interventions • Rash that requires cessation of treatment: switch to alternate TKI if the rash recurs after re-starting treatment
Gastrointestinal (GI): Diarrhea, nausea and vomiting	• Patients should monitor and report symptoms	• Take medication (except nilotinib [capsule formulation only] and asciminib) with a meal and large glass of water to avoid GI upset. • Consider the use of anti-diarrheal medications and/or fluid replacement, either prophylactically or after the onset of diarrhea. • Nausea and vomiting should be treated in accordance with the NCCN Guidelines for Antiemesis. • Consultation with gastroenterologist or dietician regarding specific food choices and management in severe cases.	• Consider dose reduction (with close monitoring) if not controlled by adequate supportive care interventions • Switch to alternate TKI if persistent despite dose reduction
Nephrotoxicity	• Patients should monitor and report changes in urinary output or frequency.	• Identify potential risk factors or drug interactions of TKI with concomitant medications. • Assess for alternative etiologies • Consultation with nephrologist is recommended.	
Hepatic symptoms, and/or LFT abnormalities (eg, elevated AST, ALT, or total bilirubin)	• Patients should monitor and report symptoms of jaundice, or tea colored urine • Limit alcohol consumption	• Monitor hepatic function panel • Identify potential risk factors or drug interactions of TKI with concomitant medications • Hold TKI for grade 3 LFT abnormalities. Monitor serum levels and resume TKI when levels return to grade ≤1. • No specific supportive care of proven efficacy • Asymptomatic elevation of indirect bilirubin may not need intervention	

[1] Adapted with permission from Lipton J, Brümmendorf TH, Gambacorti-Passerini C, et al. Long-term safety review of tyrosine kinase inhibitors in chronic myeloid leukemia - What to look for when treatment-free remission is not an option. Blood Rev 2022;56:100968.

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

DRUG INTERACTIONS OF TKIs[1,2]

Drug interactions of TKIs with the most commonly used medication and supplements are listed in the table below.
It is always important to take a detailed medication history (including herbal supplements) at every visit.

Drugs/ Supplements	Change in TKI Level					
	Asciminib	**Bosutinib**	**Dasatinib**	**Imatinib**	**Nilotinib**	**Ponatinib**
Proton Pump Inhibitors (PPIs) • Lansoprazole • Rabeprazole • Esomeprazole • Omeprazole • Pantoprazole	No major interaction	Decrease in exposure	Decrease in exposure	No major interaction	Decrease in exposure	Minor decrease in exposure
Histamine 2 Receptor Antagonists (H2RAs) • Famotidine • Ranitidine • Nizatidine	No major interaction	Decrease in exposure; AVOID; If absolutely necessary consider once-daily H2RA ≥2 hours after taking bosutinib	Decrease in exposure; AVOID; If absolutely necessary consider once-daily H2RA ≥2 hours after taking dasatinib	No major interaction	Decrease in exposure; AVOID; If absolutely necessary consider once-daily H2RA ≥2 hours after or ≥10 hours before taking nilotinib	No major interaction
Antacids	No major interaction	Decrease in exposure if concomitant; Use antacids at least 2 hours before or at least 2 hours after taking bosutinib	Decrease in exposure if concomitant; Use antacids at least 2 hours before or at least 2 hours after taking dasatinib	No major interaction	Decrease in exposure if concomitant; Use antacids at least 2 hours before or at least 2 hours after taking nilotinib	No major interaction
Antidepressants • Fluoxetine • Bupropion • Citalopram	No major interaction	Minor increase in exposure; QTc monitoring	Minor increase in exposure; QTc monitoring	Minor increase in exposure; QTc monitoring	AVOID if possible due to cumulative QTc prolongation risk	Minor increase in exposure; QTc monitoring
Cardiovascular Medications • Amiodarone • Diltiazem • Verapamil • Simvastatin	No major interaction	Increase in exposure and arrhythmia risk; Strongly consider alternative cardiac medication or TKI dose adjustment	Increase in exposure and arrhythmia risk; Strongly consider alternative cardiac medication or TKI dose adjustment	Increase in exposure; Strongly consider alternative cardiac medication or TKI dose adjustment	Increase in exposure and arrhythmia risk; AVOID	Increase in exposure; Strongly consider alternative cardiac medication or TKI dose adjustment

Continued

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

DRUG INTERACTIONS OF TKIs[1,2]

Drug interactions of TKIs with the most commonly used medication and supplements are listed in the table below.
It is always important to take a detailed medication history (including herbal supplements) at every visit.

Drugs/Supplements	Change in TKI Level					
	Asciminib	**Bosutinib**	**Dasatinib**	**Imatinib**	**Nilotinib**	**Ponatinib**
Anti-infectives • Azole Antifungals ▸ Fluconazole ≥200 mg ▸ Voriconazole ▸ Itraconazole ▸ Posaconazole ▸ Isavuconazole • Clarithromycin • Telithromycin • Ritonavir	Increase in exposure; Strongly consider alternative anti-infective or TKI dose adjustment	Increase in exposure; Strongly consider alternative anti-infective or TKI dose adjustment	Increase in exposure; Strongly consider alternative anti-infective or TKI dose adjustment	Increase in exposure; Strongly consider alternative anti-infective or TKI dose adjustment	Increase in exposure; Strongly consider alternative anti-infective or TKI dose adjustment	Increase in exposure; Strongly consider alternative anti-infective or TKI dose adjustment
Anti-infectives • Fluoroquinolones ▸ Levofloxacin ▸ Moxifloxacin ▸ Ciprofloxacin	No major interaction	QTc monitoring	QTc monitoring	No major interaction	Use with caution	No major interaction
Herbal Supplements[3,4] • Curcumin (Turmeric) • Ginkgo Biloba • Green Tea Extract	Increase in exposure; Strongly consider supplement discontinuation	Increase in exposure; Strongly consider supplement discontinuation	Increase in exposure; Strongly consider supplement discontinuation	Increase in exposure; Strongly consider supplement discontinuation	Increase in exposure; Strongly consider supplement discontinuation	Increase in exposure; Strongly consider supplement discontinuation
Herbal Supplements[3,4] • St. John's Wort	Decrease in exposure; AVOID	Decrease in exposure; AVOID	Decrease in exposure; AVOID	Decrease in exposure; AVOID	Decrease in exposure; AVOID	Decrease in exposure; AVOID

[1] Refer to package insert for full prescribing information and drug interactions: https://www.accessdata.fda.gov/scripts/cder/daf/index.cfm.
[2] van Leeuwen RW, van Gelder T, Mathijssen RH, et al. Drug-drug interactions with tyrosine-kinase inhibitors: a clinical perspective. Lancet Oncol 2014;15:e315-e326.
[3] Zhang W, Lim LY. Effects of spice constituents on P-glycoprotein-mediated transport and CYP3A4-mediated metabolism in vitro. Drug Metab Dispos 2008;36:1283-1290.
[4] Scott GN, Elmer GW. Update on natural product–drug interactions. Am J Health Syst Pharm 2002;59:339-347.

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

MANAGEMENT OF CML DURING PREGNANCY

TKI Therapy and Conception

- TKI therapy appears to affect some male hormones at least transiently, but does not appear to have a deleterious effect on male fertility; miscarriage or fetal abnormality rate is not elevated in female partners of male patients on TKI therapy.[1-5]
- TKI therapy during pregnancy has been associated with both a higher rate of miscarriage and fetal abnormalities. A prolonged washout period prior to pregnancy, prompt consideration of holding TKI therapy (if pregnancy occurs while on TKI therapy), and close monitoring should be considered.[6-10] There are no data regarding how long a patient should be off therapy before trying to become pregnant.
- Discontinuation of TKI therapy because of pregnancy in patients who are not in DMR (≤0.01% *BCR::ABL1* IS) has only been reported in a small series of patients.[11-14] Conception while on active TKI therapy is strongly discouraged due to the risk of fetal abnormalities. There are no published guidelines regarding the optimal depth of molecular response that is considered “safe” to stop TKI therapy before attempting pregnancy and the literature regarding this consists of case reports.[15]
- Prior to attempting pregnancy, patients of childbearing age and their partners should be counseled about the potential risks and benefits of discontinuation of TKI therapy, possible resumption of TKI therapy, and treatment options during pregnancy, should the CML recur. Referral to a CML specialty center and consultation with a high-risk obstetrician is recommended.
- Fertility preservation should be discussed with all patients of childbearing age prior to the initiation of TKI therapy. Referral to an in vitro fertilization (IVF) center is recommended in coordination with the patient’s obstetrician. TKI should be stopped prior to attempting oocyte retrieval, but the optimal timing of discontinuation is unknown. There are no data to recommend how long a patient should be off therapy before oocyte retrieval, although usually at least 1 month off therapy is recommended. Sperm banking can also be performed prior to starting TKI therapy, although there are no data regarding the quality of sperm in patients with untreated CML.

Treatment and Monitoring During Pregnancy

- As noted above, in patients assigned male at birth, TKI therapy need not be discontinued if a pregnancy is planned.
- In patients assigned female at birth, TKI therapy should be stopped prior to natural conception, and patients should remain off therapy during pregnancy.[6-8]
- If treatment is needed during pregnancy, it is preferable to initiate treatment with interferon alfa-2a.[16] Most of the data using interferons during pregnancy have been reported in patients with essential thrombocythemia.[17,18] If introduced earlier, the use of peginterferon alfa-2a can preserve molecular remission after discontinuation of TKI.[19] Ropeginterferon alfa-2b is also available for clinical use but there are very limited data for its use in CML during pregnancy.
- TKI therapy, particularly during the first trimester, should be avoided because of teratogenic risk. If TKI therapy is considered during pregnancy, the potential risks and benefits must be carefully evaluated in terms of maternal health and fetal risk on an individual basis.
- The panel recommends against the use of hydroxyurea during pregnancy, especially in the first trimester.[20-22]
- Leukapheresis can be used for a rising white blood cell (WBC) count and/or platelet count, although there are no data that recommend at what levels leukapheresis and/or platelet pheresis should be initiated.[23-26]
- Low-dose aspirin or low-molecular-weight heparin can be considered for patients with thrombocytosis.[27,28]
- Monthly monitoring of CBC with differential and frequent monitoring with qPCR (every 1–3 mo) would be helpful to guide the timing for initiation of TKI therapy.

Breastfeeding

- TKI therapy can be restarted after delivery. However, patients should be advised not to breastfeed while on TKI therapy, as TKIs pass into human breast milk.[29-32]
- Breastfeeding without TKI therapy may be safe with molecular monitoring, but preferably in those patients with CML who have achieved durable DMR. It may be acceptable to avoid TKIs for the short period of the first 2–5 days after labor to give the child colostrum.[32,33]
- Close molecular monitoring is recommended for patients who extend the treatment-free period for breastfeeding. If the loss of MMR after treatment cessation is confirmed, breastfeeding needs to be terminated and TKI therapy should be restarted.[32]

References on (CML-E 2 of 2)

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

MANAGEMENT OF CML DURING PREGNANCY – REFERENCES

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

CRITERIA FOR RESPONSE AND RELAPSE

Response/Relapse	Definition
Complete hematologic response (CHR)[1]	• Complete normalization of peripheral blood counts with leukocyte count <10 x 10^9/L • Platelet count <450 x 10^9/L • No immature cells, such as myelocytes, promyelocytes, or blasts in peripheral blood • No signs and symptoms of disease with resolution of palpable splenomegaly
Cytogenetic response[2,3,4]	• **Complete cytogenetic response (CCyR):** No Ph-positive metaphases • **Major cytogenetic response (MCyR):** 0%–35% Ph-positive metaphases • **Partial cytogenetic response (PCyR):** 1%–35% Ph-positive metaphases • **Minor cytogenetic response:** >35%–65% Ph-positive metaphases
Molecular response[5,6,7]	• **Early molecular response (EMR):** *BCR::ABL1* (IS) ≤10% at 3 and 6 months • **Major molecular response (MMR):** *BCR::ABL1* (IS) ≤0.1% or ≥3-log reduction in *BCR::ABL1* transcripts from the standardized baseline, if qPCR (IS) is not available • **Deep molecular response (DMR): MR4.0:** *BCR::ABL1* (IS) ≤0.01% or **MR4.5:** *BCR::ABL1* (IS) ≤0.0032%
Relapse	• Any sign of loss of hematologic response • Any sign of loss of CCyR or its molecular response correlate (**MR2.0:** *BCR::ABL1* [IS] ≤1%) – defined as an increase in *BCR::ABL1* transcript to >1% • 1-log increase in *BCR::ABL1* transcript levels with loss of MMR[8]

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[8] The loss of MMR in the presence of a CCyR does not necessarily indicate inadequate response to treatment.

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

MONITORING RESPONSE TO TKI THERAPY AND MUTATIONAL ANALYSIS

Test	Recommendation
Hematologic	• CBC every 1–2 weeks for the first 1–2 months (or until stable normalization of blood counts) and thereafter as indicated based on the persistence of cytopenias
Bone marrow cytogenetics[1]	• At diagnosis • Response milestones not reached • Any sign of loss of hematologic response • Any sign of loss of CCyR or its molecular response correlate (MR2.0: *BCR::ABL1* [IS] ≤1%) – defined as an increase in *BCR::ABL1* transcript to >1%
qPCR using IS	• At diagnosis • Every 3 months after initiating treatment. After *BCR::ABL1* (IS) ≤1% (MR2.0)[2] has been achieved, every 3 months for 2 years and every 3–6 months thereafter • If there is a 1-log increase in *BCR::ABL1* transcript levels with MMR, qPCR should be repeated in 1–3 months
BCR::ABL1 kinase domain mutation analysis[3]	• CP-CML ‣ Response milestones not reached ◊ Any sign of loss of hematologic response ◊ Any sign of loss of CCyR or its molecular response correlate (MR2.0: *BCR::ABL1* [IS] ≤1%) – defined as an increase in *BCR::ABL1* transcript to >1% ◊ 1-log increase in *BCR::ABL1* transcript levels and loss of MMR • Disease progression to AP-CML or BP-CML[3]

[1] FISH has been inadequately studied for monitoring response to treatment.
[2] CCyR correlates with *BCR::ABL1* (IS) ≤1% (MR2.0).
[3] Consider myeloid mutation panel to identify *BCR::ABL1*–independent resistance mutations in patients with no *BCR::ABL1* kinase domain mutations.

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

DISCONTINUATION OF TKI THERAPY

General Considerations

- **Discontinuation of TKI therapy appears to be safe in select patients with CML.**
- **Consult with a CML specialist to review the appropriateness for TKI discontinuation and potential risks and benefits of treatment discontinuation, including TKI withdrawal syndrome.**
- **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 patients who give consent after a thorough discussion of the potential risks and benefits.**
- **Consultation with an NCCN Panel Member or center of expertise is recommended in the following circumstances:**
  - **Any significant adverse event is believed to be related to treatment discontinuation.**
  - **There is progression to AP-CML or BP-CML at any time.**
  - **MMR is not regained after 3 months following treatment reinitiation.**
- **Outside of a clinical trial, discontinuation of TKI therapy should be considered only if *all* of the criteria included in the list below are met.**

Criteria for TKI Discontinuation

- **Age ≥18 years.**
- **CP-CML. No prior history of AP-CML or BP-CML.**
- **On approved TKI therapy for at least 3 years.[1,2]**
- **Prior evidence of quantifiable *BCR::ABL1* transcript.**
- **Stable molecular response (MR4; *BCR::ABL1* ≤0.01% IS) for ≥2 years, as documented on at least 4 tests, performed at least 3 months apart.[2]**
- **Access to a reliable qPCR test with a sensitivity of detection of at least MR4.5 (*BCR::ABL1* ≤0.0032% IS) and that provides results within 2 weeks.**
- **Molecular monitoring every 1–2 months for the first 6 months following discontinuation, bimonthly during months 7–12, and quarterly thereafter (indefinitely) for patients who remain in MMR (MR3; *BCR::ABL1* ≤0.1% IS).**
- **Prompt resumption of TKI within 4 weeks of a loss of MMR with monthly molecular monitoring until MMR is re-established, then every 3 months thereafter is recommended indefinitely for patients who have reinitiated TKI therapy after a loss of MMR. If MMR is not achieved after 3 months of TKI resumption, *BCR::ABL1* kinase domain mutation testing should be performed, and monthly molecular monitoring should be continued for another 6 months.**

[1] The feasibility of TFR following discontinuation of TKIs other than dasatinib, imatinib, or nilotinib has not yet been evaluated in clinical studies. It is reasonable to assume that the likelihood of TFR following discontinuation would be similar irrespective of TKI in patients who have achieved and maintained DMR (MR4.0; ≤0.01% *BCR::ABL1* IS) for ≥2 years, based on the extrapolation of findings from the studies that have evaluated TFR following discontinuation of imatinib, dasatinib, or nilotinib.

[2] Data from the EURO-SKI study suggest that MR4.0 (*BCR::ABL1* ≤0.01% IS) for ≥3 years was the most significant predictor for successful discontinuation of imatinib. Total duration of imatinib therapy for at least 6 years was also predictive of successful discontinuation (Saussele S, et al. Lancet Oncol 2018;19:747-757).

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

ABBREVIATIONS

1G	first-generation
2G	second-generation
3G	third-generation
ACAs	additional chromosomal abnormalities
ALL	acute lymphoblastic leukemia
ALT	alanine aminotransferase
AML	acute myeloid leukemia
AP-CML	accelerated phase CML
AST	aspartate aminotransferase
BP-CML	blast phase CML
CBC	complete blood count
CCyR	complete cytogenetic response
CHR	complete hematologic response
CML	chronic myeloid leukemia
CNS	central nervous system
CP-CML	chronic phase CML
CVD	cardiovascular disease
D-FISH	dual fusion FISH
DLI	donor lymphocyte infusion
DMR	deep molecular response
ELTS	EUTOS long-term survival
EMR	early molecular response
EUTOS	European Treatment and Outcome Study
FISH	fluorescence in situ hybridization
H&P	history and physical
H2RA	histamine 2 receptor antagonist
HCT	hematopoietic cell transplant
HLA	human leukocyte antigen
IBMTR	International Bone Marrow Transplant Registry
ICC	International Consensus Classification
IS	International Scale
IVF	in vitro fertilization
LFT	liver function test
MCyR	major cytogenetic response
MDACC	MD Anderson Cancer Center
MMR	major molecular response
PCyR	partial cytogenetic response
Ph	Philadelphia chromosome
PPI	proton pump inhibitor
qPCR	quantitative RT-PCR
QTc	QT corrected for heart rate
RT-PCR	reverse transcriptase polymerase chain reaction
TFR	treatment-free remission
TKI	tyrosine kinase inhibitor
WBC	white blood cell

NCCN Categories of Evidence and Consensus	
Category 1	Based upon high-level evidence (≥1 randomized phase 3 trials or high-quality, robust meta-analysis), there is uniform NCCN consensus (≥85% support of the Panel) that the intervention is appropriate.
Category 2A	Based upon lower-level evidence, there is uniform NCCN consensus (≥85% support of the Panel) that the intervention is appropriate.
Category 2B	Based upon lower-level evidence, there is NCCN consensus (≥50%, but <85% support of the Panel) 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 indicated.

NCCN Categories of Preference	
Preferred intervention	Interventions that are based on superior efficacy, safety, and evidence; and, when appropriate, affordability.
Other recommended intervention	Other interventions that may be somewhat less efficacious, more toxic, or based on less mature data; or significantly less affordable for similar outcomes.
Useful in certain circumstances	Other interventions that may be used for selected patient populations (defined with recommendation).

All recommendations are considered appropriate.

Discussion

This discussion corresponds to the NCCN Guidelines for Chronic Myeloid Leukemia. Last updated: November 27, 2024

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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 2024, an estimated 9280 people will be diagnosed with CML in the United States, and 1280 people will die from the disease.[1]

CML is defined by the presence of the 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.[2] In most patients, the chromosomal breakpoints are located in intron 13 or 14 of the *BCR* gene on chromosome 22 (major breakpoint cluster region; *M-BCR*). In the *ABL1* gene they are located between the two alternative *ABL1* exons Ib and Ia, or between *ABL1* exons 1 and 2.[3,4] Irrespective of the precise *ABL1* breakpoint, splicing almost invariably fuses *ABL1* exon 2 with *BCR* exons 13 or 14, resulting in e13a2 and e14a2 transcripts that code for a protein, p210, with deregulated tyrosine kinase activity, which causes CML.

Unusual *BCR::ABL1* transcripts, e1a2 encoding for p190 (involving the minor breakpoint cluster region; *m-BCR*), or e19a2 encoding for p230 (involving the micro breakpoint cluster region; µ-*BCR*), are found infrequently.[3,4] p190 is usually produced in the setting of Ph-positive acute lymphoblastic leukemia (ALL), and p230 is associated with enhanced neutrophil differentiation. Atypical *BCR::ABL1* transcripts (eg, e13a3, e14a3, e6a2) have also been detected in about 1% to 2% of patients with CML. The proportion of different *BCR::ABL1* transcripts and the impact of *BCR::ABL1* transcript type on response to tyrosine kinase inhibitor (TKI) therapy are discussed in the section *BCR::ABL1 Transcript Variants in CML*.

CML occurs in three different phases (chronic, accelerated, and blast phase) and is usually diagnosed in the chronic phase in developed countries. Untreated chronic phase CML (CP-CML) will eventually progress to accelerated phase CML (AP-CML) or blast phase CML (BP-CML) in 3 to 5 years on average.[5] Progression to AP-CML and BP-CML bridges a continuum of clinical features (ie, fever, bone pain, spleen size), cytogenetic changes, and blast count. Gene expression profiling has shown a close correlation of gene expression between AP-CML and BP-CML indicating that the bulk of the genetic changes in progression occur in the transition from CP-CML to AP-CML.[6] The activation of the beta-catenin signaling pathway in CML granulocyte-macrophage progenitors (which enhances the self-renewal activity and leukemic potential of these cells) may be a key pathobiologic event in the evolution to BP-CML.[7]

The NCCN Clinical Practice Guidelines in Oncology (NCCN Guidelines®) for Chronic Myeloid Leukemia 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 Myeloproliferative Neoplasms is recommended for all patients with *BCR::ABL1*–negative MPN.

Guidelines Update Methodology

The complete details of the Development and Update of the NCCN Guidelines are available at www.NCCN.org.

Literature Search Criteria

Prior to the update of this version of the NCCN Guidelines® for Chronic Myeloid Leukemia, an electronic search of the PubMed database was performed to obtain key literature in Chronic Myeloid Leukemia since the last guideline update using the following search terms: chronic myeloid leukemia or chronic myelogenous leukemia. The PubMed database was chosen as it remains the most widely used resource for medical literature and indexes peer-reviewed biomedical literature.[8]

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

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.

Sensitive/Inclusive Language Usage

NCCN Guidelines strive to use language that advances the goals of equity, inclusion, and representation. NCCN Guidelines endeavor to use language that is person-first; not stigmatizing; anti-racist, anti-classist, anti-misogynist, anti-ageist, anti-ableist, and anti-fat-biased; and inclusive of individuals of all sexual orientations and gender identities. NCCN Guidelines incorporate non-gendered language, instead focusing on organ-specific recommendations. This language is both more accurate and more inclusive and can help fully address the needs of individuals of all sexual orientations and gender identities. NCCN Guidelines will continue to use the terms men, women, female, and male when citing statistics, recommendations, or data from organizations or sources that do not use inclusive terms. Most studies do not report how sex and gender data are collected and use these terms interchangeably or inconsistently. If sources do not differentiate gender from sex assigned at birth or organs present, the information is presumed to predominantly represent cisgender individuals. NCCN encourages researchers to collect more specific data in future studies and organizations to use more inclusive and accurate language in their future analyses.

Diagnosis and Workup

Initial evaluation should consist of a history and physical exam, including palpation of the spleen, complete blood count (CBC) with differential, chemistry profile, and hepatitis B panel. Bone marrow aspirate and biopsy for morphologic and cytogenetic evaluation and quantitative reverse transcriptase polymerase chain reaction (RT-PCR) to establish the presence of quantifiable *BCR::ABL1* mRNA transcripts at baseline are recommended to confirm the diagnosis of CML (CML-1).

Bone marrow cytogenetics with a minimum of 20 metaphases is useful to detect additional chromosomal abnormalities (ACAs) in Ph-positive cells, also known as clonal cytogenetic evolution (discussed below).[9-13] If bone marrow evaluation is not feasible, fluorescence in situ hybridization (FISH) on the bone marrow or a peripheral blood specimen with dual probes for *BCR* and *ABL1* genes can be used to confirm the diagnosis of CML. Interphase FISH is performed on peripheral blood but can be associated with a false-positive rate of 1% to 5% depending on the specific probe used in the assay.[14] 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.[15] Double-fusion FISH (D-FISH) is associated with low false-positive rates and can detect all variant translocations of the Ph-chromosome.[16]

Quantitative RT-PCR (qPCR) should be done at initial workup to establish the presence of quantifiable *BCR::ABL1* mRNA transcripts. qPCR, usually done on 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 ≥100,000 normal cells. qPCR results can be expressed in various ways, such as the ratio of *BCR::ABL1* transcript numbers to the number of control gene transcripts.[17] An International Scale (IS) has been established to standardize molecular monitoring with qPCR across different laboratories with 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.[18] IS has become the gold standard of expressing qPCR values. More details on monitoring with qPCR using IS are provided on MS-10. Qualitative RT-PCR or D-FISH should be considered for detecting atypical *BCR::ABL1* transcripts if there is discordance between FISH and qPCR results. See the section on *BCR::ABL1 Transcript Variants in CML* below.

BCR::ABL1 transcripts in the peripheral blood at very low levels (1–10 out of 10^8 peripheral blood leukocytes) can be detected in approximately 30% of normal individuals, and the incidence of this increases with age. The risk of developing CML for these individuals is extremely low, and neither continued monitoring nor therapy is indicated.[19,20]

BCR::ABL1 Transcript Variants in CML

e13a2 and e14a2 transcripts (both encoding for p210) were the most common *BCR::ABL1* transcript variants identified in about 39% and 62% of patients, respectively; e13a2 was more frequent in males and the proportion decreased with age in both sexes.[21,22] Unusual or atypical transcripts were identified in about 2% of patients, with e1a2, e19a2, e13a3, and e14a3 being the most frequently identified transcripts.[21] The incidence of these atypical transcripts was higher in females and the proportion decreased with age in both genders. The presence of e14a2 at baseline was associated with higher molecular response rates to imatinib.[23-29] While some studies have demonstrated a trend towards better survival outcomes with e14a2 transcript,[25,26] in other studies the type of transcript did not have any significant impact on long-term survival outcomes.[24,27,30]

Limited available data from studies that evaluated the impact of *BCR::ABL1* transcript variants on response to second-generation (2G) TKI therapy suggest that nilotinib may be associated with inferior molecular response rates in patients with e13a2 as well as e14a2 transcripts compared to imatinib 800 mg or dasatinib.[25,31] The results of other studies indicate that difference in the amplification characteristics between the e13a2 and e14a2 transcripts can affect the measurement of residual disease, thus emphasizing the need to consider sequential measurement of minimal residual disease in addition to the achievement of response milestones at specific timepoints.[32-34]

The presence of e1a2 transcript (encoding for p190) is associated with a higher risk of disease progression, inferior cytogenetic and molecular responses to TKI therapy, and the presence of frequent mutations in epigenetic modifiers genes.[35-41] In a multivariate analysis, the e1a2 transcript was also identified as an independent predictor of inferior survival outcomes.[37] It is important to be aware that these data refer to the presence of dominant e1a2 transcript, not to the presence of low-level e1a2 transcripts in patients with dominant e13a2 or e14a2 transcripts. The presence of e19a2 transcript (encoding for p230) is associated with lower rates of cytogenetic and molecular response to TKIs and inferior survival outcomes, despite previous reports of an indolent disease course in the pre-TKI era.[38,39,42] Referral to centers with expertise in the management of CML is recommended.

Qualitative RT-PCR, nested RT-PCR, or Sanger sequencing are useful for identifying atypical *BCR::ABL1* transcripts.[43,44] qPCR using log-reduction from standardized baseline can be used to monitor e1a2 transcripts, and monitoring e19a2 transcripts is usually performed using qualitative RT-PCR or nested RT-PCR. However, there are no standardized qPCR assays for monitoring molecular response to TKI therapy in patients with atypical *BCR::ABL1* transcripts.[45,46] The utility of multiplex PCR assays and patient-specific genomic DNA quantitative PCR assays for monitoring atypical *BCR::ABL1* transcripts has been demonstrated in some reports.[47-51]

Clonal Cytogenetic Evolution

The prognostic significance of ACAs in Ph-positive cells is related to the specific chromosomal abnormality and other features of the accelerated phase.[9-13] The presence of "major route" ACAs in Ph-positive cells (trisomy 8, isochromosome 17q, second Ph, trisomy 19, and chromosome 3 abnormalities) at diagnosis may have a negative prognostic impact on survival and disease progression to accelerated or blast phase.[52-55] However, in another analysis that evaluated the outcomes of patients with CP-CML (with or without ACAs) treated with TKI therapy in prospective studies, the presence of ACAs in Ph positive cells at the time of diagnosis was not associated with worse prognosis.[56] Survival outcomes were not significantly different among patients with ACAs in Ph positive cells based on TKI therapy (imatinib vs. 2G TKIs) or imatinib dose (400 vs. 800 mg). It remains uncertain if 2G TKIs or high-dose imatinib would be more beneficial for patients with ACAs in Ph positive cells. Patients with ACAs in Ph positive cells at diagnosis should be monitored carefully for evidence of resistance to TKI therapy and follow-up metaphase karyotype analysis should be performed if resistance is evident.

Clonal cytogenetic evolution in Ph-negative cells has also been reported in a small subset of patients treated with TKI therapy.[57-68] The most common abnormalities include trisomy 8 and loss of the Y chromosome. Previous work suggested that the overall prognosis of Ph-negative clonal evolution is good and depends on response to imatinib therapy.[61] However, the presence of chromosome abnormalities other than loss of the Y chromosome has been associated with decreased survival in patients with CP-CML treated with various TKIs, suggesting that closer follow-up is indicated.[69] Progression to myelodysplastic syndromes (MDS) and acute myeloid leukemia (AML) have been reported in patients with monosomy 7 (del 7q).[70-72]

Additional Evaluation

Chronic Phase CML: Risk Stratification

Sokal and Hasford (Euro) scoring systems have been used for the risk stratification of patients into three risk groups (low, intermediate, and high) in clinical trials evaluating TKIs.[73,74] The Sokal score is based on the patient's age, spleen size on clinical examination, platelet count, and percentage of blasts in the peripheral blood.[73] The Euro score includes eosinophils and basophils in the peripheral blood in addition to the same clinical variables used in the Sokal score.[74]

The European Treatment and Outcome Study long-term survival (ELTS) score is based on the same variables as the Sokol score and provides the most useful predictor of CML-related death in patients treated with first-line imatinib.[75] The ELTS score has been validated in a cohort of 1120 patients with CP-CML treated with imatinib in six clinical trials. Higher age, higher peripheral blasts, bigger spleen, and low platelet counts were significantly associated with increased probabilities of dying of CML. Patients in the intermediate- and the high-risk groups had significantly higher probabilities of dying of CML than those in the low-risk group, and the probabilities were also significantly different between the intermediate- and high-risk groups. Unlike other scoring systems, the ELTS score is focused on CML-specific overall survival (OS). This is important, as many patients with CML die from non-CML causes, reflecting the efficacy of TKI therapy.

Determination of risk score using either the Sokal or Euro or ELTS scoring systems (CML-A) prior to initiation of TKI therapy is recommended for patients diagnosed with CP-CML.[73-75]

Advanced Phase CML: Diagnostic Criteria

The modified MD Anderson Cancer Center (MDACC) criteria for AP-CML (15% and 29% peripheral blood or bone marrow myeloblasts; ≥30% of peripheral blood myeloblasts and promyelocytes; ≥20% of peripheral blood or bone marrow basophils; platelet count ≤100 x 10^9/L unrelated to therapy; and clonal cytogenetic evolution in Ph+ cells) are used in many clinical trials that have evaluated the efficacy of TKIs (CML-B).[76] AP-CML defined only by clonal cytogenetic evolution on imatinib therapy is associated with a better prognosis than AP-CML defined by clonal cytogenetic evolution and additional features of progression.[52,77]

The 2022 International Consensus Classification (ICC) includes a lower threshold (10%–19%) of bone marrow or peripheral blasts and the presence of ACA/Ph+ for the diagnosis of AP-CML whereas AP-CML is not included in the updated 2022 World Health Organization (WHO) classification.[78,79] The updated WHO classification emphasizes on the high-risk features associated with the progression of CP-CML to BP-CML.[79]

The International Bone Marrow Transplant Registry (IBMTR) criteria define blast phase as the presence of ≥30% myeloblasts in the blood, bone marrow, or both, or as the presence of extramedullary disease (CML-B).[80] Any increase in lymphoblasts should be concerning for nascent lymphoid blast phase disease. IBMTR criteria were used in most of the clinical trials leading to the approval of TKIs and is best aligned with prognostication systems derived from these studies. The 2022 ICC and WHO classification require the presence of ≥20% blast cells in the peripheral blood or bone marrow, the presence of extramedullary blast proliferation, and the presence of increased lymphoblasts in peripheral blood or bone marrow to confirm the diagnosis of BP-CML.[78,79]

Clinical trials in the TKI era have almost uniformly utilized the modified MDACC or the IBMTR criteria. The use of ICC or WHO criteria for the diagnosis of AP-CML and BP-CML is not recommended.

Flow cytometry to determine cell lineage, mutational analysis, and human leukocyte antigen (HLA) testing, if considering allogeneic hematopoietic cell transplant (HCT), are recommended for patients with advanced phase CML.

Myeloid Mutational Analysis

Mutations in epigenetic modifier genes (eg, *ASXL1, IKZF1, BCOR*, *TET1/2, IDH1/2, DNMT3A/3B, EZH2)* have been described in patients with CML and the presence of epigenetic gene mutations at diagnosis has been associated with lower rates of molecular or cytogenetic responses and lower rates of progression-free survival (PFS)/event-free survival (EFS).[81-97]

Mutations in the *ASXL1* gene are the most commonly described secondary alterations in patients with CP-CML and are an independent predictor of inferior molecular/cytogenetic responses and EFS rates following TKI therapy (including 2G-TKI therapy).[94,95] In an analysis of 222 patients with CP-CML (prospectively enrolled in the CML-V study), an *ASXL1* mutation was detected in 20 patients at the time of diagnosis. All patients had received nilotinib-based TKI therapy. The probability of achieving major molecular response (MMR) or better at 12 months was significantly lower for patients with an ASXL1 mutation (55%; P = .0036) compared to 85% for patients with no mutations and 82% for patients with other non-*ASXL1* mutations.[95] However, in another study of 124 patients with newly diagnosed CP-CML, mutations in epigenetic modifier genes (including *ASXL1* mutation) were predictive of response rates only in patients treated with imatinib but did not have any impact on the outcomes in patients treated with 2G TKIs.[89]

IKZF1 exon deletions and mutations in *ASXL1, RUNX1,* and *BCOR* genes were the most frequently described secondary alterations in advanced phase CML, while *IDH1/2* mutations were detected at a markedly lower frequency.[82,87,90,92,93] *IKZF1*, *RUNX1,* and *DNMT3A* alterations were identified as important markers of disease progression to advanced phase CML and risk of relapse after discontinuation of TKI.[81,83,87,96] Mutations at diagnosis in *ASXL1*, *DNMT3A,* JAK2, and *TET2* genes have been associated with increased risk of cardiovascular events associated with TKI therapy.[97]

Next-generation sequencing (NGS) allows for the detection of low-level BCR::ABL1 kinase domain mutations and mutations in genes other than *BCR::ABL1* that may confer resistance to TKIs or portend disease progression.[98,99] In a prospective, multicenter study (NEXT-in-CML) that assessed the feasibility of NGS to detect low-level mutations in 236 consecutive patients with CML and an inadequate response to TKI therapy, NGS was more effective than conventional Sanger sequencing in the detection of low-level mutations.[99] Prospective monitoring of mutation kinetics demonstrated that TKI-resistant low-level mutations are invariably selected if the patients are not switched to another TKI or if they are switched to an inappropriate TKI or TKI dose.[99] NGS with myeloid mutation panel should be considered for patients with no identifiable *BCR::ABL1* mutations.

Testing for *BCR::ABL1*–independent mutations using NGS with myeloid mutation panel may be useful for patients with CP-CML who do not achieve optimal response milestones due to the presence of cytopenias, for those patients with TKI-resistant disease and for patients with advanced phase CML.[88,91] However, there is very limited data on the impact of *BCR::ABL1*–independent mutations in patients with newly diagnosed CP-CML. Additionally, *BCR::ABL1*-independent gene mutations have also been frequently described in Ph-negative clones.[100] The impact of mutations is also variable depending on whether they occur in Ph-positive or Ph-negative clones.

Myeloid mutational analysis using NGS can be considered for patients with CP-CML and advanced phase CML at diagnosis. This is a category 2B recommendation for patients with newly diagnosed CP-CML.

Management of Chronic Phase CML

Primary Treatment

Long-term efficacy data from randomized phase III studies for first-line TKI therapy in patients with newly diagnosed CP-CML are summarized in Table 1.[101-106] In summary, 1) all TKIs are highly effective as primary treatment for patients with newly diagnosed CP-CML, with long-term OS expected to be similar to that of aged-matched controls; 2) 2G TKIs (bosutinib, dasatinib and nilotinib) and allosteric TKI (asciminib; STAMP [specifically targeting the ABL myristoyl pocket] inhibitor), generally result in faster cytogenetic and molecular responses, with less progression to advanced phase CML, compared to imatinib; and 3) in randomized clinical trials, as of yet, there are no significant differences in OS between imatinib and a 2G TKI or asciminib.

Generic versions have been shown to be noninferior to innovator drugs in terms of efficacy with an acceptable toxicity profile.[107-111] Therefore, FDA-approved generic versions are appropriate substitutes for innovator drugs.[112] Innovator and generic drugs approved by the regulatory authorities based on pharmacokinetic equivalence can be used interchangeably.

TKI Dose

TKIs are available in different formulations, dosage forms, and strengths that are subject to different administration instructions. These products are not interchangeable. Refer to package insert of specific TKIs for full prescribing information: https://www.accessdata.fda.gov/.

Data from randomized phase III studies that have evaluated high-dose imatinib as first-line therapy for CP-CML suggest that imatinib 800 mg was not associated with lower rates of disease progression than imatinib 400 mg, despite improved early responses (Table 2).[113-115] Imatinib 800 mg was also associated with higher rates of dose interruption, reduction, or discontinuation due to grade 3 or 4 adverse events in all of the studies. However, patients who could tolerate the higher dose of imatinib achieved higher response rates than those receiving standard-dose imatinib.[116] Imatinib 800 mg is not recommended as initial therapy, given the data showing superior efficacy of 2G TKIs in newly diagnosed CP-CML.

Limited available evidence from small cohort studies suggests that initiation of select first-line TKIs (bosutinib, dasatinib, or nilotinib) at lower doses (to minimize treatment-related adverse events) and dose reduction (with close monitoring) in patients who achieve optimal responses are appropriate strategies to reduce the risk of long-term toxicities.[117,118] See the section on *Dose Modifications of TKI Therapy*. However, the minimum effective dose or optimal de-escalation of TKIs (bosutinib, dasatinib, or nilotinib) has not yet been established in prospective randomized clinical trials.

Clinical Considerations for the Selection of First-Line Therapy

The selection of first-line TKI therapy (asciminib, bosutinib, dasatinib, imatinib, or nilotinib) in a given patient should be based on the risk score, toxicity profile, patient's age, ability to tolerate therapy, and the presence of comorbid conditions (CML-2). Allogeneic HCT is no longer recommended as a first-line treatment for patients with CP-CML.

Risk Stratification

Asciminib, bosutinib, dasatinib, imatinib, or nilotinib are all appropriate options for first-line TKI therapy for patients with CP-CML across all risk scores.[101-106]

Disease progression is more frequent in patients with intermediate- or high-risk score, and prevention of disease progression to AP-CML or BP-CML is the primary goal of TKI therapy in patients with CP-CML. 2G TKIs are associated with a lower risk of disease progression than imatinib and are preferred for patients with an intermediate- or high-risk Sokal or Euro score. 2G TKIs also result in quicker molecular responses and higher rates of MMR (≤0.1% *BCR::ABL1* IS) and deep molecular response (DMR) (MR4.0 [≤0.01% *BCR::ABL1* IS] or MR4.5 [≤0.0032% *BCR::ABL1* IS]) in patients with CP-CML across all risk scores (Table 3), which may facilitate subsequent discontinuation of TKI therapy in selected patients.[102,103,105] In the ASC4FIRST study, asciminib also resulted in higher rates of MMR compared to investigator-selected TKI (imatinib or 2G TKIs) in patients with across all risk scores. There was a significant difference vs imatinib (*P* <.001), but there was no statistically significant difference in MMR rates vs 2G TKI. Therefore, 2G TKIs and asciminib are preferred for patients with an intermediate-risk or high-risk score.[106]

2G TKIs and asciminib should also be considered for specific subgroups (based on the assessment of treatment goals and benefit/risks), for example in younger patients who are interested in ultimately discontinuing treatment, particularly in young patients assigned female at birth with a goal of achieving a deep and rapid molecular response which may allow for eventual discontinuation of TKI therapy for family planning purposes. Imatinib may be preferred for older patients with comorbidities, especially cardiovascular comorbidities.

Toxicity Profile

All the TKIs are generally well tolerated. Since asciminib, bosutinib, dasatinib, and nilotinib have very good efficacy in the upfront setting, differences in their potential toxicity profiles may inform the selection of a specific TKI as initial therapy. Adverse events of first-line TKI therapy in patients with CP-CML reported in phase III randomized studies are discussed below and are summarized in Table 4.

See also the section on Special considerations for the use of TKI therapy in the algorithm (CML-C).

Asciminib, bosutinib or nilotinib may be preferred for patients with a history of lung disease or deemed to be at risk of developing pleural effusions. Bosutinib or dasatinib may be preferred in patients with a history of arrhythmias, cardiovascular disease, hypertension, pancreatitis, or hyperglycemia.

Asciminib

In the ASC4FIRST study, rash, headache, edema, muscle spasms, gastrointestinal toxicities (diarrhea, constipation and vomiting), and biochemical abnormalities (elevated aspartate aminotransferase [AST] and alanine aminotransferase [ALT]) were less common with asciminib than with imatinib and 2G TKIs.[106] Headache, rash, and elevated AST/ALT were more common with 2G TKIs whereas muscle spasms, vomiting and edema were more common with imatinib. The incidences of arterial adverse events were low across all 3 treatment groups occurring in 1% and 2% of patients treated with asciminib and 2G TKIs respectively with no such adverse event reported with imatinib. The incidence of adverse events leading to discontinuation of treatment were also lower with asciminib. However, longer term side effects are not evaluable because of the short median follow-up of 16 months.

Bosutinib

In the BFORE study, diarrhea, increased ALT and AST levels were more common with bosutinib whereas muscle spasms and peripheral edema were more common with imatinib.[103,104] Grade 3/4 thrombocytopenia was higher with bosutinib, and grade 3/4 neutropenia was higher with imatinib. Grade 3/4 anemia was similar in both groups. Discontinuation of therapy due to drug-related adverse events occurred in 14% of patients in the bosutinib group compared to 11% in the imatinib group. Increased ALT (5%) and increased AST (2%) were the most common adverse events leading to discontinuation of bosutinib. However, there were no hepatotoxicity-related fatalities during the study.

Dasatinib

In the DASISION study, the incidences of grade 3/4 hematologic toxicities (anemia, neutropenia, and thrombocytopenia) were higher for dasatinib than imatinib.[102] Nonhematologic adverse events such as muscle spasms, peripheral edema, and hypophosphatemia were more frequent with imatinib. Discontinuation of therapy because of drug-related adverse events occurred in 16% and 7% of patients in the dasatinib and imatinib arms, respectively. Dasatinib is associated with significant but reversible inhibition of platelet aggregation that may contribute to bleeding in some patients, especially if accompanied by thrombocytopenia.[119]

Pleural effusion was also more common with dasatinib (28% in the DASISION study compared to <1% with imatinib and 33% in a dose optimization study) and age has been identified as a significant risk factor for the development of pleural effusion.[120] The occurrence of pleural effusion is significantly reduced with dasatinib 100 mg once daily compared with 70 mg twice daily. Patients with prior cardiac history, with hypertension, and receiving dasatinib 70 mg twice daily are at increased risk of developing pleural effusions.[121]

Largely reversible pulmonary arterial hypertension (PAH) has been reported as a rare but serious side effect of dasatinib.[122-124] In the DASISION study, pulmonary hypertension was reported in 5% of patients treated with dasatinib compared to <1% of patients treated with imatinib.[102]

Evaluation for signs and symptoms of underlying cardiopulmonary disease prior to initiating and close monitoring during treatment with dasatinib is recommended. Dose reduction (with close monitoring) should be considered for patients at risk of developing pleural effusions. Switching to alternate TKI is recommended for persistent pleural effusion or PAH despite adequate supportive care interventions and dose reduction.

Imatinib

Chronic fatigue (often correlated with musculoskeletal pain and muscular cramps) is a major factor in reducing quality of life in patients who take imatinib.[125] Hypophosphatemia and decrease in bone mineral density have been noted in a small group of patients, suggesting that monitoring bone health should be considered for patients taking imatinib.[126,127] Skin hypopigmentation has also been reported as a side effect of imatinib and is reversible upon discontinuation or dose reduction.[128,129] Reversible renal dysfunction with prolonged use of imatinib has also been reported.[130]

Nilotinib

In the ENESTnd study, rates of nonhematologic adverse events such as nausea, diarrhea, vomiting, muscle spasm, and peripheral edema of any grade were higher for patients receiving imatinib. Conversely, rash and headache were more common with nilotinib.[105] Grade 3 or 4 neutropenia was more frequently observed in the imatinib group, whereas thrombocytopenia and anemia were similar in both groups. Electrolyte abnormalities and elevations in lipase, glucose, and bilirubin were more frequent with nilotinib than with imatinib. Patients with a previous history of pancreatitis may be at greater risk of elevated serum lipase. The overall incidences of adverse events leading to discontinuation of therapy were comparable in the nilotinib 300 mg twice-daily and imatinib arms (12% and 14%, respectively) and slightly higher in the nilotinib 400 mg twice-daily arm (20%).

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.[124] Electrolyte abnormalities should be corrected prior to initiation of treatment with nilotinib, and electrolytes should be monitored periodically. Drugs that prolong QT interval should be avoided. Electrocardiogram (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 ischemic heart disease, ischemic cerebrovascular disease, and peripheral arterial occlusive disease (PAOD).[105] The 10-year follow-up data from ENESTnd study showed a higher rate of adverse cardiovascular events with nilotinib (17% and 24%, respectively for nilotinib 300 mg twice daily and nilotinib 400 mg twice daily) versus imatinib (4%).[105]

Evaluation for pre-existing cardiovascular risk factors prior to initiating treatment with nilotinib and close monitoring for any adverse cardiovascular events during treatment with nilotinib is recommended for all patients. Referral to a cardiologist is recommended for patients with cardiovascular risk factors for additional monitoring and/or assessments. QT interval prolongation could be managed with dose reduction. Switching to alternate TKI is recommended if persistent despite dose reduction and adequate supportive care interventions.

Nilotinib tablets with improved bioavailability that allows for administration at a lower dose without mealtime restrictions has been approved by the FDA. Nilotinib products available in different formulations, dosage forms and strengths are not interchangeable. Refer to package insert for full prescribing information: https://www.accessdata.fda.gov/.

Management of Toxicities of TKI Therapy

Hematologic Toxicities

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.accessdata.fda.gov, for the recommended dose modifications of specific TKI therapy.

Assessment of reticulocyte count, ferritin, iron saturation, vitamin B12, and folate and correction of nutritional deficiencies if present is recommended for patients with grade 3–4 anemia. Red blood cell transfusions are indicated in symptomatic patients. Myeloid growth factor support can be used in combination with TKI therapy for the management of neutropenia.[131,132]

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.[133] The 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.

Nonhematologic Toxicities

Recommendations for monitoring and supportive care interventions for the management of nonhematologic adverse events are outlined in the section Special Considerations for the use of TKI Therapy in the algorithm.

Dose reduction (with close monitoring) should be considered if nonhematologic adverse events are not controlled by adequate supportive care interventions. Switching to an alternate TKI is recommended for persistent adverse events despite dose reduction.

Patients should be counseled on the potential risk factors for cardiovascular disease (CVD) and the increased risk of CVD associated with long-term TKI therapy.[134] Cardiovascular risk factors (eg, diabetes, hypertension, hyperlipidemia, smoking, estrogen use) should be identified and controlled prior to initiating TKI therapy. Patients with a history of cardiovascular risk factors or cardiovascular signs and symptoms should be carefully monitored for high blood pressure, evidence of arterial, vascular or thromboembolic events, and reduced cardiac function.[135] Switching to an alternate TKI is recommended for the onset of new arterial and vascular events, new or worsening heart failure, and severe hypertension not responsive to antihypertensive medications. Referral to a cardiologist is recommended for patients with cardiovascular risk factors for additional monitoring and/or assessments.

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 assessments (decrease in the amount of *BCR::ABL1* chimeric mRNA using qPCR). The criteria for hematologic, cytogenetic, and molecular response are summarized in CML-F.

Conventional bone marrow cytogenetics is the standard method for monitoring cytogenetic responses, and many clinical trial response analyses have been based on conventional bone marrow cytogenetics. With the advent of qPCR, bone marrow cytogenetic analyses to assess response are rarely performed. If conventional bone marrow cytogenetics yield no analyzable metaphases, cytogenetic response can be evaluated by FISH, preferably with a dual color probe to minimize false-positive rates. FISH and cytogenetic results are correlated, but are not superimposable.[136-138] Although some investigators have reported that interphase FISH can be used to monitor complete cytogenetic response (CCyR), inadequate response to TKI therapy has not been defined on the basis of FISH analysis.[139,140] The Panel feels that FISH has been inadequately studied for monitoring response to TKI therapy and 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 qPCR is the strong correlation between the results obtained from the peripheral blood and the bone marrow, allowing for molecular monitoring without bone marrow aspirations.[141,142]

Standardization of Molecular Monitoring Using the International Scale

In the IS, the standardized baseline (defined as the average expression of *BCR::ABL1* transcripts in 30 patients with untreated CML enrolled in the IRIS trial) is set to 100%. Molecular response is expressed as log-reduction from 100%. For example, a ≥2-log reduction (≤1% *BCR::ABL1* IS; MR2.0) generally correlates with CCyR and a ≥3-log reduction (≤0.1% *BCR::ABL1* IS) is referred to as MMR or MR3.0.[18,143,144]

DMR is defined by the assay's level of sensitivity [≤0.01% *BCR::ABL1* (IS), MR4.0; ≤0.0032% *BCR::ABL1* (IS), MR4.5].[145] The sensitivity of a qPCR assay depends not only on the performance of the assay, but also on the quality of a given sample.

As such, the term "complete molecular response" to denote undetectable *BCR::ABL1* transcripts (a negative qPCR test) should be abandoned, as it may refer to very different levels of response, dependent on the quality of the sample and sensitivity of the test. Laboratories can use their individual assays, but the *BCR::ABL1* transcripts obtained in a given laboratory should be converted to the IS by applying a laboratory-specific conversion factor (CF).[18,146]

Recommendations for Monitoring Response to TKI Therapy

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 to measure *BCR::ABL1* transcripts (CML-G). In patients with prolonged myelosuppression who may not be in complete hematologic response (CHR) due to persistent cytopenias or an unexplained drop in blood counts during therapy, bone marrow cytogenetics is indicated to confirm response to TKI therapy and exclude other pathology, such as MDS or the presence of chromosomal abnormalities other than Ph. Given the risk for transient myelosuppression that can occur during early disease responses, TKI therapy should not be held while bone marrow evaluation is pending.

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 (≤10% *BCR::ABL1 IS* at 3 and 6 months, ≤1% *BCR::ABL1* IS at 12 months, and ≤0.1% *BCR::ABL1* IS at >12 months). After CCyR (≤1% *BCR::ABL1* IS) 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.[147] 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. In patients with deeper molecular responses (MMR and better) and who are compliant with TKI therapy, the frequency of molecular monitoring can be reduced, though the optimal frequency is unknown. Molecular monitoring of response to TKI therapy more frequently than every 3 months is not presently recommended.

Prognostic Significance of Cytogenetic and Molecular Response

Early molecular response (EMR; ≤10% *BCR::ABL1* IS at 3 and 6 months) after first-line TKI therapy has emerged as an effective prognosticator of favorable long-term PFS and OS (Table 5).[102,115,148,149] Some reports suggest that EMR at 3 months has a superior prognostic value and supports early intervention strategies based on the *BCR::ABL1* transcript level at 3 months.[150,151] However, other studies yielded partially conflicting results regarding the predictive value of *BCR::ABL1* transcripts at 3 months.[152] From a practical perspective, it is important to consider these data points within the clinical context. For instance, if *BCR::ABL1* transcript level is minimally above the 10% cutoff (eg, 11%–15% at 3 months), it is reasonable to reassess at 6 months before considering major changes to the treatment strategy.

Some studies have suggested that the rate of decline in *BCR::ABL1* transcripts correlates with longer-term response.[153-155] 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).[153] 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.[154] 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 DMR (MR4.0; ≤0.01% *BCR::ABL1* IS) by 18 months.[155]

Achievement of CCyR or ≤1% *BCR::ABL1* IS within 12 months after first-line TKI therapy is an established prognostic indicator of long-term survival.[156,157] In the IRIS study, the estimated 6-year PFS rate was 97% for patients achieving a CCyR at 6 months compared to 80% for patients with no cytogenetic response at 6 months.[156] In an analysis of patients with newly diagnosed CP-CML treated with imatinib or 2G 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.[157]

MMR (≤0.1% *BCR::ABL1* IS) as a predictor of PFS and OS has also been evaluated in several studies.[141,158-164] In all of these studies, the analyses were done for different outcomes measures at multiple time points, but failed to adjust for multiple comparisons, thereby reducing the validity of the conclusions. The general conclusion from these studies is that the achievement of MMR is associated with durable long-term cytogenetic remission and lower rate of disease progression, but MMR is not a significant predictor of superior OS in patients with a stable CCyR. Importantly, with longer follow-up, CCyR becomes an ever-stronger indicator of MMR, reducing the added prognostic value of MMR. Although the CML IV study showed that MR4.5 (≤0.0032% *BCR::ABL1* IS) at 4 years was associated with a significantly higher OS (independent of therapy) than MR2.0 (≤1% *BCR::ABL1* IS, which corresponds to CCyR), this study demonstrated no significant differences in OS in patients who achieved MMR (≤0.1% *BCR::ABL1* IS) and those who achieved MR2.0 (≤1% *BCR::ABL1* IS).[163]

The absence of MMR in the presence of a CCyR is therefore not considered as an inadequate response to treatment. While some investigators have reported that dose escalation of imatinib might benefit patients in CCyR with no MMR,[165] there are no randomized studies to show that a change of therapy would improve survival, PFS, or EFS in this group of patients.[166] However, the achievement of MMR (≤0.1% *BCR::ABL1* IS) at 12 months is associated with a very low probability of subsequent loss of response and a high likelihood of achieving a subsequent DMR (MR4.0; ≤0.01% *BCR::ABL1* IS), which may facilitate discontinuation of TKI therapy.[46,164] In view of the ongoing evolution of treatment goals (OS vs. treatment-free remission [TFR]), expert Panels have emphasized the importance of joint decision-making between patient and provider, particularly in ambiguous situations.[167]

Response Milestones After First-Line TKI Therapy

The most important goals of TKI therapy are to prevent disease progression to AP-CML or BP-CML and to achieve either MR2.0 (≤1% *BCR::ABL1* IS, which corresponds to CCyR) or MMR (≤0.1% *BCR::ABL1* IS) within 12 months after first-line TKI therapy. The guidelines emphasize that achievement of response milestones must be interpreted within the clinical context, before making drastic changes to the treatment strategy, especially in ambiguous situations.

The Panel has included ≤10% *BCR::ABL1* IS at 3 and 6 months after initiation of first-line TKI therapy as a response milestone since the achievement of EMR after first-line TKI therapy is an effective prognosticator of favorable long-term PFS (CML-3). Achievement of >0.1% to 1% *BCR::ABL1* IS (≤1% *BCR::ABL1* IS, which correlates with CCyR) is considered the optimal response milestone at 12 months if the goal of therapy in an individual patient is long-term survival, whereas the achievement of MMR (≤0.1% *BCR::ABL1* IS) at 12 months should be considered as the optimal response milestone if the treatment goal in an individual patient is TFR. Patients who achieve these response milestones are considered to have TKI-sensitive disease, and continuation of the same dose of TKI and assessment of *BCR::ABL1* transcripts with qPCR (IS) every 3 months is recommended for this group of patients.

Inability to achieve ≤10% *BCR::ABL1* IS at 3 months or ≤1% *BCR::ABL1* IS at 12 months is associated with a higher risk for disease progression. Clinical judgment should be used in patients with a >10% *BCR::ABL1* IS at 3 months and >1% *BCR::ABL1* IS at 12 months, considering problems with adherence (which can be common given drug toxicity at the initiation of therapy), rate of decline in *BCR::ABL1*, and how far from the cutoff the *BCR::ABL1* value falls.

Patients with *BCR::ABL1* that is slightly >10% at 3 months (with a steep decline from baseline level) may achieve <10% *BCR::ABL1* IS at 6 months and have favorable outcomes.[152-155] Therefore, many patients with >10% *BCR::ABL1* at 3 months can continue the same dose of TKI (asciminib, bosutinib, dasatinib, imatinib, or nilotinib) for another 3 months (but imatinib is associated with slower molecular responses) or switch to alternate TKI. *BCR::ABL1* mutational analysis should be considered.

Achievement of ≤10% *BCR::ABL1* IS (which correlates with MCyR) within 2 years is associated with favorable long-term OS, even if deeper molecular response is not achieved.[168] These data suggest that patients with >1% to 10% *BCR::ABL1* at 12 months have favorable outcomes. Patients with >50% reduction in *BCR::ABL1* levels compared to baseline or if *BCR::ABL1* is minimally above 10% cutoff at 12 months can continue the same dose of TKI for another 3 months. Bone marrow cytogenetics should be considered to assess for CCyR at 12 months in cases where the *BCR::ABL1* transcript level is between 1% and 10%. The same dose of TKI can be continued if CCyR is achieved. Switching to alternate 2G TKI or asciminib or 3G TKI should be considered if CCyR is not achieved or in the absence of continuing decline in *BCR::ABL1* transcript levels. *BCR::ABL1* mutational analysis should be considered.

In patients with >0.1% to 1% *BCR::ABL1* IS at 12 months, shared decision-making is recommended depending on the goal of therapy in individual patients (longer-term survival vs. TFR). As discussed before, although not associated with increased OS, MMR at 12 months is associated with a lower rate of disease progression and a higher likelihood of achieving DMR, which is a prerequisite for TFR.[46,164] Switching from imatinib to a 2G TKI or asciminib may increase the probability of achieving MMR (≤0.1% *BCR::ABL1* IS) at 12 months. However, the side effect profile of alternative TKIs may differ. Referral to specialized CML centers and/or enrollment in a clinical trial should be considered.

Patients with >10% *BCR::ABL1* IS at 6 and 12 months are considered to have TKI-resistant disease. Evaluation for allogeneic HCT (discussion with a transplant specialist, which might include HLA testing) is recommended. Bone marrow cytogenetic analysis to assess ACAs should be considered. Alternative treatment options should be considered as described below.

Second-Line Therapy

Dose escalation of imatinib up to 800 mg daily has been shown to overcome some cases of primary resistance and is particularly effective for cytogenetic relapse in patients who had achieved cytogenetic response with imatinib 400 mg daily, although the duration of responses has typically been short.[169-172] However, it is unlikely to benefit patients who do not achieve hematologic response or those who never had a cytogenetic response with imatinib 400 mg daily. In patients with >10% *BCR::ABL1* IS at 3 months after imatinib 400 mg, switching to nilotinib or dasatinib has been shown to result in higher rates of MMR at 12 months than dose escalation of imatinib.[173-175] Although dose escalation of imatinib has been shown to be beneficial for patients in CCyR without MMR, no randomized studies have shown that a change of therapy would improve PFS or EFS in this group of patients.[165,166]

Dasatinib and nilotinib retain activity against many of the imatinib-resistant BCR::ABL1 kinase domain mutants except T315I and are effective treatment options for CP-CML that is resistant to imatinib and also for patients who are intolerant to imatinib.[176,177] Bosutinib also has demonstrated activity in CP-CML that is resistant to multiple TKIs (imatinib, dasatinib, and nilotinib).[178-181] Ponatinib and asciminib are active against most of the resistant BCR::ABL1 kinase domain mutants, including T315I.[182-185]

Long-term efficacy data from clinical trials on second-line and subsequent TKI therapy for CP-CML are summarized in Table 6.

Ponatinib was initially approved as a treatment option for patients with a T315I mutation and/or for patients for whom no other TKI is indicated based on the results of the PACE trial (Table 6).[182] Ponatinib, at the recommended initial dose of 45 mg once daily, was associated with increased risk of arterial and vascular adverse events. The incidence of cardiovascular adverse events was highest among patients with preexisting cardiovascular risk factors.[182,186-188] In the PACE trial, serious arterial and vascular adverse events (cardiovascular, cerebrovascular, and peripheral vascular) and venous thromboembolic events occurred in 31% and 6% of patients, respectively.[182] Cardiovascular, cerebrovascular, and peripheral vascular adverse events were reported in 16%, 13%, and 14% of patients, respectively.

See Special Considerations for the use of TKI Therapy in the algorithm for the supportive care interventions and treatment recommendations for the management of arterial and cardiovascular adverse events associated with ponatinib.

In the OPTIC trial that evaluated the safety and efficacy of response-adjusted dosing regimen, patients were randomized to ponatinib starting doses of 45 mg, 30 mg, and 15 mg, with dose reduction to 15 mg with achievement of ≤1% *BCR::ABL1* (IS) in the 45 mg and 30 mg cohorts.[183] Ponatinib was effective at all 3 dose levels (45 mg, 30 mg, and 15 mg) and the maximum benefit was observed with 45 mg. After a median follow-up of 32 months, *BCR::ABL1* (IS) ≤1% at 12 months was achieved in 44% of patients in the 45 mg cohort compared to 29% and 23% in the 30 mg and 15 mg cohorts, respectively. After response-based dose reduction to 15 mg, responses were maintained in 73% and 79% of patients in the 45 mg and 30 mg cohorts, respectively. The rate of any arterial and vascular adverse events reported in the OPTIC trial (10% in the 45 mg cohort; 5% and 3% in the 30 mg and 15 mg cohorts, respectively) was lower than that reported for ponatinib 45 mg in the PACE trial. Based on the results of the OPTIC trial, the FDA has approved a response-adjusted dosing regimen for ponatinib [starting dose of 45 mg once daily with a reduction to 15 mg upon achievement of *BCR::ABL1* (IS) ≤1%] for patients with CP-CML with resistance or intolerance to at least two prior kinase inhibitors.

Asciminib is also approved for patients with CP-CML having the T315I mutation and/or previously treated CP-CML. In the phase III randomized study (ASCEMBL), asciminib 40 mg twice daily achieved higher molecular response rates (MMR, MR4.0, and MR4.5) than bosutinib 500 mg once daily in patients with CP-CML previously treated with ≥2 prior TKIs.[184,185] The recommended initial dose of asciminib is 80 mg once daily or 40 mg twice daily in patients without a T315I mutation and 200 mg twice daily for patients with a T315I mutation. Gastrointestinal toxicities (diarrhea, nausea, and vomiting) and biochemical abnormalities (increased ALT and AST levels) were notably higher with bosutinib. Arterial and vascular adverse events were reported in 3% and 1% of patients treated with asciminib and bosutinib, respectively.[184] The incidence of adverse events leading to treatment discontinuation was also lower with asciminib (6% vs. 21%).

Clinical Considerations for the Selection of Second-Line TKI Therapy

EMR (≤10% *BCR::ABL1* IS at 3 and 6 months) after second-line TKI therapy with dasatinib or nilotinib has also been reported to be a prognosticator of OS and PFS (Table 7).[176,177] 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.

BCR::ABL1 kinase domain mutation analysis (see below), evaluation of drug interactions, and adherence to therapy are recommended prior to the initiation of second-line TKI therapy. As discussed earlier, myeloid mutational analysis using NGS to identify *BCR::ABL1*–independent mutations may also be useful for patients with CP-CML who do not achieve optimal response milestones due to the presence of cytopenias and for those with TKI resistant disease.

Drug Interactions

All TKIs are metabolized in the liver by cytochrome P450 (CYP) enzymes, and concomitant use of drugs that induce or inhibit CYP3A4 or CYP3A5 enzymes may alter the therapeutic effect of TKIs.[189,190]

Drugs that are 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. Asciminib is also a CYP2C9 inhibitor and concomitant use of asciminib increases the plasma concentration of other drugs that are CYP2C9 substrates.

Concomitant use of drugs metabolized by these enzymes requires caution, and appropriate alternatives should be explored to optimize treatment outcome. If coadministration cannot be avoided, dose modification should be considered.

See Drug Interactions of TKIs in the algorithm (CML-D) for specific drug interactions of TKIs with the most commonly used medications and supplements.

Adherence to Therapy

Treatment interruptions and non-adherence to therapy may lead to undesirable clinical outcomes.[191-193] In the ADAGIO study, non-adherence to imatinib was associated with poorer response. Patients with suboptimal response missed significantly more imatinib doses (23%) than did those with optimal response (7%).[191] Adherence to imatinib therapy has been identified as the only independent predictor for achieving complete molecular response (CMR) on standard-dose imatinib.[192] The 6-year probability of achieving CMR was significantly higher for patients with >90% adherence rate (44% compared to 0% for patients with ≤90% adherence rate; *P* = .002).[192] Poor adherence to imatinib therapy has also been identified as the most important factor contributing to cytogenetic relapse and inadequate response to imatinib.[193] Patients with adherence of ≤85% had a higher probability of losing CCyR at 2 years than those with adherence of >85% (27% and 2%, respectively). Poor adherence to therapy has also been reported in patients receiving dasatinib and nilotinib following inadequate response to imatinib.[194,195]

Patient education on adherence to therapy and close monitoring of each patient's adherence is critical to achieving 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.[196] Short interruptions or dose reductions, when medically necessary, may not have a negative impact on disease control or other outcomes. Adequate and appropriate management of side effects and scheduling appropriate follow-up visits to review side effects may be helpful to improve patient adherence to therapy.[197]

Switching to an alternate TKI because of intolerance is appropriate for patients with disease responding to TKI therapy and it might be beneficial for selected patients with acute grade ≥3 nonhematologic toxicities or in those with chronic, low-grade nonhematologic toxicities that are not manageable with adequate supportive care interventions.[198,199] Asciminib and ponatinib are appropriate treatment options for CP-CML with intolerance to prior 2G TKIs.

Resistance to TKI Therapy

Aberrant expressions of drug transporters[200-202] and plasma protein binding of TKI[203-205] could contribute to primary resistance by altering the intracellular and plasma concentration of TKI.

Pretreatment levels of organic cation transporter 1 (OCT1) have been reported as the most powerful predictor of response to imatinib.[206] On the other hand, cellular uptake of dasatinib or nilotinib seems to be independent of OCT1 expression, suggesting that patients with low OCT1 expression might have better outcomes with dasatinib or nilotinib than with imatinib.[207-210]

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, and assays that measure plasma levels of imatinib are not widely available.

BCR::ABL1 Kinase Domain Mutation Analysis

Point mutations in the BCR::ABL1 kinase domain are a frequent mechanism of secondary resistance to TKI therapy and are associated with poor prognosis and a higher risk of disease progression.[211-216]

E255K/V, F359C/V, Y253H, and T315I mutants are most commonly associated with disease progression and relapse.[217,218] Among the BCR::ABL1 kinase domain mutations, T315I confers complete resistance to imatinib, dasatinib, nilotinib, and bosutinib.[219,220]

T315A, F317L/I/V/C, and V299L mutants are resistant to dasatinib and the E255K/V, F359V/C, and Y253H mutants are resistant to nilotinib.[217,221-223] The G250E and V299L mutants are resistant to bosutinib.[178]

Dasatinib and bosutinib have demonstrated activity in patients with *BCR::ABL1* mutants resistant to nilotinib (Y253H, E255K/V, and F359C/I/V).[180,181,223] Bosutinib has minimal activity against the F317L mutation (which is resistant to dasatinib) and nilotinib may be preferred over bosutinib in patients with the F317L mutation.[217,222,224] Ponatinib is active against *BCR::ABL1* mutants resistant to dasatinib or nilotinib, including E255V, Y253H, F359V, and T315I.[182]

There are limited data available regarding the impact of new myristoyl-pocket mutations detected during asciminib treatment on the efficacy of asciminib. Patients with detectable bosutinib-resistant *BCR::ABL1* mutations (T315I or V299L) were ineligible to participate in the ASCEMBL trial.[184] In addition to T315I, asciminib has been reported to be active against select *BCR::ABL1* mutants resistant to bosutinib, dasatinib, or nilotinib (G250E, Y253H, E255V). However, A337T, P465S, F359V/I/C and M244V are considered as contraindicated mutations to asciminib.[225,226]

Response rates to TKI therapy based on BCR-ABL mutation status are listed in Table 8.

BCR::ABL1 compound mutations (variants containing ≥2 mutations within the same *BCR::ABL1* allele that presumably arise sequentially) confer different levels of resistance to TKI therapy, and compound mutants involving T315I confer the highest level of resistance to all TKIs, including ponatinib.[227,228] In another study that used NGS to detect low-level and *BCR::ABL1* compound mutations in 267 patients with heavily pretreated CP-CML from the PACE trial, no compound mutation was identified that consistently conferred resistance to ponatinib, suggesting that such compound mutations are uncommon following treatment with bosutinib, dasatinib, or nilotinib for CP-CML.[229]

BCR::ABL1^{35INS} has been associated with resistance to imatinib.[230,231] In one study, *BCR::ABL1*^{35INS} was detected in 23% of patients (64 out of the 284 patients; 45 patients with CP-CML).[231] Among the 34 patients with CP-CML treated with imatinib, primary refractory disease, disease progression while on imatinib and disease progression after dose interruption were reported in 24% (n = 8), 32% (n = 11), and 12% (n = 4) of patients respectively. *BCR::ABL1*^{35INS} was also associated with grade 3 or 4 hematologic toxicity. This study, however, was not powered to determine the efficacy of 2G TKI against *BCR-ABL1*^{35INS} since very few patients with this mutation received either dasatinib or nilotinib.

BCR::ABL1 kinase domain 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.[232] The guidelines recommend *BCR::ABL1* kinase domain mutational analysis for patients who do not achieve response milestones, for those with 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.

BCR::ABL1 kinase domain mutational analysis provides additional guidance for selecting subsequent TKI therapy only in patients with identifiable mutations. Treatment options based on BCR::ABL1 kinase domain mutation status are outlined on CML-5.

Switching to an alternate TKI (based on the BCR::ABL1 kinase domain mutation status) is recommended for patients with disease that is resistant to primary treatment with imatinib. Patients with disease that is resistant to primary treatment with asciminib, bosutinib, dasatinib, or nilotinib could be switched to an alternate TKI (based on the BCR::ABL1 kinase domain mutation status). However, there is no clear evidence to support that switching to an alternate TKI would improve long-term clinical outcome for this group of patients.[233]

Subsequent therapy with an alternate TKI is expected to be effective only in patients with identifiable *BCR::ABL1* mutations that confer resistance to TKI therapy. Ponatinib is a treatment option for patients with a T315I mutation in any phase (preferred for AP-CML or BP-CML) and asciminib is a treatment option for patients with CP-CML having a T315I mutation.

Ponatinib is also preferred for patients with no identifiable *BCR::ABL1* mutations.

In patients with no identifiable mutations, the selection of subsequent TKI therapy should be based on the patient's age, ability to tolerate therapy, presence of comorbid conditions, and toxicity profile of the TKI. Adverse events of second-line and subsequent TKI therapy in patients with CP-CML are summarized in Table 9. Evaluation of allogeneic HCT or enrollment in a clinical trial should be considered for this group of patients

Rising BCR::ABL1 Transcripts

Rising *BCR::ABL1* transcripts are associated with an increased likelihood of detecting BCR::ABL1 kinase domain mutations and cytogenetic relapse.[234-238] In patients who had achieved very low levels of *BCR::ABL1* transcripts, emergence of BCR::ABL1 kinase domain mutations was more frequent in those who had a >2-fold increase in *BCR::ABL1* transcripts compared to those with stable or decreasing *BCR::ABL1* transcripts.[234] A serial rise has been reported to be more reliable than a single ≥2-fold increase in *BCR::ABL1* transcripts.[235,236] Among patients in CCyR with a ≥0.5-log increase in *BCR::ABL1* transcripts on at least two occasions, the highest risk of disease progression was associated with loss of MMR and >1-log increase in *BCR::ABL1* transcripts.[236]

Rising transcript levels should prompt an investigation of treatment adherence and reassessment of coadministered medications. The precise increase in *BCR::ABL1* transcripts that warrants a mutation analysis depends on the performance characteristics of the qPCR assay.[238] Some labs have advocated a 2- to 3-fold range,[161,237,238] while others have taken a more conservative approach (5- to 10-fold).[236] Obviously, some common sense must prevail, since the amount of change in absolute terms depends on the level of molecular response. For example, a finding of any *BCR::ABL1* after achieving a DMR (MR4.5; ≤0.0032% *BCR::ABL1* IS) is an infinite increase in *BCR::ABL1* transcripts. However, a change in *BCR::ABL1* transcripts from a barely detectable level to MR4.5 is clearly different from a 5-fold increase in *BCR::ABL1* transcripts after achieving MMR.

Currently there are no specific guidelines for changing therapy only based on rising *BCR::ABL1* levels as detected by qPCR, and it should be done only in the context of a clinical trial.

Discontinuation of TKI Therapy

The feasibility of discontinuation of TKI therapy (dasatinib, imatinib, or nilotinib) with close monitoring in carefully selected patients who have achieved and maintained DMR (≥MR4.0; ≤0.01% *BCR::ABL1* IS) for ≥2 years has been evaluated in several clinical studies.[239-253] Longer-term follow-up data from the TKI discontinuation trials are summarized in Table 10.

The results of the RE-STIM study demonstrated the safety of a second TKI discontinuation after a first unsuccessful attempt.[254] The rate of molecular relapse after the first TKI discontinuation attempt was the only factor significantly associated with outcome. The TFR rate 24 months after the second TKI discontinuation was higher for patients who remained in DMR within the first 3 months after the first TKI discontinuation (72% vs. 32% for other patients).

Approximately 40% to 60% of patients who discontinue TKI therapy after achieving DMR experience recurrence within 12 months of treatment cessation, in some cases as early as 1 month after discontinuation of TKI therapy. Several factors may help predict the risk of recurrence after TKI discontinuation (a higher Sokal risk score, female gender, lower natural killer cell counts, suboptimal response or resistance to imatinib, duration of TKI therapy, and DMR prior to TKI discontinuation). However, only the duration of TKI therapy and DMR prior to discontinuation of TKI therapy have been associated with TFR with a high level of consistency.[239,244,248,249]

In the EURO-SKI study, duration of treatment with imatinib (≥6 years) and duration of DMR (MR4.0 for 3 years) were significantly associated with MMR maintenance at 6 months after discontinuation of imatinib and lack of MR4.0 at 36 months after discontinuation of TKI therapy was highly predictive of subsequent loss of MMR.[248,255] A rapid initial decline in *BCR::ABL1* transcripts after initiation of first-line TKI therapy has also been shown to be an independent predictor of TFR eligibility and sustained TFR.[256]

Resumption of TKI therapy immediately after recurrence results in the achievement of DMR in almost all patients. 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.[239,240] The results of the A-STIM study showed that loss of MMR (≤0.1% *BCR::ABL1* IS) could be used as a practical criterion for restarting TKI therapy. The estimated probability of MMR loss was 35% at 12 months and 36% at 24 months after discontinuation of imatinib.[242]

TKI withdrawal syndrome (aggravation or new development of musculoskeletal pain and/or pruritus after discontinuation of TKI therapy) has been reported during the TFR period in some TKI discontinuation studies.[244,249,251,252] The occurrence of imatinib withdrawal syndrome was associated with a lower rate of molecular relapse in the KID study.[244]

The feasibility of TFR following discontinuation of TKIs other than dasatinib, imatinib, or nilotinib has not yet been evaluated in clinical studies. In the EURO-SKI study that evaluated TFR after discontinuation of any first-line TKI therapy (imatinib, dasatinib, or nilotinib) in eligible patients, the type of first-line TKI therapy did not significantly affect molecular relapse-free survival.[248] Therefore, it is reasonable to assume that the likelihood of TFR following discontinuation would be similar irrespective of TKI in patients who have achieved and maintained DMR (MR4.0; ≤0.01% *BCR::ABL1* IS) for ≥2 years.

Clinical studies that have evaluated the safety and efficacy of discontinuation of TKI have used 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 at least MR4.5 (*BCR::ABL1* ≤0.0032% IS) and the availability of test results within 2 weeks is one of the key requirements to monitor patients after discontinuation of TKI therapy and ascertain their safety.

Based on 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, consenting patients (in early CP-CML) who have achieved and maintained a DMR (≥MR4.0) for ≥2 years. The Panel acknowledges that more frequent molecular monitoring is essential following discontinuation of TKI therapy for the early identification of loss of MMR. Frequency of molecular monitoring has varied substantially among different studies, and the optimal frequency of molecular monitoring in patients with a loss of MMR after discontinuation of TKI therapy has not been established.

The criteria for the selection of patients suitable for discontinuation of TKI therapy and recommendations for molecular monitoring in TFR phase are outlined on CML-H. The Panel emphasizes that discontinuation of TKI therapy outside of a clinical trial should be considered only if *ALL* the criteria included on the list are met.

Limited available data (mainly from case reports) suggest that stable and well-controlled chronic CML (≥MR2.0) is not an absolute contraindication for solid organ transplant.[257-259] The Panel acknowledges that the management of TKI along with antirejection therapy (in patients who undergo transplant) will require close coordination between their oncologist and the transplant team.

Dose Modifications of TKI Therapy

Limited available evidence (mostly from non-randomized studies and retrospective analysis) suggests that initiation of TKIs (bosutinib, dasatinib, nilotinib) at lower doses and/or de-escalation for all TKIs (with close monitoring) in patients who achieve optimal responses are appropriate strategies for the prevention and management of treatment-related adverse events and to avoid long-term toxicities. However, except for ponatinib (OPTIC trial), the minimum effective dose or optimal de-escalation of TKI has not yet been established in prospective phase III randomized clinical trials.

Initiation of TKIs at Lower Dose

Low-dose TKIs for first-line or dose modifications for intolerance or resistance have been evaluated mostly in non-randomized studies and retrospective analyses.

Data from selected studies are outlined in Table 11 and Table 12.

Bosutinib

The recommended starting dose of bosutinib is 400 mg daily for patients with newly diagnosed CP-CML (which is better tolerated than the 500 mg daily dose that was used in the initial randomized phase III trial) and 500 mg once daily for intolerant or resistant CP-CML.

In patients with newly diagnosed CP-CML, recommendations from an expert Panel suggest initiating bosutinib at 200 to 300 mg once daily (with dose escalation as clinically indicated) in most patients and initiation at 400 mg daily is recommended only for patients with high-risk disease.[260]

The results of a retrospective analysis suggest that dose reduction of bosutinib to 300 mg or 400 mg results in better tolerability and improved efficacy in patients with CP-CML resistant imatinib, dasatinib and/or nilotinib.[261]

Dasatinib

The recommended starting dose of dasatinib is 100 mg once daily for patients with CP-CML.

Long-term follow-up of a single-arm study (81 evaluable patients) suggest that dasatinib 50 mg once daily may have similar efficacy in patients with low- or intermediate-risk CP-CML.[262,263] Dasatinib 20 mg once daily has also been shown to be an appropriate starting dose for patients 65 years and over with newly diagnosed CP-CML.[264,265] Intermittent dosing (on/off treatment with a drug holiday) or dose reduction to 50 mg once daily has also been shown to be effective as second-line and subsequent therapy in patients with CP-CML resistant/intolerant to imatinib.[266-269]

Dasatinib at 50 mg (20 mg with careful monitoring in selected patients) should be considered for patients with clinically significant intolerance to dasatinib 100 mg once daily to avoid serious adverse events (eg, pleural effusion, myelosuppression), necessitating the discontinuation of dasatinib.

Imatinib

The recommended starting dose of imatinib is 400 mg once daily for patients with CP-CML.

In a phase II study that evaluated imatinib 400 mg in 481 patients with newly diagnosed CML, dose reduction was required in 46% of patients due to intolerance and excessive dose reductions to <300 mg was associated with inferior response rates and survival outcomes.[270]

Nilotinib

The recommended starting dose of nilotinib is 300 mg twice daily for patients with newly diagnosed CP-CML and 400 mg twice daily for resistant or intolerant CP-CML.

In a retrospective analysis of 70 patients with newly diagnosed CP-CML, early dose reduction of nilotinib to <600 mg/day resulted in a lower rate of adverse events and better therapeutic efficacy.[271] One-year MMR and overall MR4.5 rates were 90% and 60%, respectively for the 10 patients treated with 600 mg/day of nilotinib throughout the study, with no disease progression to advanced phase.

The ENESTswift study showed that switching to nilotinib 300 mg twice daily (which is lower than the recommended dose of 400 mg daily in the second-line setting) was effective and well-tolerated in most patients with CP-CML with intolerance to imatinib or dasatinib in the first-line setting.[272]

Nilotinib tablets with improved bioavailability (without compromise in efficacy) that allows for administration at a lower doses has been approved by the FDA. Refer to package insert for full prescribing information: https://www.accessdata.fda.gov/.

Ponatinib

The recommended initial dose of ponatinib is 45 mg once daily.

In the OPTIC trial, the optimal benefit was observed with 45 mg once daily for all patients including those with the T315I mutation. Ponatinib at lower dose levels (30 mg once daily and 15 mg once daily) resulted in clinical benefit in patients without theT315I mutation (Table 6). These data support initiation of ponatinib at 45 mg once daily for patients with the T315I mutation followed by dose reduction to 15 mg once daily upon achievement of *BCR::ABL1* (IS) ≤1%.[183]

The results of a retrospective analysis showed that ponatinib 15 mg daily was associated with a lower incidence of drug related adverse events (AEs) with no impact on efficacy.[273]

De-escalation or Intermittent Dosing of TKI

TKI de-escalation has been shown to be feasible in patients, primarily those without prior TKI resistance, who had received TKI therapy for ≥2 years with durable MMR or DMR for ≥12 months.[274-281]

Data from selected clinical trials that have evaluated this approach are summarized in Table 13.

The phase II INTERIM study first established that intermittent dosing of imatinib is feasible in patients 65 years and over in stable MMR or MR4, after ≥2 years of treatment.[274] The interim analysis of the phase III OPTkIMA study demonstrated that this approach is also feasible for patients treated with dasatinib or nilotinib.[281] OPTkIMA is an ongoing study that is evaluating the potential de-escalation of all TKIs after achieving a stable DMR.

The DESTINY trial showed the feasibility of de-escalating TKIs (imatinib, dasatinib, or nilotinib) to half the standard dose for 12 months (imatinib 200 mg once daily; dasatinib 50 mg once daily, or nilotinib 200 mg twice daily) in patients achieving MMR or MR4 followed by discontinuation for 24 months (with frequent monitoring).[277,278]

The NILO-RED study (published only as an abstract) demonstrated the feasibility of maintenance therapy with reduced dose nilotinib (once daily) in patients achieving MMR on standard-dose nilotinib (twice daily).

Management of Advanced Phase CML

Imatinib has induced favorable hematologic and cytogenetic response rates in patients with AP-CML or BP-CML.[282-286] Dasatinib,[287-289] nilotinib,[290,291] bosutinib,[292] and ponatinib[182] have demonstrated activity in imatinib-resistant or imatinib-intolerant AP-CML and/or BP-CML. Ponatinib is a treatment option for patients with a T315I mutation or patients for whom no other TKI is indicated.

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.[293-296] Hyper-CVAD in combination with imatinib or dasatinib is also effective for patients with lymphoid BP-CML, particularly when followed by allogeneic HCT.[297,298] Treatment with TKI in combination with intensive chemotherapy resulted in better outcomes (higher response rates, lower risk of relapse, and improved OS and EFS rates) compared to treatment with TKI alone in patients with myeloid BP-CML.[299]

Long-term follow-up data from phase II/III studies of TKI therapy for disease progression to AP-CML and BP-CML are summarized in Table 14 and Table 15, respectively.

Treatment Considerations

Participation in clinical trials and evaluation for allogeneic HCT is recommended for all patients with AP-CML and BP-CML. Disease progression to AP-CML or BP-CML while on TKI therapy has a worse prognosis than de novo AP-CML or BP-CML. Patients with disease progression from CP-CML to AP-CML while on a TKI therapy have a high rate of progression to BP-CML, with predictably poor survival. These patients should be considered for a clinical trial and/or allogeneic HCT.

De novo AP-CML can often be initially managed like CP-CML with single-agent TKI followed by evaluation for allogeneic HCT.[300,301] Treatment with a course of alternate 2G or 3G TKI (not received before) can be beneficial as a “bridge” to allogeneic HCT in patients with disease progression to AP-CML. In patients with disease progression to AP-CML or BP-CML, the selection of TKI therapy is based on prior therapy and/or BCR::ABL1 kinase domain mutational analysis. Imatinib is not recommended for patients with disease progression on prior TKI therapy. However, imatinib may be an appropriate option for patients with disease progression to AP-CML on TKI therapy with a contraindication to 2G or 3G TKI.[302] Asciminib has also demonstrated activity in a small series of patients with AP-CML and is included as an option for patients with AP-CML.[303]

A significant proportion of patients with advanced phase CML treated with TKI therapy achieve a MCyR but not a concomitant CHR because of persistent cytopenias, which in turn is associated with an inferior outcome.[304] There is a lack of evidence for the definition of optimal response milestones on TKI therapy. Evaluation for allogeneic HCT should be considered if response milestones (recommended for CP-CML) are not achieved at 3, 6, and 12 months.

Induction therapy followed by consolidation with allogeneic HCT is the preferred treatment approach for de novo BP-CML and disease progression to BP-CML.[299,305] TKI in combination with induction chemotherapy (ALL type chemotherapy for lymphoid BP CML and AML type chemotherapy for myeloid BP CML) is the recommended treatment option. TKI + steroids is appropriate for patients with lymphoid BP-CML and TKI alone is an option for those with myeloid BP-CML, who are not candidates for induction chemotherapy. Consolidation chemotherapy and TKI maintenance is recommended for patients who are not candidates for allogeneic HCT. Since TKI (alone or in combination with minimal chemotherapy or steroids) is less effective in BP-CML compared to Ph-positive ALL, interphase FISH for the detection of *BCR::ABL1* transcript on blood granulocytes is recommended to differentiate between de novo BP-CML and de novo Ph-positive ALL.

Central nervous system (CNS) involvement has been described in case reports of BP-CML.[306-309] Lumbar puncture and CNS prophylaxis is recommended for lymphoid BP-CML. Documented CNS involvement in patients with lymphoid BP-CML should be managed according to the standard of care for AML or ALL. Dasatinib has been reported to cross the blood brain barrier and may represent the best TKI option for patients with CNS disease.[310] TKI therapy has not been optimized for patients with CNS involvement.

Allogeneic Hematopoietic Cell Transplant

Allogeneic HCT is a potentially curative treatment for patients with CML. Ongoing advances in alternative donor sources (such as unrelated donors and cord blood), more accurate HLA testing for a stringent selection of unrelated matched donors, and the use of reduced-intensity conditioning regimens have improved outcomes following allogeneic HCT.[311-317]

Allogeneic HCT is an appropriate treatment option for the very rare patients presenting with BP-CML at diagnosis, patients with disease progression to AP-CML or BP-CML while on TKI therapy, and patients with CP-CML that is resistant and/or intolerant to all available TKIs.[318-321] Several studies have confirmed that prior TKI therapy does not compromise the outcome following allogeneic HCT or increase transplant-related toxicity.[322-328]

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.[329] A low HCT comorbidity index is a prognostic indicator of lower non-relapse mortality and improved survival.[330] 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 second chronic CP-CML compared to patients with AP-CML or BP-CML.[331-336] Therefore, the potential use of allogeneic HCT must be tied to faithful monitoring of disease, since the major potential pitfall in delaying transplantation is "missing" the chronic phase interval.

Monitoring Response After Allogeneic HCT *(CML-6)*

BCR::ABL1 transcripts may persist for many years in patients after allogeneic HCT. The prognostic significance of *BCR::ABL1* positivity is influenced by the time of testing after allogeneic HCT. A positive qPCR assay for *BCR::ABL1* at 18 months or more after allogeneic HCT is associated with a lower risk of relapse than a positive qPCR assay for *BCR::ABL1* at 6 to 12 months after allogeneic HCT.[337-344] Early detection of *BCR::ABL1* transcripts after allogeneic HCT may be useful to identify patients who may be in need of alternative therapies before overt relapse occurs.

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, although it is more effective in patients with chronic phase relapse than advanced phase relapse.[345-351] However, DLI is associated with complications such as graft-versus-host disease (GVHD), susceptibility to infections, and immunosuppression.[345] 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.[352-356]

Imatinib induces 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.[357-364] Very limited data are available on the use of dasatinib and nilotinib in patients with post-transplant relapse.[365-368] 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.[369] Retrospective studies have shown that TKIs are superior to DLI alone or in combination with TKI for post-transplant relapse.[370,371] However, these observations are yet to be confirmed in randomized trials. Post-transplant TKI therapy is also effective to prevent relapse following allogeneic HCT in high-risk patients.[372-374]

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 1 year in this cohort of patients who are in remission following allogeneic HCT.[372-374]

TKI with or without DLI 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 therapy, the side effect profile of the TKI under consideration, the presence of comorbidities, and *BCR::ABL1* mutation status. Pre-existing mutations in the *BCR::ABL1* kinase domain, frequently associated with resistance to TKIs, are detectable in the majority of patients who relapse after allogeneic HCT.[375] BCR::ABL1 mutational analysis is therefore essential prior to the selection of TKI for the treatment of post-transplant relapse.

In patients with CML that has not responded to previous imatinib, there are no data to support the use of post-transplant imatinib. Dasatinib, nilotinib, bosutinib or ponatinib or asciminib may be more appropriate options. However, there are no data to support the use of post-transplant bosutinib or ponatinib or asciminib. CNS relapse of CML following allogeneic HCT has been described in few case reports.[376,377] Participation in a clinical trial is highly desirable. Dasatinib may also be an effective treatment for extramedullary relapse following allogeneic HCT.[310,378,379]

Emerging Treatment Options

Novel BCR::ABL1 inhibitors are being evaluated in ongoing clinical trials in all three phases of CML. Results from selected published phase II/III studies are outlined in Table 16.

The use of pegylated interferons in combination with 2G TKIs is also being explored as a potential strategy to improve TFR in ongoing clinical trials.[380-382] Immunologic approaches such as the use of *BCR::ABL1* immune peptides, immune checkpoint blockade, leukemia-associated antigens, and dendritic cell vaccines are also being evaluated to improve molecular response.[383]

Management of CML During Pregnancy and Breastfeeding

The median age of disease onset is 65 years, but CML occurs in all age groups. The EUTOS population-based registry has reported that approximately 37% of patients at the time of diagnosis are of reproductive age.[384] 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.

TKI Therapy and Conception

TKI therapy appears to affect some male hormones at least transiently but does not appear to have a deleterious effect on male fertility. Furthermore, the miscarriage or fetal abnormality rate is not elevated in female partners of males on TKI therapy.[385-389]

TKI therapy during pregnancy has been associated with both a higher rate of miscarriage and fetal abnormalities.[390-395] In one report on the outcome of pregnancies in 180 patients exposed to imatinib during pregnancy, 50% of pregnancies with known outcome were normal and 10% of pregnancies with known outcome had fetal abnormalities.[390] Eighteen pregnancies ended in spontaneous abortion. In another report on the outcomes of pregnancy and conception during treatment with dasatinib, among 46 patients treated with dasatinib, 15 patients (33%) delivered a normal infant.[391] Elective or spontaneous abortions were reported in 18 (39%) and 8 patients (17%), respectively, and 5 patients (11%) had an abnormal pregnancy. Fetal abnormalities were reported in 7 cases. Among 33 patients who conceived with males who had received treatment with dasatinib, 30 (91%) delivered infants who were normal at birth. In a report of 16 pregnancy cases among patients assigned female at birth treated with bosutinib noted six live births, four abortions, and six unknown outcomes.[396]

Although there is paucity of data regarding the outcome of pregnancy in patients receiving bosutinib or ponatinib or asciminib at the time of conception, all TKIs also must be considered unsafe for use during pregnancy. Conception while on active TKI therapy is strongly discouraged due to the risk of fetal abnormalities. Close monitoring, and prompt consideration of holding TKI therapy (if pregnancy occurs while on TKI therapy) should be considered.

Depending on other factors such as age, a natural pregnancy may occur months after stopping TKI therapy.[397,398] A prolonged washout period prior to pregnancy should be considered, although there are no data regarding how long a patient should be off TKI therapy before trying to become pregnant. There are no published guidelines regarding the optimal depth of molecular response that is considered “safe” to stop TKI therapy before attempting pregnancy.[399]

Discontinuation of TKI therapy because of pregnancy in patients assigned female at birth who were not in DMR (≤0.01% *BCR::ABL1* IS) has only been reported in a small series of patients.[397,398,400,401] In one series, among 10 patients who stopped imatinib because of pregnancy after a median of 8 months of therapy, five of the nine patients who had achieved a CHR lost the response after stopping therapy, and six had an increase in Ph-positive metaphases.[397] At 18 months after resuming therapy, all nine patients had achieved a CHR but only three females achieved a CCyR and none had achieved an MMR. In another series that reported the outcomes of seven patients who were not in DMR at the time imatinib was stopped because of pregnancy, three were in an MMR.[398] All seven patients had disease relapse. The three who had an MMR at the time imatinib was stopped could regain the same response once the drug was restarted, whereas the remaining four patients did not.

Planning a Pregnancy

In patients assigned male at birth, the general recommendation is that TKI therapy need not be discontinued if a pregnancy is planned. However, experience is limited. Sperm banking can also be performed prior to starting TKI therapy, but there are no data regarding quality of sperm in males with untreated CML.

In patients assigned female at birth, due to the risk of miscarriage and fetal abnormalities during pregnancy, TKI therapy should be stopped prior to natural conception and patients should remain off therapy during pregnancy.[390-392]

Fertility preservation should be discussed with all patients of childbearing age prior to the initiation of TKI therapy. Referral to an in vitro fertilization (IVF) center is recommended in coordination with the patient’s obstetrician. TKI should be stopped prior to attempting oocyte retrieval, but the optimal timing of discontinuation is unknown. There are no data to recommend how long a patient should be off therapy before oocyte retrieval, although usually at least 1 month off therapy is recommended.

In addition to the high incidence of disease recurrence off TKI therapy, patients should also be made aware of the significant obstacles related to IVF (eg, lack of access to centers that perform the procedure, high costs associated with drugs, surgical procedures and embryo/oocyte storage that may not be covered by insurance, variable access to surrogate programs, the need to take family medical leave from work to attend IVF appointments).

Prior to attempting pregnancy, patients 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. Referral to a CML specialty center and consultation with a high-risk obstetrician is recommended.

Treatment During Pregnancy

Most of the literature regarding treatment during pregnancy consists of case reports. TKI therapy, particularly during the first trimester, should be avoided because of teratogenic risk. If TKI therapy is considered during pregnancy, the potential benefit for the mother and the potential risk to the fetus of continuing TKI therapy versus the risk of treatment interruption leading to the loss of optimal disease response must be carefully evaluated on an individual basis.

Leukapheresis can be used for a rising white blood cell (WBC) count and/or platelet count, although there are no data that recommend at what level leukapheresis and/or platelet pheresis should be initiated.[402-405] Low-dose aspirin or low-molecular-weight heparin can be considered for patients with thrombocytosis.[406,407]

The Panel also recommends against the use of hydroxyurea during pregnancy, especially in the first trimester.[408-410] If treatment is needed during pregnancy, it is preferable to initiate treatment with interferon alfa-2a and most of the data using interferons during pregnancy have been reported in patients with essential thrombocythemia.[411-413] If introduced earlier, interferons can preserve molecular remission after discontinuation of TKI.[414,415]

Peginterferon alfa-2a and ropeginterferon alfa-2b are available for clinical use in the United States but there are very limited data for the use of ropeginterferon alfa-2b in patients with CML during pregnancy. Monthly monitoring of CBC with differential and frequent monitoring with qPCR (every 1–3 months) would be helpful to guide the timing for initiation of TKI therapy, although specific thresholds for treatment reinitiation have not been defined.

Breastfeeding

TKI therapy can be restarted after delivery. However, patients on TKI therapy should be advised not to breastfeed, as TKIs pass into human breast milk.[416-419] Breastfeeding without TKI therapy may be safe with molecular monitoring, preferably in those patients with CML who have durable DMR. It may be acceptable to avoid TKIs for the short period of the first 2 to 5 days after labor to give the child colostrum.[419,420]

Close molecular monitoring is recommended for females who extend the treatment-free period for breastfeeding. If the loss of MMR after treatment cessation is confirmed, breastfeeding needs to be terminated and TKI should be restarted.[419]

Specific Considerations for Children with CML

CML accounts for <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. Due to 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 several factors should be considered when treating pediatric patients with CML.[421]

Selection of TKI

Bosutinib, dasatinib, imatinib, and nilotinib (capsules) are approved for treatment of CML in children.[422-424] Bosutinib is approved based on the results of the BCHILD trial (published only an abstract). Higher dose imatinib (340 mg/m²) has also been shown to be effective and well tolerated in children.[425-427] There are very little data on the safety and efficacy of ponatinib and asciminib in children.[428]

The validity of prognostic scores (eg, Sokal, Euro) for risk assessment or to make treatment decisions has not been established in the pediatric population.[429] The ELTS score has demonstrated better differentiation of PFS than Sokal and Euro scores in children treated with imatinib.[430]

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 are potential long-term side effects (such as delayed growth, changes in bone metabolism, thyroid abnormalities, and effects on puberty and fertility) that may not be seen in adults.[431]

A number of studies have reported impaired longitudinal growth in children with CML treated with TKI therapy, and the effect is more significant when treatment was initiated during prepubertal age.[432-438] Growth should be monitored closely, and a bone age x-ray should be obtained if longitudinal growth is delayed. A dual-energy x-ray absorptiometry (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.

The feasibility of discontinuation of imatinib in children in sustained DMR for ≥2 years has been demonstrated in two small studies.[439,440] Further studies in a larger cohort of patients are needed to identify the criteria for discontinuation of TKI therapy in children. Therefore, discontinuation of TKI therapy in children is not recommended outside the context of a clinical trial.

Immunizations

There are little data regarding the long-term impact of TKIs on the immune function of patients with CML receiving TKI therapy. Available evidence suggests that TKI therapy could potentially hinder routine immunization with some vaccines in adults and children with CML.[441-443] A study that evaluated the safety and efficacy of H1N1 influenza vaccine in patients with hematologic malignancies showed a higher seroconversion rate in adult patients with CML compared to patients with B-cell malignancies or recipients of HCT.[441] The findings from another study that evaluated the impact of TKI therapy on B-cell responses to vaccination in patients with CML suggest that TKI therapy with dasatinib, imatinib, or nilotinib is associated with impaired B-cell response to polysaccharide pneumococcal (PPS) vaccine due to the off-target inhibition of kinases involved in B-cell signaling pathway.[442]

In general, the use of inactivated killed vaccines for children on TKI therapy is safe, although it is unknown whether responses are comparable to those seen in healthy children. Administration of live vaccines during TKI therapy is not recommended in general, although preliminary findings from a few case reports have shown that MMR and varicella vaccine could be safely given to some children with immune deficiency.[443,444] Live attenuated annual influenza vaccine (nasal spray) should be avoided, and the inactivated killed vaccine (flu shot) should be used for children receiving TKI therapy. Live vaccines could be considered after stopping TKI therapy for several weeks in patients with a DMR.[445] In the United

States, all required live vaccines are completed by age 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.

The mRNA-based vaccines have shown safety and efficacy against the SARS-CoV-2 infection (COVID-19) among immunocompetent individuals.[446] Studies that have evaluated the efficacy of these vaccines in patients with hematologic malignancies have reported higher seroconversion rate and robust memory T-cell responses in patients with CML in contrast to patients with solid tumors or other hematologic malignancies.[447-450] The mRNA-based vaccines are considered inactivated vaccines.

The FDA has given full approval for the use of mRNA-based vaccines in individuals 16 years and over and emergency use authorization (EUA) for use in children beginning at 6 months of age. The Centers for Disease Control and Prevention (CDC) recommends COVID-19 vaccination for everyone 6 months and over. See the CDC COVID-19 Vaccination Clinical & Professional Resources for dosage and administration of COVID-19 vaccine.

Table 1: First-Line TKI Therapy for CP-CML: Long-Term Follow-up Data from Phase III Studies

Trial	Study Arms	No. of Patients	Median Follow-up	CCyR[a]	MMR[b]	Disease Progression n (%)	PFS[c]	OS
IRIS[101,d]	**Imatinib (400 mg once daily)**	553	11 years	83%	—	38 (7)	92%	83%
	Interferon alpha plus low-dose cytarabine	553		—	—	71 (13)	—	79%[e]
DASISION[102]	**Dasatinib (100 mg once daily)**	259	5 years	—	76% (*P* = .002)	12 (5)	85%	91%
	Imatinib (400 mg once daily)	260		—	64%	19 (7)	86%	90%
ENESTnd[105]	**Nilotinib (300 mg twice daily)**	282	10 years	—	78% (*P* < .0001)	11 (4)	86%	88%
	Imatinib (400 mg once daily)	283		—	63%	24 (8.5)	87%	88%
BFORE[104]	**Bosutinib (400 mg once daily)**	268	60 months	83%	74%	6 (2)	—	95%
	Imatinib (400 mg once daily)	268		77%	65%	7 (3)	—	95%
ASC4FIRST[106]	**Asciminib**	101	16 months (16.3)	84%	69%	—	—	—
	Imatinib	102		62%	40%	—	—	—
	Asciminib	100	16 months (15.7)	90%	66%	—	—	—
	Investigator-selected 2G TKI	102		83%	58%	—	—	—

CCyR, complete cytogenetic response (≤1% *BCR::ABL1* IS); MMR, major molecular response (≤0.1% *BCR::ABL1* IS); OS, overall survival; PFS, progression-free survival

a. Confirmed CCyR rate at 12 months was the primary endpoint of DASISION study.
b. MMR (≤0.1% *BCR::ABL1* IS) rate at 12 months (48 weeks) was the primary endpoint of ENESTnd, BFORE and ASC4FIRST studies.
c. Primary endpoint of IRIS trial in the imatinib group.
d. Due to the high rate of crossover to imatinib (66%) and the short duration of therapy (<1 year) before crossover among patients who had been randomly assigned to interferon alfa plus cytarabine, the long-term follow-up data focused on patients who had been randomly assigned to receive imatinib.
e. Data include survival among the 363 patients who crossed over to imatinib.

Table 2: High-Dose Imatinib as First-Line Therapy for CP-CML: Long-Term Follow-up Data from Phase III Studies

Trial	Study Arms	No. of Patients	Median Follow-up	MMR	MR4.5	PFS	OS
TOPS study[113,a]	Imatinib (800 mg once daily)	319	42 months	79%	—	96% at 48 months	93% at 48 months
	Imatinib (400 mg once daily)	157		76%	—	94% at 48 months	94% at 48 months
CML IV study[115,b]	Imatinib (800 mg once daily)	420	10 years	89%	71%	77%	79%
	Imatinib (400 mg once daily)	400		92%	67%	80%	80%
SWOG study[114,c]	Imatinib (800 mg once daily)	73	12 months	53%	19%	92% (4-year PFS)	95% (4-year OS)
	Imatinib (400 mg once daily)	72		36%	9%	80% (4-year PFS)	90% (4-year OS)

MMR, major molecular response (≤0.1% *BCR::ABL1* IS); MR, molecular response; MR4.5: ≥4.5-log reduction in *BCR::ABL1* transcripts from baseline; OS, overall survival; PFS, progression-free survival

a. Primary endpoint: MMR rate at 12 months (≤0.1% *BCR::ABL1*), which corresponds to a 3-log reduction in *BCR::ABL1* transcripts compared with the standardized baseline established in IRIS study.
b. Primary endpoint: The impact of MMR on survival at 12 months. This study had 5 treatment arms (imatinib 400 mg once daily alone; imatinib 800 mg twice daily; imatinib 400 mg once daily with interferon or cytarabine; and imatinib after prior interferon treatment). Only the data for imatinib 400 mg once daily alone vs. imatinib 800 mg twice daily are included in this table.
c. Primary endpoint: MR4.0 (≥4-log reduction in *BCR::ABL1* transcripts from baseline) at 12 months. Results from the first part of SWOG S0325 study; follow-up after 12 months was not required for this study.

Table 3: First-Line TKI Therapy for CP-CML: Outcomes According to Risk Score

Trial	Study Arms	Low-Risk			Intermediate-Risk			High-Risk		
		MMR	MR4.5	PFS/OS[a]	MMR	MR4.5	PFS/OS[a]	MMR	MR4.5	PFS/OS[a]
DASISION[102] (Euro risk score)	**Dasatinib (100 mg once daily)**	90%	55%	—	71%	43%	—	67%	31%	
	Imatinib (400 mg once daily)	69%	44%	—	65%	28%	—	54%	30%	
ENESTnd[105] (Sokal risk score)	**Nilotinib (300 mg twice daily)**	—	51%	94%/95%	—	55%	87%/88%	—	40%	74%/77%
	Imatinib (400 mg once daily)	—	39%	98%/99%	—	30%	84%/84%	—	23%	78%/79%
BFORE[103] (Sokal risk score)	**Bosutinib (400 mg once daily)**	58%	—		45%	—		34%	—	
	Imatinib (400 mg once daily)	46%	—		39%	—		17%	—	

MMR, major molecular response (≤0.1% *BCR::ABL1* IS); MR, molecular response; MR4.5: 4.5-log reduction in *BCR::ABL1* transcripts from baseline; OS, overall survival; PFS, progression-free survival

a. 10-year outcomes according to Sokal risk score.

Table 4. Adverse Events of First-Line TKI Therapy in CP-CML

Toxicity	DASISION[102]		ENESTnd[105]		BFORE[103]		ASC4FIRST[106]		
	Dasatinib 100 mg QD	Imatinib 400 mg QD	**Nilotinib 300 mg BID**	Imatinib 400 mg QD	**Bosutinib 400 mg QD**	Imatinib 400 mg QD	**Asciminib 80 mg QD or 40 mg BID**	Imatinib 400 mg QD	2G TKI
Biochemical abnormalities (Grade 3/4)									
Increased lipase	NR	NR	10%	4%	13%	6%	3%	1%	11%
Increased glucose	NR	NR	9%	<1%	2%	2%	NR	NR	NR
Decreased phosphate	7%	28%	9%	13%	5%	17%	NR	NR	NR
Increased ALT	NR	NR	4%	3%	23%	3%	2%	2%	8%
Increased AST	NR	NR	NR	NR	12%	3%	<1%	1%	3%
Nonhematologic toxicities (any grade)[a]									
Rash	13%	18%	39%	21%	20%	13%	13%	10%	22%
Headache	13%	11%	34%	25%	19%	13%	14%	8%	22%
Fatigue	9%	11%	25%	20%	19%	18%	14%	8%	22%
Diarrhea	21%	22%	21%	48%	70%	34%	16%	26%	26%
Constipation	NR	NR	23%	9%	NR	NR	10%	4%	13%
Nausea	10%	24%	22%	42%	35%	39%	9%	21%	18%
Vomiting	5%	11%	17%	28%	18%	16%	6%	12%	6%
Muscle spasms	23%	41%	14%	35%	2%	26%	2%	19%	5%
Peripheral or Periorbital edema	13%	37%	12%	23%	4%	14%	1%	10%	1%
Pleural effusion	28%	<1%	NR	NR	NR	NR	NR	NR	NR
Hypertension	NR	NR	16%	6%	NR	NR	NR	NR	NR
Pulmonary hypertension	5%	<1%	NR	NR	NR	NR	NR	NR	NR

ALT, alanine aminotransferase; AST, aspartate aminotransferase; BID, twice daily; NR, not reported; QD, once daily.
a. Non-hematologic toxicities from the DASISION study (except pleural effusion) are from the 3-year follow-up. No new adverse events were observed with 5-year follow-up.

Table 5. Early Molecular Response (≤10% *BCR::ABL1* IS at 3 months) After First-Line TKI Therapy and Survival Outcomes

Trial	Study Arms	5-Year PFS		5-Year OS	
		BCR::ABL1 ≤10%	*BCR::ABL1* >10%	*BCR::ABL1* ≤10%	*BCR::ABL1* >10%
DASISION[102]	Dasatinib (100 mg once daily)	89%	72%	94%	81%
	Imatinib (400 mg once daily)	93%	72%	95%	81%
CML IV Study[148]	Imatinib (400 mg once daily)	92%	87%	94%	87%
ENESTnd[149]	Nilotinib (300 mg twice daily)	95%	78%	98%	82%
	Nilotinib (400 mg twice daily)	96%	89%	96%	93%
	Imatinib (400 mg once daily)	98%	79%	99%	79%

OS, overall survival; PFS, progression-free survival

Table 6. Second-Line and Subsequent TKI Therapy for CP-CML: Long-Term Follow-up Data from Phase II/III Studies

TKI/Trial	Study Arms (No. of patients)	Median Follow-up	MCyR	CCyR	MMR	PFS	OS
Dasatinib[176,a] (100 mg once daily)	Imatinib-R (n = 124)	7 years	—	—	43%	39%	63%
	Imatinib-I (n = 43)		—	—	55%	51%	70%
Nilotinib[177,b] (400 mg twice daily)	Imatinib-R (n = 226) Imatinib-I (n = 95)	4 years	59%	45%	—	57%	78%
Bosutinib (BYOND)[181] (500 mg once daily)	Imatinib-R (n = 53)	≥3 years	86%	84%	73%	—	—
	Dasatinib and/or nilotinib-R (n = 29)		69%	62%	41%	—	—
	TKI intolerant (n = 74)		88%	87%	82%	—	—
Ponatinib (PACE)[182,c] (45 mg once daily)	Dasatinib or nilotinib-R or I (n = 203)	57 months	56%	49%	35%	52% at 5 years	76% at 5 years
	T315I mutation (n = 64)		72%	70%	58%	50% at 5 years	66% at 5 years
Ponatinib (OPTIC)[183]	45 mg (n = 93)	32 months	51%	44%	34%	73% at 3 years	89% at 3 years
	30 mg (n = 93)		33%	29%	25%	66% at 3 years	89% at 3 years
	15 mg (n = 91)		44%	23%	23%	70% at 3 years	92% at 3 years
Asciminib (ASCEMBL) (40 mg twice daily)[185,d]	Asciminib (40 mg twice daily; n = 157)	30 months	—	40%[e] at 96 weeks	38% at 96 weeks	94% at 2 years	97% at 2 years
	Bosutinib (500 mg once daily; n = 76)		—	16%[e] at 96 weeks	16% at 96 weeks	91% at 2 years	99% at 2 years

CCyR, complete cytogenetic response; I, Intolerant; MCyR, major cytogenetic response; MMR, major molecular response (≤0.1% *BCR::ABL1* IS); OS, overall survival; PFS, progression-free survival; R, resistant

a. Primary endpoint: MCyR rate at 6 months when administered 100 mg once daily versus 70 mg twice daily.
b. Primary endpoint: MCyR rate in patients with imatinib intolerance or imatinib-resistant disease.
c. Primary endpoint: MCyR at any time within the first 12 months.
d. Primary endpoint: MMR rate at 24 weeks; Secondary endpoint: MMR rate at 96 weeks.
e. CCyR rate in patients who were not in CCyR at baseline.

Table 7. Early Molecular Response (≤10% *BCR::ABL1* IS) After Second-Line TKI Therapy and Survival Outcomes

TKI	Median Follow-up	Progression-Free Survival (PFS)				Overall Survival (OS)			
		BCR::ABL1 ≤10%		*BCR::ABL1* >10%		*BCR::ABL1* ≤10%		*BCR::ABL1* >10%	
		3 months	6 months	3 months	6 months	3 months	6 months	3 months	6 months
Dasatinib[176] (100 mg once daily)	7 years	56%	57%	21%	4%	72%	74%	56%	50%
Nilotinib[177] (400 mg twice daily)	4 years	67%	58%	42%	39%	81%	82%	71%	73%

Table 8. Responses to TKI Therapy Based on *BCR::ABL1* Mutation Status

BCR::ABL1 Mutations		Bosutinib[178]	Dasatinib[223]		Nilotinib[217]		Ponatinib[229]
		MCyR	CCyR	MCyR	CCyR	MCyR	MCyR
Contraindicated to bosutinib	**G250E**	0/5 (0%)	20/60 (33%)	29/60 (48%)	3/5 (60%)	3/5 (60%)	8/12 (67%)
Contraindicated to bosutinib and dasatinib	**F317L**	1/7 (14%)	1/14 (7%)	2/14 (14%)	—	—	13/29 (45%)
	V299L	0/2 (0%)	—	—	—	—	3/8 (38%)
Contraindicated to nilotinib	**E255K**	—	6/16 (38%)	9/16 (56%)	0/7 (0%)	3/7 (43%)	8/13 (62%)
	E255V	—	4/11 (36%)	4/11 (36%)			1/4 (25%)
	F359C	1/2 (50%)	3/5 (60%)	3/5 (60%)	0/11 (0%)	1/11 (9%)	1/7 (14%)
	F359V	2/3 (67%)	14/27 (52%)	17/27 (63%)			11/20 (55%)
	F359I	2/2 (100%)	7/12 (58%)	10/12 (83%)	—	—	3/4 (75%)
	Y253H	5/6 (83%)	14/23 (61%)	15/23 (65%)	0/8 (0%)	1/8 (13%)	1/2 (50%)

CCyR, complete cytogenetic response; MCyR, major cytogenetic response.

Table 9. Adverse Events of Second-Line and Subsequent TKI Therapy in CP-CML

Toxicity (any grade)	Dasatinib[176] (100 mg once daily)	Nilotinib[177] (400 mg twice daily)	Bosutinib[180] (500 mg once daily)	Ponatinib[182] (45 mg once daily)	Asciminib (40 mg twice daily)[184]
Rash	33%	31%	15%	47%	7%
Headache	—	18%	28%	43%	16%
Fatigue	37%	21%	24%	30%	10%
Myalgias/Arthralgias	38%	11%	14%	24%/33%	9%
Pleural effusion	28%	—	17%	—	—
Hypertension	—	—	—	37%	12%
Hemorrhage	26%	—	—	—	—
Diarrhea	42%	12%	88%	20%	12%
Constipation	—	13%	17%	41%	—
Nausea	27%	25%	40%	29%	12%
Vomiting		13%	33%	19%	7%
Increased blood creatinine	—	—	15%	—	—
Increased lipase	—	—	—	27%	
Increased ALT/AST	—	—	20% (AST) 26% (ALT)	—	4%

ALT, alanine aminotransferase; AST, aspartate aminotransferase.

Table 10. Summary of Longer-Term Follow-up Data from the TKI Discontinuation Trials

Trial	Treatment Prior to Discontinuation	No. of Patients	Depth and Duration of MR Required for Discontinuation	Trigger to Resume TKI Therapy	Median Follow-up	Treatment-free Remission (TFR) Rate
STIM1[240]	Imatinib ± interferon	100	MR5.0 for at least 2 years	Loss of MR5.0	77 months	38% at 60 months
TWISTER[245]	Imatinib ± interferon	40	MR4.5 for at least 2 years	Loss of MR5.0	103 months	45% (molecular relapse-free survival 45% at 8 years)
HOVON[241]	Imatinib + cytarabine	15	MR4.5 for at least 2 years	Loss of MR4.5	36 months	33% at 24 months
A-STIM[242]	Imatinib ± interferon	80	MR5.0 for at least 2 years	Loss of MMR	31 months	61% at 36 months
ISAV study[243]	Imatinib (after prior treatment with interferon or hydroxyurea)	108	CMR for at least 18 months	Loss of MMR	36 months	52% at 36 months
KID study[244]	Imatinib ± interferon	90	MR4.5 for at least 2 years	Loss of MMR	27 months	59% at 24 months
Stop 2G-TKI[246]	Dasatinib/Nilotinib (first- or second-line)	60	MR4.5 for at least 24 months	Loss of MMR	47 months	54% at 48 months
DASFREE[249]	Dasatinib (first- or second-line)	84	MR4.5 for 12 months	Loss of MMR	2 years	46% at 24 months
ENESTFreedom[251]	Nilotinib (first-line)	190	MR4.5 for 12 months	Loss of MMR	5 years	43% at 5 years
ENESTop study[252]	Nilotinib (second-line)	126	MR4.5 for 12 months	Loss of MMR	5 years	43% at 5 years
DADI[250]	Dasatinib (first-line)	68	MR4.5 for at least 24 months	Loss of MMR	23 months	55% at 6 months
DADI[247]	Dasatinib (second-line)	63	MR4.0 for at least 12 months	Loss of MR4.0	44 months	44% at 36 months
EURO-SKI[248]	Any TKI	758	MR4.0 for at least 1 year	Loss of MMR	27 months	50% at 24 months

CMR, complete molecular response (undetectable *BCR::ABL1* by qPCR as determined by local laboratories); TKI, tyrosine kinase inhibitor; MMR, major molecular response (≤0.1% *BCR::ABL1* IS); MR, molecular response; MR4.0, ≤0.01% *BCR::ABL1* IS; MR4.5, ≤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; MR5.0, 5-log reduction in *BCR ABL1* levels and undetectable minimal residual disease on qPCR with a sensitivity of ≥4.5-log reduction

Table 11. Initiating Lower Dose First-line TKI Therapy

TKI	Study	Patient Characteristics	TKI Dose	Study Findings
Dasatinib	**Single center Pilot Study**[262]	81 evaluable patients (majority of patients had low-risk (n = 55; 66%) or intermediate-risk (n = 21; 25%) disease by Sokol score Minimum follow up: 12 months	50 mg/day	The cumulative rates for MMR, MR4, and MR4.5 at 12 months were achieved in 81%, 55%, and 49% of patients respectively.
	DAVLEC (Phase II study)[265]	52 patients; aged >70 years; Median follow-up of 366 days	20 mg/day	MMR at 12 months was achieved in 60% of patients.

MMR, major molecular response; MR, molecular response; MR4.0, ≤0.01% *BCR::ABL1* IS; MR4.5, ≤0.0032% *BCR::ABL1* IS

Table 12. Dose Modifications for Intolerance or Resistance

TKI	Study	Patient Characteristics	TKI Dose	Study Findings
Dasatinib	**NordCML006 (Phase II study)**[268]	Newly diagnosed CP-CML; dasatinib (n = 22) vs. imatinib (n = 24)	Dose reduction due to intolerance in 27% of patients (50 mg/day; mean dose was 50 mg at 36 months)	MR4.5 rates were comparable for the dose-reduced group and the standard dose group (100 mg once daily)
	Japanese LD-CML study[269]	CP-CML resistant to imatinib ≤200 mg/day (n = 9)	Starting dose 50 mg/day	5 patients attained MMR by 12 months and 3 patients achieved a deep molecular response (DMR) by 18 months
Imatinib	**JALSG CML202 (Phase II study)**[270]	481 patients with newly diagnosed CP-CML	Dose reduction due to intolerance (n = 90; 300 mg group); (n = 67; 200 mg group)	Response rates and survival were significantly inferior in the 200 mg group compared to 300 mg group
Nilotinib	**ENESTswift (Phase IIIb Study)**[272]	CP-CML intolerant to imatinib (n = 16) or dasatinib (n = 4)	Starting dose 300 mg BID	MR4.5 at any time point (up to 24 months) was achieved in 10 of 20 patients (50%)
Ponatinib	**OPTIC (Phase II Dose ranging study)**[183]	CP-CML resistant to or intolerant of at least 2 prior TKIs or with T315I mutation	271 patients randomized to 45 mg, 30 mg, and 15 mg; Dose reduction to 15 mg in the 45 mg and 30 mg cohorts after achievement of *BCR::ABL1* (IS) ≤1%	Results demonstrated the safety and efficacy of response-adjusted dosing regimen for ponatinib (Table 6)

MMR, major molecular response; MR, molecular response; MR4.5, ≤0.0032% *BCR::ABL1* IS

Table 13. De-escalation or Intermittent Dosing of TKI

TKI	Study	Patient Characteristics	TKI Dose	Study Findings
Imatinib	**INTERIM**[274]	76 patients (≥ 65 years) on imatinib for ≥2 years with a stable CCyR and MMR; Minimum follow-up: 6 years	Intermittent imatinib (1 month ON/OFF)	21% of patients lost CCyR and MMR; All patients regained CCyR and MMR after resumption of imatinib
Imatinib, Dasatinib, or Nilotinib	**DESTINY**[277,278]	174 patients with CP-CML on TKI therapy for a median of 7 years (imatinib, n = 148; dasatinib, n = 10; nilotinib, n = 16)	De-escalation to half the standard dose for 12 months after achieving MMR (n = 49) or MR4 (n = 125), then stop for a further 24 months	During the dose reduction phase, loss of molecular response occurred in 3 (2%) patients with MR4 and 9 (19%) of patients with MMR. At 36 months, the RFS rates were 72% and 36% for patients with MR4 and MMR group, respectively. All recurrences regained MMR within 5 months of resumption of TKI therapy.
	OPTkIMA (Phase III study)[281]	Patients with CP-CML (≥60 years) in stable MMR or MR4.0 after ≥2 years of TKI therapy (imatinib, dasatinib, nilotinib) randomized to receive "fixed" (n = 99) or "progressive" (n = 86) intermittent dosing of TKI until loss of MMR	Intermittent dosing of TKI; "fixed" (1 month ON/OFF) vs "progressive" (1 month ON/OFF for the 1st year; 1 month ON/2 months OFF for the 2nd year; 1 month ON/3 months OFF for the 3rd year)	"Fixed" intermittent dosing of any TKI (1 month ON/OFF) maintained MMR /MR4.0 in 81% of the patients during the first 12–24 months. All 24% of patients who lost MMR regained after resumption of TKI therapy.

CCyR, complete cytogenetic response; MMR, major molecular response; MR, molecular response; MR4.0, ≤0.01% *BCR::ABL1* IS; RFS, relapse-free survival; TKI, tyrosine kinase inhibitor.

Table 14. TKI Therapy for Disease Progression to AP-CML: Long-Term Follow-up Data from Phase II/III Studies

TKI	No. of Patients	Median Follow-up	MCyR	CCyR	OS	PFS
Dasatinib[287,a] (140 mg once daily)	Imatinib-R (n = 117)	24 months	36%	29%	63%	51%
	Imatinib-I (n = 41)		46%	41%		
Nilotinib[290,b] (400 mg twice daily)	Imatinib-R (n = 109)	24 months	30%	19%	70%	33%
	Imatinib-I (n = 27)		41%	30%		
Bosutinib[292,c] (500 mg once daily)	Prior imatinib only (n = 49)	48 months	48%	35%	66%	—
	Imatinib followed by dasatinib or nilotinib (n = 30)		27%	23%	45%	—
Ponatinib[182,d] (45 mg once daily)	Dasatinib or nilotinib-R or I (n = 65)	32 months	45%	28%	48% at 5 years	19% at 5 years
	T315I mutation (n = 18)		67%	44%	52% at 5 years	29% at 5 years

CCyR, Complete cytogenetic response; I, Intolerant; MCyR, major cytogenetic response; OS, overall survival;
PFS, progression-free survival; R, Resistant

a. Primary endpoint: Major hematologic response (MaHR). The rate of MaHR at 5 years was 67% for 140 mg once daily and 69% for 70 mg twice daily (Ottmann O, et al. Blood Cancer J 2018;8:88).
b. Primary endpoint: Confirmed complete hematologic response rate, achieved in 30% of patients with imatinib-resistant disease and 37% of imatinib-intolerant patients.
c. Primary endpoint: Confirmed overall hematologic response by 48 weeks.
d. Primary endpoint: MaHR at any time within the first 6 months.

Table 15. TKI Therapy for Disease Progression to BP-CML: Long-Term Follow-up Data from Phase II/III Studies

TKI	No. of Patients	Median Follow-up	MCyR	CCyR	OS
Dasatinib[289,a] (140 mg once daily)	Lymphoid blast phase (n = 33)	24 months	50%	38%	21%
	Myeloid blast phase (n = 75)		25%	14%	24%
Nilotinib[291,b] (400 mg twice daily)	Lymphoid blast phase (n = 31)	24 months	52%	32%	10%
	Myeloid blast phase (n = 105)		38%	30%	32%
Bosutinib[292,c] (500 mg once daily)	Prior imatinib only (n = 36)	48 months	50%	37%	28%
	Imatinib followed by dasatinib or nilotinib (n = 28)		21%	17%	17%
Ponatinib[182,d] (45 mg once daily)	Dasatinib or nilotinib-R or -I (n = 38)	6 months	18%	16%	9% at 3 years
	T315I mutation (n = 24)		29%	21%	

CCyR, complete cytogenetic response; I, Intolerant; MCyR, major cytogenetic response; OS, overall survival; R, Resistant

a. Primary endpoint: Major hematologic response (MaHR).
b. Endpoints: Duration of MaHR, MCyR, and OS.
c. Primary endpoint: Confirmed overall hematologic response by 48 weeks.
d. MaHR at any time within the first 6 months.

Table 16: Results from Selected Published Clinical Trials Evaluating Novel Treatment Options

Drug Class	Clinical Trial	TKI	No. of Patients	Median Follow-up	Response Rates
BCR::ABL1 inhibitors	**Phase III (REPRISE study)[451]** Newly diagnosed CP-CML	**Radotinib** (300 mg twice daily)	n = 79	≥48 months	MMR: 85%; MR4.5: 58%
		Radotinib (400 mg twice daily)	n = 81		MMR: 83%; MR4.5: 56%
		Imatinib (400 mg once daily)	n = 81		MMR: 75%; MR4.5: 49%
	Phase III (FESTnd study)[452] Newly diagnosed CP-CML	**Flumatinib** (600 mg once daily)	n = 196	12 months	EMR: 82%; MMR at 12 months: 53%
		Imatinib (400 mg once daily)	n = 198		EMR: 53%; MMR at 12 months: 40%
	Phase II[453] CP-CML with resistance or intolerance to imatinib	**Radotinib** (400 mg twice daily)	n = 77	23 months	MCyR: 65%; CCyR: 47%; MMR:14%
	Phase I/II[454] CP-CML or AP-CML with resistance to TKI	**Olverembatinib** (40 mg on alternate days for 28-day cycles)	CP-CML (n = 127)	34 months	MCyR: 79%; CCyR: 69%; MMR:56%
			AP-CML (n = 38)		MCyR: 47%; CCyR: 47%; MMR:45%

EMR, early molecular response; MCyR, major cytogenetic response; MMR, major molecular response; TKI, tyrosine kinase inhibitor

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